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Determinants of Investments in Sustainable Agricultural Intensification Practices in Ethiopian Central Highlands

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Abstract

Improving agricultural productivity and food security while reducing land degradation and poverty using sustainable agricultural intensification practices (SAIPs) has been a key development policy agenda in Ethiopia. However, investment in sustainable agricultural intensification practices remains low. Using a multivariate probit (MVP) and an ordered probit model (OPM), this paper investigates the factors influencing farmers' choice decisions and the extent of investments in eight SAIPs including improved crop varieties, inorganic fertilizers, pesticides, organic fertilizers, cereal-legume rotation, vegetation, drainages and soil conservation structures based on 385 household and 1465 plot surveys in the Ethiopian central highlands. Results reveal that some practices in major crop production are complementary while others are substitutable, and the factors had heterogeneous impacts on the choice decisions of farmers to invest in multiple SAIPs. Overall, results reveal variables such as crop income, livestock holding, access to extension and credit services, income diversification, membership to agricultural cooperatives, and agricultural commercialization clusters are important in determining choice decisions and the extent of investments in multiple SAIPs. Complementarity between practices and factors that positively determine investments in sustainable practices should be taken into consideration in agricultural policies. Specifically, strengthening local institutions (extension, microfinance, and cooperatives) and training on SAIPs and income diversification need to be in place to enhance sustainable production.

Keywords: Determinants, investment, sustainable practices, multivariate probit model

Introduction

Agriculture is the most important economic sector in Ethiopia. It constitutes about 33% share of Gross Domestic Product (GDP), contributes 25% to average real GDP growth, generates 82% of export earnings, and absorbs more than 66% of the labor force (EEA, 2021). It also provides an incentive to reduce poverty and improve food security and livelihoods, yet yields are low (2.9 t/ha for cereals compared to a global average of 4 t/ha) and food insecurity affects more than 16.7% of the population (CSA, 2021; FAO *et al*., 2021; Mare *et al*., 2022). Land degradation, soil nutrient depletion, climate change and low investments in sustainable agricultural intensification practices (SAIPs) have limited agricultural production and productivity, leading to food insecurity and poverty (Etongo *et al*., 2018; Horner and Wollni, 2021; Nigussie *et al*., 2018; Smith *et al*., 2017; Teklewold *et al*., 2013). Land degradation is particularly severe in the Ethiopian highlands where 23% of the cultivated land is adversely affected (Gashaw *et al.*, 2014; Nyanga *et al*., 2016). This underlines the need to enhance investment in SAIPs for improving productivity, food security, and conserving resources.

Investments in SAIPs are the main concern in SSA highlands, where rain-fed farming on the hillside often causes soil erosion leading to low yields and food insecurity (Abera *et al.*, 2020; Nyanga *et al*., 2016). Subsequently, for several decades, a range of SAIPs have been promoted in SSA including Ethiopia (Kassie *et al*., 2015; Teklewold *et al.*, 2013). These practices include land management and agronomic practices such as crop rotation, compost, crop residues, soil conservation structures, drainage (farm water management), and vegetation to improve soil fertility and maintain soil organic matter, and modern purchased inputs such as improved seeds, inorganic fertilizers, and pesticides (herbicides, fungicides, and insecticides) to sustainably enhance productivity (Abera *et al.*, 2020; Kassie *et al*., 2015; The Montpellier Panel, 2013). Farmers have started to invest in SAIPS. Investments referred to all exertions in the form of labor and fiscal and financial capital for some benefits.

Several studies in developing countries testified that SAIPs increased productivity, reduced poverty, built resilience to shocks, and maintained the quality of resources (Hundie *et al.*, 2017; Liao and Brown, 2018; Pretty *et al*., 2011; Reddy *et al*., 2020; Vanlauwe *et al*., 2019). While recognizing that sustainability is a disputed term, we identify farm practices that are commonly viewed as sustainable as they maintain yields and minimize adverse impacts on the environment. These include soil conservation structures, drainages, manure/compost, vegetation, rotation, improved seeds, inorganic fertilizers, and prudent use of pesticides. SAIPs is a broad term used to describe genetic materials, inputs, equipment, structures and farming techniques, and evolving processes that can vary in time and space (Godfray, 2015; Pretty and Bharucha, 2014; Ruzzante *et al*., 2021). Despite extensive past efforts from research and development actors to promote SAIPs and benefits, SAIPs investments remain low in Ethiopia (Kassie *et al*., 2015; Teshome *et al*., 2016; Teklewold *et al.*, 2013; Zeweld *et al*., 2019). Evidence suggests that SAIP investments by smallholder farmers are constrained by several, often interrelated factors. These factors include household demographics, resource endowments, institutional factors, weather conditions, farm characteristics, and risk and uncertainties (Asfaw *et al*., 2016; Kassie *et al*., 2013; Feder *et al*., 1985; Manda *et al*., 2016).

Several studies in developing countries have reported that SAIP investment decisions at the household level vary according to households' human capital including age, education, and family size, and resource endowments such as livestock holding, farm size and income (Ahmed, 2015; Hundie *et al*., 2017; Jabbar *et al*., 2020; Kassie *et al*., 2013; Ndiritu *et al*., 2014; Sileshi *et al*., 2019; Teklewold *et al*., 2013; Wainaina *et al*., 2016) and sex of the household head (Bekele *et al*., 2017; Ndiritu *et al*., 2014), plot characteristics including size, slope, fertility and distance (Ahmed, 2015; Asfaw *et al*., 2016; Hundie *et al*., 2017; Kassie *et al*., 2015; Ndiritu *et al*., 2014; Wainaina *et al*., 2016), institutional factors including extension service, cooperative/group membership, market access and access to credit (Asfaw *et al*., 2016; Kassie *et al*., 2015; Kassie *et al*., 2013; Ndiritu *et al*., 2014; Wainaina *et al*., 2016), and weather conditions such as rainfall, and temperature (Asfaw *et al*., 2016; Jabbar *et al*., 2020; Kassie *et al*., 2015; Kassie *et al*., 2013; Wainaina *et al*., 2016).

Nonetheless, most of the above prior studies focused on the single commodity of project interest particularly maize despite the fact that farmers grow several crops which often compute for land, capital, and labor. With the exception of the studies by Yirga *et al*. (2015) who included improved varieties of barley, potato, wheat, and faba bean crops, and Horner and Wollni (2021) who considered improved varieties of maize, wheat, and *tef* crops, and inorganic and organic fertilizers in their technology adoption analysis, with little attempt in sustainable agronomic and land management practices. In addition, investment in soil and water conservation practices (long-term) is not crop-specific but rather in a blend of crops. Further, smallholder farmers often face choice decisions between multiple SAIPs that have to be made simultaneously to solve multiple constraints faced by farming. Hitherto, most previous studies have also focused on a single technology/practice (Amsalu and de Graaff, 2007; Asrat and Simane, 2017; Mekuriaw and Horni, 2015; Mihretu and Yimer, 2017; Tefera *et al*., 2020), which ignores the interdependent and endogeneity of practices and choice decisions (Yirga *et al*., 2015; Kassie *et al*., 2015). Failure to recognize the interdependencies of SAIPs' choice in examining resource allocation constraints results in biased and inefficient estimates.

Overall, land degradation and low agricultural productivity persist as a challenge, partly due to problems with investments and sustained use of SAIPs, particularly in the Ethiopian central highlands (Abera *et al*., 2020). To this end, these areas require SAIPs policies, programs, strategies, and development measures. There is a strong need to generate information on the determinants of choice decisions and the extent of investments in SAIPs. Previous studies on the investments of SAIPs are largely limited to a few practices; they ignored the use of pesticides as farm inputs which is important to sustain production and productivity in the face of climate change, and failed to address the influence of income diversification and agricultural commercialization cluster in their analysis. This paper looks into these identified gaps in the literature by investigating factors influencing choice decisions and the extent of investments in SAIPs at the plot level in the Ethiopian central highlands.

Materials and Methods

The study areas

The study was conducted in the west Shewa zone of Oromia and North Shewa zone of Amhara regional states. Four districts namely Ejere and Toke Kutaye from west Shewa, Basona Werana and Mojana Wedera from North Shewa zone were selected. Further, twelve *kebeles*[1]three from each woreda were included in the study (Figure 1). Ejere has 26 rural and 3 urban *kebeles*. Toke Kutaye has 23 rural and 4 urban *kebeles.* Basona Werana has 30 rural and 3 urban *kebeles, and* Mojana Wadera has 13 rural and 2 urban *kebeles*.

These areas were chosen for this study because they are an area where knowledge about severe land degradation and SAIPs measures is widely available (Gashaw *et al*., 2014). The Ethiopian central highlands are characterized by a densely populated which resulted in frequent splits and shrinking of farmlands and expansion to hillsides farming, and 50% of arable land for agricultural production is affected by soil degradation in terms of erosion and nutrient depletion, which in turn results in low crop productivity, persistent poverty and food insecurity (EEA, 2021; Tesfa and Mekuriaw, 2014). Smallholder agriculture accounts for more than 90% of economic activity. Most farmers undertake mixed crop-livestock production mainly under rainfed conditions. The areas are dominated by the cultivation of cereals including *tef*, wheat, barley, and maize, legumes mainly faba bean, field peas, and chickpeas, and other crops such as potatoes and oilseeds (CSA, 2021.) The dominant livestock types include dairy cattle (both zebu and cross-bred), sheep, goats, equines, and chickens.

[1] The smallest administrative unit in Ethiopia

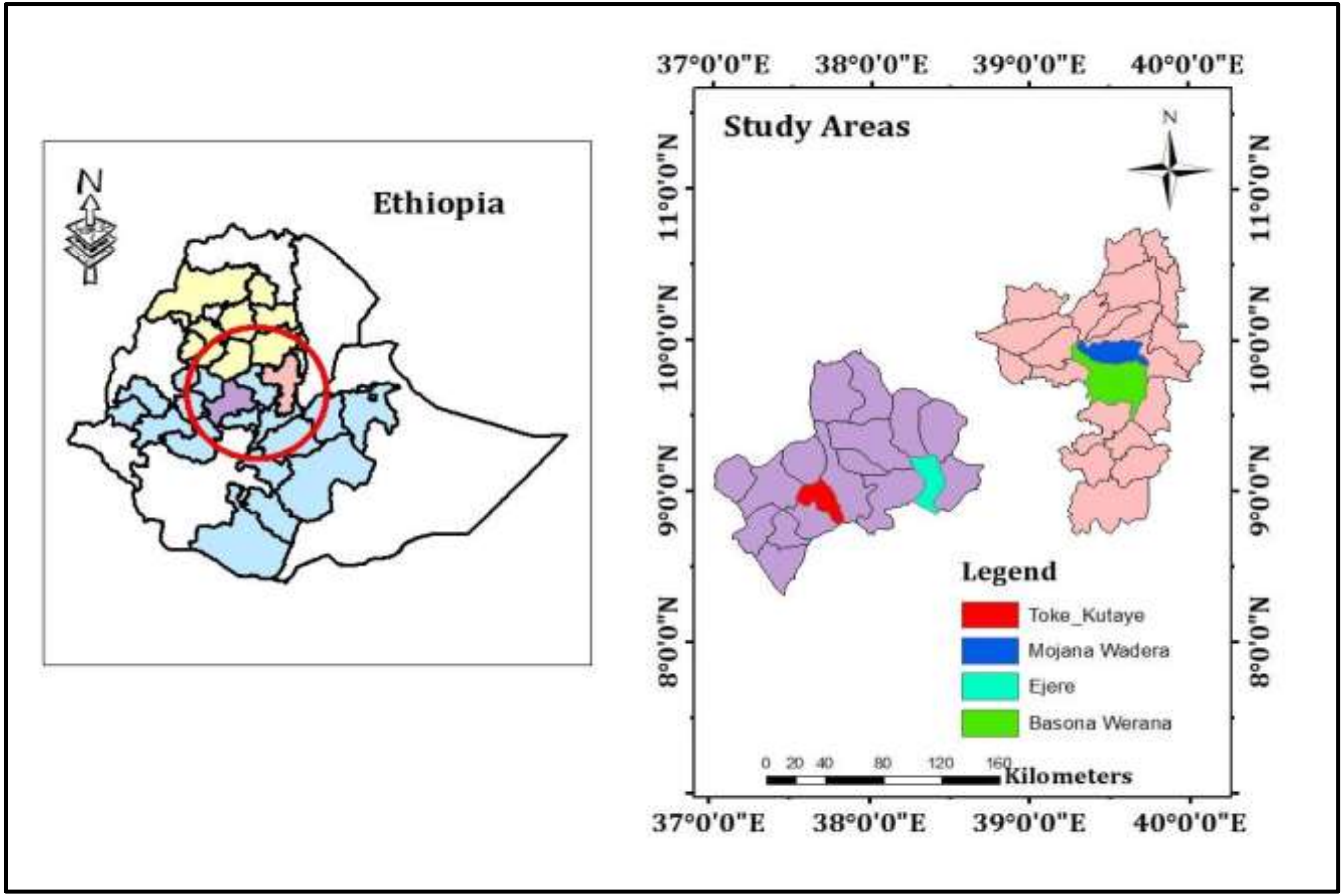

Figure 1. Map of study areas

Data collection and sample selection techniques

The required dataset was collected using combinations of standard data collection methods. These methods included desk review and qualitative and quantitative surveys. The desk review was made from print (both published and unpublished material sources) and electronic source. Information obtained from desk review has helped to design survey instruments of structured and semi-structured questionnaires. Supplementary information was collected through focus group discussions (FGDs) employing a qualitative approach. Qualitative information was collected from selected farm households (five to ten members per FGD per *kebele*), and experts representing different disciplines both at the district and *kebele* level Office of Agriculture. This has helped to understand and details of SAIPs and socioeconomic variables and describe and narrate quantitative results. Finally, the quantitative data were collected through a quantitative survey method.

Three-stage sampling techniques were used to select the regions, zones, districts, *kebeles*, and farm households. Based on the widely available knowledge on SAIP measures, first, two zones from two regions were purposively selected. Second, two districts and three *kebeles* were randomly selected from a list of districts and *kebele*s recorded by zonal and district levels of the Office of Agriculture based on SAIPs implementation. Finally, 23-39 sample households in each *kebeles* were selected based on a proportionate systematic random sampling technique.

The population of interest for this study was farming households as the objective of this study was to investigate the determinants of investments in SAIPs because investment in sustainable agricultural practices is not mainly crop-specific as opposed to previous studies. To obtain a representative sample size for this study, the sample size determination formula by Cochran (1977) was employed:

$$N_s = \frac{Z^2 * pq}{e^2} = 385 \quad (1)$$

Where N_s is the required sample size, Z is the inverse of the standard cumulative distribution that corresponds to the level of confidence, p is the estimated proportion of an attribute present in the population, q= 1-p, and e is the desired level of precision. The value of Z is found from the statistical table which contains the area under the normal curve of 95% confidence level, 5% precision level, and assumed the occurrence rate of p = 50% (the ratio of farm households who at least invested in one of the SAIPs on their plots), and hence q = 50%, and finally the Cochran formula gives a total of 385 samples to sufficiently represent the target population in the study areas.

Primary data were collected using a structured and pre-tested questionnaire designed with CSPro 7.5 software and a computer-assisted personal interview (CAPI). The data collected included information about households' demographics, asset ownerships, plot characteristics, land management practices, inputs used, access to institutional services, and their perceptions of land degradation. The survey questionnaire was administered by trained and experienced enumerators who have knowledge of local farming systems and languages. The survey was conducted between January and March of 2021, referring to the 2019/20 cropping season. In addition, we collected secondary data about *kebele* level rainfall and temperature (point data) from a national meteorological agency (NMA) through an official letter. Collected data were processed and analyzed using a complete and integrated statistical software Stata 15 package.

Modeling framework

Farm households' choice decisions to invest in available individuals or several technologies at a time was theoretically framed on random utility theory (McFadden, 1974) with a bounded rationality framework (Simon, 2000). The standard classical random utility theory assumes that smallholder farmers as rational economic agents with perfect information make choice decisions to invest in available technologies and maximize utility. However, this is highly criticized for human beings who have limited cognitive ability to make choice decisions to maximize utility because of limited information and knowledge (Simon, 2000). Henceforth, there is a shift from standard rationality to real bounded rational theory for economic agents to make optimal decisions which is sufficient to compare alternative utilities (Simon, 2000). While the utility is not directly observed the actions of farm households are often observed through the choice decision they make. Thus, the observed outcome of farmers' choice decisions to invest in multiple practices can be modeled following random utility formulation. Consider the h^{th} households (h = 1, ..., H) which is challenging a decision on whether or not to invest in the available sustainable agricultural practices on the same or another plot p (p = 1, …, P) over a specified time horizon.

Suppose, U_i represent the perceived expected benefits to the farmer from the conventional production system, and U_m represent the benefits of investing in the m^{th} SAIPs, and X_i and X_m are vectors of explanatory variables that influence the perceived benefits from technology choices i and m. Following Greene (2012), the utility of a farm household is specified as:

$$U_m = \beta'_m X_m + \varepsilon_m \text{ and } U_i = \beta'_i X_i + \varepsilon_i \quad (2)$$

Where β_m and β_i are parameters to be estimated, and ε_m and ε_i are the stochastic noise terms, presumed to be independently and identically distributed. It follows that the perceived benefit or utility for the h^{th} household from choice m is greater than the utility derived from option i is presented as:

$$U_{hm}(\beta'_m X_m + \varepsilon_m) > U_{hi}(\beta'_i X_i + \varepsilon_i), m \neq i \quad (3)$$

Assume that Y is the choice decision to invest in m so that Y takes the value of 1 if m is chosen and 0 otherwise, the probability that a farm household invests in SAIPs conditional on X can be specified as:

$$P(Y) = 1|X = P(U_{hm} > U_{hi}) \qquad (4)$$
$$= \mathrm{P}(\beta'_m X_h + \varepsilon_m - \beta'_i X_h - \varepsilon_i > 0|X)$$
$$= \mathrm{P}(\beta'_m X_h - \beta'_i X_h + \varepsilon_m - \varepsilon_i > 0|X)$$
$$= \mathrm{P}(\beta^* X_h + \varepsilon^* > 0|X) = \mathrm{F}(\beta^* X_h)$$

Where P is a probability function, $\varepsilon^* = \varepsilon_m - \varepsilon_i$ is a random error term, $\beta^* = \beta'_m - \beta'_i$ is a vector of unknown parameters to be estimated and can be interpreted as the net influence of the vector of explanatory variables influencing choice decisions of SAIPs and $\mathrm{F}(\beta^* X_i)$ is the cumulative distribution function of ε^* evaluated at $\beta^* X_i$. The distribution of F depends on the distribution of ε^*, and utilities and explanatory variables are defined above.

Empirical estimation strategies

Both descriptive and econometric models were used for the analysis. The descriptive analysis involves summarization of dependent and independent variables used in the econometric models. A MVP model was used for estimating the determinants of farmers' choice of interrelated SAIPs, whereas an ordered probit model was used for estimating the determinants of the extent of investments in SAIPs.

A multivariate probit model

Farm households choose a mix of farm practices and inputs to deal with multiple farming constraints, implying that the choice decisions to invest in these technologies is integrally multivariate. Attempting single equation modeling such as probit, logit, Tobit, or multinomial model would exclude useful economic information contained in interdependent and simultaneous choice decisions to invest in technologies (Dorfman, 1996). We employ MVP model, which simultaneously models the influence of the set of explanatory variables on each of the different technologies while allowing for potential correlation between unobserved disturbances, as well as the relationship between the decision to invest in different SAIPs (Asfaw *et al*., 2016; Kassie *et al*. 2015; Teklewold *et al*., 2013). The possible sources of correlation in MVP model may be complementarity/synergy (positive correlation) or substitutability/trade-off (negative correlation between different practices (Kassie *et al*., 2015). Correlations (positive or negative) may also occur if there are unobservable household-specific features that influence several choice decisions but cannot be easily captured by measurable proxies (Ahmed, 2015). Attempting univariate probit or logit models while such correlation exists would result in biased and inefficient estimates (Greene, 2012; Kassie *et al*., 2015).

The MVP model consists of eight binary choice equations which include investments in improved crop varieties (V), crop rotation (R), inorganic fertilizers

(F), organic fertilizer (O), chemicals (C), drainage (D), vegetation (P) and soil conservation structures (S) which can be simultaneously analyzed. Following the above utility equations (2-4), the net benefit (Y^*_{hpm}) that the farmer derives from investing in the m^{th}SAIPs is a latent variable determined by observed explanatory variables and error terms. The equations for both latent and observed binary variables are:

$$Y^*_{hpm} = X_{hpm}\beta_{mp} + \bar{X}_i\gamma_k + \varepsilon_{hp}, \text{ (m= V, R, F, O, C, D, P, S)} \quad (5)$$

$$Y_{hpm} = \begin{cases} 1 \text{ if } Y^*_{hpm} > 0 \\ 0 \text{ otherwise} \end{cases} \quad (6)$$

Where Y^*_{hpm} is a latent variable that holds the degree to which a farm household views SAIPs m as useful and its estimation is based on observable Y_{hpm} which indicates whether or not a farm household invested in a particular SAIPs on his/her on p^{th} plot in the reference year, X_{hp} represents a vector of observed household and plot-level characteristics, and other factors, β_{mp} is a vector of parameters to be estimated, $\bar{X}$ is a vector of the mean value of Mundlak fixed effects (plot-varying variables including slope and fertility conditions of plots) added additionally to control for unobserved heterogeneity (Mundlak, 1978; Wooldridge, 2002) and ε_{hp} (for m=1, 2, …8) represent the unobserved random error terms, which are jointly follow a multivariate normal distribution with zero conditional mean and variance-covariance matrix (ω), is normalized to unity on the leading diagonal, and correlation $\rho_{mj} = \rho_{jm}$ as off-diagonal elements, and (ƐV, ƐR, ƐF, ƐO, ƐC, ƐD, ƐP, ƐS,)' ~MVN (0, ω), is shown in (eqn.7).

$$\omega = \begin{pmatrix} 1 & \rho VR & \rho VF & \rho VO & \rho VC & \rho VD & \rho VP & \rho VS \\ \rho RV & 1 & \rho RF & \rho RO & \rho RC & \rho RD & \rho RP & \rho RS \\ \rho FV & \rho FR & 1 & \rho FO & \rho FC & \rho FD & \rho FP & \rho FS \\ \rho OV & \rho OR & \rho OF & 1 & \rho OC & \rho OD & \rho OP & \rho OS \\ \rho CV & \rho CR & \rho CF & \rho CO & 1 & \rho CD & \rho CP & \rho CS \\ \rho DV & \rho DR & \rho DF & \rho DO & \rho DC & 1 & \rho DP & \rho DS \\ \rho PV & \rho PR & \rho PF & \rho PO & \rho PC & \rho PD & 1 & \rho PS \\ \rho SV & \rho SR & \rho SF & \rho SO & \rho SC & \rho SD & \rho SP & 1 \end{pmatrix} + (-) \quad (7)$$

Where ρ (rho) stands for the pairwise correlation coefficient of the error terms corresponding to any two investments in SAIPs. The fundamental of this assumption is that equation (5) produces an MVP model that jointly represents decisions to invest in particular SAIPs. The off-diagonal elements in the covariance matrix represent unobserved correlation between the error terms of several latent SAIPs equations, which can affect the choice of technologies. If each of the off-diagonal elements becomes non-zero, then equation 7 carries important information on correlation.

