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Impact of Teff commercialization on smallholder farmers' food security in Northwestern, Ethiopia

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ABSTRACT

Teff, a versatile crop, serves both as a food source and a cash crop in Ethiopia. It is recognized for its potential to enhance the income of smallholder farmers, improve food security, and contribute to sustainable development goals. This study aims to assess the impact of Teff commercialization by smallholder farmers on food security. Both primary and secondary data were used using the 2020/2021 cropping season. A three-stage sampling procedure was used to draw 352 sample households. Food security was assessed using proxy indicators**:** household dietary diversity and food consumption score. The descriptive statistical results showed that 182 (51.7%) and 170 (48.3%) sample households were subsistence, and commercialized household heads respectively. Notably, commercial farmers exhibited better household dietary diversity (91.2%), whereas subsistence farmers scored lower in terms of food consumption (29.1%). Male household headship reduced HDDS for commercializing farmers (−1.6); credit usage boosted HDDS for commercialized groups (1.1), and livestock ownership improved HDDS for subsistence groups (0.21) in the second-stage endogenous switching regression. The model result also showed that, Teff commercialization positively impacted HDDS and FCS, with average treatment effects of 3.81 and 4.46, respectively. Transitional heterogeneity results showed that commercialized farmers had lower household dietary diversity (−0.47) and lower food consumption score (−14.19) than subsistence households. In light of these findings, encouraging smallholder farmers to transition from subsistence production to commercialization is crucial for supplementing their overall production. Additionally, government efforts should focus on raising awareness about nutrition-sensitive agricultural practices.

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1. Introduction

In Africa agriculture contributes 33% of national income, 70% of full-time employment, and 40% of total export earnings which is an engine for economic growth (Mekouar, 2020). About 80% of Ethiopia's population of 120 million lives in rural areas where, agriculture is the dominant sector in the Ethiopian economy, accounting for 72.7% of providing employment opportunities, generates about 90% of the foreign exchange earnings of Ethiopia, supplies over 70% of inputs for domestic industries, and 42% of gross domestic product (GDP). Among these crop production shares 72% of the country's gross national product, 20% from livestock, and 8.6% from others. About 10% of the total land area is cultivated by large commercial farms, while 90% of the total cultivated land, majority of the agricultural workforce is accounted for by smallholder farms. The sector is also characterized by low productivity, backward farming technologies, limited resources and market access, low farming capacity, and subsistence farming (Ali et al., 2023; Yigezu Wendimu, 2021).

Currently, this subsistence agricultural sector cannot feed the rapidly growing population of Ethiopia. In addition to rapid population growth, Tigray conflict, internally displaced persons, natural disaster, recurrent drought and floods, climate change, locust crisis, and socio-economic impact of COVID-19 were already undermining food security status, and livelihoods in many contexts (Ethiopian Red Cross Society, 2021; Kassegn & Endris, 2021). Ethiopia's Global Hunger Index

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(GHI) score of 25.0, classified as 'serious' by the FAO, underscores the severity of hunger, exacerbated by recurrent droughts and erratic rainfall patterns (Global Hunger Index, 2022). With 19.7% undernourishment prevalence, a significant portion of the population lacks adequate food access (WHO, 2022). In Africa, including countries like Ethiopia, food insecurity is a pressing issue, particularly for smallholder farmers, worsened by corruption, political instability, climate change, poverty, and conflicts. These challenges impede agricultural production, distribution, and marketing, affecting food security and livelihood sustainability. Studies highlight that effective corruption control and political stability may alleviate food insecurity by enhancing food distribution efficiency and resource allocation transparency (Nugroho et al., 2022). Moreover, promoting investment, economic development, and social cohesion are crucial for ensuring food security in such contexts (Mulyo et al., 2023).

To address these challenges, the government of Ethiopia set agricultural commercialization clusters (ACC) initiatives aiming at increasing commercialization and achieving food security, and reducing poverty. The ACC initiative targets four regions (Amhara, Oromia, SNNPR, and Tigray) among cereals prioritizing Teff, wheat, and maize (Covarrubias & Cicowiez, 2021). Among those crops, the current Teff export policy allows for the international export of processed Teff, largely in the form of ready-to-eat Teff *injera* and packed flour. The global world utilized Teff in the form of cake, pasta, porridge, and biscuit and surprisingly they made 'Addis' beer from Teff soon. Canada, China, India, the Netherlands, South Africa, the United Kingdom, and the United States are among the largest international sellers of Teff, alongside Ethiopia. Despite being the world's largest producer and consumer of the ancient grain Teff by volume, Ethiopia is unable to benefit from international trade due to an export ban on its indigenous crop (Assefa et al., 2015).

Ethiopia, the origin of Teff cultivation, holds a long-standing history of growing this tiny, gluten-free grain. Teff, crucial for millions of people, is predominantly cultivated within the country, maintaining its global dominance in production, with over 95% (4.8 million metric tons) of the world's output, and 85% Africa's Teff production in the 2021–2022 period. While countries like Eritrea and Djibouti contribute to regional production, their output remains limited. Teff, despite its modest size, significantly contributes to global trade, particularly through Ethiopia's exports of Teff grains, flour, and processed products to countries such as the United States, Europe, and the Middle East, bolstering trade earnings and foreign exchange reserves. Formerly grown primarily for subsistence, Teff has transitioned into a commercial crop, with exports reaching beyond 220,000 metric tons in 2022 (Food and Agriculture Organization of the United Nations [FAO], 2022).

The rising commercialization of Teff in Ethiopia, a crop covering 29.1% of cultivated land and involving 6.3 million farmers, with 25–30 million people directly reliant on Teff production, offers a potential pathway to enhance the livelihoods of rural households (CSA, 2022; Mekbib et al., 2016). Teff is more consumed in urban households, with prices significantly two to three times higher than maize, impacting accessibility (Covarrubias & Cicowiez, 2021). Globally, its popularity rises due to its nutritional value and gluten-free nature, notably seen in increasing demand for Teff injera, especially in markets with substantial Ethiopian communities like the UAE, USA, Bahrain, and Sweden (Neumann et al., 2023).

Teff farming sustains rural economies and livelihoods, highlighting its significant role in Ethiopia's agriculture, particularly for smallholder farmers' income and poverty reduction (Gebremedhin & Berhe, 2021). Studies explore how agricultural commercialization affects food security among smallholders, stressing the need for nuanced understanding (Berhanu & Poulton, 2021). Tailored interventions are urged to address malnutrition and food insecurity (Tamru et al., 2017). Similarly, cassava commercialization shows promise in food security and poverty reduction, with research focusing on post-harvest losses and market access (Droppelmann et al., 2018). A study was conducted on agriculture commercialization and nutrition in smallholder farm households using propensity score matching (Ogutu et al., 2020). Likewise Justus et al. (2015) applied PSM to analyze the impact of Agricultural commercialization on household food security in the Great Lakes region of central Africa. Jaleta et al. (2015) analyzed the impact of improved maize variety adoption on household food security in Ethiopia using an endogenous switching regression model. Similarly, the model was used to analyze the impact of contract farming on rice farm performance by Bidzakin et al. (2019).