Ordered probit model

An ordered probit model (OPM) was used for examining the extent of investments in SAIPs. Several options exist for measuring the extent of adoption including Tobit (Dadi *et al*, 2001; Mwaura *et al*., 2021), Cragg's double hurdle (Danso-Abbeam *et al*., 2019), Heckman two-stage (Legesse *et al*, 2001), ordered probit (Aryal *et al*., 2017; Kiconco *et al*., 2022; Mengsitu and Assefa, 2019; Teklewold *et al*., 2013), and count data models (Kolady *et al*., 2021). These approaches have their own limitations, for example, in using Tobit, Heckman two -stages, and double hurdle models, the proportion of land under given technologies is used as the dependent variable implying less attention is paid to the number of package technologies adopted. In using count data models like Poisson, the assumption that all technologies have the same probability of adoption has a serious problem while they have a different probability of being adopted (Teklewold *et al*., 2013).

Several studies have used an OPM model for estimating the extent/intensity of adoption of several technologies as the MVP models only consider probability choices (Aryal *et al*., 2017; Kiconco *et al*., 2022; Mengsitu and Assefa, 2019; Teklewold *et al*., 2013). The study conducted by Gonzaga *et al*. (2019) also used an ordered logit to estimate the intensity of the adoption of multiple technologies. These studies, however, are with limitations in considering the number of technologies (count data) as ordinal data and could have been estimated with a Poisson regression model. More specifically, ordered probit/logit models are often used to account for the ordinality nature of outcome variables. We, therefore, use an OPM to investigate the determinants of the extent of investment in a bundle of SAIPs by scaling down the number of eight SAIPs (unrestricted) to five (restrict) extent levels (ordinal). Following Wooldridge (2002), the OP model, which allows the response variable to have more than two ordinal categorical is specified as:

$$Y'_{hp} = \begin{cases} 1 \ \text{none of SAIPs} \\ 2 \ \text{low lovel } (1-3 \text{ SAIPs}) \\ 3 \ \text{moderate level } (4 \text{ SAIPs}) \\ 4 \ \text{high leve } (5-7 \text{ SAIPs}) \\ \ \text{very high } (8\text{SAIPs}) \end{cases} = \mathrm{X}'_{\mathrm{hp}}\beta + u_i \qquad (8)$$

Where $\mathrm{Y}'_{\mathrm{hp}}$ is a latent variable representing the extent of investments in SAIPs at a plot level, and u_i is the error term which is assumed to be normally distributed with a standard normal cumulative function. For m = 1-4 categories, following a standard ordered probability model, the probability of observing outcome i corresponds to:

$$\Pr\left(\text{outcome}_\mathrm{j} = \mathrm{i}\right) = \Pr(\mathrm{m}_{\mathrm{i}-1} < \mathrm{X}'_\mathrm{i}\beta + \mathrm{u}_\mathrm{i} < \alpha_\mathrm{i}) \qquad (9)$$

Where β is a vector of coefficients to be jointly estimated with the cut points α_1, α_2, …, α_{m-1} and m is the number of possible outcomes. For investment levels in SAIPs, both the likelihood ratio test (Greene and Hensher, 2010) and Akaike and

Bayesian information criterion (AIC and BIC) are used for comparison of unrestricted (L) and restricted (L^*) OP models. That is, λ=L*/L; 0≤λ≤1, and LR=2(ln L - ln L^*) ~ χ^2_m (m restriction), higher pseudo R^2 widely dispersed cut-points, and a smaller of AIC and/ or BIC indicates better goodness of fit.

Description and measurement of variables

The dependent variables in the MVP model include eight dummy variables corresponding to investments in improved crop varieties, inorganic fertilizers, pesticides, cereal-legume rotation, organic fertilizers, drainages, vegetation, and soil conservation structures. Brief description, measurement and summary statistics are given in Table 1.

Table 1. Description and summary statistics of dependent variables (N=1465)

Variables	Description	measures	Rates (%)
Improved variety	Used improved varieties of wheat, *tef*, barley, faba bean and others, but recycled at most four seasons for self-pollinated and ones for cross-pollinated (maize) crops	1=yes, 0=no	47
Cereal-legume rotation	Used legumes (mainly faba bean, field peas and chickpea) as a precursor crop for rotation	1=yes, 0=no	32
Inorganic fertilizer	Used at least one blended fertilizer (NPS/NPSB) or urea	1=yes, 0=no	84
Organic fertilizer	Used manure or compost	1=yes, 0=no	19
Pesticides	Used at least one pesticide (herbicide, fungicide, insecticide)	1=yes, 0=no	69
Drainage	Used either ditches or waterways	1=yes, 0=no	56
Vegetation	Used at least one of the forage trees, broadleaved trees or grasses	1=yes, 0=no	11
Soil conservation structures	Used at least one practice (terrace, soil bund, stone bund, soil-stone bund or fanya juu)	1=yes, 0=no	45

Source: Own survey, 2021

Based on economic theories, empirical evidence, and field observation, relevant explanatory variables were included in the econometric models (Aryal *et al*., 2017; Dorfman, 1996; D'Souza *et al*., 1993; Kassie *et al*., 2013; Kassie *et al*., 2015; Kolady *et al*., 2021; Teklewold *et al*., 2013). The explanatory variables included in this study can be reported as: (1) household characteristics, (2) asset endowments, (3) plot characteristics, (4) institutional factors, and (5) weather conditions. Brief descriptions, measures, summary statistics and expected sign of the variables are presented in Table 2.

Table 2. Description and summary statistics of explanatory variables

Variables	Description	Mean	Std. Dev.	Expected sign
Continuous				
Age	Age of the household head in years	46	11.4	+/-
Education	Years of schooling of the household members	5	2	+
Family size	Family size in number of working-age groups	4	2	+
Livestock	Livestock holding in tropical livestock unit (TLU)	6.3	3.8	+
Plot size	Size of the plot under consideration in ha	0.48	0.37	+-
Temperature	Point (kebele level) historical (1981-2018) maximum temperature in coefficient of variation (456 observation)	8.7	0.8	+-
Rainfall	Point (kebele level) historical (1981-2018) rainfall in coefficient of variation (456 observation)	122.6	19.3	+-
Plot distance	Distance of the plot from a residence in waking minutes	23	22	-
Diversification	Intensity of income diversification (index) (%)	30	25	-
Income	Cash income earned from crops sale (1000 ETB)	23.51	21.7	+
Salary	Monthly salary of the head of development agents (1000 ETB)	8.386	1.87	+
Peer farms	Number of adjacent peer farmers reported	2	2	+
Dummy				
Sex	Sex of the household head (male=1, female=0)	0.92	0.28	+/-
Certificate	If a household had a land certificate for his/her plot (Yes=1, No=0)	0.86	0.34	+
Credit	If a household received credit to buy inputs (Yes=1, No=0)	0.23	0.42	+
ACC	If a household had at least one plot in agricultural commercialization cluster (Yes=1)	0.18	0.38	+
Membership	Household's membership to agricultural cooperative (Yes=1, No=0)	0.31	0.46	+/-
Soil fertility status	Good (Yes=1, No=0)	0.26	0.44	+-
	Poor (Yes=1, No=0)	0.09	0.29	+/-
Slope of the plot	Gentle (Yes=1, No=0)	0.35	0.48	+/-
	Steep (Yes=1, No=0)	0.17	0.38	+/-
Location	The study area (West Shewa zone=1, North Shewa=0)	0.50	0.5	+/-
Perception	A household perceived that a plot was degraded (Yes=1)	0.29	0.45	+/-
Training	If a household received training on crop production (Yes=1, No=0)	0.54	0.5	+

Source: Own survey, 2021

Results and Discussion

Descriptive results

In the study area, smallholder farmers were found to produce a blend of crops (Figure 2). From a total of 1465 plots, most (36%) of the plots were covered by wheat followed by *tef* (24%), faba bean (13%), barley (12%) and other crops including maize, sorghum and potato (15% in sum). On average, 65%, 49%, 18%, 42%, and 30% of wheat, *tef*, faba bean, barley, and other crop plots were sown with improved crop varieties, respectively (Table 3). Legume-cereal-crop rotation was used on 47%, 26%, 56%, and 9% of wheat, *tef*, barley, and other crops plots, respectively. Inorganic fertilizers were applied on 92%, 88%, 69%, 77%, and 77% of wheat, *tef*, faba bean, barley, and other crop plots, respectively. Organic fertilizer was used on 19%, 9%, 25%, 32%, and 16% of wheat, *tef*, faba bean, barley, and other crop plots, respectively. About 76%, 75%, 59%, 58%, and 60% of wheat, *tef*, faba bean, barley, and other crop plots were treated with pesticides, respectively. Drainage practices were used in 58%, 62%, 53%, 51%, and 50% of wheat, *tef*, faba bean, barley, and other crop plots, respectively. Live plants (vegetation) were used as a component of SAIPs on 11%, 10%, 13%, 15%, and 12% of wheat, *tef*, faba bean, barley, and other crop plots, respectively. On average, 44%, 39%, 56%, 57%, and 38% of the plots covered by wheat, *tef*, faba bean, barley, and other crop had soil conservation practices, respectively.

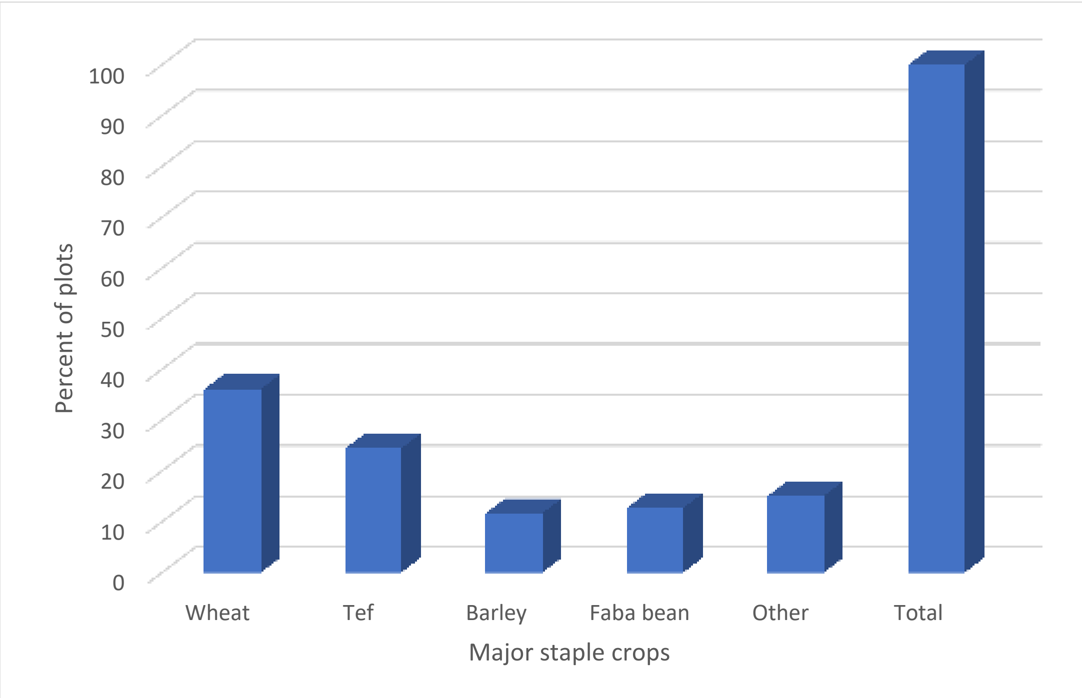

Figure 2. Distribution of plots by crops

Table 3. Summary statistics of SAIPs by plots of major crops

SAIPS	Major crops (% of plots with SAIPs)				
	Wheat (N=529)	*Tef* *(N=358)*	Faba bean (N=186)	Barley (N=171)	Other crops (N=221)
Improved variety	65	49	18	42	30
Cereal-legume rotation	47	26	X	56	9
Inorganic fertilizer)	92	88	69	77	77
Organic fertilizer	19	9	25	32	16
Pesticides	76	75	59	58	60
Drainage	58	62	53	51	50
Vegetation (agroforestry)	11	10	13	15	12
Soil conservation practices	44	39	56	57	38

Source: Own survey data, 2021. Note: X= cereals

The distribution of plots by the number of SAIPs farmers invested in combinations is presented in Table 4. The majority (79%) of the plots were treated with more than two SAIPs, about 25% of the plots were treated with more than half (4) of the SAIPs. The likelihood of investing from two to three SAIPs increased by 30% and from three to four SAIPs increased by 12%, implying that the likelihood of investing in a combination of SAIPs is higher than single/no SAIPs. Compared to a possible combination of practices, the descriptive results showed full (100%) combinations for two and all (eight) SAIPs, and 88%, 68%, 66%, 50%, and 43% of combinations for seven, six, three, five, and four SAIPs, respectively. These results imply that farmers only invest in a subset of practices; though applying the whole practice would be more profitable for different reasons (Mponenla *et al*., 2016). Moreover, descriptive results showed that most (77%) of plots were treated with both at least one external/purchased inputs such as improved seeds, inorganic fertilizers and pesticides, and sustainable practices such as land management practices (soil conservation structures, vegetation, and drainages,) and agronomic practices (cereal-legume rotation and organic fertilizers). The rest of the plots (14%) were treated with only external inputs while 8% of plots were treated only with sustainable practices, implying that the sole use of external inputs is much higher than the sole use of sustainable practices.

Table 4. Distribution of plots by SAIPs combinations

Number of SAIPs	Freq.	Percent	Cum.	Combinations		
				Possible (A)	Observed (B)	Proportion (B/A) *100
Zero (local)	16	1	1	1	1	100
One	62	4	5	8	1	13
Two	236	16	21	28	28	100
Three	421	29	50	58	38	66
Four	384	26	76	70	30	43
Five	200	14	90	56	28	50
Six	98	7	97	28	19	68
Seven	38	3	99	8	7	88
All (8) SAIPs	10	1	100	1	1	100
Only external inputs	207	14				
Only LWMPs	122	8				
Both practices	1121	76.5				
Total (N)	1465	100				

Source: Own survey, 2021

Regarding the extent of investments in a combination of SAIPs, descriptive results showed that plots were treated with different number of SAIPs (Figure 3). The majority (49%) of the plots received low level of SAIPs (1-3) followed by moderate (26%) and high (23%).

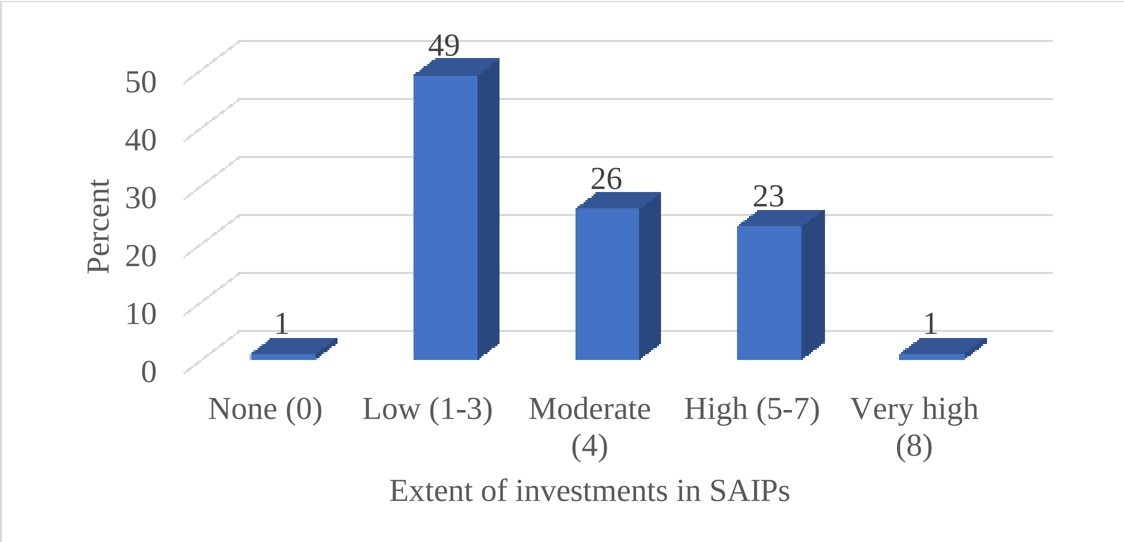

Figure 3. Extent of SAIPs

Econometric results

Factors influencing the choice decisions of investments in SAIPs

The MVP model is estimated with the maximum likelihood approach on plot level observation with Mundlak's average plot varying variables. The goodness of the MVP model is evaluated using the Wald test [Wald chi2 (208) =1937.6, p=0.000], implying that the null hypothesis that all regression coefficients of explanatory variables in each equation are jointly equal to zero is rejected. More specifically, the explanatory variables in each equation contribute significantly to explain the decision to invest in SAIPs. The correlation between the covariance of the error terms is evaluated using the likelihood ratio test [Wald chi2 (28) =270.29, p=0.000] result implies the null hypothesis of no correlation between covariance of the error terms between the decision to invest in SAIP across eight equations is also rejected. More specifically, the correlation coefficient among the eight equations is significantly different from zero at a 1% level, implying that the MVP model best fits the dataset, which accounts for the unobserved correlations across decisions to invest in multiple SAIPs.

Table 5 presents the simultaneous estimates of explanatory variables across eight equations and the correlations between error terms from MVP model results. It provides the direction and coefficient of the driving forces behind farmers' choice decisions to invest in SAIPs. Results showed that the choice decision to invest in SAIPs is different and the factors driving the decision of each of them are also different but interrelated implying the heterogeneity in the decision to invest in SAIPs. Apart from the main variables of interest, the estimates of the MVP model revealed that a number of hypothesized household and plot characteristics, asset endowments, institutional and environmental factors had a significant and differential impact on the choice decision to invest in SAIPs.

Male headed households are more likely to invest in improved seeds and inorganic fertilizers than their counterparts. This is consistent with the findings by Therioult *et al*. (2016). Nigussie *et al.* (2018) also reported that gender of the household increases inorganic fertilizers adoption. However, it is in contrast with the findings by Ndiritu *et al*. (2014), who found gender had no effect on the adoption of improved seed and chemical fertilizers, and Yirga *et al*. (2015), who found that household type in terms of gender negatively affects adoption of improved barley seeds. The results indicate that female-headed managed plots have less chance of receiving improved crop varieties and inorganic fertilizers implying that technology adoption is not gender-neutral. The possible explanation for this is that female-headed households own fewer resources, information, and credit on these inputs which may limit them to use. We also found that the gender of the household declines the decision to invest in drainages, implying that male-headed households are less likely to use drainages on their plots. In other words, plots managed by female-headed households are more treated with drainage. The possible explanation for this is that female-headed households mainly operate their own plots, in which drainage activities can be easily implemented with oxen plows.

Age of the household head was found to positively influence farmers' decisions to invest in both cereal-legume rotation and soil conservation practices. This indicates that plots managed by older farmers were more treated with legumes as a precursor crop and soil conservation practices. This is consistent with the findings by Theriault *et al*. (2016) and Nigussie *et al*. (2018) who found that age of the household head impacts the adoption of soil conservation practices. The possible explanation for this is that older farmers have more experience with these practices than their counterparts. The results showed that the average years of schooling of the household members positively impacted farmers' decisions to invest in improved seeds and declined farmers' decisions to invest in soil conservation and vegetation (agroforestry) practices. This is in line with findings by Asfaw *et al*. (2016) who found that education of the household positively impacted the adoption of modern inputs including improved seeds and Nigussie *et al*. (2018) who found that education declines the adoption of soil and water conservation practices. The possible explanation for this is that farmers are at a level of education (5 years of schooling on average). The results highlight the important role of a household's education for the choice to invest in improved seeds because it helps to acquire more information about improved seeds and interpret the advantages.

The results revealed that family size in the working-age group negatively influenced farmers' decisions to invest in most of SAIPs including improved seeds, drainages, and soil conservation practices, unexpectedly. This indicates that plots managed by a greater number of household members are less likely to receive improved seeds, drainages, and soil conservation practices. This is in line with the findings by Jabbar *et al*. (2020) who found that family size negatively affected adoption of agricultural technologies. However, Ndiritu *et al*. (2014) and Kassie *et al*. (2015) found family size positively correlated with the adoption of soil and water conservation practices. The possible explanation for this is persons in the working-age group may engage in various non-farm activities (observed) which may limit them to invest their time in labor-intensive practices and have liquidity constraints to buy improved seeds.

Livestock ownership positively and significantly influenced farmers' decisions to invest in organic fertilizers (manure/ compost), but declined the use of inorganic fertilizers. This implies that farm households with greater numbers of livestock are more likely to invest in organic fertilizers but less likely to invest in inorganic fertilizers. This is in line with the findings by (Teklewold *et al*., 2013; Ndiritu *et al*., 2014; Kassie *et al*., 2015) who found that livestock holding positively affected adoption of manure. This might be for the obvious reason that the availability of manure depends on the size of livestock a household owns. The negative effect on the choice of inorganic fertilizers indicates that the use of manure/compost substitutes inorganic fertilizers use.

The results revealed that plot size positively and significantly influenced the choice decisions of investments in drainage, but reduced choice decisions to invest in improved seeds, legume-cereal rotation, inorganic fertilizers, manure/compost, pesticides, vegetation, and soil conservation practices. This is similar to the findings by Kassie *et al*. (2015), Asfaw *et al*. (2016) and Nigussie *et al*. (2018) who found that increased farm size positively affected water conservation practices. It is contrary to the findings by Kassie *et al*. (2013) who found that plot size positively influenced the decision to invest in improved seeds, and Theriault *et al*. (2016) who found that plot size positively influenced the adoption of yield-enhancing inputs (improved seeds and mineral fertilizers) and yield-protecting inputs (herbicides, fungicides, and insecticides). This implies that large-sized plots are more likely to be treated with drainage practices compared to other SAIPs.

Temperature and rainfall are the most important weather variables which condition the use of modern inputs and soil-restoring practices. The results revealed that greater variability in maximum temperature positively and significantly influenced farmers' choice decisions to invest in drainage and soil conservation practices. Jabbar *et al*. (2020) also reported that high variability in temperature positively impacts the adoption of improved seeds, rotation, and organic fertilizers. We also found that greater variability in rainfall positively and significantly influenced farmers' choice decision to invest in improved seeds, inorganic fertilizers, drainage, and declined farmers' choice decision to invest in soil conservation practices. This is in line with findings by Theriault *et al*. (2016) who reported that an increase in the coefficient of variation of rainfall positively impacts the adoption of yield-enhancing practices. This indicates that rainfall with less variability means high rainfall which may cause waterlogging (common in highland areas) which suppresses crop growth and production. However, it is contrary to findings by Asfaw *et al.* (2016) who found that greater variability in rainfall is inversely related to the adoption of modern inputs (improved seeds and mineral fertilizers) which is common in water stress areas. Findings suggest that smallholder farmers are responding to climate variables diversely depending on the availability of SAIPs and the weather conditions taken into account.