Investigating Teff commercialization's impact on income and food security, prompted by government concerns, reveals contrasting views. While some argue it boosts household income and improves food security by diversifying diets, others warn of risks such as reduced food availability and nutritional value due to resource shifts towards cash crops (Amsalu, 2014; Kemaw, 2017). Ethiopia's Teff export ban, aimed at

prioritizing domestic food security, inadvertently exacerbates affordability issues for many, despite potential benefits for commercial farmers. Increased Teff market access and processing could bolster farmers' income and livelihoods, yet intensified commercialization may threaten land use change, crop diversity, promote market driven production systems, and resilience against food shocks (Crymes, 2015). Exporting raw Teff risks exacerbating land conflicts and food insecurity, potentially forcing farmers to substitute with less nutritious cereals such as sorghum, barley, wheat, and maize as a staple cereal in their diet. The export ban appears to safeguard subsistence Teff producers' food security (Tesfaye & Tirivayi, 2016).

Research on the commercialization of Teff in Ethiopia and its impact on smallholder farmers' food security is crucial due to its economic significance. Despite this, its effect on food security in the Nortwestern, Ethiopia hasn't been studied using recently developed methodological tools. It was found that income from Teff commercialization was often directed towards purchasing non-food items such as guns, houses, and oxen. The current study aimed to investigate the impact of Teff commercialization on food security, taking into account these theoretical, empirical limitations, practical disagreement, and other multidimensional gaps. Understanding these dynamics is vital for shaping policies and agricultural strategies to enhance food security sustainably and support livelihoods from Teff commercialization.

2. Research methodology

2.1. Description of the study area

The research was conducted in the Andabet district, located in Northwestern Ethiopia, approximately 689 km North of Addis Ababa and 151 km East of Bahir Dar, Capital city of Amhara Region (see Figure 1). Andabet District is well-known for its substantial potential in Teff production within the Amhara region. Of the district's 35,331 hectares of cultivable land, 20,278 hectares are dedicated to Teff cultivation annually, yielding a total production of 540,609 quintals during the 2021/2022 cropping season (CSA, 2022).

2.2. Data type and methods of data collection

The research has used cross-sectional (survey) design. Primary data was collected from sample smallholder farmers a semi-structured questionnaire. Before the actual survey, a pilot survey was conducted to test data collection instruments, assess the clarity of the questions, and estimate the time required. Qualitative data was collected using unstructured interviews with key informants: agricultural and rural experts. The validity of collected data, and information were triangulated through focus group discussions with key informants using checklists. Besides, relevant secondary data sources like reports of the agricultural office, farmers' cooperative, central statistical agency,

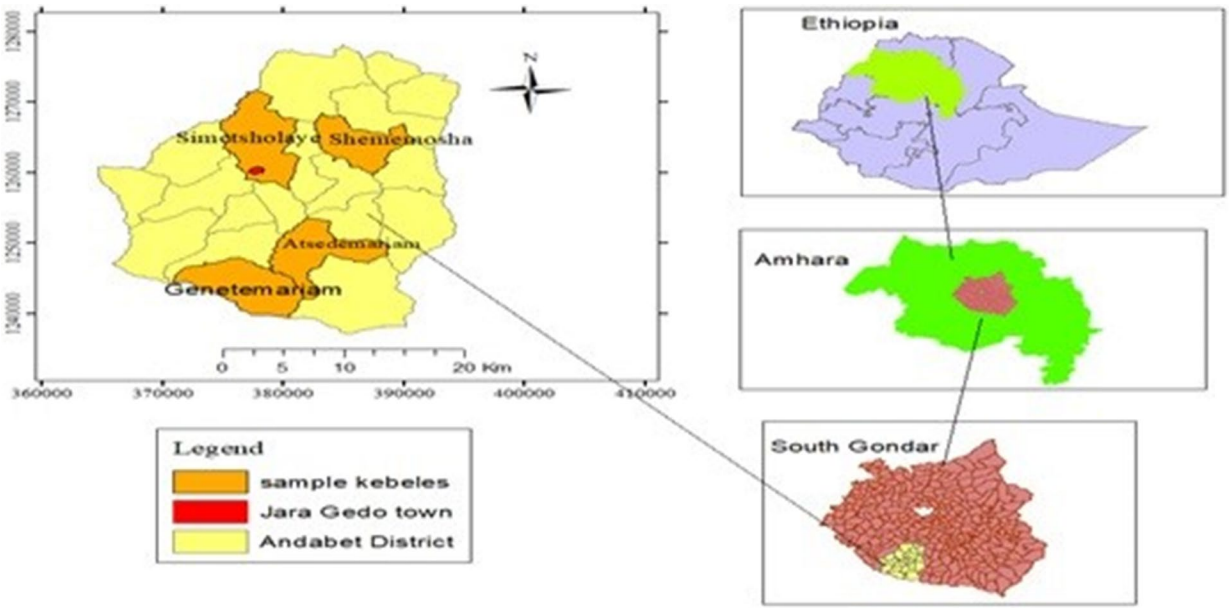

Figure 1. Location of North-western, Ethiopia. *Source:* GIS own computation (2022).

published and unpublished documents were reviewed to supplement the survey data.

2.3. Sampling technique and sample size determination

This study aims to evaluate the impact of smallholder farmers' Teff commercialization on food security status. A three-stage sampling procedure was used to address the objectives of the study. In the first stage, from 24 rural and two urban kebeles, four rural kebeles were selected using a simple random sampling technique. In the second stage, from each kebele Teff producer farmers' were identified and listed. In the third stage, sample Teff producers were drawn using systematic random sampling techniques based on probability proportional to size. The number of respondents was determined using the Cochran formula that was widely used when there is a large population and when the study needs accurate variability and heterogeneity of the population (Cochran, 1977).

$$n_o = \frac{Z^2 q(1-q)}{e^2} \quad (1)$$

n_o = required sample size; Z = standard normal value which is 1.96 for 95% confidence interval (5% significance level); p = estimated proportion of population (maximum variability) (0.5); q = (1 − p) or estimated proportion of failure; e = the desired level of precision (0.05).

Therefore,

$$\frac{1.96^2 * 0.5(1-0.5)}{0.05^2}$$

$$\frac{3.8416*0.5*0.5}{0.0025} = \frac{0.9604}{0.0025} = 384.16 \approx 385$$ household heads.