Secure land tenure is believed to encourage farmers to invest in sustainable practices on their farms. The results revealed that land security in terms of having a land certificate positively and significantly influenced farmers' choice decisions to invest in drainage practices on their plots, holding other things constant. However, getting a land certificate was found to decline the likelihood of investments in inorganic fertilizers. The results indicate that plots with a land certificate are more likely to be drained, and plots without a land certificate are mainly rented/shared in-plots, which may limit the adoption of other sustainable practices. This is contrary to the findings by Theriault *et al*. (2016) who found that tenure security positively affects the adoption of yield-enhancing inputs including inorganic fertilizers.

Plot distance from a residence is an important variable to limit investment in agricultural practices, mainly soil-restoring activities. The results revealed that plots away from a residence are more likely to receive improved seeds but less likely to be treated with vegetation and soil conservation practices. This is similar to the findings by Teklewold *et al.* (2013), Ndiritu *et al.* (2014) and Asfaw *et al.* (2016) who found that plot distance positively affected adoption of improved seeds but negatively affected soil conservation practices. This implies that plots far away plot managers' residences are less likely to receive most sustainable practices implying distance bears more transaction costs via transportation, mainly for investments in labor-intensive practices.

Rural income diversification could be an important variable that limits investments in agricultural technologies through resources (labor, land, and finance) allocations. The results revealed that a relatively high level of income diversification positively and significantly influenced farmers' choice decisions to invest in cereal-legume rotation, organic fertilizers, pesticides, and vegetation. The results indicate that plots managed by households with more income-diversification are more likely to receive more than half of the SAIPs, implying a linkage exists between income diversification and investments in SAIPs. The possible explanation is earnings from diversification leverage to invest in the components of SAIPs. This is contrary to the findings by Nigussie *et al*. (2018) who reported income diversification (off-farm) negatively affects the adoption of soil and water conservation practices and inorganic fertilizers.

Farm income is an important element for rural livelihoods which may limit investments in agricultural technologies (Benitez-Altuna *et al*., 2021). As expected, we found that cash income from the sale of staple crops positively and significantly influenced farmers' decisions to invest in almost all SAIPs including improved seeds, legume-cereal rotation, inorganic fertilizers, manure/compost, pesticides, vegetation, and soil conservation practices. The results indicate that plots managed by households with higher cash crop income are more likely to receive almost all sustainable intensification practices. This implies that there exists a positive relationship between income and investments in agricultural technologies. This finding is in line with findings by Teklewold *et al*. (2017) who found that net farm income positively impacted drainage (farm water management), improved seeds, and inorganic fertilizers.

The agricultural commercialization cluster (ACC) is believed to enable smallholder farmers to engage in higher productivity and market-oriented production through information and input provision (FAO, 2010). The results revealed that ACC positively and significantly influenced farmers' decisions to invest in improved crop varieties and farm water management (drainages). This is in line with the findings by Ochieng *et al*. (2016) who found that ACC enhanced adoption of improved seeds and fertilizers. The results indicate that plots consolidated in ACC are more likely to receive improved seeds and drainages. This is because ACC mostly targets yield-enhancing improved crop varieties and farm water management often done in consensus with neighboring farm owners in the cluster.

The results revealed that access to credit positively and significantly influenced farmers' decisions to invest in vegetation and soil conservation practices. The results indicate that plots managed by households who received credit are more likely to receive vegetation and soil conservation practices. This is contrary to the findings by Ndiritu *et al*. (2014) who reported that access to credit less likely impacted the decision to invest in improved seeds, soil and water conservation practices, and minimum tillage. Other findings by Nigussie *et al*. (2018) reported that credit positively impacted manure application and Teklewold *et al*. (2013) also reported that credit influences the adoption of improved seeds and inorganic fertilizers.

Membership in any type of agricultural cooperative is believed to influence the adoption of agricultural technologies (Wossen *et al*., 2013). The results revealed that membership to agricultural cooperatives positively and significantly influenced farmers' decisions to invest in improved crop varieties, inorganic fertilizers and vegetation. This is in line with the findings by Kolade and Harpham (2014), and Hasen (2015) and Manda *et al*. (2020 who found that cooperative membership influenced adoption of improved seeds and fertilizers. The results indicate that plots managed by members of a cooperative are more likely to receive improved seeds, inorganic fertilizers, and vegetation. The results suggest the need for policies that promote agricultural cooperative and improve their effectiveness for scaling-out/ up of improved technologies.

Regarding plot characteristics, the results showed that plots with moderate to poor soil fertility conditions are more likely to receive farm water management and soil conservation practices, but they are less likely to receive cereal-legume rotation. Farmers' choice decision to invest in soil conservation practices is more likely on plots with steep topography. Plots with gentle to medium topography are less likely to receive soil conservation practices, and plots with steep topography are less likely to receive water management practices. The results suggest that investments in sustainable practices are heterogeneous based on plot-specific attributes. This is consistent with the findings by Teklewold *et al*. (2013), Kassie *et al*. (2015), Asfaw *et al*. (2016), and Theriault *et al*. (2016) who found that plots with steep slope received soil and conservation practices.

The results revealed that, on average, the amount of salary paid to extension (development) agents at the *kebele* level positively and significantly influenced farmers' decision to invest in improved seeds, inorganic fertilizers, and drainages, and declined the use of soil conservation practices. This is similar to the findings by Ndiritu *et al.* (2014), Asfaw *et al*. (2016), Theriault *et al*. (2016) and Jabbar *et al*. (2020) who found that extension contact enhanced adoption of external inputs. The results indicate extension agents with a better salary stay in their mandate *kebeles* to make frequent contact with farmers and share information, and hence plots in this area are more likely to receive these practices. Nigussie *et al*. (2018) also found that extension service negatively affects soil conservation, vegetation, and farm water management practices. The results revealed that training positively and significantly affects farmers' choice to invest in improved seeds and inorganic fertilizers. The results suggest the need for policies that strengthen extension systems to include soil-restoring practices in their daily routines.

Farmers usually learn new farming practices from their neighboring farms either through copying the same practices or teaching each other. Peer farmers and farms are alternative information sources on technology uptake (Adegbola and

Gardebreok, 2007). The results revealed that having a greater number of peer farms near the plots positively and significantly influenced the decision to invest in water management practices, but reduced the uptake of manure/compost. In other words, plots surrounded by a greater number of peer farms are more likely to receive drainages but less likely to receive manure/compost. The results also showed that plots perceived degraded are more likely to receive water management and vegetation practices.

With respect to study location which reflects unobservable spatial differences, the results revealed the differential effect of location on the decision to invest in SAIPs. *Ceteris paribus*, farmers' decision to invest in improved seeds, inorganic fertilizers, and manuring practices in the west Shewa zone are higher. Differently, investment in legume rotation, farm water management, and soil conservation by farmers were lower in the West Shewa zone. The results suggest that efforts to increase short term investments in improved crop varieties and inorganic fertilizers (yield-enhancing inputs) would likely be effective if directed towards north Shewa in the Amhara region, and long-term investments in soil-restoring practices of legume rotation, farm water management, and soil conservation would be effective if directed towards in west Shewa zone in Oromia region. This is consistent with the findings of Yirga *et al*. (2015) who found study sites affected adoption of agricultural technologies.

Study results also revealed that some of the sustainable agricultural intensification practices show complementarity/synergy while some others show substitutability/trade-offs. More specifically, improved variety and inorganic fertilizer, pesticides and inorganic fertilizer, vegetation, and organic fertilizer, and soil conservation practices and vegetation are positively correlated at a 1% significant level implying high complementarity between them. A negative correlation is observed between inorganic and organic fertilizers, pesticides and organic fertilizers, vegetation and cereal-legume rotation, soil conservation practices and variety, rotation and fertilizer use, implying investment in soil conservation practices can significantly reduce investments in other external inputs.

Table 5. Estimates of the multivariate probit model with Mundlak's approach

Variables	Variety Coefficient (SE)	Rotation Coefficient (SE)	Fertilizer Coefficient (SE)	Manure/com. Coefficient (SE)	Pesticides Coefficient (SE)	Drainage Coefficient (SE)	Vegetation Coefficient (SE)	Soil cons Coefficient (SE)
Sex	0.363** (0.142)	-0.086 (0.149)	0.356** (0.168)	-0.090 (0.175)	0.136 (0.136)	-0.313** (0.136)	-0.246 (0.206)	0.048 (0.157)
Age	-0.002 (0.004)	0.008* (0.004)	-0.004 (0.004)	-0.001 (0.004)	-0.005 (0.004)	-0.005 (0.003)	0.004 (0.005)	0.008** (0.004)
Education	0.057*** (0.020)	-0.027 (0.022)	-0.002 (0.027)	-0.009 (0.026)	-0.012 (0.020)	0.002 (0.020)	-0.089*** (0.034)	-0.042* (0.024)
Family size	-0.072** (0.029)	-0.011 (0.031)	0.053 (0.038)	-0.013 (0.036)	-0.028 (0.029)	-0.102*** (0.028)	0.080* (0.045)	0.002 (0.034)
Livestock	-0.039 (0.080)	-0.136 (0.086)	-0.330*** (0.115)	0.395*** (0.104)	-0.015 (0.078)	0.032 (0.079)	0.010 (0.122)	-0.002 (0.093)
Plot size	-1.451*** (0.156)	-1.062*** (0.156)	-1.135*** (0.198)	-1.192** (0.170)	-0.285* (0.155)	0.271* (0.139)	-1.007*** (0.211)	-1.341*** (0.162)
Temperature	-0.575 (0.385)	-0.695 (0.433)	-0.390 (0.573)	0.575 (0.518)	-0.649 (0.401)	0.983** (0.374)	0.471 (0.666)	0.886* (0.455)
Rainfall	1.016** (0.398)	0.783* (0.457)	3.587*** (0.956)	0.519 (0.576)	-0.628 (0.394)	2.439*** (0.411)	0.292 (0.777)	-1.509*** (0.540)
Land certificate	0.055 (0.121)	0.125 (0.133)	-0.374* (0.186)	0.072 (0.159)	-0.039 (0.121)	0.446*** (0.119)	0.019 (0.208)	0.160 (0.140)
Plot distance	0.121*** (0.033)	-0.007 (0.035)	-0.219*** (0.042)	-0.015 (0.038)	-0.067** (0.032)	-0.017 (0.032)	-0.106** (0.046)	-0.062* (0.037)
Extent of income diversification	-0.074 (0.167)	0.384** (0.181)	0.112 (0.213)	0.491** (0.201)	0.303* (0.165)	0.067 (0.162)	0.650*** (0.250)	0.126 (0.188)
Crop income	1.757*** (0.151)	1.284*** (0.149)	1.411*** (0.188)	1.206*** (0.162)	0.482*** (0.145)	-0.104 (0.131)	0.988*** (0.199)	1.470*** (0.153)
Plot clustering (ACC)	0.231** (0.103)	0.106 (0.106)	0.161 (0.126)	-0.072 (0.114)	0.145 (0.100)	0.238*** (0.102)	-0.134 (0.136)	-0.385 (0.120)
Credit	0.039 (0.091)	-0.172* (0.097)	0.149 (0.123)	-0.015 (0.109)	-0.088 (0.089)	0.035 (0.090)	0.466*** (0.120)	0.400*** (0.105)
Membership to coop	0.215*** (0.080)	0.047 (0.085)	0.431*** (0.112)	0.105 (0.094)	-0.010 (0.080)	0.060 (0.079)	0.314*** (0.116)	0.010 (0.093)

Table 5. (continued)

Variables	Variety	Rotation	Fertilizer	Manure	Pesticides	Drainage	Vegetation	Soil cons
	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)
Soil fertility (moderate)	0.105 (0.121)	-0.065 (0.131)	0.203 (0.159)	0.111 (0.149)	0.049 (0.122)	0.211* (0.117)	-0.031 (0.194)	0.359** (0.139)
Soil fertility (poor)	-0.154 (0.210)	-0.493** (0.225)	-0.068 (0.250)	0.082 (0.244)	-0.038 (0.202)	0.462** (0.202)	-0.209 (0.306)	0.433* (0.231)
Slope (gentle to medium)	0.058 (0.128)	-0.008 (0.134)	-0.019 (0.161)	0.101 (0.154)	-0.099 (0.127)	-0.055 (0.124)	0.087 (0.202)	-0.497*** (0.147)
Slope (steep)	-0.111 (0.119)	-0.121 (0.126)	-0.230 (0.148)	0.072 (0.142)	-0.106 (0.118)	-0.360*** (0.116)	-0.117 (0.185)	0.250* (0.135)
Salary of DAs	2.237*** (0.340)	0.341 (0.404)	1.936*** (0.548)	-0.752 (0.506)	-0.027 (0.355)	0.744** (0.325)	0.561 (0.670)	-1.865*** (0.402)
Training on crop production	0.224*** (0.079)	-0.088 (0.084)	0.372*** (0.100)	-0.080 (0.095)	0.080 (0.078)	-0.027 (0.077)	0.152 (0.124)	-0.043 (0.092)
Peer farms	-0.007 (0.015)	-0.013 (0.016)	-0.019 (0.018)	-0.067*** (0.018)	-0.024 (0.015)	0.037** (0.015)	0.001 (0.021)	-0.013 (0.017)
Perception to plot degradation	0.061 (0.090)	0.129 (0.094)	-0.104 (0.113)	0.277 (0.102)	-0.039 (0.088)	0.425*** (0.089)	0.633*** (0.118)	0.907 (0.102)
Location	1.663*** (0.208)	-0.737*** (0.235)	3.035*** (0.452)	1.096*** (0.294)	-0.428 (0.206)	-1.515*** (0.208)	0.490 (0.390)	-2.567*** (0.265)
Constant	-40.691*** (3.928)	-20.249*** (4.423)	-42.273*** (6.948)	-13.202*** (5.211)	-1.448 (3.854)	17.072*** (3.691)	-21.700*** (7.320)	2.509 (4.492)
Number of observations (plots)	1465							
Number of observations (HHs)	385							
Wald chi2 test (208)	1937.6							
Prob >chi2	0.000							
Log likelihood	-5249.49							

Table 5. (continued)

SAIPs	Variety	Rotation	Fertilizer	Manure	Pesticides	Drainage	Vegetation	Soil conservation
Rotation	0.258*** (0.045)							
Fertilizers	0.259*** (0.054)	0.134** (0.055)						
Manure/com	-0.015 (0.051)	-0.040 (0.052)	-0.408*** (0.050)					
Pesticides	0.012 (0.044)	-0.023 (0.046)	0.482*** (0.044)	-0.312*** (0.047)				
Drainage	-0.076* (0.043)	-0.025 (0.045)	-0.012 (0.050)	-0.024 (0.048)	0.054 (0.042)			
Vegetation	-0.087 (0.062)	-0.150** (0.064)	-0.089 (0.068)	0.174** (0.068)	-0.183*** (0.064)	-0.018 (0.064)		
Soil conservation	-0.148*** (0.049)	-0.106** (0.052)	-0.180*** (0.058)	-0.011 (0.053)	-0.016 (0.049)	0.028 (0.049)	0.138** (0.063)	

Notes: LR test of rho21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho81 = rho32 = rho42 = rho52 = rho62 = rho72 = rho82 = rho43 = rho53 = rho63 = rho73 = rho83 = rho54 = rho64 = rho74 = rho84 = rho65 = rho75 = rho85 = rho76 = rho86 = rho87 = 0: chi2(28) = 270.291 Prob > chi2 = 0.000; Significance level: *=10%; **=5% and ***=1%

The ordered probit model results

In the previous section, we investigated factors that influence farmers' choice decisions to simultaneously invest in particular SAIPs, taking into account the fact that the decision may be potentially correlated. Therefore, an ordered probit model examines factors that influence the extent of investments in various combinations of SAIPs (scaling the total number of SAIPs applied). Moreover, the variables that influence farmers' choice decisions to invest may differently influence the extent of investments in SAIPs.

The estimates of the restricted and unrestricted ordered probit model and results of marginal effects of explanatory variables are presented in Table 6. Although the magnitude of coefficients is different, the same variables were significant in both restricted and unrestricted models. We rejected the null hypothesis that the restricted and unrestricted ordered probit models are the same (χ^2_3 =12.838: Prob >chi2 = 0.000) with three degrees of freedom. Higher values of Pseudo R^2 (0.198), widely dispersed cut-points and a decrease in AIC and BIC magnitude implies a better improvement in the model's goodness-of-fits. Most of the explanatory variables such as coefficient of variation in maximum temperature and rainfall, income diversification, crop income, agricultural commercialization cluster, access to credit, membership to cooperative, perceived soil fertility and plot's slope condition, and extension services measured in monthly salary of extension agents had a strong positive relationship with the extent of investments in SAIPs. However, family size, plot size, steep topography, study sites, and a number of peer farms showed a strong negative relationship with the extent of investments in a combination of SAIPs.

Regarding the marginal effects, the results revealed that family size reduced the extent of investments in moderate to a high level of SAIPs by 1% and 1.6%, respectively. Plots operated by farm households with more livestock holding received a high level of investment in more than four SAIPs. Plot size was found to reduce the extent of investments in a bundle of SAIPs. More specifically, it drastically reduces moderate, high, and very high levels of investments by 27%, 45.6%, and 0.3%, respectively. Rainfall in coefficient of variation was found to increase the extent of investments in a greater number of SAIPs, this may be the same possible reason mentioned in above. Land tenure security in terms of having a land certificate was found to increase the extent of investments in moderate to a high level of SAIPs by 3.1% and 4.4%, respectively. Plots operated by farm households with greater income diversification received moderate to a high level of SAIPs and increased by 3.8% and 6.4%, respectively.

Cash income from staple crops sales was found to substantially increase the extent of investments in moderate to a high level of SAIPs at the plot level by 32.4%, 54.8%, and 0.4%, respectively. Agricultural commercialization clustering was found to increase the extent of investment in moderate to high levels of SAIPs by 2.7% and 5.5%, respectively. Access to credit to buy agricultural inputs was found to increase the extent of investments in moderate to high levels of SAIPs by 2% and 3.7%, respectively. Membership to agricultural cooperatives was found to increase the extent of investments in moderate to very high levels of SAIPs by 3.7%, 7.2% and 0.1%, respectively. Plot characteristics such as fertility and topography were found to influence the extent of investments in various combinations of SAIPs. Extension services were also found to substantially increase the extent of investments in moderate to very high levels of SAIPs by 12.2%, 20.6% and 0.2%, respectively. Plots perceived degraded were found to receive an increased number of SAIPs; more specifically, it increases the extent of investments in moderate to a very high level of SAIPs by 6.3%, 15.5%, and 0.2%s, respectively. The results also showed that study sites reduce the extent of investments in a multiple of SAIPs (from moderate to high level).

Table 6. Coefficient estimates of the ordered probit model

Variables	Restricted (fixed-effect) OP model							Unrestricted (random) OP model	
	Coefficient	RoSE	Marginal effects on each outcome					Coefficient	RoSE
			None (1)	Low (2)	Moderate (3)	High (4)	Very high (5)		
Sex	0.131	0.135	0.001	-0.052	0.021	0.031	0.000	0.118	0.111
Age	0.002	0.003	-0.000	-0.001	0.000	0.001	0.000	0.000	0.003
Education	-0.010	0.019	0.000	0.004	-0.001	-0.002	-0.000	-0.007	0.016
Family size	-0.065**	0.029	0.000	0.025**	-0.010**	-0.016**	-0.000	-0.058**	0.024
Livestock	0.005	0.068	-0.000	-0.002	0.001	0.001*	0.000	0.007	0.058
Plot size	-1.826***	0.203	0.008***	0.721***	-0.270***	-0.456***	-0.003**	-1.566***	0.177
Temperature	0.092	0.348	-0.000	-0.036	0.014	0.023	0.000	0.279	0.287
Rainfall	1.511***	0.319	-0.006**	-0.597***	0.223***	0.377***	0.003*	1.284***	0.271
Land certificate	0.189*	0.105	-0.001	-0.074*	0.031*	0.044*	0.000	0.175**	0.086
Plot distance	-0.046	0.030	0.000	0.018	-0.007	-0.012	-0.000	-0.081***	0.026
Income diversification	0.257*	0.143	-0.001	-0.101*	0.038*	0.064*	0.000	0.277**	0.127
Crop income	2.196***	0.201	-0.009***	-0.867***	0.324***	0.548***	0.004**	1.900***	0.173
ACC	0.209**	0.092	-0.001**	-0.082**	0.027**	0.055**	0.000	0.214**	0.084
Credit	0.143*	0.079	-0.001	-0.056*	0.020*	0.037*	0.000	0.187***	0.072
Membership to coop	0.276***	0.068	-0.001	-0.109***	0.037***	0.072***	0.001*	0.227***	0.061
Soil fertility (mod.)	-0.049	0.187	0.000	0.019	-0.007	0.012	-0.000	-0.047	0.160
Soil fertility (poor)	0.227*	0.134	-0.001	-0.089*	0.035	0.055*	0.000	0.222*	0.115
Slope (gentle)	-0.055	0.113	0.000	0.022	-0.008	-0.014	-0.000	-0.090	0.098
Slope (steep)	-0.178*	0.101	0.001	0.070*	-0.029	-0.042*	-0.000	-0.186**	0.087
Salary of DAs	0.826***	0.296	-0.003*	-0.326***	0.122***	0.206***	0.002*	0.787***	0.23
Training	0.044	0.068	-0.000	-0.018	0.007	0.011	0.000	0.101*	0.059
Peer farms	-0.023*	0.013	0.000	0.009*	-0.003*	-0.006*	-0.000	-0.019*	0.011
Perception to degradation	0.562***	0.078	0.002**	-0.218***	0.063***	0.155***	0.002***	0.532***	0.071
Location	-0.414**	0.171	0.002*	0.163**	-0.061**	-0.103**	-0.001	-0.468***	0.146

Notes: *** p<0.01, ** p<0.05, * p<0.1

Table 6. (Continued)

Variables	Coefficient	RoSE	Coefficient	RoSE
μ_1	34.916***	3.766	30.656***	3.115
μ_2	37.934***	3.800	31.485***	3.115
μ_3	38.902***	3.807	32.457***	3.123
μ_4	41.224***	3.830	33.442***	3.13
μ_5			34.384***	3.139
μ_6			35.139***	3.144
μ_7			35.88***	3.149
Chi-square	522.789		533.663	
Prob > chi2	0.000		0.000	
Pseudo r-squared	0.198		0.128	
Log-likelihood	-1318.176		-2258.	
LR	1880.492, χ^2_3 =12.838 (Prob >chi2 = 0.000)			
AIC	2696.353		4584.845	(1888.5)
BIC	2855.041		4764.692	(1909.6)
Observation (plots)	1465			
Observation (households)	385			

Notes: *** *p<0.01*, ** *p<0.05*, * *p<0.1*

Conclusions and Implications

Investment in SAIPs is vital for increasing crops productivity, reducing poverty and hunger, and ensuring food security in Ethiopia. This study attempts to examine the determinants of decisions and extent of investments in multiple SAIPs by farm households using 1465 plot level observations. We employed a MVP model to examine determinants of farmers' decisions to invest in multiple SAIPs, and an OPM to investigate factors influencing extent of investments in SAIPs. The SAIPs considered include improved seeds, inorganic fertilizers, pesticides, organic fertilizers, cereal-legume rotation, vegetation, drainages, and soil conservation structures. Results from the MVP model show that while there is heterogeneity with regard to the determinants of investments in any of the eight SAIPs, variables such as gender and age of the household head, average education level of family members, livestock holding, crop income, membership to cooperatives, access to extension and credit services, training, agricultural commercialization cluster, income diversification, rainfall and maximum temperature, and perceived poor soil fertility and steep slope conditions were found to influence the choice decisions of farmers to invest in multiple SAIPs. The results demonstrate that the same factors display different influences and relationships (positive or negative) on decisions to invest in SAIPs. For instance, gender has a positive influence on improved seeds and inorganic fertilizers use, but a negative influence on drainage.

Results also reveal that there are strong complementarities between improved seeds and inorganic fertilizers, improved seeds and rotation, inorganic fertilizers and rotation, soil conservation and vegetation, and substitutability between inorganic fertilizers and manure/compost, inorganic fertilizers and soil conservation, and pesticides and vegetation, and other SAIPs, implying the interdependence of investments in SAIPs. Studies that consider investments in SAIPs in isolation ignore important correlation effects and potentially generate biased model estimates, and overlook heterogeneity effects of the same variables. These significant economic relationships are good characteristics of MVP model outcomes that cannot be captured by univariate models. Results from an ordered probit model also show that the extent of investments in a number of SAIPs is influenced by most of the same variables suggesting that decisions to invest and the extent of investment in SAIPs are governed by the same factors.

Our results offer important policy implications in Ethiopia and other developing countries. First, it can be concluded that SAIPs are interdependent. This suggests that the interdependency nature of farming practices should be considered in designing effective plans for development and diffusion of SAIPs by development practitioners. The knowledge on cross-SAIPs correlation offer policy changes for the convenience of promoting SAIPs jointly to take benefits of their complementarities/synergies, and help to target resource saving production from substitutability of practices. Last, given that several factors influence investments in different blend of SAIPs, policymakers should take into consideration the heterogeneity effects of policy variables including gender, extension, credit, income and plot specific features. This will require provision of gender-based extension and credit services and instant information on weather conditions to make farmers to benefit from SAIPs. This study contributes to the existing SAIPs uptake literature by highlighting the important variables which influence decisions to invest and extent of investments in multiple SAIPs in Ethiopia. Further research that explores the output, peril and wellbeing and environmental implications will be helpful.

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References

Abera W., M. Assen and J. Budds. 2020. Determinants of agricultural land management practices among smallholder farmers in the Wanka watershed, northern highlands of Ethiopia. *Land Use Policy*, 99, p. 1-9.

Adegbola P. and C. Gardebroek. 2007. The effect of information sources on technology adoption and modification decisions. *Agricultural Economics*, 37, p. 55-65.

Ahmed H.M. 2015. Adoption of multiple agricultural technologies in maize production of the Central Rift Valley of Ethiopia. *Studies in Agricultural Economics*, 117, p. 162-168.

Amsalu A. and J. de Graff. 2007. Determinants of adoption and continued use of stone terraces for soil and water conservation in an Ethiopian highland watershed. *Ecological economics,* 61, p. 294-302.

Aryal P.J., T.B. Sapkota, A. Khatri-Chhetri, K. Kassie, B.D. Rahut and S. Maharjan. 2017. Adoption of multiple climate smart agricultural practices in the Gangetic plains of Bihar, India. *International Journal of Climate Change Strategies & Management,* 10 (3), p. 407-427. DOI 10.1108/IJCCSM-02-2017-0025

Asfaw S., F. Di Battista and L. Lipper. 2016. Agricultural Technology Adoption under Climate Change in the Sahel: Micro-evidence from Niger. *Journal of African Economies*, p. 1-33. DOI: 10.1093/Jae/ejw005.

Asrat P. and B. Simane. 2017. Household- and plot-level impacts of sustainable land management practices in the face of climate variability and change: empirical evidence from Dabus Sub-basin, Blue Nile River, Ethiopia. *Agriculture & Food Security*, p. 1-12.

Beitez-Altuna F., J.Trienekens, V.C. Materia and J. Bijman. 2021. Factors affecting the adoption of ecological intensification practices: A case study in vegetable production in Chile. *Agricultural Systems*, 194, p. 1-13.

Cochran W. 1977. Sampling techniques. 3rd edition. John Wiley and Sons. Inc. New York.

CSA (Central Statistical Agency of Ethiopia). 2021. Report on Area and Production of Major crops. Ethiopian Agricultural Sample Survey Private Peasant Holdings, *Meher* Season (2020/21) – Volume I. Statistical Bulletin 590, Addis Ababa: CSA.

Dadi, L., M. Burton and A. Ozanne. 2001. Adoption and intensity of fertilizer and herbicide use in the central highlands of Ethiopia. Agricultural Economics Research, Policy and Practice in Southern Africa, 40(3), p. 316-333.

Danso-Abbeam G., G. Dagunga, and D.S. Ehlakpor. 2019. Adoption of Zai technology for soil fertility management: evidence from Upper East region, Ghana. *Journal of Economic structures,*8(32), p. 1-14.

Di Falco S., M. Veronesi and M. Yesuf. 2011. Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *Amer. J. Agr. Econ*., 93(3), p. 829-846.

Dorfman J. 1996. Modeling Multiple Adoption Decisions in a Joint Framework. *American Journal of Agricultural Economics,* 78, p. 547-557.

D'Souza G., D. Cyphers, and T. Phipps. 1993. Factors affecting the adoption of sustainable agricultural practices. *Agricultural & Resource Economics Review, p.* 159-165.

EEA (Ethiopian Economic Association). 2021. State of the Ethiopian Economy 2020/2021: Economic development, Population dynamics, and Welfare. Addis Ababa, Ethiopia.

Etongo D., T.E. Epule, N.I. Djenontin and M. Kannine. 2018. Land management in rural Burkina Faso: the role of socio-cultural and institutional factors. *Natural Resources Forum,* p. 1-13. DOI: 10.1111/1477-8947.12153

FAO, IFAD, UNICEF, WFP and WHO. 2021. *The State of Food Security and Nutrition in the World 2021*. *Transforming food systems for food security, improved nutrition and affordable healthy diets for all*. Rome.

FAO (Food and Agricultural Organization of the United Nations). 2010. Agro-based Cluster in Developing Countries: Staying Competitive in a Globalized Economy. Agricultural Management, Marketing and Finance Occasional Paper, 25.

Feder G., R.E. Jus and D. Zilberma. 1985. Adoption of Innovations in developing countries. *Economic Development & Cultural Change, 33(2), p.* 255-298. http://www.jstor.org/stable/1153228 .

Gashaw T., A. Bantider and H. Gebresilassie. 2014. Land degradation: Causes, impacts and rehabilitation techniques. *Journal of Environment & Earth Science*, 4(9), p. 98-105.

Godfray H.C. 2015. The debate over sustainable intensification. *Food Security*, 7, p. 199–208.

Gonzaga J.F., O.F. Vilpoux and G.W. Pereira. 2019. Factors influencing technological practices in the Brazilian agrarian reform. *Land Use Policy*, 80, p. 150-162.

Greene W.H. 2012. *Econometric Analysis*, 7^{th} Edition. Prentice Hall, Boston.

Greene W.H. and D.A. Hensher. 2010. *Modeling Ordered Choices*: A primer. Cambridge University Press, New York.

Horner D. and M. Wollni. 2021. Integrated soil fertility management and household welfare in Ethiopia. *Food Policy*, 100, p. 1-14.

Hundie B., A. Alene, V. Manyong, I. Hoeschlezeledon and A. Larbi. 2017. Adoption and Impacts of Sustainable Intensification Practices in Ghana. *International Journal of Agricultural Sustainability, DOI: 10.1080/14735903.2017.1369619*

Jabbar A., Q. Wu, J. Peng, J. Zhang, A. Imran, and L.Yao. 2020. Synergies and determinants of sustainable intensification practices in Pakistan agriculture. *Land*, 110, p. 1-16.

Kassie M., H. Teklewold, M. Jaleta, P. Marenya and O. Erenstein. 2015. Understanding the Adoption of a Portifolio of Sustainable Intensification Practices in Eastern and southern Africa. *Land Use Policy*, 42, p. 400-411.

Kassie M., M. Jaleta, B. Shiferaw, F. Mmbando and M. Mekuria. 2013. Adoption of Interrelated Sustainable Agricultural Practices in Smallholder Systems: Evidence from rural Tanzania. *Technological Forecasting & Social Change*, 80, p. 525-540.

Kiconco S., S.C. Babu and K. Akankwasa. 2022. Adoption Patterns and Intensity for multiple BananaTechnologies in Uganda. *Sustainability*, 14, p. 1-14.

Kolade O. and T. Harpham . 2014. Impact of cooperative membership on farmers' uptake of technological innovations in Southwest Nigeria. *Development Studies Research*. 1(1), p. 340-353. DOI: 10.1080/21665095.2014.978981

Kolady D.E., E.V. der Sluis, M. Uddin and A.P. Deutz. 2021. Determinants of adoption intensity of precision agriculture technologies: evidence from South Dakota. *Precision Agriculture*, 22, p. 689-710.

Liao C. and D. Brown. 2018. Assessments of synergistic outcomes from sustainable intensification of agriculture need to include smallholder livelihoods with food production and ecosystem services. *Current Opinion in Environmental Sustainability*, 32, P. 53-59.

Manda J. A., Alene, C. Gardebroek, M. Kassie and G. Tembo. (2016). Adoption and Impacts of Sustainable Agricultural Practices on Maize Yields and Incomes: Evidence from Rural Zambia. *Journal of Agricultural Economics*, 67 (1), p. 130–153.

Manda J., M.G. Khonje, A. Alene, A. Hirpa, T. Abdoulaye, M. Mutenje, P. Setimela and V. Manyong. 2020. Does cooperative membership increase and accelerate agricultural technology adoption? Empirical evidence from Zambia. *Technological Forecasting & Social Change*, 158, p. 120-160.

Mare T., P. Zahonogo and K. Savadogo. 2022. Factors affecting sustainable agricultural intensification in Burkina Faso. *International Journal of Agricultural Sustainability*. DOI: 10.1080/14735903.2022.2070341

McFadden D. 1974. Conditional logit analysis of qualitative choice behavior. p. 105-142. In Zarembka P. (ed.) Frontiers in Econometrics. Academic Press, New York.

Mekuriaw A. and H. Hurni. 2015. Analysing factors determining the adoption of environmental management measures on the highlands of Ethiopia. *Civil and Environmental Research*, 7(12), p. 61-72.

Mengistu F. and E. Assefa. 2019. Farmers' decision to adopt watershed management practices in Gibe basin, southwest Ethiopia. *International Soil and Water Conservation Research*, 7, P. 376-387.

Mihretu A. and A.A.Yimer. 2017. Determinants of farmers' adoption of land management practices in Gelana sub-watershed of northern highlands of Ethiopia. *Ecological Processes*. 6(11): 1-11. DOI 10.1186/s13717-017-0085-5

MoARD (Ministry of Agriculture and Rural Development). 2010. Sustainable land management technologies and approaches in Ethiopia. The Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia.

Mponela P, Lulseged Tamene, Ndengu G, Magrete R, Kihara J, and Mango N. 2016. Determinants of integrated soil fertility management technologies adoption by smallholder famers in the Chinyanja Triangle of Southern Africa. *Land Use Policy.* 59: 38-48.

Mundlak Y. 1978. On the Pooling of Time Series and Cross Section Data. *Econometrica*, 46 (1), p. 69-85.

Mwaura G.G., M.N. Kiboi, E.K. Bett, J.N. Mgwe, A. Muriuki, G. Nicolay and F.K. Ngetich. 2021. Adoption intensity of selected organic-based soil fertility management technologies in the cenetral highlands of Kenya. *Frontiers Sustainable Food System*, 4, p.1-17.

Ndiritu W.S., M. Kassie and B. Shiferaw. 2014. Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food policy*, 49, p. 117-127.

Nigussie Z., A. Tsunekawa, N. Hargeweyn, E. Adgo, M. Nohmi, M. Tsubo, D. Aklog, D.T. Mersha and S. Abele. 2018. Factors influencing small-sacale farmers' adoption of sustainable land management technologies in north-western Ethiopia. *Land use Policy*, 67, p. 57-64.

Nyanga A., A. Kessler and A. Tenge. 2016. Key socio-economic factors influencing sustainable land management investments in the west Usambara highlands, Tanzania. *Land Use Policy,* 51, p. 260-266.

Ochieng J., B. Knerr, G. Owuor and E. Ouma. 2016. Commercialization of Food Crops and Farm Productivity: Evidence from Smallholders in Central Africa, *Agrekon*, 55(4), p. 458-482.

Pretty J., and Z.P. Bharucha. 2014. Sustainable Intensification in Agricultural Systems. *Annals of Botany*, 114, p. 1571–1596.

Pretty J., C. Toulmin and S. Williams. 2011. Sustainable Intensification in African Agriculture. *International Journal of Agricultural Sustainability*, 9(1), p. 5-24.

Reddy R.V., T. Chiranjeevi and G. Syme. 2020. Inclusive sustainable intensification of agriculture in West Bengal, India: Policy and institutional approaches. *International Journal of Agricultural Sustainability*: doi.org/10.1080/14735903.2019.1698489

Ruzzante S, Labarta R, and Bilton A. 2021. Adoption of agricultural technology in the developing world: A meta-analysis of the empirical literature. *World Development*. 146. www.elsevier.com/locate/worlddev.

Sileshi M., R. Kadigi, K. Mutabazi and S. Sieber. 2019. Determinants for Adoption of Physical Soil and Water Conservation Measures by Smallholder Farmers in Ethiopia. *International Soil and Water Conservation Research*, 7, p. 354-361.

Simon H.A. 2000. Bounded rationality in social science: Today and tomorrow. *Mind and Society,* 1, p. 25-39.

Smith A., S. Snapp, R. Chikowo, P. Thorne, M. Bekunda and J. Glover. 2017. Measuring sustainable intensification in smallholder agroecosystems: A review. Global Food Security. http://dx.doi.org/10.1016/j.gfs.2016.11.002

Tefera T., E. Elias and C. van Beek. 2020. Determinants of smallholder farmers' decision on fertilizer use for cereal crops in the Ethiopian highlands. Experimental agriculture, p. 1-11. doi:10.1017/S001447972000023X

Tesfa A. and S. Mekuriaw. 2014. The effect of land degradation on farm size dynamics and crop-livestock farming systems in Ethiopia: a review. *Open Journal of Soil Science*, 4, p. 1-5. http://dx.doi.org/10.4236/ojss.2014.41001

Teklewold H., M. Kassie and B. Shiferaw. 2013. Adoption of Multiple Sustainable Agricultural Practices in Rural Ethiopia. *Journal of Agricultural Economics*, 64(3), p. 597-623.

Teklewold H., A. Mekonnen, G. Kohlin, and S. DiFalco. 2017. Does adoption of multiple climate-smart practices improve farmers' climate resilience? Empirical evidence from the Nile basin of Ethiopia. Climate Change Economics, 8(1), p. 1-30. DOI: 10.1142/S2010007817500014

Teshome A., J. Graaf and M. Kassie. 2016. Household-Level Determinants of Soil and Water Conservation Adoption Phases: Evidence from North-Western Ethiopian Highlands. *Environmental Management*, 57, p. 620–636.

The Montpellier Panel. 2013. Sustainable Intensification: A New Paradigm for African Agriculture. Agriculture for Impact; London, UK.

Theriault V., M. Smale and H. Haider. 2016. How does gender affect the sustainable intensification of cereal crops in the West Africa Sahel? Evidence from Burkina Faso. *World Development*: http://dx.doi.org/10.1016/j.worlddev.2016.12.003

Vanlauwe B., M. Hungria, F. Kanampiu and K.E. Giller. 2019. The Role of Legumes in the Sustainable Intensification of African Smallholder Agriculture: Lessons Learnt and Challenges for the Future. *Agriculture, Ecosystems and Environment*, 284, p. 2-13.

Wainaina P., S. Tongruksawattana and M. Qaim. 2016. Tradeoffs and Complementarities in the Adoption of Improved Seeds, Fertilizer, and Natural Resource Management Technologies in Kenya. *Agricultural Economics*, 47, p. 351-362.

Wooldridge J. 2002. Econometric Analysis of Cross-section and Panel data. Cambridge: MIT Press.

Wossen T., T. Berge, T. Mequaninte and B. Alamirew. 2013. Social Network Effects on the Adoption of Sustainable Natural Resource Management Practices in Ethiopia. *International Journal of Sustainable Development and World Ecology*, 20(6), p. 477-483.

Yirga C., M. Jaleta, B. Shiferaw, H. de Groote, M. Kassie, T. Meberatu and A. Mohammed. 2013. Analysis of adoption and diffusion of improved wheat technologies in Ethiopia. Research Report 101, Addis Ababa, Ethiopia.

Yirga C., Y. Atnafe and A. AwHasan. 2015. A Multivariate Analysis of Factors Affecting Adoption of Improved Varieties of Multiple Crops: A Case Study from Ethiopian Highlands. *Ethiop. J. of Agric. Sci.*, 25(2), p. 29-45.

Zeweld W., G.V. Huylenbroeck, G. Tesfay, H. Azadi and S. Speelman. 2019. Smallholder Farmers' Behavioral Intensions Towards Sustainable Agricultural Practices. *Journal of Environmental Management*, 187, p. 71-81.

Impact of Malt-Barley Commercialization Clusters on Productivity at Household Level: The Case of Selected Districts of Oromia Region, Ethiopia

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Abstract

The Ethiopian government has been implementing a clustering program in smallholder agriculture to transform the sector from subsistence to commercial level via increased quantity and quality of products and thereby income of farmers. Nonetheless, such a program can solicit more resources and best be scaled if its benefits can be well known and documented. To this end, this study aims to evaluate the influence of commercialization clusters on the productivity of malt barley at the household level in the Arsi and West Arsi zones of the Oromia region. A multistage stratified random sampling technique was applied for selecting samples. The sample for this analysis includes 360 households for 180 each member and non-members. Descriptive statistics and Inverse probability weighted regression adjustment were applied to analyze the data. Accordingly, there was a significant difference between members and non-members of the cluster program in age and access to the market. More than a half hectare of land per household is covered with malt barley annually with an average of 24 quintals per hectare. The yield difference was significant between members and non-members on the Nearest-neighbour matching result. Expanding malt barley cluster farming on a larger scale can help the nation in general.

Keywords: Barley, Cluster, inverse probability weighted regression

Introduction

Smallholder farmers who spread over many parts of the world strongly relied on agriculture as the main source of food, income, and employment. Against this background, agricultural development has been acknowledged as one of the main pathways for poverty alleviation (World Bank, 2015). Ethiopia has a total land area of 1.14 million square kilometres of which 45 and 3 % of it is arable and irrigated land respectively. The population density in 2020/21 was 95.8 person per square kilometres (NBE,2021). The Ethiopian economy continued to register growth in 2020/21 amid the instability in the northern part of the country and the impact of the COVID-19 pandemic. During the review fiscal year, real GDP had a 2,114.2 billion Birr volume and showed a 6.3 percent growth, slightly higher than the 6.1 percent growth last year. The growth of real GDP in 2020/21 was attributed to the growth of industry 7.3%, services 6.3%, and agriculture 5.5% . Nominal GDP per capita stood at USD 1,092, depicting a 1.1 percent marginal improvement relative to the previous year (NBE, 2021). In a similar mid-year, Ethiopia's population with more than 80 percent living in rural areas reached nearly 101.9 million. From 2011 to 2016, poverty dropped by 20 percent in Ethiopia. However, poverty in rural areas increased during the same time frame (World Bank, 2015).

Agro-clusters relate to the indigenous specialisation and attention of an agricultural commodity. They encompass tilling conditioning, recycling units, and trades (Dadan *et al*, 2015). Indeed, as Barrett, (2008) and Barkley and Henry (1997) depicted, agro-clusters may play an important role in reducing poverty rates by offering profitable growth at the micro-level by raising productivity. The clusters may offer positive externalities and invention (Ferragina and Mazzotta, 2014). Secondly, agricultural productivity growth may be associated with advanced profitable performance and a lower poverty rate (De Janvry and Sadoulet, 2010). Barley is the hardest of all cereal grains. It's one of the first cultivated grains in history and it remains one of the most extensively consumed grains, worldwide. Its civilization extends further north than any other crop and at the same time, it can be cultivated in sub-tropical countries (Hailemiceal *et al*, 2011). Barley has a short growing season and is also fairly failure and saltiness tolerant. Worldwide, barley is ranked fourth among grains in volume produced behind sludge, rice, and wheat (FAO,2020).

Barely was officially introduced as a food crop by Ethiopia which the country became a center of origin and diversity for this crop, and landraces have been cultivated by farmers for further than 5000 years. The country is also the top barley patron in Sub-Saharan Africa, with 3.7 million farmers in 2019 (CSA, 2019). Barley kinds are generally classified in two orders: food barley and malt barley. Ethiopian product of malt barley is inadequate to meet domestic demand, and the country accounts for nearly two- thirds of its consumption (Kosmowski *et al*, 2020). In order to increase product and at least meet the domestic demand, a commercialization cluster program has been enforced in malt barley products. In order to ensure sustainable relinquishment and promote upscaling, its benefit and the associated good practices should well be known. Given the indigenous capabilities of Oromia malt barley product, marketing and consumption, there's meagre information about the profitable impact of malt barley slightly commercialization clusters. To this end, this study has the ideal of assessing the impact of commercialization clusters on the productivity of malt barley slightly at the ménage position in the Arsi and west Arsi zones of the Oromia region.

Material and Methods

Description of the Research Area

This study is undertaken in the Arsi and West Arsi zones in the Oromia region of Ethiopia. The zones produce different types of agricultural products including cereals, pulses, vegetables and fruits. Malt barley is the dominant cereal crop based on both the size of land allocated to it and the number of households producing in the respective zones (Zones offices of MOA). From the selected zones, two districts namely Kofele and Digelu Tijo from West Arsi zone and Tiyo district from Arsi Zone were selected based on their extent of malt barley production. The altitude of Kofele woreda ranges from 2000 to 3050 meters above sea level. Digelu Tijo wereda has an estimated area of 889.22 square kilometres, it has a latitude and longitude of 7°45′N 39°15′E with average elevation of 2,713 meters. Tiyo Wereda is located 175 km Southeast Addis Ababa at 7°56′N 856E and 39°08′N 260E, 2436 masl and it is one of the Twenty Weredas found in Arsi Zone of Oromia Regional State situated in the North Western part of the Zone.