Then, the study made adjustments using the reduced formula of Cochran below.

$$n = \frac{n_o}{1+\frac{n-1}{N}} Or = \frac{n * N}{n_o + (N-1)}$$

Where n = required reduced sample known sample size; N = known sample size (4014); n_o = Sample size for unknown population (385)

$$n = \frac{n_o * N}{n_o + (N-1)} = \frac{385 * 4014}{385 + (4014-1)}$$
$$= \frac{1{,}545{,}390}{4{,}398} = 351.3847203274216 \approx 352$$

The following table summarizes the population size of each kebeles, share of sample sizes, and an actual number of respondents for each kebeles (Table 1).

2.4. Methods of data analysis

2.4.1. Descriptive and inferential analysis

The statistical values of mean, standard deviation, percentages, frequencies, and ratios were used to examine and understand the socioeconomic and demographic characteristics of sample households, Teff commercialization index (TCI), household dietary diversity score (HDDS), and food consumption score (FCS) categories were also used to make comparisons between Teff commercialized, and subsistence smallholder farmers' food security status using the chi-square test (for categorical variables) and T-test for continuous variables.

2.4.1.1. Household commercialization index (HCI). Many studies have assessed the extent of household commercialization by computing the degree of commercialization measured by a simple index formula defined as the ratio of the gross value of all crop sales by a household in a year to the gross value of all crops produced by the same household in the same year expressed as a percentage. For this study degree of commercialization is computed as the Teff commercialization index (TCI). TCI is the ratio of the gross value of all Teff sales to the gross value of all Teff production by households of the district. Several authors adopted this definition and used it to calculate the commercialization index of different crops (Anteneh

Table 1. Sample size distribution by sample kebeles.

	Total households				
Kebele name	Men	Women	Total	Share%	Sample households
Atsede Mariam	844	122	966	24.15	85
Shima Mosha	553	68	621	15.65	55
Genete Mariam	716	213	929	23.01	81
Simat Sholaye	1240	258	1498	37.22	131
Total	3353	661	4014	100	352

Source: Calculated using data from each kebele's census report (2022).

& Endalew, 2023; Leta, 2018; Leul et al., 2023). Similarly, the commercialization index of Teff producers is given as:

$$TCI = \frac{Gross\ value\ of\ all\ Teff\ sales}{Gross\ value\ of\ all\ Teff\ production} * 100$$

Based on the market orientation (TCI), a household that sells less than 50% of its product and sales greater than 50%, the household was classified as subsistence and commercialized groups respectively. This categorization is quite appropriate for Ethiopia, as a predominantly agrarian country and smallholder-dominated nation (Fikadu et al., 2023).

2.4.1.2. Measuring household food security. According to Riches (2002), food security is defined as a situation that exists when all people at all times can have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. The present study follows the definition by FAO (2010) defined food security as availability and access to food. The current study used household dietary diversity score and food consumption score as proxy variables for food security. The formers sign the presence of food access and diversity, while the latter indicates the presence of food availability, and food frequency.

2.4.1.3. Household dietary diversity score (HDDS). According to FAO (2010) household dietary diversity score is an indication of household economic access to food. The Household Dietary Diversity Score (HDDS) evaluates the range of foods consumed by household members within a 24-h recall period, typically on a daily basis. Unlike focusing on quantities, HDDS emphasizes the variety of food groups consumed, reflecting the overall dietary diversity of the household. It is derived from the consumption of 12 predetermined food groups, with households categorized based on their level of dietary diversity. Respondents report consumption of food groups such as cereals, vegetables, fruits, meat, eggs, fish, legumes, milk, fats, sugary foods, root vegetables, and condiments, with each group scored as 1 if consumed and 0 if not. The total HDDS is the sum of these scores, with 'yes' responses coded as 1 and 'no' responses coded as 0 (Cordero-Ahiman et al., 2021). Households are then classified into potential score ranges from 0 to 12 for HDDS, where ≤3, 4–5, and ≥ 6 indicate low, medium, and high dietary diversity, respectively. Higher HDDS scores signify increased dietary diversity, which correlates with enhanced nutrient intake and improved health outcomes.

2.4.1.4. Food Consumption Score (FCS). According to FAO (2010) as cited by Marivoet et al. (2019), the Food Consumption Score (FCS) is a comprehensive metric that considers dietary diversity, food frequency, and the relative nutritional importance of various food groups. It is derived from the frequency of consumption of different food groups by a household during the 7 days preceding the survey. The FCS serves as a tool to evaluate the food security status of households based on their food consumption patterns over a specified period, usually a week. It factors in the types and quantities of foods consumed by household members, assigning weights to different food groups based on their nutritional significance and energy content. The food groups included in the FCS and their respective weights typically comprise main staples (weight = 2), pulses (weight = 3), vegetables (weight = 1), fruits (weight = 1), meat and fish (weight = 4), eggs (weight = 4), milk and milk products (weight = 4), sugar (weight = 0.5), oil (weight = 0.5), and condiments (weight = 0). The score is computed by summing the weighted consumption of these various food groups, with higher scores indicating better food security. The FCS is categorized into three levels: FCS of 0–21, 21.5–35, and >35, indicating poor, borderline, and acceptable household consumption, respectively (Hoddinott & Yohannes, 2002).

2.4.2. Econometric analysis

Previous studies used propensity score matching (PSM), instrumental variable approach (IV), structural equation model (SEM), simultaneous equation model, and endogenous switching regression model (ESRM) to analyze impact.

Propensity score matching tries to compare the observed difference between the outcome variables of subsistence and commercialized groups with similar characteristics in terms of quantity, it cannot control for unobservable bias because it only controls the observed variables. The unobservable factors may fall under personal, social, or institutional characteristics including farmer's ability, skills, and motivation, which could potentially affect both the level of commercialization decision and household food security. To handle unobservable heterogeneity, and to control for selection bias, the study applied an endogenous switching regression model (Lokshin & Sajaia, 2004). Endogenous switching regression was first developed by Lee and Porter (1984). The analysis was done on movestay command using commercialization decisions as to the selection variable (subsistence and commercialized) and food security as an outcome variable (HDDS and FCS). Various literature

shows that many impacts based on cross-sectional data have moved towards endogenously switching regression model.