Type and Method of Data Collection

The survey was administered on sample households that are drawn using a multistage stratified random sampling technique. Structured questionnaires were prepared and administered by pre-testing it for inclusion of any necessary details. Our target population is malt barley producers in West Arsi and Arsi zones who have at least one-year experience of growing malt barley as a means of inclusion into the study. In the first stage, three districts (two from West Arsi and one from Arsi) zones were chosen based on their malt barley production potential and participation in malt barley markets. In the second stage, three farmers' associations (kebeles) per district were randomly selected. In the third stage, malt barley producing households were stratified in each kebele as participants and non-participants in malt barley commercialization cluster farming. From each district, three kebeles were selected namely Gurimich, Buchi and Afamo from Kofele district, Digelu Bora, Sagure Molea and Shaldo Mankula from Digelu Tijo district and Haro Bilalo, Dosha and Ankaka Koncha from Tiyo district. A total sample of 360 of which 180 members and 180 non-members of malt barley commercialization cluster farming. Finally, representative sample households were selected using probability proportional to size (PPS). To determine the desired sample size, a formula developed by Krejcie (1970) was applied. Hence, using 95% level of confidence and chi-square value for one degree of freedom, and proportion of population assumed to be 0.5 with degree of accuracy of 0.05, the sample size was determined based on the formula given by

$$n = \frac{X^2NP(1-p)}{d^2(N-1)+X^2P(1-p)} = \frac{(3.841)^2X30{,}492X0.5(1-0.5)}{(0.05)^2(30{,}492-1)+(3.841)^2 0.5(1-0.5)} = 360$$
(1)

Where:
n = required sample size
X^2X^2 = tabulated value of chi-square for 1 degree of freedom at 5% significance level (3.841)
N = the population size which is the size of Malt barley farm households
P =proportion of population assumed to be 0.5 since this would provide maximum sample size
d = the degree of accuracy expressed as proportion (0.05) i.e. standard error

Identification strategy

The major challenge in evaluating the impact of a given intervention is the unavailability of baseline data. Finding a valid counterfactual group is key to identify the impacts but in the absence of baseline data, we could not rely only on quantitative approaches. Thus, we adopted a mixed-method approach from the design stage of the impact evaluation. The counterfactual selection process has proceeded as follows.

First, we obtained the full list of farmers in malt barley commercialization clusters and non-members as well. The lists of farmers served as a population for selecting sample size determination. Nearest neighbourhood matching was run for each district to match the members and non-members of the cluster farming. In each district, the matching variables included binary indicators of sex of household, availability of access to information, presence of training, credit constraints, and oxen for cultivation rent for tractor, rent for combined harvester, extension worker contacts, and access to improved malt barley seed.

Non-members of malt barley commercialization cluster farming that did not fall within the common support with the data collecting peasant association were dropped. From the list of farmers found from the administrative office of the selected peasant association, participants of commercial cluster farming were prepared with up to two replacements (second and third best match). Both lists of members and non-members of the cluster were validated by development agents based at the peasant association. The lists were ranked best, second and third matched. Both quantitative and qualitative matching methods were applied to list members and non-members of cluster farming. The second step was the selection of counterfactual households. Even though members and non-members were curiously similar, we had to make sure the counterfactual households were similar from members of cluster farming households.

Inverse probability weighted regression adjustment (IPWRA)

The fundamental concept of using the propensity score matching system is erected on a strong supposition that observable characteristics determine the selection of treatment and control groups. Thus, matching estimators are frequently disposed to selection bias. This allows us to control for selection bias at both the treatment and outgrowth stages. Therefore, the IPWRA estimator has the double-robust property, which means that only one of the two models is rightly specified to constantly estimate the impact (StataCorp, 2017). The Inverse probability weighted regression adjustment estimators use a model to prognosticate treatment status, and they use another model to prognosticate issues. Because IPWRA estimators have the double-robust property, only one of the two models must be rightly specified for the IPWRA estimator to be harmonious.

This study also used the IPWRA approach to identify the impacts of cluster farming on malt barley productivity. In order to achieve this ideal, the study applies the ‘ teffects IPWRA command in STATA 15 and estimates the model. The average Treatment Effect for Treated (ATET) is estimated to probe the impacts of cluster husbandry practice. The variables like sex, education, age, family size, ranch experience, training, access to bettered seed, access to fertiliser, the distance of the main road to a ménage head occupant, the distance of the extension office from the homestead, access to credit malt barley slightly yield were included.

We use both parametric and non-parametric styles to estimate the malt barley slightly commercialization cluster average treatment effect (ATE) and treatment effects on the treated (ATT). Ordinary least squares (OLS) is used to estimate ATE on income, prices, trade volumes, and other livelihood issues. Inverse probability weighted regression adjustment (IPWRA) is used to estimate ATT, non-parametrically. In the absence of baseline data, these estimators control for selection on observable attributes only. Selection bias from unobservable attributes isn't controlled for, but we perform several robustness checks. Equation 1 shows the estimating equation for the OLS estimator.

$Y_i = \propto + \beta T_i + \gamma X_i + \varepsilon_i Y_i = \propto + \beta T_i + \gamma X_i + \varepsilon_i$-------------------------------------(2)

Y_i is an outcome interest, T_i is the double index for malt barley slightly commercialization cluster husbandry, X_i is the vector of observable characteristics of the household i, and ε_i is the error term. Standard errors are clustered at the household level because utmost product opinions and practices are made by the individual household. The coefficient β is the estimate of the malt barley commercialization cluster husbandry impacts on outcome Y.

The IPWRA estimator combines the inverse probability weighted (IPW) and the retrogression adaptation (RA) estimators. The regression adjustment method adds one further term in the OLS equation (1) – the commerce between being a member of cluster framing indicator and mean corrected control covariates ($\boldsymbol{X}_i - \bar{\boldsymbol{X}}$). It has been used preliminarily to estimate the impacts of agrarian interventions (FAO, 2020; Montiflor, 2008). Specifically, the retrogression specification is as follows

$Y_i = \propto + \beta T_i + \gamma X_i + \delta(X_i - \bar{X})T_i + \varepsilon_i Y_i = \propto + \beta T_i + \gamma X_i + \delta(X_i - \bar{X})T_i + \varepsilon_i$-(3)

In Equation 2, $\bar{\boldsymbol{X}}$ is the vector of the average of the observable characteristics of household i, and β is the ATE estimate, which is mathematically represented as

$\beta_{ate}RA = \frac{1}{N}\sum_{i=1}^{N}[E(Y_i|X_i, T_i = 1) - E(Y_i|X_i, T_i = 0)]$

$\beta_{ate}RA = \frac{1}{N}\sum_{i=1}^{N}[E(Y_i|X_i, T_i = 1) - E(Y_i|X_i, T_i = 0)]$----------------------------(4)

Replacing $\bar{\boldsymbol{X}}$ with $\bar{\boldsymbol{X}_i}$ in equation 3 (where $\bar{\boldsymbol{X}i}$ is the average over treatment households only) yields the ATT estimate.

The inverse probability weighted (IPW) estimator gets rid of the confounding factors by creating a pseudo-population. It uses the antipode of the estimated propensity score as weight (Wooldridge, 2010). The propensity score can be estimated using probit and also used to cipher the treatment goods as follows

$\beta_{ate,IPW} = \frac{1}{N}\sum_{i=1}^{N}\frac{[T_i - \rho(X_i)Y_i]}{P(X_i)[1-\rho(X_i)]}\beta_{ate,IPW} = \frac{1}{N}\sum_{i=1}^{N}\frac{[T_i - \rho(X_i)Y_i]}{P(X_i)[1-\rho(X_i)]}$ ---------------------- (5)

The IPWRA models the likelihood of malt barley commercialization cluster participation and estimates the cluster impacts contingent on the liability (Rola *et al*, 2013; Rosenbaum *et at*, 1983). Each observation in the dataset is assigned weights according to the following matrix

ww(t,x)=t + (1-t)$\frac{p(x) \quad p(x)}{1-P(X_i)1-P(X_i)}$--- (6)

Where ω(t,x) is the weight applied, t represents $T_i = 1T_i = 1$, $P(X)$ is the estimated propensity score and X is a vector of covariates.

Our preferred method for this analysis is the inverse probability-weighted regression adjustment (IPWRA) method for its doubly robust properties. Both the matching and regression adjustment methods may have issues of selection bias because both of these methods can account for observable characteristics only.
IPWRA estimators use probability weights to obtain outcome-regression parameters that account for the missing-data problem arising from the fact that each subject is observed in only one of the implicit issues. The adjusted outcome-regression parameters are used to compute averages of treatment-level predicted

outcomes. The contrasts of these averages provide estimates of the treatment effects. Because IPWRA estimators have the double-robust property, only one of the two models must be correctly specified for the IPWRA estimator to be harmonious (Wooldridge, 2010)..

IPWRA estimators use a three-step approach to estimate treatment effects:

1. We estimate the parameters of the treatment model and compute inverse-probability weights.
2. Using the estimated inverse-probability weights, we fit weighted regression models of the outcome for each treatment level and obtain the treatment-specific predicted outcomes for each subject.
3. We compute the means of the treatment-specific predicted outcomes. The contrasts of these averages give the estimates of the ATEs. By confining the calculations of the means to the subset of treated subjects, we can gain the ATETs.

Results and Discussions

Descriptive Statistics

The results of descriptive statistics play a significant role to verify the econometrics results. It helps to provide information regarding the sample respondents and variables used in the econometrics model. Accordingly, Tables 1 and 2 present the descriptive statistics of variables used for this study. The mean age of the sample respondents categorised in combined, members and non-members of malt barely commercialization clusters is 40.7 years having no significant difference between members and non-members of malt barley cluster farming. The family size and farm experience were 6 persons and 12 years, respectively of which both have no significant difference between members and non-members. Members have better market access with 2.75kms than non-members (3.05km) with a significant difference at 5%.

The average area covered by malt barely is 0.65 hectares with an average yield of 24 quintals per hectare. There was a significant difference in malt barely seed rate amount between members and non-members of cluster farming. However, this rate difference was not significantly reflected on the final harvest per hectare (Table 1).

Table 1. Summary statistics of the continuous variables used in the analysis

Variables	Combined (360)		Members of MB ACC (180)		Non-Members of MB ACC (180)		t-test
	Mean.	Std.Dev	Mean	Std.Dev.	Mean.	Std.Dev	
Age-HH	42.6	12.15	42.77	12.20	38.72	11.04	0.334
Family size	6.41	3.42	6.42	3.43	6.37	3.40	-0.619
MB experience(yrs)	12.72	10.15	12.82	10.23	11.66	9.31	-0.492
Dist. to market (Km)	2.78	2.38	2.75	2.35	3.05	2.61	-2.167
Dist. to FTC (minute)	26.6	19.55	26.84	19.73	24.23	17.81	0.442
MB- yield (Qt/ha)	23.47	13.09	25.65	14.31	23.31	13.00	-0.430
MB-area(ha)	0.64.	0.43	0.65	0.43	0.64	0.43	1.603
MB seed rate (Kg/ha)	128	37	137.60	39.78	127.49	36.85	5.986

Source- Authors' calculation using the survey data, 2021, MB- Malt Barley

The household sex composition, access to market information, training opportunity, the existence of constraints on credit, availability of oxen, rent of tractor for ploughing, rent of combined harvester, extension worker contact and access to improved malt barley seed were selected as categorical variables. Accordingly, there is a significant difference between members and nonmembers of malt barley cluster farming on availability of oxen, rent tractor for ploughing, combined harvester and extension worker contact (Table 2).

Table 2. Summary statistics of the categorical variables used in the analysis

Variables	Combined (360)		Members of MB ACC (180)		Non-Members of MB ACC (180)		X^2-test
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev	
Sex-HH	0.86	.35	0.88	0.36	0.78	0.32	1.591
Acc. to Mart info. (Y/N)	0.97	0.16	0.97	0.16	0.97	0.16	1.692
Training (Y/N)	0.71	0.29	0.76	0.31	0.69	0.28	1.145
Credit constraint (Y/N)	0.42	0.61	0.42	0.61	0.42	0.61	3.045
Oxen for cultivation (Y/N)	0.76	0.24	0.88	0.19	0.64	0.42	12.713
Rent tractor for ploughing (Y/N)	0.61	0.45	0.78	0.27	0.44	0.63	7.977
Rent combined harvester (Y/N)	0.79	0.24	0.92	O,09	0,66	0.46	13.203
Extension worker contact (Y/N)	0.73	0.28	0.89	0,19	0.57	0.48	11.515
Access for improved Malt barley seed (Y/N)	0.59	0.44	0.67	0.35	0.51	0,48	1.726

Source: Authors' calculation using the survey data. 2021, Y/N- Yes/No

Econometrics Results

Impact of malt barley commercialization cluster on productivity

De Janvry and Sadoulet (2010) and Louhichi *et al* (2019) highlighted for ensuring the balancing condition is a decisive issue in PSM as it reduces the influence of confounding variables. Hence, a covariate balancing test was done as presented in

Table 3. The result shows that the pseudo-R^2 was also reduced significantly from 11.4% before matching to a range of 0.4–0.8% after matching and was equitably low, indicating that after matching there were no systematic differences in the distribution of covariates between the two studied groups (members and non-members of malt barely commercialization clusters). The total bias was also reduced significantly via the matching process. Furthermore, all covariates in the probit model depicted a significant difference in the post matching comparison in the P-values of LR tests which was not in the before matching. The standardised mean difference for overall covariates used in the estimation process reduced from 31.7% before matching to a range of 3.2–5.4% after matching. Hence, specification of the propensity score estimation process is successful in balancing the distribution of covariates between members and non-members.

Table 3. Matching quality indicators before and after matching

Matching algorithm	Pseudo- R^2		LR chi^2		P> chi^2		Mean standardized bias		Total % bias reduction
	Before matching	After matching	Before matching	After matching	Before matching	After matching	Before matching	After matching	
Nearest neighbor	0.114	0.004	59.94	2.96	0.00	0.988	31.7	3.9	97.6
Radius matching	0.114	0.008	59.94	3.76	0.00	0.866	31.7	5.4	99.4
Kernel matching	0.114	0.005	59.94	3.41	0.00	0.955	31.7	3.2	96.9

Source: Field Survey data calculated by authors, 2021

Result of Average Treatment Effect on Treated (ATETs)

The result of PSM becomes unbiased and consistent when the selection equation is correctly specified. However, according to Wossen *et al* (2017), the result can be biased if there is a misspecification of the propensity score matching model. The IPWRA results in Table 4 show that the causal effects of being the member of malt barley commercialization cluster on household net income is nearly 36% more than non-members of cluster farming with a significant difference at 1% level of significance. The involvement of members and non-members of MB commercialization cluster farming on purchase of agricultural inputs like fertilizer and chemicals was assessed and there was a significant difference depicted as cost. Members are very much aware about how to compensate for the overall production cost of malt barley with the revenue they get from the sale of their harvest. Accordingly, the result depicted in table 4, members incurred 11% more than non-members. However, this difference leads members to harvest 9% yield more than non-members and earn more. There was a significant difference on prices of MB between members and non-members of cluster farming; This could be because of early access to the market, proper quality standard setting mechanisms among members, high bargaining power of big volume supply and quality packaging services. This finding, supported by Bernard *et al* (2008) , shows that being a member of an agricultural cooperative can give its members a better price and relatively pleasant way of payment scheme. Similarly, our result of a progressive association between cluster farming and getting better price for their harvest is also in line with Barham & Chitemi (2009) for Tanzania, their findings suggest that cooperatives improve market performance.

Farmers in the study area are also involved in producing other crops like wheat and vegetable crops. Accordingly, there was a significant difference between members and non-members of the MB commercialization cluster at 10% level of significance. This finding is similar with the findings of Yuying *et al* (2019) who reported a positive impact of agricultural cooperatives in searching for a better market for members resulting in a higher income in China.

Table 4. Average treatment effects using IPWRA

Performance indicators	Mean Outcomes		Differences (ATT)	% Change
	Members of MB Cluster farming	Non-Members of MB Cluster farming		
Yield (Qt/ha)	25.65	23.31	11.84 (3.47)***	9.12
Cost (ETB /ha)	5726	5095	763 (68)***	11.02
Price (ETB/ Qt)	3550	2950	730 (80)***	16.91
Share sold (%)	67	59	0.102(0.03)***	11.94
Net Income (ETB)	55,282.53	35476.05	42,434(11573)***	35.82
Income from other crops (ETB)	10201	10050	172 (75.32)*	2.27

Source: Field survey, 2021 standard errors in parenthesis ***P<0.01, **P<0.05, *<0, 10, ETB-Ethiopian Birr, MB- Malt barely

Inverse Probability Weighted Regression Adjustment (IPWRA)

To check the robustness of the study results from PSM findings, we employed IPWRA to address misspecification bias. Table 5 below reports the mean differences of treatment effect estimates for cluster farming participation on malt barley productivity and commercialization using PSM and IPWRA estimation techniques. The result shows the yield of malt barley cluster farming practice and non–cluster farming practice is 26 qt/ha and 23 qt/ha, respectively. Participation in cluster farming increases malt barley yield by about 3 qt/ha (13%) change using the IPWRA specifications. It can be seen from the result that the impact of cluster farming practice participation is robust for both estimation strategies, showing the important role of cluster farming practice on better malt barley productivity. This finding is supported by the finding by Rola-Rubzen *et al* (2013) who reported that farmers could take some advantage of being a member of agricultural commercialization clusters mainly for agricultural input distribution, information exchange on reducing transaction costs, better agricultural practice implementation, and boosting bargaining power both for input purchase as well as output selling.

Table 5. Average treatment effects on treated (ATT) using inverse probability weighted regression adjustment (IPWRA) model

Outcome indicators	Mean outcomes		ATT difference	Percent change
	CLFP	NCFP	CLFP vs NCFP	
Malt Barley yield(qt/ha)	25.66	23.31	2.93(0.74) ***	9.15

Robust standard errors are reported in parentheses, *** represent statistical significance at the 1% levels. CLFP-Cluster farming practice, NCFP-Non-cluster farming practice.
Source – Own survey result, 2021

Conclusion and Policy implication

In this study, we examine the impact of malt barley cluster farming on household malt barley productivity in Arsi and West Arsi zones of Oromia Region, Ethiopia. We employ Inverse probability weighted regression adjustment models for assessing these relationships. We use household survey data from two zones of the region where malt barley is one of the dominant crops in terms of area coverage. According to our results, the following main conclusions are drawn. The initial conclusion about the impact of being a member of malt barley cluster farming on household productivity verified that farmers who are in cluster farming had an opportunity to get more yield than non-members.
The IPWRA results indicate that being a member of the MB commercialization cluster in sampled areas has a 36% net income difference than non-members of cluster farming. The membership of the malt barley commercialization cluster creates an opportunity to sell more shares of their harvest than non-members. The annual area coverage on malt barley is more than a half hectare per household with a mean yield of 24 quintals per hectare. The Nearest-neighbor matching result indicated a significant yield difference between members and non-members of small malt barley commercialization clusters. We found that malt barley cluster farming resulted in intensification of malt barley production, increased commercialization of malt barley, better quality yield, higher farm gate prices, increased net malt barley income. Our estimated results are robust, consistent across different matching methods.

The result also suggests that strengthening farmers' organizations on cluster farming are critical for potentially enhancing, not only access to and use of agro-inputs, but also facilitating access to Malt barley markets through boosting quality, arranging easy ways for information and knowledge as well as creating flexible platform for involvement of policymakers. The result also indicates that supporting malt barley cluster farming in the malt barley chains is an effective way to contribute to reaching the government aim of expansion and intensification of malt barley production and quality upgrading. Public support on capacity building of farmers who are involved in cluster farming also helps smallholder linkages to modern chains and the smooth functioning of cluster arrangement. The findings of this study stress the need for relevant intervention policies particularly on expanding cluster farming into wider areas of the region in particular and nationwide in general.

Availability of data and materials

Data used for the analyses in this article are available from the corresponding author upon request.

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Contributions

The corresponding author contributed to survey design, data collection, cleaned the data, analyzed the data, and wrote the first draft of the manuscript. The other authors contributed to reading, editing, and structuring the manuscript. All authors read and approved the final version of the manuscript.

Declaration of competing interest

The authors declare that they have no competing interests.

Data availability

Data will be made available on request.

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Notes

a) Kebele is the smallest administrative hierarchy in Ethiopia.
b) Every kebele administration has a full list of households living in the area. We used this list as a sample frame. When the randomly selected farmer does not produce malt barely s/he was replaced by the farmer next to him/her on the list.
c) List and definition of variables used for this study are presented in Table:A_1

References

Barham, J., & Chitemi, C. 2009. Collective action initiatives to improve marketing performance: Lessons from farmer groups in Tanzania. Food Policy, 34(1), 53–59. https://doi.org/10.1016/j. foodpol.2008.10.002

Barrett, C.B. 2008. Smallholder market participation: Concepts and evidence from Eastern and Southern Africa. Food Policy 33, 299–317.doi:10.1016/j.foodpol.2007.10.005.

Barkley, D. L., & Henry, M. S. 1997. Rural Industrial Development: To Cluster or Not to Cluster? Review of Agricultural Economics 19(2), 308-325. doi: 10.2307/1349744

Bernard, T., Taffesse, A. S., & Gabre-Madhin, E. (2008). Impact of cooperatives on smallholders' commercialization behavior: Evidence from Ethiopia. Agricultural Economics, 39(2), 147–161. https://doi.org/10.1111/j.1574-0862.2008.00324.x

CSA (Central Statistical Agency of Ethiopia). 2019. Agricultural sample survey 2018/19 (2011nE.C.) Report on area and production of major crops. Addis Ababa.

Dadan Wardhana, Rico Ihle, Wim Heijman.. 2015. The Effects of Agro-clusters on Rural Poverty: A Spatial Perspective for West Java of Indonesia. Paper prepared for presentation at the 150th EAAE Seminar 'The spatial dimension in analysing the linkages between agriculture, rural development and the environment' Edinburgh, UK, October 22-23, 2015.

De Janvry, A., & Sadoulet, E. 2010. Agricultural Growth and Poverty Reduction: Additional Evidence. The World Bank Research Observer, 25(1), 1-20. doi: 10.1093/wbro/lkp015.

FAO. 2017. Territorial tools for agro-industry development – A Sourcebook, by Eva Gálvez Nogales and Martin Webber (eds.), Rome, Italy.

FAO. 2020. Ten years of the Ethiopian Agricultural Transformation Agency. An FAO evaluation of the Agency's impact on agricultural growth and poverty reduction. Rome. https://doi.org/10.4060/cb2422en

Godtland, E.M., Sadoulet, E., de Janvry, A., Murgai, R. and Ortiz, O. 2004. The impact of farmer field schools on knowledge and productivity: A study of potato farmers in the Peruvian Andes. *Economic Development and Cultural Change* 53(1): 63-92

Hailemiceal S, Sopade A. Ethno-botany. .2011. Diverse Food Uses, Claimed Health Benefits and Implications on Concentration of Barley Landraces in North-eastern Ethiopia Highlands. Journal of Ethno-botany and Ethno-medicineVol. 7, No.19; 11-86

Krejcie, R.V. and D.W. Morgan. 1970. Determine sample size for research activities. Educational and Psychological Measurement 30: 607-610.

Jacquet, F., Butault, J.-P., Guichard, L. 2011. An economic analysis of the possibility of reducing pesticides in French field crops. Ecological Economics 70, 1638-1648.

Louhichi, K., Temursho, U., Colen, L., Gomez, Y., & Paloma, S. 2019. Upscaling the productivity performance of the Agricultural Commercialization Cluster Initiative in Ethiopia, EUR 29950 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-12941-7, doi:10.2760/57450, JRC117562.

Montiflor, M.O. 2008. Cluster Farming as a Vegetable Marketing Strategy: the Case of Smallholder Farmers in Southern and Northern Mindanao.

Rola-Rubzen, M. F., Murray-Prior, R., Batt, P. J., Concepcion. S. B., Real, R. R., Lamban, R. J. G., Axalan, J. T., Montiflor, M. O., Israel, F. T., Apara, D., & Bacus, R. H. 2019. Impacts of clustering of vegetable farmers in the Philippines. Proceedings of ACIARPCAARRD Southern Philippines Fruits and Vegetables Program Meeting, Jul 3, 2012.ACIAR Proceedings No. 139: 90- 202. Cebu, Philippines: Australian Centre for International Agricultural Research.

Rosenbaum, P. R., and D. B. Rubin. 1983. The Central Role of the Propensity Score in Observational Studies for Causal Effects."Biometrika 70 (1): 41–55

Stata Corp. 2017. Stata treatment-effects reference manual: Potential outcomes/counterfactual outcomes release 15. College Station, Texas Stata Press.
Wooldridge, J.M. 2007. Inverse probability weighted estimation for general missing data problems. *Journal of Econometrics*.141(2): 1281-1301
Wooldridge, J.M..2010. *Econometric Analysis of Cross Section and Panel Data*. MIT Press.
World Bank. 2015. Ending Poverty and Hunger by 2030: An Agenda for the Global Food System. World Bank, Washington, DC.
National Bank of Ethiopia 2021. Annual Report, PP 6-7
Wossen T, T Abdoulaye, A. Alene, M.G. Haile, S. Feleke, A. Olanrewaju and V. Manyong. 2017. Impacts of extension access and cooperative membership on technology adoption and household welfare*Journal of Rural Studies* 54: 223-233
Yuying Liua, Wanglin Mab, Alan Renwickc and Xinhong Fu. 2019. The role of agricultural cooperatives in serving as a marketing channel: evidence from low-income regions of Sichuan province in China RESEARCH ARTICLE. International Food and Agribusiness Management Review Volume 22 Issue 2, ; DOI: 10.22434/IFAMR2018.0058.

Appendix

\Table A_1. List and definition of variables used

Variable	Unit	Definition
Improved MB seed	Dummy	1 if the farmers utilized improved MB varieties; 0 otherwise.
Age_HH	Dummy	Years Number of years the household head live
Sex_HH	Dummy	1 if the household is male; 0 otherwise
Education HH	Dummy	1 if the household head is literate; 0 otherwise.
Malt Barely Experience	Years	Number of years the household head cultivated malt barely
Membership of MB CC	Dummy	1 if the household is member of MB Commercialization custers ; 0 otherwise
Extension contact	Days	Number of contacts with the extension agent per year
Access to Market info	Dummy	1 if the household has access to market information; 0 otherwise
Training	Dummy	1 if the household gets training regarding maize production; 0 otherwise
Social Responsibility	Dummy	1 if the household social responsibilities; 0 otherwise
Credit constraint	Dummy	1 if the household faces credit constraints; 0 otherwise
Distance to market	Minute	Walking distance between the house of the respondent and the nearest market
Distance to FTC	Minute	Walking distance between the house of the respondent and farmers training center
Family size	Number	Number of family members
Malt barely yield	Kg	physical amount of malt barely produced
Malt barely _area	Hectare	Size of land that allocated to Malt barely production
Malt barely _ Fertilizer	Kg	Amount of fertilizer used for malt barely production
Malt barely _ seed	Kg	the quantity of Malt barely that used
Malt barely _ labour	Man-equivalent	both family and hired labor used for different agronomic practices of malt barely production

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Does Cereal Commercialization Enhance Farm Households' Input Use, Efficiency, and Productivity? A Conditional Mixed Process (CMP) Approach from Rural Ethiopia

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Abstract

The paper explores how cereal commercialization affects farm households' input use, technical efficiency, and productivity in major teff-based mixed-farming areas of Ethiopia. Analytical tools which included descriptive statistics, conditional mixed process model, dose-response function, and three-stage least squares regression model (3SLS) were employed. Our results indicate that farm households sell, on average 38% of cereal crops produced with variability across the cereal crops. The simultaneous equation model estimates confer that commercialization positively and significantly increases farm households' input use and cereal yield at 1% level. Ceteris paribus, a 10% increase in the degree of commercialization increases nitrogen fertilizer, agrochemical, and cereal yield in monetary terms per hectare by 6.8%, 23.4%, and 5.5%, respectively. The results also substantiate that commercialization enhances the likelihood of using high-yielding varieties and hiring additional labor to cultivate cereal crops. Hence, the more the farm households are oriented to the market, the higher they invest in modern technologies. The 3SLS estimation also confirmed the bi-directional causation between technical efficiency and commercialization of farm households, signifying that improving farm households' input use efficiency leads to a higher degree of commercialization and vice-versa. Moreover, the results show that the extent of cereal commercialization is positively determined by sex of the household head, land size, credit service, mobile phone ownership, improved seed, and agricultural assets, while negatively influenced by family size, dependency ratio, and non-farm employment. Therefore, the findings of this study call for policy efforts to mitigate bottlenecks in access to modern inputs and address factors that hinder the commercial transformation of farm households.

Keywords: Cereal, input use, productivity, production efficiency, commercialization, Ethiopia

Introduction

Commercial transformation has been pursued as an important pathway for successful smallholder agriculture development in developing countries. Commercialization entails a transition from subsistence-oriented to market-oriented patterns of production (Govereh, *et al*., 1999; Poulton, 2017). Market-oriented production systems enable farm households to adopt knowledge-intensive technologies (Pingali & Heisey, 1999) and thereby improve the most efficient use of available resources (von Braun & Kennedy, 1994). Farm households' adoption of improved technology further alters market participation choices by increasing input utilization efficiency and productivity (Barrett, 2008; Poulton, 2017). Evidence from Asia during the green revolution (Pingali & Heisey, 1999) shows that efficient application of land-augmented technologies has considerable scope to significantly increase cereal crop yield, implying a contribution to the improvement of smallholder welfare.

In Ethiopia, it has prioritized food security, poverty reduction, and improved smallholder welfare through productivity growth and market-oriented production transition (MoFED, 2003; NPC, 2016). To this end, the government has been pursuing all-inclusive measures to supply and improve the use of agricultural inputs. The government, for example, has been working to increase the availability of certified seed from 1887,000 tons (2015) to 365,000 tons by 2020, which amounts to about 8% annual average growth rate (Alemu & Berhanu, 2018). In addition to this, the same source noted that the availability of fertilizer was targeted to reach 2.06 million metric tons, by increasing 15% every year. As a result of which, the share of smallholder farmers using agricultural inputs in the sector has increased over the last decades.

However, despite the efforts, crop production in general and the cereal sub-sector, in particular, is still characterized by a subsistence production system on account of its low productivity. Many factors contribute to the low levels of productivity in the country. These encompass, among others, limited access, utilization, and inefficiency in the use of production inputs, weak introduction of technologies, inadequate marketing infrastructure (MoFED,2014; Yu, et al., 2011; Dorosh & Rashid, 2012; Tilahun, 2014; Urgessa, 2015; Merga & Haji, 2019). The extent of output commercialization is also very low with considerable variability across different locations in the country. For example, the 2019/20 estimate indicates, on average 23% of the grain crops produced by smallholders were marketed in 2019/20 (CSA, 2020). Existing empirical studies (Bekele, 2009; Berhanu & Moti, 2010; Abafita, et al., 2016) also reinforced the national estimates that smallholders have sold on average 25% of the crop, implying the intensity of market participation of smallholders is low. This substantiates the requirement of better understanding of the factors influencing smallholder commercialization and the policy importance of studying the input use, efficiency, and productivity effects of commercialization.

Only a few empirical studies have been conducted in developing countries to address the association between commercialization, input use, productivity, and efficiency. Strasberg et al, (1999) in Kenya studied fertilizer use and productivity effects of agricultural commercialization using the Tobit estimation procedure. Accordingly, they found that agricultural commercialization positively and significantly influences food crop fertilizer use and productivity among rural households. Consistent with this, Salau, et al. (2018) assessed the fertilizer use effect of maize commercialization in Nigeria. They found the positive effect of commercialization on fertilizer usage among maize farming households. Rios et al. (2008) is a good example of a study that analyzed the direction of causality between market participation measured by sale index and productivity measured in terms of technical efficiency for the total crops grown by farm households in Tanzania, Vietnam, and Guatemala using 2SLS procedure. The study has found a positive and significant correlation between commercialization and productivity in Vietnam and Guatemala but insignificant in Tanzania. In Ethiopia, the study by Bekele, et al. (2010) explores the productivity effect of commercialization by taking the most important cereal and pulse crops in their respective areas and shows that the productivity of farm households is positively and significantly influenced by the commercialization orientation factor.

Many of the studies reviewed above address only the fertilizer use effect of commercialization, suggesting the need to conduct an all-inclusive study that systematically explores the input use effects of commercialization by taking improved seed, chemical fertilizers both UREA and NPS, agrochemical, and hired labor into account. Besides, except for Rios et al. (2008), most of them did not analyze the bi-directional causality between market participation and productivity. Therefore, considering the existing knowledge gap, the current study expands on earlier empirical findings using plot-level data collected from randomly chosen farm households in rural Ethiopia. Unlike previous studies, the current study included a simultaneous mixed process model, dose-response function, and three-stage regression framework (3SLS). The 3SLS method was used to determine the bidirectional causation between technological efficiency and cereal crop commercialization. This renders the simultaneous solution of all questions using generalized least squares (Heck, 1977), and provides a more efficient estimate as compared to all IV estimators (Greene, 2012).

The study report is organized as follows. In the first section, the data and the methodology employed to address the research questions are introduced. Section two provides the key analytical results and their associated discussion. The final section presents the concluding remarks and the way forward.

Methodology

Description of the study area

The empirical analysis of this study is based on a plot- and household-level survey carried out in Oromia and Amhara, major *teff*-producing regions of Ethiopia (Figure 1). Together, the regions accounted for 81% of cereal cultivated land, 82% of total cereal production, 85% of *teff* cultivated land, and 87% of total *teff* production in the country (CSA, 2020). From the region, East Shewa in the Oromia region and East Gojjam in the Amhara region are two of the country's most intensive *teff*-based mixed farming areas, where crop and livestock production are the primary sources of income for households.

Method of data collection

Using a cross-sectional survey, primary data were generated from 392 farm households randomly drawn from six *Kebeles* in intensive teff-based mixed farming areas of Ethiopia. The study also used semi-structured checklists applied using key informant interviews and focus group discussions. Secondary data was also gathered from zonal and '*Weredas'* level agricultural offices, CSA cereal production and productivity data, other policy documents, and specific studies carried out in Ethiopia.

Sampling strategy

The study's population and unit of analysis were farm households in Oromia and Amhara, the two main *"teff"*-growing regions. Following multi-stage stratified sampling procedures, the final sample farm households were chosen at random from the final study districts, Adea and Enemay Wereda, taking into account the Weredas' high potential and suitable agro-ecology for *"teff" production*. A total of six kebeles, or three kebeles per Wereda, were chosen at random from all of the rural *'Kebeles'* in the study '*Weredas'* given the time, resources, and existing similar production system. The sample size of 392 farm households, including a 10% contingency, was determined at random using the formula developed by Kothari (2004), as specified below. We excluded 14 observations out of 392 due to missing information. Cereal, such as teff, wheat, barley, maize, and sorghum were the major crops considered in this study.

$$n = \frac{Z^2pqN}{e^2(N-1)+Z^2pq} \quad \text{--- (1)}$$

where, n denotes the desired sample size, Z represents the standard cumulative distribution that corresponds to the level of confidence with the value of 1.96; e is the desired level of precision; p is the estimated proportion of an attribute present in the target population with a value of 0.5 to get the desired minimum sample size of the household at 95% confidence level and ±5% precision; q = 1-p; and N is the size of the total population from which the sample is drawn.

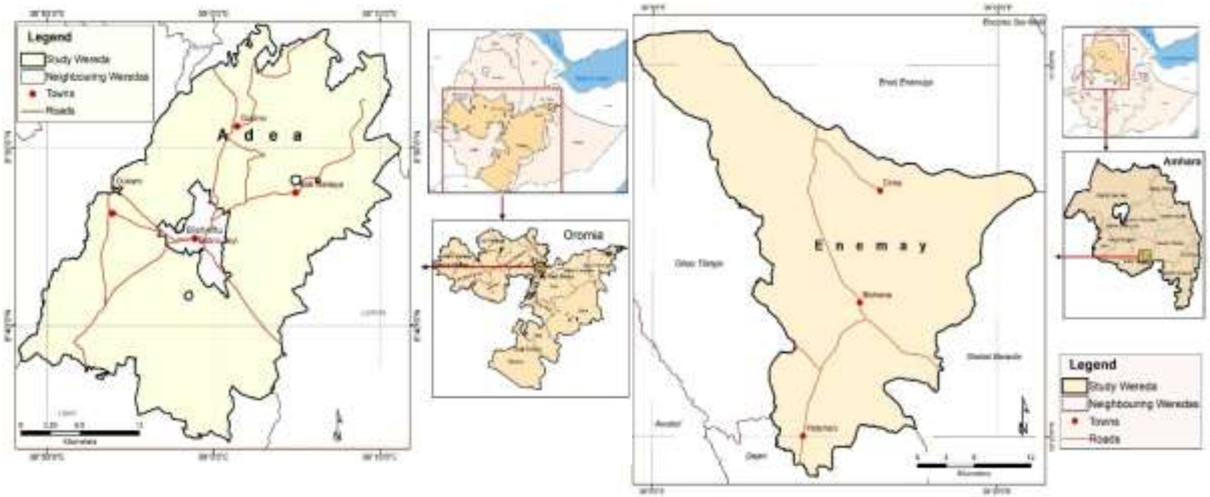

Figure 1: Location map of the study areas

Analytical approaches

Measuring agricultural commercialization: Commercialization of cereal crops was measured using Commercialization Index (CCI) proposed by von Braun & Kennedy (1994). It was computed as the share of the value of cereal crop sales to the total value of the total cereal production. This index would be zero, indicating total subsistence, while a value approaching 100 signifies a higher degree of commercialization or a great percentage of marketed cereal crops. The index is specified as follows:

$$CCI_{ij} = \frac{\sum_{k=1}^{K} S_{ik}\bar{P}_k}{\sum_{k=1}^{K} Q_{ik}\bar{P}_k} = \begin{cases} = non - seller \\ > 0\ seller \end{cases} \quad \text{--- (2)}$$

where, CCI_i a continuous variable that signifies the degree of commercialization of household from the output side, S_{ik} is the quantity of cereal output k sold by household i, $\bar{P}_j$ is the average price of cereal output k at the community level, Q_{ij} is the total quantity of cereal output k by household i.

Measuring technical efficiency: Technical efficiency scores of cereals-producing farm households were constructed using a two-step meta-frontier framework of Huang, et al. (2014)[1]. This approach is used because of the prevailing heterogeneity in terms of production technology between the sample *Weredas* of the study. To determine this, we conducted an LR test, which is defined by $LR = -2^{*}(lnL_p - (lnL_A + lnL_E)$, where, lnL_p, lnL_A, and lnL_E represents the log-likelihood values, which are obtained from the pooled data set of the overall stochastic frontiers and the sum of the values of the log-likelihood functions for the sample study frontiers, respectively. The degree of freedom was 22, calculated as the difference between the number of parameters estimated under pooled data and the parameters estimated in the respective study *Weredas*. Therefore, the result of the LR test [chi2=82.96 (p=.0000)] provides enough evidence to reject the null hypothesis of homogeneous production technology for the study. Following (Huang, et al., 2014), the two-step approach to estimating the meta-frontier has two stochastic frontier production functions as defined below:

$$ln\ lny_i^k = f^k\left(x_i^k, \beta^k\right) + v_i^k - u_i^k\ , \quad i = 1, \dots, n(k) \quad \text{----(3)}$$

$$ln\hat{f}^k\left(x_i^k, \beta^k\right) = f^M\left(x_i^k, \beta\right) + v_i^M - u_i^M \ldots\text{..(4)}$$

where, y_i^k represents the value of the total cereal output of the *i-th* sample farm household in the k^{th}*Wereda*, $x_i^k$is a kx1 vector of direct inputs of the *i-th* farm household; β^k a vector of unknown parameters to be estimated; v_i^kdenotes the random variation in output (y_i^k) due to factors outside the control of the firm

[1]Many studies (Ng'ombe, 2017; Alem, et al., 2018) employed this approach to estimate, and compare the efficiency scores for smallholders.

(measurement errors and other noises), and u_i^k is a non-negative technical inefficiency component of the error term that captures factors under the control of the farm; v_i^k is assumed to be independently and identically distributed as $N(0, \sigma_v^{k2})$ and is independent of u_i^k; $ln\hat{f}^k(x_i^k, \beta^k)$ is the estimate of the group-specific frontier from Eq.(3). Since the $ln\hat{f}^k(x_i^k, \beta^k)$ are group-specific, the SFA is estimated two times, one for each *Wereda*. The output estimates from the two *Weredas*/groups are then pooled to estimate Eq. (4). The meta-frontier should be larger than or equal to the group-specific frontier that is, $f^k(x_i^k; \beta^k) < f^M(x_i^k, \beta^k)$. The technical efficiency scores of the farm households by construction range between 0 and 1, indicating the value approach to 1 shows a higher level of technical efficiency.

Empirical model and estimation strategy

Effect of commercialization on input use and cereal yield: In our estimation of the input use and yield effects of commercialization, we considered cereal yield and five types of inputs namely the use of the improved seed, chemical fertilizers (UREA and NPS), agrochemical, and hired labor. Because the level of yield and its associated input use is dependent on each other, and similarly the use of one type of input is contingent on the other, the effects of commercialization on yield and input use of farm households are estimated simultaneously. Thus far, to account for the simultaneity, interdependency, and nature of the exogenous variables, six system equations were specified and estimated based on Conditional Mixed Process (CMP) approach. By doing so, the study represents the first application of the CMP framework in farm productivity and input use research. The framework can be applied to estimate several interdependent binary and continuous outcomes simultaneously (Roodman, 2011). The model is specified as the form stated below.

$$
\begin{aligned}
Y_i^* &= X_1^{'}\beta_1 + \varepsilon_{1i}, \\
S_i^* &= X_2^{'}\beta_2 + \varepsilon_{2i}, \\
U_i^* &= X_3^{'}\beta_3 + \varepsilon_{3i}, \\
N_i^* &= X_4^{'}\beta_4 + \varepsilon_{4i}, \\
C_i^* &= X_5^{'}\beta_5 + \varepsilon_{5i}, \\
L_i^* &= X_6^{'}\beta_6 + \varepsilon_{6i},
\end{aligned}
\quad --- \quad (5)
$$

where, Y_i^*, $S_i^*, U_i^*, N_i^*, C_i^*$, and L_i^* are cereal yield, which is measured by the monetary value of cereal crops per hectare, the use of improved seed (1 if household used improved variety on some proportion of farmland, 0 otherwise), the intensity of nitrogen fertilizer (UREA) used (ETB/ hectare); NPS fertilizer (ETB/hectare); agrochemical (ETB/hectare); and the use of hired labor (1 if the household used hired labor in the production season, 0 otherwise), respectively. X_1 to X_6 are the vector of control variables; β_1 to β_6 vector of the parameter to be estimated; and ε_{1i} to ε_{6i} are error terms. It is assumed that X_i are fixed, rank $(X_i) = k_i$, the mean of the error term is equal to zero $E(\varepsilon_i) = 0$, $E(\varepsilon_i \varepsilon_i') = \sigma_{ii} I_T$, where σ_{ii} is the variance of the disturbances in the i^{th} the equation for each observation in the sample, and the error terms are strictly exogenous, homoscedastic, and uncorrelated across observations but correlated across equations. We estimated the input and yield effects of commercialization via STATA's CMP command. In addition to the estimation technique mentioned above, we used a dose-response function with the *Generalized Propensity Score (*GPS) (following Hirano & Imbens, 2004) to complement the findings of fertilizer (UREA and NPS) and the agrochemical use effect of commercialization. Unlike OLS regression analysis, which assumes constant effects, such estimation techniques have the advantage of seizing up the dynamic effects of the treatment on outcome variables at different doses/treatment levels. The dose-response function is estimated using a STATA command developed by Bia & Mattei (2008).

Nexus between technical efficiency and commercialization of farm households: In this study, cereal crop commercialization is assumed to relate to the technical efficiency of farm households and vice-versa. Moreover, both technical efficiency scores and commercialization of farm households are potential endogenous variables, and neglecting this results in biased estimates. To address the reverse causality and the possible endogeneity problem, the study made use of a method of estimation, defined as a three-stage simultaneous model (3SLS), which jointly estimates the entire system of equations. 3SLS, which was first designed by Zellner & Theil (1962) is a structural equation where some equations consist of endogenous explanatory variables among the dependent variables from other equations in the system.

In a three-stage simultaneous model, the coefficients are estimated from a three-step process. First, build the instrumented values for all endogenous variables from the predicted values obtained from the regression of each endogenous variable on all exogenous variables within the system. Second, obtain a consistent estimate for the covariance matrix of the equation disturbances based on the residuals from a 2SLS estimation of each structural equation. Finally, using the covariance matrix estimated in the second stage and the instrumented values, the model performs a GLS-type estimation for the structural parameters of interest in the models. GLS estimator is more efficient than SUR estimator (Greene, 2012).