2.4.3. Endogenous switching regression models

Endogenous switching regressions model is a variant of the classical Heckman selection model (Heckman, 2001). Theoretically, a farmer decides to commercialize in treatment groups when the expected utility received from Teff commercialize (*C*) is greater than the utility received from subsistence (*C**). As expected utility is not observed but commercialization in treatment groups is observed, the commercialization of Teff (*C*) is treated as a dichotomous choice: $C=1$ if $C^{*}>C$ 0 and $C=0$ if $C>C^{*}$. Thus, using an underlying latent variable model, the participation decision in Teff commercialization can be modeled as follows:

$$C = aZ + \varepsilon \tag{2}$$

Where *C* is a dummy variable that equals 1 for farmers who commercialize Teff, and zero otherwise, *Z* represents explanatory variables to be estimated, *a* is a parameter, and ε is a normally distributed error term with mean zero and constant variance (a^2). The endogenous switching regression model has a two-step procedure to correct self-selection bias and simultaneity bias. The first stage is the Probit model and the second stage is OLS/Pooled regression which is used to examine the relationship between the outcome variables and a set of explanatory variables conditional on the commercialization decision (Maddala & Lahiri, 1992).

$$\text{Regime 1}(\text{commercialized}): Y_{1=} X_j B_j + \varepsilon 1 \, if \; C = 1 \tag{3}$$

$$\text{Regime 2}(\text{subsistence}): Y_{2=} X_j B_j + \varepsilon o \, if \; C = 0 \tag{4}$$

Y_1 and Y_2 indicate food secured (high HDDS and FCS) and food-insecure households (low FCS and HDDS) respectively. *Xj* represents an explanatory variable and βj is a *k* x 1 vector of parameters to be estimated (Lindesay et al., 1997). The selection problem arises if the error ε of the selection equation (Equation 2) is correlated with the errors $\varepsilon 1$ and εo of the outcome equations (Equations 3 and 4). This may lead endogeneity problem. An efficient method to fit the endogenous switching regression model is full information maximum likelihood (FIML) using the movestay command in STATA (Lokshin & Sajaia, 2004). More specifically, for the model to be identified, it is important to use at least one variable as a selection instrument that directly affects the commercialization decision but not the outcome variable (Greene, 2012). The estimates for the effects of the average treatments on the treated (ATT), average treatments effects on the untreated (ATU), and the heterogeneity effect (HE) show the impact of Teff commercialization on household's inherent characteristics on food security (HDDS and FCS) are presented below.

The commercialized group with commercialized in Teff production (observed in the sample)

$$E(Y_1 / C = 1) = X_1 B_1 + a\varepsilon_1 \varepsilon \lambda_1 \tag{5}$$

Subsistence without commercialized in Teff production (observed in the sample)

$$E(Y_2 / C = 0) = X_0 B_0 + a\varepsilon_0 \varepsilon \lambda_0 \tag{6}$$

Commercialized had they decided do not commercialize in Teff production (counterfactual)

$$E(Y_2 / C = 1) = X_1 B_0 + a\varepsilon_0 \varepsilon \lambda_1 \tag{7}$$

Subsistence had they decided to commercialize in Teff production (counterfactual)

$$E(Y_1 / C = 0) = X_0 B_1 + a\varepsilon_1 \varepsilon \lambda_0 \tag{8}$$

Where $\lambda_1 = \frac{\varnothing za}{\varnothing za}$, $\lambda_0 = \frac{-\varnothing za}{\varnothing za}$, where φ and Φ are the probability density and the cumulative the distribution function of the standard normal distribution, respectively and $\sigma\varepsilon 1\varepsilon$ and $\sigma\varepsilon 0\varepsilon$ represent the covariance between ε, ε1, and ε0, respectively. Statistically significant estimates of $\sigma\varepsilon 1\varepsilon$ ($\lambda 1$) and $\sigma\varepsilon 0\varepsilon$ (λ_0) indicate that a sample selection bias exists by unobserved factors.

The average treatment effect on the treated (ATT) is computed as the difference between Equations 5 and 7 (see Table 6). The average treatment effect on the untreated (ATU) is computed as the difference between Equations 6 and 8. The change in food secured due to Teff commercialization groups that are, the return to subsistence groups, is calculated as follows, which is generally referred to as 'treatment on the treated (ATT).

$$\begin{aligned} ATT &= E(Y_1 / C = 1) - E(Y_2 / C = 1) \\ &= X_1((\beta_1 - \beta_0) + (\sigma\varepsilon_1\varepsilon - \sigma\varepsilon_0\varepsilon)\lambda_1 \end{aligned} \tag{9}$$

$$ATU = E(Y_2 / C = 0) - E(Y_2 / C = 0) = X_1((\beta_1 - \beta_0) + (\sigma\varepsilon_1\varepsilon - \sigma\varepsilon_0\varepsilon)\lambda 0 \quad (10)$$

Households who are commercialized Teff will be better in food security than those that don't decide to commercialize Teff that occurs due to unobservable factors which are addressed by base heterogeneity. Base heterogeneity is the effect of the outcome variable of commercialized and it's counterfactual on counterfactuals of subsistence and subsistence groups respectively. The transitional heterogeneity effect is the difference between the base heterogeneity of commercialized and the base heterogeneity of subsistence smallholder household heads (Carter & Milon, 2005). It helps to determine whether the impact of Teff commercialization on food security (HDDS and FCS) is smaller or larger for commercialized and non-commercialized households relative to the counterfactual scenarios.

The second stage results of ESRM holds ancillary parameters like sigma 1, sigma 2, *rho_1,* and *rho_2* were justified and interpreted. The signs and significance of the correlation coefficients (*rho_1* and *rho_2*) indicate the existence of selection bias. The significance level of *rho* has four conditions: If *rho* is significant at regime one but not at regime 2 there is condition one. This shows an absolute advantage of commercialized households. Similarly, if *rho* is insignificant at regime 1 and significant at regime 2 we call it condition 2. Condition 3 illustrates that *rho* is significant in both regimes and the reverse is true for condition 4 (Lokshin & Sajaia, 2004). The overall explanatory variables used in the study, and included in two-stage least square, and Movestay commands were computed below in Table 2.

2.5. Variable definitions and expected sign

The study used binary notation for analysis, with 1 indicating commercialization and 0 otherwise (subsistence and commercial), to examine the impact of Teff commercialization on smallholder farmers' food security as a treatment variable. The outcome variables of the study are the food consumption score and household dietary diversity. The research hypothesized that Teff commercialization does not impact smallholder farmers' food security, or there is no relationship between Teff commercialization and food security. Definitions and expected signs of several explanatory variables are illustrated in Table 2.

2.6. Ethical approval and informed consent

Ethical approval for this study was obtained from 'Research Ethics Approval Committee of Debre Markos University, Ethiopia and Authorized by College of Agriculture and Natural Resources with Ref.A/N/R/C 1920/25/2021'. Written Informed Consent was also obtained from smallholder farmers and approved by the College Research and Technloghy Transfer office, Debre Markos University.

3. Results and discussions

3.1. Level of Teff commercialization

According to Gebremedhin and Tegegne (2012); Mamo et al. (2017), commercialization levels are classified into three tiers: subsistence (0–25), semi-commercialized (26–50), and commercialized (>50). In this study, smallholder farmers are grouped based on their Teff commercialization extent, with households scoring less than 50% classified as subsistence and those scoring more than 50% as commercialized (refer in Table 3). The average commercialization level among sampled Teff producers in the Andabet district stands at 50.06%, calculated as the mean of the Teff Commercialization Index.