The 3SLS model can be specified as follows:

$$y_1 = \gamma_1 y_2 + \beta_{11} x_1 + \beta_{12} x_2 + \cdots + \beta_{1i} X_i + \varepsilon_1, \text{---} \ (6)$$

$$y_2 = \gamma_2 y_1 + \beta_{21} x_1 + \beta_{22} x_2 + \cdots + \beta_{2i} X_i + \varepsilon_1 \quad \text{---} \ (7)$$

where, y_1 and y_2 refers to endogenous variables, in our case the technical efficiency scores and the commercialization index of the farm household i; γ's are the coefficients of endogenous variables; x's are control variables; ε's are the error terms with mean zero, constant variance, and zero covariance but non-zero covariance between$y$'s and ε's.

In our empirical model, to estimate consistent estimates from the structural equation (3SLS), both equations must satisfy the rank and order conditions of identification. For the rank condition to be fulfilled, the second question must contain at least one exogenous variable with a non-zero coefficient that is excluded from the first equation, whilst, for the order condition to be satisfied, at least one of the exogenous variables with a non-zero coefficient must be excluded from the first equation (Wooldridge, 2012). In addition to this, as stated in Gujarati (2004), for an equation to be identified in a model of M simultaneous equations, we must exclude at least $M - 1$ variables, and the number of predetermined variables excluded from the equation must not be less than the number of endogenous variables included in that equation less one. Intuitively, to estimate the parameters consistently, we specified two main equations (Eq. 8 and 9) as specified below and considered several variables to be excluded from both equations.

Commercialization equation (Eq.8):

$$TE = \beta_0 + \beta_1 Com + \beta_2 Age\_hd + \beta_3 Edu\_hd + \beta_4 hhsize + \beta_5 Extn + \beta_6 Non\_farm + \beta_7 Coop + \beta_8 No\_Crop + \beta_9 Crop\_dmg + \beta_{10} Mkt\_info + \beta_{11} Dis\_input + \beta_{12} Pop\_pres + \beta_{13} Road\_con + \beta_{14} TLU + e_1$$

Technical efficiency equation (Eq.9):

$$Com = \alpha_0 + \alpha_1 TE + \alpha_2 Age\_hd + \alpha_3 Edu\_hd + \alpha_4 hhsize + \alpha_5 Extn + \alpha_6 Mkt\_dist + \alpha_7 Non\_farm + \alpha_8 Coop + \alpha_9 No\_Crop + \alpha_{10} Cell\_phone + \alpha_{11} Land\_qlty + \alpha_{12} No\_plot + \alpha_{13} Pop\_pres + \alpha_{14} Road\_con + \alpha_{15} lnAst + e_2$$

Explanation of variables used in the empirical models

The major outcome variables considered in the analysis include cereal yield, improved seed, hired labor, cost of nitrogen fertilizer, cost of NPS fertilizer, agrochemical, technical efficiency scores, and scale of commercialization of farm households (Table 1). Moreover, the study identified several covariates (Table 2) from the review of various theoretical and empirical literature that are to be used as a control variable in estimating the input use, yield, and efficiency effects of commercialization among farm households.

Table 1: Hypothesized effects of cereal commercialization on input use, TE, and cereal yield

Variables	Outcome variables						
	Cereal yield (ETB/ha)	Improved seed (Binary: yes=1)	Hired labor (Binary: yes=1)	UREA fertilizer (ETB/ha)	NPS fertilizer (ETB/ha)	Agro-chemicals (ETB/ha)	TE (0-1)
Commercialization index (CI)	+	+	+	+	+	+	+

Table 2: Control variables used in the model

Variables	Unit
Head age	Years
Head education	Years
Household size	Adult equivalent units
Access to extension service	Binary: yes=1
Distance to input center	km
Distance to nearest market	km
Road condition	Binary: good=1
Cooperative membership	Binary: yes=1
Non-farm employment	Binary: yes=1
Market information	Binary: yes=1
Population pressure	Ratio of family size to farm size
Number of crops	Number of crops grown by the HH
Household owns cellphone	Binary: yes=1
Land quality[2]	Index
Total assets owned (log)	ETB
Livestock ownership	TLU
Crop damage	Proportion of area of cultivated land affected by stresses
Number of plots	Number of plots owned by the household

Results and Discussion

Characteristics of farm household commercialization

In the study area, farm households grow *'teff'*, wheat, barley, maize, and sorghum, in order of their importance. The result shows that despite the significant variation among cereal crops, on average, farm households sold close to 38% of their cereal outputs. The amount is relatively higher than the national average that, on average, farm households in Ethiopia who participated in the market sell 23% of cereals (CSA, 2020). The scale of crop commercialization in different parts of Ethiopia was reported in several studies. For example, Gebremedhin & Jaleta (2010) in three districts of Bure, Goma, and Meiso found that on average farm households sold 25% of crop output, indicating moderate market participation. In central

[2] Land quality index is constructed based on multiplying the plots slope and the fertility indicators of the plots, implying a low index value indicates better land quality, while high index value would indicate the lowest quality evaluated at household level (Nisrane, et al., 2015).

Ethiopia, it is reported that farm households who participated in the market sold 22% of crop output (Demeke & Haji, 2014). Similarly, in Malawi, Uganda, and Tanzania, farm households sell an average of 18%, 26%, and 28% of the aggregate crop output, respectively (Carletto, et al., 2017). Moreover, on average, 59% of farm households sold 35-65% of the cereal crop produced. The majority of the farm households (82%) used a donkey and the rest 8% made use of the foot, cart, and motorized vehicle as a means to convey cereal out to the marketplaces.

Farm households in the study area sold cereal outputs to multiple options of market outlets, such as farmer traders in the village, rural assemblers, cooperatives, consumers, retailers, and wholesalers. Twenty nine percent of farm households sold cereal crops to retailers, followed by farmer traders in the village (26%) and consumers (19%) (Figure 2). Nonetheless, 40% of farm households who sold more than 65% of cereal crops traded a higher proportion of cereal outputs with wholesalers and retailers. This indicates that wholesalers and retailers, in that order, are the main market outlet choices of farm households for a higher volume of cereal outputs. Abate, et al. (2019) reported that the volume of crop output has a positive and significant association with the likelihood of choosing wholesaler and retailer market outlets.

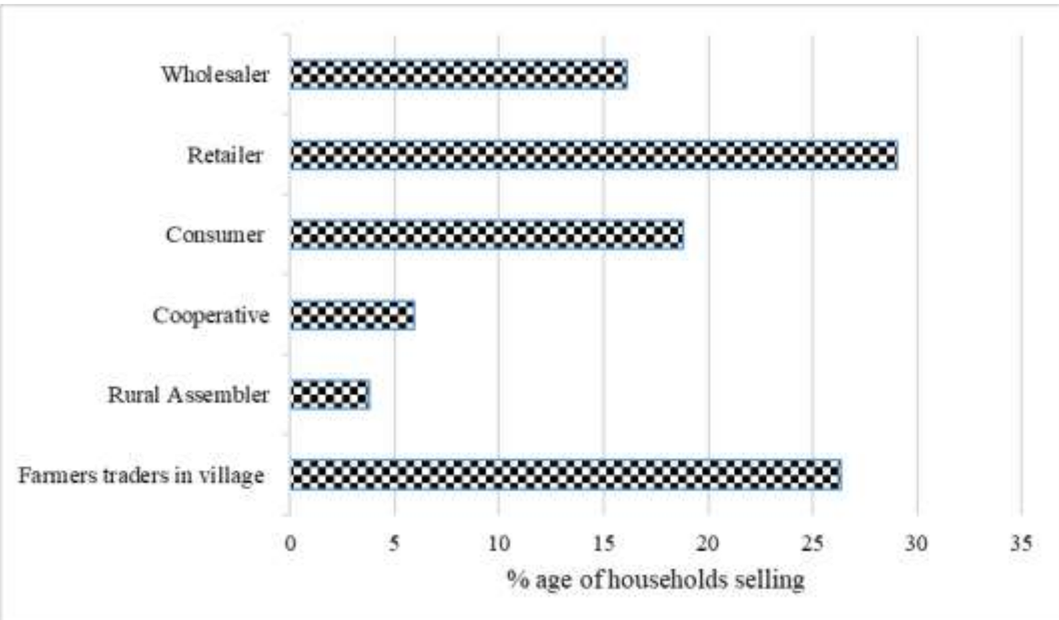

Figure 2: Proportion of households selling market outlets
Source: Authors' analysis using primary data (2020)

Yield, input use, and technical efficiency by household commercialization

Table 3 presents the comparative assessment of yield, input use, and technical efficiency of farm households by their commercialization status[3]. On average, farm households earned an annual income of 36137.35 ETB/ha from cereal cultivation. On average, farm households spent up to 1785 ETB/ha, 1799 ETB/ha, and 233 ETB/ha to cover the cost of nitrogen fertilizer, NPS fertilizer, and agrochemicals, respectively. Almost all farm households in the study area intensively used both nitrogen fertilizer and NPS in cereal crops. The one-way analysis of variance shows that cereal yield, the intensity of nitrogen fertilizer, and technical efficiency varied significantly across the commercialization status of farm households.

Table 3: Comparative assessment of the key continuous variables by commercialization status

Variables	Full sample [Mean]	Commercialization index			F-Value
		Subsistence [<30%]	Semi-commercialized [30-65%]	Commercialized [>65%]	
Cereal Yield (ETB/ha) log	10.41	10.27	10.45	10.65	11.24***
Nitrogen Fertilizer (ETB/ha) log	7.23	6.97	7.33	7.44	4.42**
NPS fertilizer (ETB/ha) log	7.30	7.36	7.30	7.05	0.98
Agrochemicals	2.46	3.28	3.47	4.35	1.3
Technical efficiency	0.58	0.49	0.61	0.71	33.03***

Source: Authors' analysis using primary data (2020)
Coefficients with ***, and ** are significant at 1 and 5 percent levels of significance, respectively

More than 35% of farm households used high-yielding varieties (HYVs) mainly for *'teff'*, wheat, and maize (Table 4). From which, 41% and 60% of them were semi-commercialized and commercialized farm households, respectively. From the Chi-square test result, we can see that there was a significant difference in the use of high-yielding varieties across the commercialization scale of farm households. The other key variable considered in this study is the use of hired labor, assuming that with an increased level of commercialization, farm households tend to progressively hire labor in addition to the available family labor. As per our prior expectation, farm households employed additional hired labor with an increasing level of commercialization. The result of the Chi-square test also confirmed that the use of hired labor varies positively and significantly with the commercialization scale of farm households. This appears to be associated with the high demand for labor to cultivate *'teff'*, produced mainly for the market, as compared to other crops.

[3] Farm households were classified into three sub-groups by their commercialization status, such as subsistence, semi-commercialized and commercialized following Gebreselassie & Sharp (2008); Goshu (2012).

Table 4: Comparative assessment of the key categorical variables by commercialization status

Variables	Full sample [%age]	Commercialization index			Chi-square
		Subsistence [<30%]	Semi-commercialized [30-65%]	Commercialized [>65%]	
HYVs (yes)	35.45	20.18	40.57	60.00	19.96***
Hired labor (yes)	78.04	65.54	81.97	90.00	21.63***

Source: Authors' analysis using primary data (2020)
Coefficients with *** is significant at 1 percent levels of significance

Input use and yield effects of commercialization

The conditional mixed process model estimation on the yield and input use effect of commercialization of cereal crops is provided in Table 5 below. As per our prior expectation, cereal crop commercialization had a positive and significant effect on yield and input use (nitrogen fertilizer and agrochemical). The model results suggest that a 10% increase in the scale of cereal crop commercialization leads to a 5.5% increase in cereal crop productivity, holding other factors being constant. In the same way, keeping other factors constant, a 10% change in cereal crop commercialization enhances the expenditure on nitrogen fertilizer and chemicals by 6.8% and 23.4%, respectively. Plot-level cost-benefit analysis of cereal crops was undertaken to estimate the net income and confirm the input use implication of commercialization. Accordingly, as it can be learned from cost-benefit analysis, on average, to obtain a net benefit of 29042.61 ETB/ha from producing cereal crops, the farm households are expected to incur an estimated total production cost of 7094.74 ETB/ha, excluding the cost of family labor and draft power. This validates the positive input use effects of commercialization among farm households.

Contrary to our expectation, the estimated coefficient for NPS fertilizer was found negative and insignificant, suggesting that the input use effect of commercialization of food crops is more responsive to nitrogen fertilizer than NPS. The plausible explanation of the findings is related to farm households' perception of the higher yield effect of the use of nitrogen fertilizer as compared to the NPS counterparts. The use of high-yielding varieties and hired labor is also positive and significant with the scale of commercialization at 1% level, ceteris paribus, suggesting that commercialization enhances the probability of farm households using high-yielding varieties and hiring additional labor to cultivate cereal crops. Our findings support the result of earlier studies (Strasberg, et al., 1999; Salau, et al., 2018) that food crop commercialization enhances the input use and productivity of farm households.

Our empirical evidence suggested that as the degree of commercialization rises, farm households increasingly use more hired labor as a source of power than subsistence farm households. However, farm households during focus group discussion reported that wage for hired labor is rising from time to time, such that it becomes unaffordable for many households. As stated in Pingali (1997), using hired labor in conducting intensive farm operations will not be profitable under escalating farm wage conditions.

Table 5: CMP model result on yield and input use effect of commercialization

Variables	Yield (ETB/Ha)	UREA (ETB/HA)	NPS (ETB/Ha)	Chemical (ETB/Ha)	HYVs (Yes/No)	Hired labor (Yes/N0)
Commercialization index	0.5499*** (0.1174)	0.6808** (0.3128)	-0.2869 (0.2599)	2.3446** (1.1635)	1.6936*** (0.5048)	1.2497*** (0.4337)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Constant	10.7097*** (0.2123)	7.4181*** (0.5657)	7.8786*** (0.4683)	-1.0295 (2.1314)	-0.8027 (0.9608)	-1.5512** (0.7602)
Number of observations LR chi2(83) Prob > chi2 Log-likelihood	378 262.44 0.0000 -2387.36					

Source: Authors' analysis using primary data (2020)
Coefficients with *** and ** are significant at 1 and 5 percent levels of significance, respectively

To triangulate the econometric model estimation of the input use and yield effects of commercialization, we further estimated the dose-response function with a generalized propensity score (GPS). Accordingly, Figures 3, 4, and 5 displayed the estimated dose-response function (DRF) and the marginal treatment effect function (MTE) of the effect of commercialization on input use (nitrogen fertilizer, NPS, and agrochemical) in monetary terms.

The result of the dose-response estimation in Figure 3 shows that the relationship between farm households' scale of commercialization and the use of nitrogen fertilizer is positive and significant, demonstrating the more the farm households earn income from the sale of marketable surpluses, the higher the farm households can cover the cost of nitrogen fertilizer, which is consistent with the result of CMP model estimation. The DRF shows that the positive effect of commercialization on nitrogen fertilizer use was increasing at a fast rate with some variability between the levels of commercialization at 30% to 50%. However, as it is seen in Figure 4, the MTE displayed that the effect of commercialization on the use of nitrogen fertilizer tends to increase up to 60% of the commercialization level of farm households and starts to flatten out at 80% and immediately after this point begins smoothly declining. This suggests that additional income greater than 60% of the sale of surplus production of cereal grains does not count any incremental effect on the use of nitrogen fertilizer.

In contrast to this situation, the input use of the effect of commercialization on NPS was found negative and insignificant, suggesting that the use of NPS fertilizer among the farm households is less responsive to additional income earned from the sale of cereal grains (Figure 4). Figure 5 displays the positive effect of commercialization on the use of agrochemicals, indicating that the more the farm households are oriented to the market, the higher they invest to purchase agrochemicals for pest, disease, and weed controls. The result on the positive and significant effects of cereal commercialization calls for an improved and efficient input supply system in the country. In relation to this, primary cooperatives are in charge of input distribution throughout the country and private vendors are also engaged in supplying agrochemicals to the farming community. The result from the focus group discussions, however, disclosed that the input market was not as efficient as expected particularly in the supply of agrochemicals on account of the limited capacity of primary cooperatives and entrusted private vendors. In theoretical literature, it is established that even though the commercialization of smallholder agriculture involves the withdrawal of government from input supply control and the removal of subsidies, the private sector is not entrusted (Sokoni, 2008) and may lead to a rapid increase in input price and adulteration. Therefore, at this stage of development, key informants informed that capacitating primary cooperatives through all-inclusive business models and financial arrangements may help to partly circumvent challenges related to input price and adulteration.

Nexus between Technical Efficiency and Commercialization

Table 6 presents the three-stage estimate on the nexus between technical efficiency and commercialization of farm households. The possible endogeneity problem that might be stemmed from the endogenous regressors of technical efficiency and commercialization in both of the models was sorted out by the 3SLS model, implying the estimation is unbiased and consistent. The finding shows that there is a statistically positive relationship between technical efficiency and the commercialization of farm households. The result implies that improving the technical efficiency of farm households by 10% increases the commercialization level by 4.9%, whereas, an increase in the commercialization level of farm households by 10%, the technical efficiency level is improved by 6.1%, suggesting the existence of bidirectional causality between technical efficiency and commercialization among the farm households. The plausible explanation for this result is that technically efficient farm households are more likely to be commercialized and vise-versa because commercialized farmers can purchase and use modern inputs as compared to subsistence farmers and their counterparts. The findings of this study are consistent with Rios, et al. (2008).

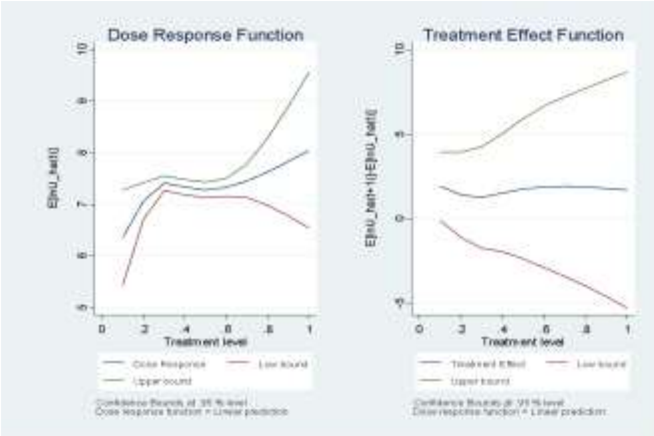

Figure 3: Estimated input use effect of dose-response function (UREA)
Source: Authors' analysis using primary data (2020)

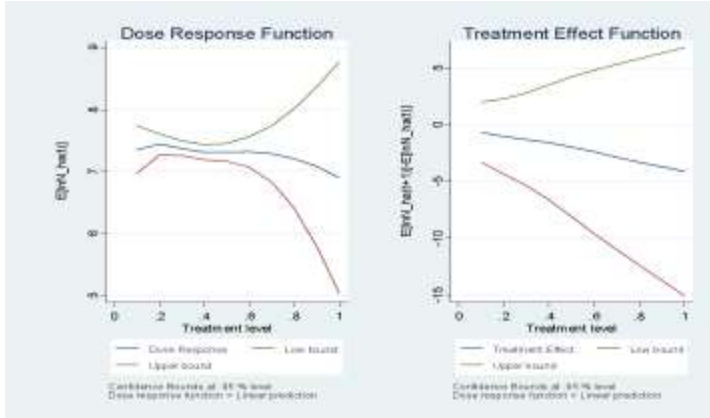

Figure 4: Estimated input effect of dose-response function (NPS)
Source: Authors' analysis using primary data (2020)

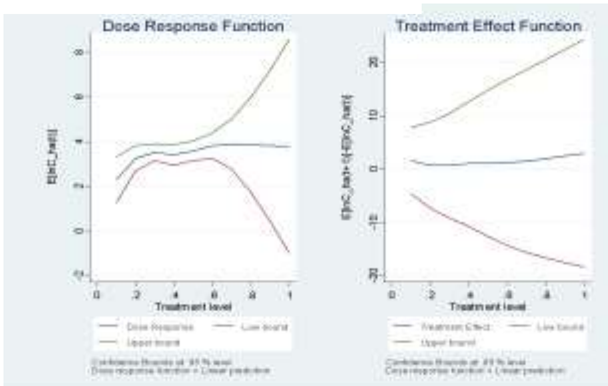

Figure 5: Estimated input effect of dose-response function (agrochemicals)
Source: Authors' analysis using primary data (2020

Table 6: Three-stage estimate for the nexus between technical efficiency and commercialization

Variables	Technical efficiency		Commercialization	
	Coefficients	Std. Err.	Coefficients	Std. Err.
Technical efficiency	-	-	0.4864***	0.1731
Commercialization index	0.6105***	0.1775	-	-
Control and identifier variables	Yes		Yes	
Constant	0.3462***	0.0815	0.0852	0.1232
Wald chi2	128.70		119.21	
Prob > chi2	0.0000		0.0000	
R-squared	0.294		0.221	

Source: Authors' analysis using primary data (2020)
Coefficients with *** is significant at 1 percent levels of significance

Conclusion and Recommendation

The study sought to investigate the input, efficiency, and productivity effects of cereal crop commercialization in the *'teff'*-based mixed farming areas of Ethiopia. Our findings revealed that, on average, farm households sold 38% of their cereal output in value terms, suggesting that farm households retained more than 60% of cereal production for household consumption and other purposes. Crop-wise, among cereal crops, a higher proportion of farm households engaged in *'teff'* marketing, suggesting *'teff'* is an important source of income for farm households. The study reveals that 29% of farm households sold cereal crops to retailers, followed by farmer traders in the village (26%) and consumers (19%). Nonetheless, a large proportion of farm households (40%) who sold more than 65% of cereal crops preferred selling cereal grains to wholesalers, indicating wholesaler is the main market outlet for volume sales.

In this study, the input use effect of cereal crop commercialization is considered for those inputs such as high-yielding variety, hired labor, nitrogen fertilizer, NPS fertilizer, and agrochemicals. From the result of the CMP estimations, we deduced that the commercialization of cereal crops has a positive effect in speeding up the use of modern input except for NPS fertilizer. The effect of commercialization is stronger in accelerating the use of nitrogen fertilizer than NPS fertilizer mainly due to its higher perceived effects among farm households on the yield and yield components of cereal grains. The use of agrochemicals among farm households has also been found positive along with the increased level of commercialization of farm households, confirming the use of inorganic inputs which tends to be intensive along the transformation process from subsistence-oriented farming to market-oriented one. The findings from the dose-response function also triangulated our prior results that the effect of commercialization on the use of nitrogen fertilizer and agrochemicals was found positive except for NPS fertilizer.

The productivity effect of commercialization was also verified as positive on the yield of cereal crops and technical efficiency of cereal-producing farm households. The findings of this study implied that farm households on the one hand can improve the level of farm-level productivity through an increased level of commercialization, which is channeled through its income effects, and on the other hand an increased level of productivity through efficient use of production inputs helps to produce marketable surplus and link the farm households with the market. Hence, the findings of the study shed light that alleviating bottlenecks in access to modern inputs and addressing factors associated with limited access to marketing and financial services is a key area of policy intervention.