3.2. Demographic, socio-economic, and institutional characteristics of smallholder farmers

The average age of commercial, and subsistence smallholder farmers was 37.2, and 44.98 years respectively. The result showed that 91.76% and 8.24% of commercialized smallholder farmers were male and female-headed households respectively. The average family size of commercial smallholder farmers was 3.6 family members and the average family size of subsistence farmers was 4.57 people. Commercial household heads were more educated and accessed input, credit, and they are owned more land than subsistence heads, while subsistence heads far away from the market. From the commercialized sample of household heads, 67.06% and 32.94% were engaged in off/non-farm and not engaged in off/non-farm activities respectively. The T-test showed that the mean statistical difference between the groups for the discussed variables was significant at a 1% level of significance unlike for total land size (Table 4).

Based on the survey result the average frequency of extension contact per month for commercial, and subsistence farmers was 4.54, and 1.86 units

Table 2. Summary of explanatory variables for econometrics analysis.

Variable (item)	Operational definition of the variable	Expected sign	Literature
Age of head	Age of household head in years of living	−ve	Gebrehiwot & van der Veen (2021)
Sex of head	Sex of household head; 0 = female 1 = male	+ve	Negesse et al. (2020)
Household size	Total family size in man equivalent	−ve/+ve	Muche et al. (2014)
Education level	Years of schooling the household attended	+ve	Maku et al. (2023)
Distance to the nearest market	Total distance from home to nearest market measured in kilo meters	−ve	Abafita et al. (2016)
Cultivated land for Teff production	Total amount of land allocated for Teff production measured in hectare	+ve	Anteneh & Endalew (2023)
Non and off-farm income	Summed amount of money gained measured in ETB Birr	−ve	Kirui & Njiraini (2013
Credit usage	Weather the household has accessed credit or not; 0 = no,1 = yes	+ve	Benti et al. (2022)
Quantity of Teff produced	Total quantity of Teff produced measured in quintal	+ve	Leta (2018)
Input access	Weather the household has accessed input or not; 0 = no,1 = yes	+ve	Getahun (2020)
Oxen ownership	Quantity of oxen for ploughing	+ve	Nasir et al. (2017)
Livestock ownership	Measured in Tropical livestock unit	+ve	Tesafa et al. (2023)
Frequency of extension contact	Farmers frequency of contact with extension actors	+ve	Gebre et al. (2021)
Seed type	Whether the household adopted modern seed type or not; 0 = no,1 = yes	+ve	Abebe & Alemu (2017)
Availability of neighbuor group member	Household has neighboring members with social, economic, or institutional connections (0 = no 1 = yes)	+ve	Justus et al. (2015)

Source: Computed from literature (2022).

Table 3. Level of Teff commercialization by sampled households.

Commercialization index	Frequency	Percent
Subsistence (0–50%)	182	51.70
Commercialized (>50%)	170	48.30

Source: Household Survey Data (2022).

respectively. Table 6 results showed that about 67.06% and 32.94% of commercialized groups have available neighbor group members and not respectively. The statistically mean difference between the two groups was addressed by T-test/X^2. Mean for continuous, the frequency for dummy variables, and standard errors in the parenthesis are addressed below (Table 4).

3.2.1. Relationship between food security and level of Teff commercialization

The relationship between food security and the level of commercialization were presented below in Figures 2 and 3. The association between subsistence and commercial smallholder farmers with the outcome variable (FCS and HDDS) was highly significant at the l% level of significance. In FCS categories 29.1%, 59.9%, and 11.00% of subsistence households were under poor, borderline, and acceptable consumption scores respectively. Around 65.9% and 28.2% of commercial household heads were under acceptable consumption score and borderline FCS categories respectively (Figure 2).

In HDDS categories 54.5%, 27.3%, and 18.2% of subsistence households were under low, medium, and high dietary diversity food security status respectively. About 90.7% and 6.8% of commercial household heads were under high dietary diversity score and medium food security status respectively (Figure 3). More or less in the two food security measurement types, a farmer who is commercialized Teff commodity can easily sustain his/her food security status.

3.3. Econometric results and discussions

3.3.1. Impact of Teff commercialization on smallholder farmer's food security (N = 352)

As indicated by the descriptive statistics and Teff commercialization analysis above there is a significant difference in several relevant variables and food security indicators between subsistence and commercialized smallholder farmers. These differences could be due to several observable and unobservable factors which are captured by applying the endogenous switching regression model. Regarding conducting the model three diagnostic tests were checked using two stages of least square criteria (2SLS). The endogeneity problem existed when it was tested using the Durbin Watson test. 3SLS was regressed to check the presence of causality (simeltaniety bias) between food security and commercialization. Hence, HDDS affects commercialization and commercialization affects HDDS at a 1% level of significance. Availability of neighbor group members and distance to the nearest market are the two instrumental variables that significantly affected Teff commercialization positively and negatively respectively, were insignificant in the outcome equation (Table 5). Previously, a study was conducted by Opondo and Owuor (2018) used those variables as an instrument. Instrumental validity, weakness, and over-identification

tests were checked using the Sergan Hanson test and first stage regression summary. Accordingly, the instruments are valid, relevant, strong, and the model is adequate (goodness of fit) at a l% level of significance. The three equations are jointly dependent which are the commercialization equation, household dietary diversity (HDDS_1), and similar for FCS.

The endogenous switching regression model has first and second stage analysis at a time. In the first stage, the model had estimated determinants of the commercialization decision of smallholder farmers. The second stage of the ESR model is used to estimate the effect of different variables on the two food security measurements (Table 5). Based on the movestay second stage result the study had discussed different factors affecting food security measurements for both commercialized and subsistence groups below.

Table 4. Descriptive statistics of sample households.

Variables	Subsistence (*N* = 182)	Commercial (N = 170)	T-test/X^2
Age (years)	44.98 (**1.06**)	37.20 (**0.84**)	5.67***
Sex (male)	77.47	91.76	13.61***
Household size (man-equivalent)	4.57 (**0.11**)	3.6 (**0.13**)	5.46***
Education level (grade)	3.02 (**0.22**)	4.73 (**0.23**)	5.25 ***
Distance to the nearest market (km)	4.76 (**0.30**)	2.79 (**0.11**)	10.34***
Cultivated land for Teff (hectares)	2.58 (**0.09**)	3.87 (**1.44**)	8.83***
Non/off-farm income (yes)	33.52	67.06	39.56***
Credit usage (yes)	18.13	78.82	130***
Quantity of Teff produced (quintal)	17.04 (**0.63**)	22.02 (**0.83**)	4.82***
Input access (yes)	24.73	80.59	110***
Frequency of extension contact	1.86 (**0.31**)	4.54 (**0.16**)	12.87***
Oxen ownership (Number)	2.09 (**0.07**)	2.88 (**0.06**)	−7.99***
Livestock ownership (TLU)	5.14 (**0.13**)	3.87 (**0.12**)	6.95***
Seed type (improved)	29.67	77.65	92.48***
Availability of neighbor group member (yes)	76.00	32.94	62***

Source: Household survey results (2022).
** and *** indicate significance at the 5% and 1% levels, respectively. Standard errors are shown in parentheses.

3.3.1.1. Determinants of food security status among smallholder farmers (N = 352).

3.3.1.1.1. Sex of the household head. The study result showed that being a male household head negatively and significantly influenced HDDS for commercializing smallholder farmers at a 1% level of significance. The negative relationship indicates males may invest most of the income gained from commercialization into social activities and buying a gun and consuming an outside home. While females might be diversified their food menu and may have been allocated their income for food-related activities. But, recent studies by Djurfeldt et al. (2018) shed light gender disparities in access to land, credit, and extension services may disproportionately affect female-headed households, limiting their ability to engage in profitable commercialization activities. Traditional gender roles in the study area and cultural norms may restrict women's participation in decision-making processes related to agricultural production and marketing, further exacerbating food insecurity among female-headed households. In

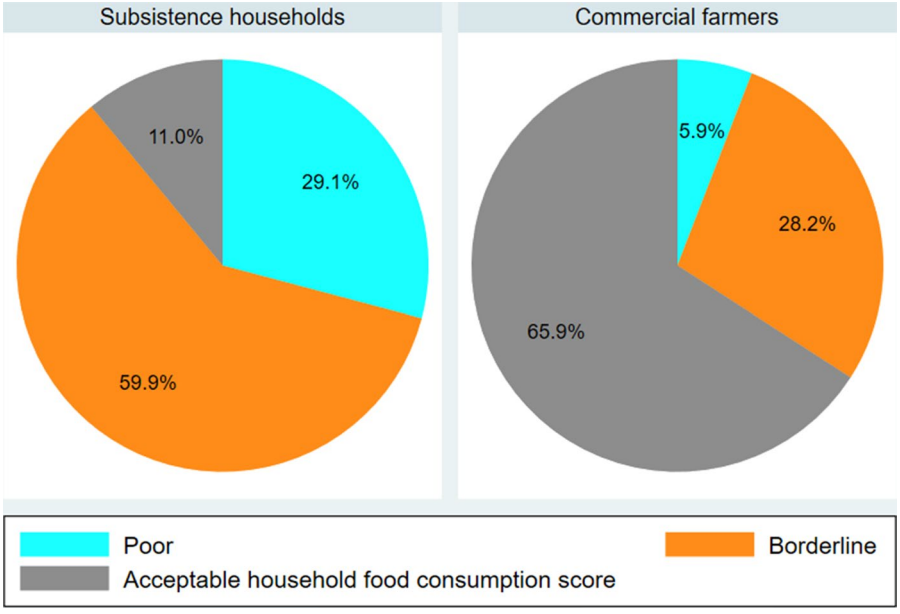

Figure 2. Relationship between FCS and level of Teff commercialization.

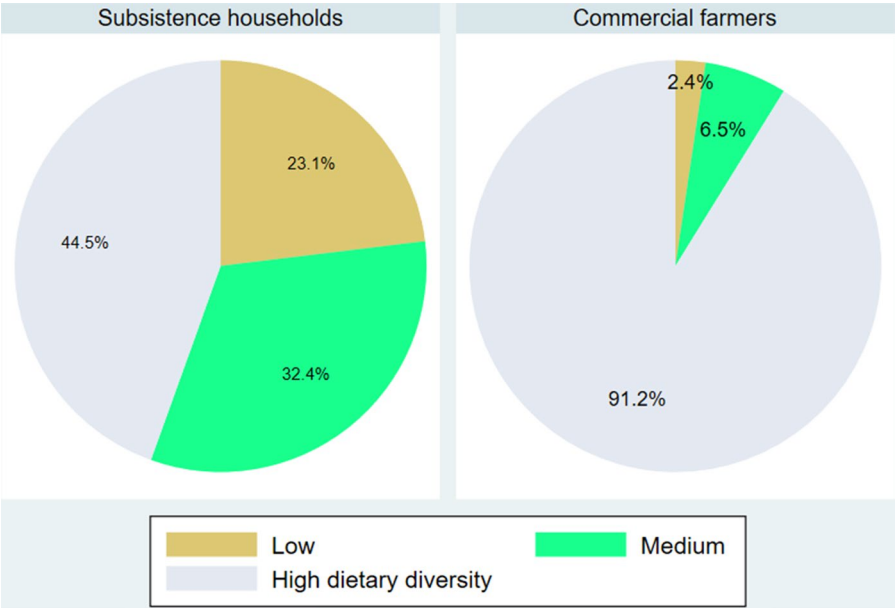

Figure 3. Relationship between Teff commercialization and HDDS.

Table 5. Full information maximum likelihood estimation of endogenous switching regression model ($N = 352$).

Variables	HDDS_1	HDDS_0	FCS_1	FCS_0
Sex	−1.6(**0.48**)***	0.12(**0.38**)	2.5(**1.7**)	2.37(**1.4**)*
Age	0.05(**0.02**)**	0.03(**0.06**)	0.17(**0.04**)***	−0.008(**0.04**)
Education level	0.05(**0.052**)	0.057(**0.052**)	−0.094(**0.19**)	0.39(**0.2**)**
On/non-farm	0-.09(**0.3**)	−0.15(**0.3**)	−2.8(**0.97**)***	0.7(**1.1**)
Credit usage	1.1(**0.39**)***	−0.13(**0.45**)	1.29(**1.06**)	1.16(**1.2**)
Livestock owners	0.042(1.**0**)	0.21(**0.09**)**		
Family size			0.9(**0.29**)***	−0.8(**0.4**)**
Ownership of oxen			−1.1(**0.58**)*	1.4(**0.7**)**
sigma_1	1.95(**0.12**)***		6.57(**0.43**)***	
sigma_2	2.0(**0.1**)***		7.06(**0.4**)***	
rho_1	−0.38(**0.19**)*		−0.88(**1.0**)***	
rho_2	−0.015(0.26)		−0.19(**0.34**)	
	LR test of independence: ch2(1) =3.04 Prob > chi2 = 0.0812 for HDDS			
	LR test of independence: ch2(1) =11.82 Prob > chi2 = 0.0006 for FCS			

Source: Survey Data (2022). Note: *, **, and *** denote significance at the 10% ($p < 0.1$), 5% ($p < 0.05$), and 1% ($p < 0.01$) levels, respectively. Values of 0 and 1 in the dependent variables represent regime 1 and 2, respectively. LR refers to the likelihood ratio.

Table 6. Impact of Teff commercialization on households' food security.

Outcome	Treatment effect	Decision stage		Treatment effect
		Commercialize	Subsistence	
HDDS	ATT	a (8.11)	b (4.3)	I (3.81)***
	ATU	d (9.61)	c (5.33)	II (4.28)***
	HE	e (−1.5)	f (−1.03)	III (−0.47)
FCS	ATT	a (35.35)	b (30.3)	I (5.05)***
	ATU	d (45.5)	c (26.26)	II (19.24)***
	HE	e (−10.15)	f (−4.04)	III (−14.19)

Source: Survey Data (2022). ***Significant at the 1% level. Note: (e) = (a)–(d), (f) = (b)–(c), (I) = (a)–(b), (II) = (d)–(c), (III) = (e)–(f) or (I–II).

reeverse, male household heads may prioritize commercialization efforts that are more profitable but less diversified, leading to reduced dietary diversity and nutritional outcomes. The result was confirmed by earlier researchers showing that females tend to spend more on dietary quality and nutrition than men (Kilimani et al., 2022; Ogutu et al., 2020).

3.3.1.1.2. Age of household head. Age of household head was positively and significantly correlated with HDDS and FCS security measurements only for commercialized household heads at 5% and 1% levels of significance respectively which underscores the importance of experience and knowledge in navigating agricultural commercialization. Older farmers may have established social networks and access to resources that facilitate participation in commercialization activities and enable them to capitalize on market opportunities. Recent studies by Abebe (2018) provided that older household heads often possess extensive traditional knowledge and experience in agricultural practices, which may contribute to better adaptation to commercialization trends and enhanced food security outcomes. Moreover, older household heads in the area may prioritize diversified and sustainable agricultural practices, leading to

Ohigher dietary diversity and food security. This may be older commercialized household heads has farming experience and can improve their income level and can fulfill their food requirement. This result was consistent with the findings of Mohamed (2017).

3.3.1.1.3. Education level. The education level of household head was positively and significantly correlated with FCS only for subsistence smallholder farmers at a 5% level of significance. The argument would be that subsistence educated households may be allocated their lands for food crops. Mayorga-Martínez et al. (2023) provided that education equips household heads with the knowledge and skills necessary to adopt improved agricultural practices, access market information, and engage in off-farm income-generating activities, which are essential for enhancing food security among subsistence farmers. Additionally, educated household heads may have better decision-making abilities and resource management skills, enabling them to allocate resources effectively to meet food needs and invest in productive assets. Moreover, education often empowers individuals to seek out opportunities for capacity-building and skill development, further contributing to improved food security outcomes. This result is in agreement with a prior expectation and the findings of Langat et al. (2011).

3.3.1.1.4. Off/non-farm income. Off/non-farm income has a negative and significant effect with FCS for commercializing groups at a 1% level of significance. The negative relationship shows that commercialized households who have off/non-farm income may allocate the income for non-food expenditures. Recent studies by Kahsay (2017) indicated that off/non-farm income diversification is often considered a strategy to enhance household resilience and income stability, its negative association with FCS among commercializing groups may indicate underlying challenges or trade-offs. One possible explanation could be that households heavily reliant on off/non-farm income may prioritize income generation over food production, leading to reduced investment in agricultural activities and reliance on market purchases for food consumption. Additionally, fluctuations in off/non-farm income may introduce income volatility, making it difficult for households to maintain consistent food access and consumption levels. Moreover, the negative effect of off/non-farm income on FCS may also reflect disparities in income distribution within commercializing groups, where certain households may benefit more from off/non-farm activities than others (Mohammed, 2021).

3.3.1.1.5. Credit usage. Credit usage has positively and significantly influenced HDDS only for commercialized groups. The possible suggestion is that, if farmers who have credit access may invest in agriculture activities and favor production and commercialization which favor the status of household dietary diversity score. Recent studies by Hailua et al. (2015) was resulted access to credit enables commercialized smallholder farmers to invest in agricultural inputs, such as improved seeds, fertilizers, and irrigation equipment, leading to increased productivity and diversified crop production. Additionally, credit may facilitate investment in value-added activities, such as food processing and marketing, which can contribute to higher household income levels and improved dietary diversity. Moreover, credit usage may provide commercialized farmers with the financial flexibility to manage production risks, purchase food during lean seasons, and invest in resilience-building measures, thereby enhancing overall food security. The result has disagreed with Muricho (2015) who found subsistence groups accessing this input credit goes directly to boost their food crop production only.

3.3.1.1.6. Livestock ownership. Livestock ownership has a positive and significant relation with HDDS only for subsistence groups at a 1% level of significance. The positive result may show that a household exploring an income from livestock may not commercialize Teff and may sustain his/her food security status without commercializing Teff. Livestock is a key asset for food security among smallholder farmers primarily engaged in subsistence agriculture in the study area. Recent studies by Tesafa et al. (2023) provide insights into potential justifications for this result. Livestock ownership provides subsistence smallholder farmers with a diversified source of food, including meat, milk, and eggs, which may contribute to improved dietary diversity and nutritional outcomes. Moreover, livestock serve as a form of savings and insurance for subsistence farmers, enabling them to cope with income shocks and food shortages through the sale of livestock or consumption of livestock products during lean periods. Additionally, livestock play a crucial role in enhancing soil fertility and agricultural productivity through manure production and draft power, which can further contribute to improved food security outcomes. The result was in agreement with the findings of Nasir et al. (2017) who found positive results for the non-commercialized household. However, it has a negative and significant relation with FCS for subsistence groups at a 5% level of significance. Also, smallholder farmers with large

family sizes may improve their household income through a varied portfolio of activities that enhance food consumption scores (Tirkaso, 2013).

In conclusion, the study highlights a significant shortcoming of Teff development in Ethiopia, namely the exacerbation of gender disparities in resource access and decision-making. This is particularly evident in male-headed households' inclination to allocate income from Teff commercialization towards non-food expenditures, potentially resulting in diminished dietary diversity and nutritional outcomes for female-headed households.

Ancillary parameters which are sigma 1 and sigma 2 are the square root of the residuals in the model, and *rho_1* and *rho_2* are the correlations of the error term of the outcome and treatment equations of the model were discussed. The coefficient of *rho_1* shows the correlation between the selection equation (commercialization decision) and HDDS and FCS of commercialized groups. Likewise, *rho_2* shows the correlation between the selection equation and HDDS and FCS subsistence smallholder farmers.

As observed from Table 5, *rho_1* is less than *rho _2* (necessary conditions for consistency are fulfilled). This indicates that the impact of Teff commercialization on food security is consistent. The correlation coefficient *rho_1* is statistically significant and shows the presence of a selection bias problem and correlation between the commercialization equation and household food security indicators (regime 1). This implies commercialized groups would gain greater benefits than subsistence households if subsistence households had chosen to commercialize Teff. The insignificant correlation coefficient of *rho_2* shows commercialization decision equation and outcome equation have the same value given their observed characteristics. The negative signs of the *rho* value indicate a positive bias, suggesting that smallholder farmers with above-average HDDS and FCS have a higher probability of commercializing in Teff production vice versa for positive signs.

3.3.1.2. Conditional and unconditional expectations and heterogeneity effects of food security status. In this subsection, the most important question is whether Teff commercialized household groups are better or not in terms of food security using proxy indicator variables (FCS and HDDS). The expected or probability of average treatment effect (ATT), the average treatment effect on the untreated (ATU), and transitional heterogeneity effect results were described. As reported in Table 6 below, ATU, ATT, and transitional heterogeneity are significant for all outcome variables. Table 6 below the value across the diagonals in each food security measurement in cells (a) and (d) represents the expected mean values of commercialized and subsistence groups respectively. The values in cells (c) and (b) are the counterfactual expected values of subsistence and commercialized groups respectively. The values (e) and (f) in each outcome variable represent the base heterogeneity for commercialized and subsistence groups in each food security measurement respectively. The value in cell (I), cell (II), and cell (III) represents the ATT, ATU, and transitional heterogeneity respectively.

Table 7. Propensity score matching results by a logit model.

Outcome variable	Commercialize	Subsistence	ATT
HDDS	8.35	4.85	3.5***
FCS	36.4	25.53	10.87***

Source: Own survey (2022). *Note:* *** Significant at 1% level of significance.

As observed from Table 6 above, the expected value of commercialization of Teff has a positive and significant impact on household dietary diversity score and food consumption score. The average treatment effect on HDDS and FCS for commercialized groups is 3.81 and 5.05 respectively. This shows that commercialized groups increase their HDDS and FCS by 88.6% and 16.6% respectively. For subsistence household heads the average treatment effect on HDDS and FCS is 4.28 and 19.24 respectively. The result was in agreement with the findings of Kilimani et al., 2022). For a robustness check, the study has confirmed propensity score matching to compute the impact of Teff commercialization on food security using the Nearest neighbor method. Accordingly, the average treatment(ATT) for both outcome variables is positive, indicating Teff commercialization has a positive impact on HDDS and FCS (Table 7).

The transitional heterogeneity result showed a negative (−0.47) in terms of the HDDS outcome variable. This indicates that Teff commercialization on HDDS is significantly greater for farmers who are subsistence compared to those that commercialized in Teff production. This is not may due to their decision to commercialize Teff, but possibly due to unobservable factors. Moreover, commercialization may lead to less diversification of crops and more specialization at the smallholder level. The result is consistent with the findings of Tesfaye and Tirivayi (2016). The transitional heterogeneity effect is positive (−14.19) in terms of the FCS food security measurement variable (Table 6). This implies that Teff commercialization on FCS is significantly smaller for households who are commercialized in Teff production compared to those that did not commercialize Teff. This is since the resulting income from Teff

commercialization is may not necessarily be spent on food crops and related food sources. The result was in line with the finding of Janssen and Linderhof (2018).

4. Concluding remarks, and policy implications

The study was aimed to analyze the impact of Teff commercialization on smallholder farmers' food security in the Amhara region, Ethiopia. The study has used household dietary diversity (HDDS) and food consumption score(FCS) as proxy indicators of food security. The Teff commercialization index (TCI) showed that out of the total sampled household heads, 182 (51.7%) and 170 (48.30%) households were subsistence, and commercialized households respectively. The study found that male household heads negatively influenced dietary diversity scores for commercializing smallholder farmers, while age and credit usage positively impacted dietary diversity and food consumption scores for commercialized households. Additionally, education level improved food consumption scores for subsistence farmers, whereas off/non-farm income negatively affected commercializing groups, and livestock ownership boosted dietary diversity for subsistence groups. To estimate the impacts of Teff commercialization and to correct selection bias and systematic differences endogenous switching regression model was used. The average treatment effect on HDDS and FCS for commercialized groups is 3.81 and 4.46 respectively. As a result, Teff commercialization may contribute to mitigating seasonal gaps in food availability and uses as a source of cash to purchase other food items to diversify and complement the available food for home consumption.

Teff commercialization has a significant positive relationship with household dietary diversity score and food consumption score but has low HDDS for commercialized households. This may be because resources may shift to cash crops and land conflict may arise and subsistence households mostly produced food-related crops, unlike commercialized households. The positive relationship of food consumption score with Teff commercialization may generate income and may purchase food in the market. Households who did not commercialize in Teff production would be better off if they commercialize in Teff production. Therefore, the regional government and the district government need to encourage Teff commercialization through strengthening extension services, model farmers, and using multi-medias. The government and traders need to access non-locally produced products in all markets and need to create conditions for farmers to receive proper training in household nutrition. Moreover, smallholder farmers need to transform their subsistence farming into commercialization to supplement their production. Finally, future analysis is needed using a panel and time-series data, a variety of food security measurements to control unobservable factors, and to check whether results are consistent over time in different areas.

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Authors' contributions

Desyalew Assefa: Contributed to the design of the research including the formulation of the research questions, objectives, and hyphothesis, collaborated with other team members to develop the study protocol, responsible for collecting and organizing research data, partook in the selection of suitable data collection tools, involved in developing or utilizing software tools for data analysis, created visual representations, conducted detailed analysis and exploration of data, and contributed to writing the initial draft of the manuscript. **Bosena Tegegne Delele**: Contributed to shaping the research idea and overall study design, provided oversight and guidance throughout the research process, performed model result interpretation, ensured the accuracy and reliability of data and findings, and critically reviewed and improved the manuscript. **Abateneh Molla**: Actively participated in data collection, processing, organization of data, contributed to the design of the study, and supervised household survey analysis. Additionally, the team collectively worked on policy recommendations based on the research findings. All the authors read and approved this manuscript.

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Bosena Tegegne Delele Contributed to shaping the research idea and overall study design, provided oversight and guidance throughout the research process, performed model result interpretation, ensured the accuracy and reliability of data and findings, and critically reviewed and improved the manuscript.

Abateneh Molla Actively participated in data collection, processing, organization of data, contributed to the design of the study, and supervised household survey analysis. Additionally, the team collectively worked on policy recommendations based on the research findings. All the authors read and approved this manuscript.

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Data availability statement

The data used to support the findings of this study are available from the corresponding author upon request.

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