References

Abafita, J., Atkinson, J. & Kim, C.-S., 2016. Smallholder Commercialization in Ethiopia: Market Orientation and Participation. International Food Research Journal, 23(4), pp. 1797-1807: https://doi.org/10.2499/9780.

Abate, T. M., Mekie, T. M. & Dessie, A. B., 2019. Determinants of market outlet choices by smallholder teff farmers in Dera district, South Gondar Zone, Amhara National Regional State, Ethiopia: a multivariate probit approach. Journal of Economic Structures, 8(39), pp. 1-14: https://doi.org/10.1186/s40008-019-0167-x.

Abdullah, R. et al., 2019. Determinants of commercialization and its impact on the welfare of smallholder rice farmers by using Heckman's two-stage approach. Journal of the Saudi Society of Agricultural Sciences, p. 224–233.

Ademe, A., Legesse, B., Haji, J. & Goshu, D., 2017. Smallholder Farmers' Crop Commercialization in the Highlands of Eastern Ethiopia. Review of Agricultural and Applied Economics, XX (2), pp. 30-37: doi:10.15414/raae/2017.20.02.30-37.

Alem, H., Lien, G., Hardaker, J. B. & Guttormsen, A., 2018. Regional differences in technical efficiency and technological gap of Norwegian dairy farms: a stochastic meta-frontier model. Applied Economics, pp. 1-14. DOI: 10.1080/00036846.2018.1502867.

Alene, A. D. et al., 2008. Smallholder market participation under transactions costs: Maize supply and fertilizer demand in Kenya. Food Policy, Volume 33, p. 318–328: DOI:10.1016/j.foodpol.2007.12.001.

Barrett, C. B., 2008. Smallholder market participation: Concepts and evidence from eastern and southern Africa. Food Policy, Volume 33, p. 299–317.

Bekele, A., 2009. Determinants of commercial orientation of smallholder farm households in risk-prone areas of Ethiopia: analysis of the Central Rift Valley. PhD Dissertation. Haramaya University, Ethiopia.

Bekele, A., Belay, K., Legesse, B. & Lemma, T., 2010. Effects of crop commercial orientation on the productivity of smallholder farmers in drought-prone areas of the central Rift Valley of Ethiopia. Journal of Rural Development, 33(4), pp. 105-128.

Berhanu, G. & Moti, J., 2010. Commercialization of smallholders: Does market orientation translate into market participation? Nairobi, Kenya, ILRI.: Improving Productivity and Market Success (IPMS) of Ethiopian Farmers Project Working Paper 22.

Bia, M. & Mattei, A., 2008. A Stata package for the estimation of the dose–response function through adjustment for the generalized propensity score. The Stata Journal, 8(3), p. 354–373: doi:10.1177/1536867X0800800303.

Carletto, C., Corral, P. & Guelfi, A., 2017. Agricultural commercialization and nutrition revisited: Empirical evidence from three African countries. Food Policy, Volume 67, pp. 106-118.

CSA, 2020. Agricultural Sample Survey 2019/2020 (2012 E.C.). Report on Crop and Livestock product utilization. Volume VI, Addis Ababa, Ethiopia: Central Statistical Agency (CSA).

Cunningham, L. T., Brorsen, B. W., Anderson, K. B. & Tost˜ao, E., 2008. Gender differences in marketing styles. Agricultural Economics, Volume 38, pp. 1-7: https://doi.org/10.1111/j.1574-0862.2007.00225.x.

Demeke, L. B. & Haji, J., 2014. Market Participation of Smallholder Farming in Central Ethiopia Econometric Analysis of Factors Affecting Market. Journal of Agricultural Economics, Extension and Rural Development, 2(6), pp. 094-104: https://mpra.ub.uni-muenchen.de/77024/.

Gebremedhin, B. & Hoekstra, D., 2007. Cereal Marketing and Household Market Participation in Ethiopia: The Case of Teff, Wheat and Rice. African Association of Agricultural Economists (AAAE). Second International Conference, August 20-22, 2007, Accra, Ghana, pp. 243-252: DOI: 10.22004/ag.econ.52102.

Gebremedhin, B. & Jaleta, M., 2010. Commercialization of smallholders: Does market orientation translate into market participation? Nairobi, Kenya, ILRI: Improving Productivity and Market Success (IPMS) of Ethiopian farmers project Working Paper 22.

Gebreselassie, S. & Sharp, K., 2008. Commercialization of Smallholder Agriculture in Selected Tef-growing Areas of Ethiopia: Future Agricultures Consortium, Discussion Paper 006. DFID.

Goshu, D., 2012. Agricultural Technology Adoption, Diversification, and Commercialization for Enhancing Food Security in Eastern and Central Ethiopia, Haramaya: PhD Dissertation, Haramaya University.

Goshu, D., 2020. Economic Welfare in Ethiopia: Growth Scenarios for Exiting Poverty, Addis Ababa, Ethiopia: Volume XXVIII, No. I. Ethiopian Economics Association.

Govereh, J., Jayne, T. & Nyoro, J., 1999. Smallholder Commercialization, Interlinked Markets, and Food Crop Productivity: Cross-Country Evidence in Eastern and Southern Africa.: Department of Agricultural Economics and the Department of Economics, Michigan State University (MSU).

Greene, W. H., 2012. Econometric Analysis. 7 ed. Upper Saddle River: NJ: Prentice Hall.

Gujarati, D., 2004. Basic Econometrics. 4th Ed. The McGraw−Hill Companies.

Heck, J. L., 1977. A Pedagogic Note: Comparison of 0LS, 2SLS, and 3SLS Estimation Methods. Studies in Economics and Finance, 1(1), pp. 28-33: http://dx.doi.org/10.1108/eb028587.

Hirano, K. & Imbens, G. W., 2004. The propensity score with continuous treatments. In: A. Gelman & X. Meng, eds. Applied Bayesian Modeling and Causal Inference from Incomplete-Data Perspectives. West Sussex, England: John Wiley & Sons, pp. 73-84.

Huang, C. J., Huang, T.-H. & Liu, N.-H., 2014. A new approach to estimating the Meta frontier production function based on a stochastic frontier framework. J Prod Anal, Volume 42, pp. 241–254. DOI 10.1007/s11123-014-0402-2.

Immin, M. D. C. & Alarcon, J. A., 1993. Household Income, Food Availability, and Commercial Crop Production by Smallholder Farmers in the Western Highlands of Guatemala. Economic Development and Cultural Change, 41(2), p. 319–342.

Kothari, C., 2004. Research Methodology: Methods and techniques. 2 ed. New Delhi, India: New Age International.

Lerman, Z., 2004. Policies and institutions for commercialization of subsistence farms in transition countries. Journal of Asian Economics, Volume 15, pp. 461-479: DOI:10.1016/j.asieco.2004.05.004.

Martey, E., Al-Hassan, R. M. & Kuwornu, J. K. M., 2012. Commercialization of smallholder agriculture in Ghana: A Tobit regression analysis. African Journal of Agricultural Research, 7(14), pp. 2131-2141.

MoFED, 2003. Rural Development Policy and Strategies. Addis Ababa, Ministry of Finance and Economic Development (MoFED), FDRE.

Moti, J., Berhanu, G. & Hoekstra, D., 2009. Smallholder commercialization: Processes, determinants and impact, Nairobi, Kenya. 55 pp: Discussion Paper No. 18. Improving

Productivity and Market Success (IPMS) of Ethiopian Farmers Project, ILRI (International Livestock Research Institute.

Nisrane, F., Koru, B. & Seyoum, A., 2015. Productivity and efficiency of smallholder teff farmers in Ethiopia, Addis Ababa, Ethiopia: Working Paper 79. Ethiopian Strategy Support Program (ESSP), EDRI, and IFPRI.

Ng'ombe, J. N., 2017. Technical efficiency of smallholder maize production in Zambia: a stochastic meta-frontier approach. Agrekon, 56(4), pp. 347-365, DOI:10.1080/03031853.2017.1409127.

NPC, 2016. Growth and Transformation Plan II (GTP II) (2015/16-2019/20), Volume I: Main Text. Addis Ababa, Ethiopia: National Planning Commission (NPC).

Pingali, P. & Heisey, P., 1999. Cereal Crop Productivity in Developing Countries, CIMMYT Economics Paper 99-03: Mexico D.F.: CIMMYT.

Pingali, P. L., 1997. From Subsistence to Commercial Production Systems: The Transformation of Asian Agriculture. Amer. 1. Agr. Ecan., Volume 79, pp. 628-634.

Poulton, C., 2017. What is Agricultural Commercialization, Why is It Important, and How Do We Measure It? Working Paper 06 |. Brighton, Agricultural Policy Research in Africa (APRA.

Rios, A. R., Masters, W. A. & Shively, G. E., 2008. Linkages between Market Participation and Productivity: Results from a Multi-Country Farm Household Sample. s.l.:Prepared for presentation at the American Agricultural Economics Association Annual Meeting, Orlando, FL, July 27-29, 2008.

Roodman, D., 2011. Estimating Fully Observed Recursive Mixed-Process Models with CMP. The Stata Journal, 11(2), pp. 159-206.

Rubhara, T. & Mudhara, M., 2019. Commercialization and its determinants among smallholder farmers in Zimbabwe. A case of Shamva District, Mashonaland Central Province. African Journal of Science, Technology, Innovation and Development, pp. 1-9: https://doi.org/10.1080/20421338.2019.1571150.

Salau, S., Omotesho, O. & Muhammad-Lawal, A., 2018. Agricultural Commercialization, Fertilizer Use, and Non-Farm Employment: What Options for Smallholder Farmers in Nigeria? Vancouver, 30th International Conference of Agricultural Economists July 28 - August 2, 2018.

Siziba, S. et al., 2011. Determinants of cereal market participation by sub-Saharan Africa smallholder farmer. Learning Publics Journal of Agriculture and Environmental Studies, 2(1), pp. 180-193.

Sokoni, C., 2008. Commercialization of smallholder production in Tanzania: implications for sustainable resources management. The Geographical Journal, 174(2), pp. 158-161.

Strasberg, P. et al., 1999. Effects of Agriculture Commercialization on Food Crop Input Use and Productivity in Kenya. MSU International Development Working Papers No. 71.

von Braun, J. & Kennedy, E., 1994. Agricultural Commercialization, Economic Development, and Nutrition. Baltimore: The Johns Hopkins University Press.

Wooldridge, J. M., 2012. Introductory Econometrics: A Modern Approach. 5 ed. Mason, OH 45040, USA: South-Western, Cengage Learning.

Zellner, A. & Theil, H., 1962. Three-Stage Least Squares: Simultaneous Estimation of Simultaneous Equations. Econometrica, 30(1), pp. 54-78: http://www.jstor.org/stable/1911287.

Appendix

Table A1: Distribution of treatment interval

Level of cereal crops commercialization	Number of farms HH	Percentage (%)
Treatment interval 1 (below 0.30)	81	23.48
Treatment interval 2(from 0.30 to 0.65)	244	70.72
Treatment interval 3(from 0.65 to 0.90)	20	5.08
Total	345	100

Source: Authors' analysis using primary data (2020)

Table A2: Estimated OLS Coefficients given treatment variable and GPS (UREA)

Outcome variables: UREA in ETB/ha (log)	OLS Coefficients	Standard Errors
Treatment	2.6443	1.5057
treatment_sq	-0.3917	1.5901
pscore	2.9759	1.1859
pscore_sq	-1.1565	1.3845
Treatment*pscore	-4.2343	1.8285
Constant	6.0590	0.2274

Source: Authors' analysis using primary data (2020)

Table A3: Estimated OLS Coefficients given treatment variable and GPS (NPS)

Outcome variables: NPS in ETB/ha (log)	OLS Coefficients	Standard Errors
Treatment	1.7698	1.2787
treatment_sq	-1.9898	1.3504
pscore	0.1035	1.0071
pscore_sq	-0.3497	1.1758
Treatment*pscore	-0.4313	1.5529
Constant	7.1938	0.1931

Source: Authors' analysis using primary data (2020)

Table A4: Estimated OLS Coefficients given treatment variable and GPS (Chemical)

Outcome variables: Chemical in ETB/ha (log)	OLS Coefficients	Standard Errors
Treatment	-0.7879	3.8392
treatment_sq	1.5062	4.0545
pscore	5.6270	3.0238
pscore_sq	-5.3842	3.5302
Treatment*pscore	0.4141	4.6624
Constant	2.2719	0.5797

Source: Authors' analysis using primary data (2020)

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Distribution and Severity of Crenate Broomrape (*Orobanche crenata*) on Faba Bean (*Vicia faba*) in Northern Highlands of Ethiopia

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Abstract

A root holo-parasite, crenate broomrape (Orobanche crenata Forskal) becomes a major threat for faba bean (Vicia faba L.) production in northern highlands of Ethiopia. Information on distribution and problem of crenate broomrape can help to design suitable management options to reduce its negative impact in already infested areas and further spread to new areas. To determine the weed species status in the crop fields, biophysical survey on the parasitic plants' spatial distribution and infection was conducted in small holder farmers' faba bean fields of Amhara and Tigray National Regional States in 2018 cropping season. The crenate broomrape was found in all surveyed districts of the regions; Farta, Fogera, Tach-Gaint, Dessie-Zuria, Kutaber, Mekdela, Tenta, Enda-Mahony and Ofla district with varying density and infection levels. Maximum mean density of 60 and 44 crenate broomrape shoots per square meter, and infection of 1.35 and 1.15 shoots of the parasite per faba bean plant were recorded in Dessie-Zuria and Tenta districts, respectively. Therefore, the crenate broomrape is a serious problem for faba bean production and requires appropriate management strategy for sustainable production and productivity of the crop in the area.

Keywords: density, food legume, holo-parasite, infection severity

Introduction

Faba bean (*Vicia faba* L.) is cultivated mainly for food as the major source of protein, and also for its cash value, animal feed and pest breaking role in cereal-based cropping systems of Ethiopia. The productivity of faba beans is about 2.122 t ha^{-1} with high variation among major growing regions in the country (CSA, 2021). Farmers are obtaining less than 40% of yield potential of faba beans in the crop growing areas (Wondafrash *et al*., 2019). The high yield gap is due to low yielding variety, moisture and soil fertility, foliar disease, and weed infestation including the parasitic weeds serious infection.

Three parasitic weed species namely *Orobanche crenata* Forskal., *O. minor* Smith and *Phelipanche ramosa* (L.) Powel are reported attacking food legumes in Ethiopia (Asefa, 2007). These species are widely distributed in the world as a major constraint on cool-season food and forage legumes as well as other dicot plants (Restuccia *et al*., 2009). However, very recently two major crenate broomrape populations were found in samples collected from Amhara and Tigray Regions of the country (Gashaw *et al.*, 2020). Similarly, genetic variability and host differentiations of *O. crenata* is reported in north African countries like Algeria and Morocco (Mounia *et al*., 2017; Bendaoud *et al*., 2022).

The crenate broomrape (*O. crenata*) is believed to be introduced to few villages of northeast part of the country unintentionally along with food aid in the 1980's (Besufekad *et al*., 1999) and then gradually has expanded to different parts of the northern highlands (Teklay *et al.*, 2013; Negussie *et al.*, 2018). The parasitic weed is attacking majorly faba bean (*Vicia faba* L), and also field pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik), grass pea (*Lathyrus sativus* L.), lupin (*Lupinus* spp) and 'dekoko' (*P. sativum* var. *abyssinicum*) in the country (Takele *et al.*, 2019).

The dominance of crenate broomrape is recognized as a serious production threat on faba bean (Besufekad *et al*., 1999; Rezene and Kedir, 2006; Asefa, 2007; Teklay *et al.*, 2013; Mekonnen, 2016; Gashaw *et al.*, 2020). They further stated that the impacts include yield loss of up to 100% and make the straw unpalatable to livestock. In the South Wollo Zone, farmers abandoned cool-season food legumes, and replaced them with cereals and spice crops. They also indicated with the field surveys made over years that the parasite is expanding its geographic coverage from infested to the weed-free areas most probably due to seed exchange among farmers.

Rubiales and Fernandez-Aparicio (2012) reviewed all available innovations in managing parasitic weeds in legume crops including integrating different management options. Currently, in Ethiopia a faba bean variety called Hashengie (ILB-4358) as partial resistant to the parasite was released (MoANR, 2016). Some attempts were made to develop integrated management of the weed in faba bean using the partially resistant cultivar and one to two sprays of sub-lethal glyphosate (Mekonnen, 2016). Thus, some preliminary investigations indicated that the weed distribution and management practices were tried but detailed information was not documented from both regions in smallholder faba bean fields.

Documenting the distribution and infection status of crenate broomrape on faba bean enables to plan and execute further research, and to recommend suitable management practice to smallholder farmers. Many local field surveys were carried out in tracking the importance of crenate broomrape in the northern parts of the country (Besufekad *et al*., 1999; Teklay *et al.*, 2013), but there is no adequate and up to date information that show the current status of the weed and its importance in the county at large. Moreover, consistent weed monitoring is needed to manage the weed sustainably. Thus, the objective was to determine current distribution and infection level of crenate broomrape in faba bean fields of northern highlands of Ethiopia.

Survey Methodology

Survey area and time

The survey was conducted in major faba bean growing zones of northern Ethiopia; South Gondar, Southern Tigray and South Wollo (Fig. 1) in October and November of 2018. In each zone, by consulting respective offices of agriculture, faba bean production and orobanche infestation suspected districts were selected. Agro-ecologically the two zones were dominantly tepid sub-moist and cool sub-moist mid highlands (MoARD, 2006). Thirty years' mean annual rainfall and temperature status of the surveyed zones have been indicated in Table 1 (Fick and Hijmans, 2017).

Table 1. Long-term rainfall and temperature status of the surveyed zones in northern Ethiopia, 1970-2000

Status	Mean annual rainfall (mm)			Mean annual temperature (°C)		
	South Gondar	South Wollo	Southern Tigray	South Gondar	South Wollo	Southern Tigray
Minimum	755	625	505	7	6	9
Maximum	1539	1409	924	28	29	30
Mean	1166	1061	723	21	19	23

Source: Fick and Hijmans (2017)

Data collection and analysis

At the flowering stage of faba bean, its field surveys were inspected along all- and dry-weather roads at about five-kilometer intervals. At a stop, the faba bean field was sampled following "X" pattern, a 1m x 1m ($1m^2$) quadrate was used systematically at three to five spots per field, and number of faba bean plants and crenate broomrape shoots were counted and recorded. In addition, data on altitude, latitude and longitude were recorded using handheld Global Positioning System (GPS). Then, a total of 33 faba bean fields with 121 sampling spots were assessed.

The count data of crenate broomrape shoots per quadrate were categorized to different density levels; low (<10), medium (10-30) and high (>30), and then the number of fields under each density level described as frequency of occurrence. In addition, mean number of crenate broomrape shoots per faba bean plant calculated using the following formula (Rodenburg *et al.*, 2005).

$$\text{Infection severity} = \frac{\text{Count of crenate broomrape shoots per quadrat}}{\text{Count of faba bean stands per quadrat}}$$

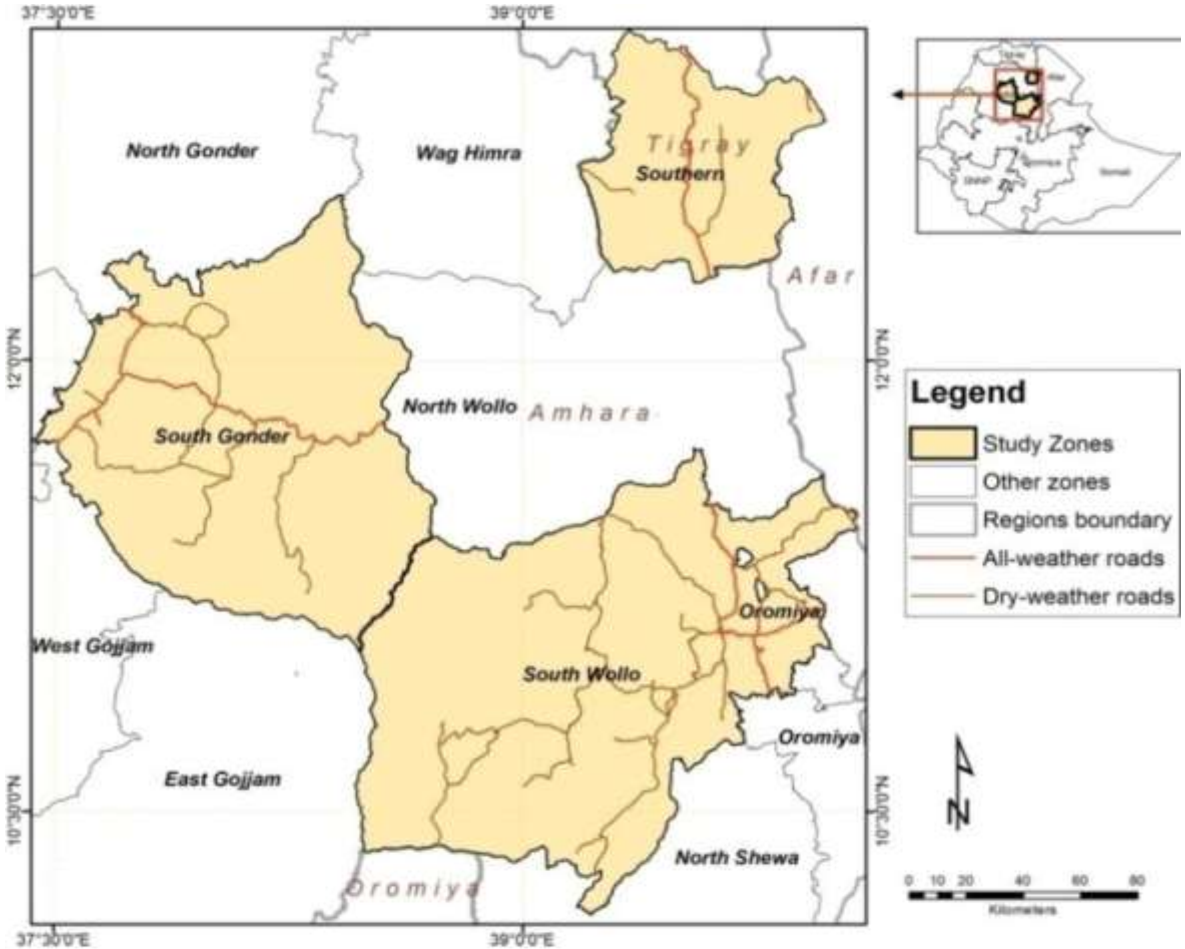

Figure 1. Surveyed zones of northern Ethiopia

The mean value represents severity of the parasite infection on the host plant i.e., infection severity at each sampling spot. The values enable to estimate mean number of emerged parasite shoots attached to roots of the host plant in each quadrate that were classified into low (0.01-0.09), medium (0.10-0.99), high (1.00-2.00) and very high (>2.00) shoots per host plant infection severity.

The on-field collected crenate broomrape density level and obtained infection severity data were analyzed using descriptive statistics, and SAS Version 9.3 (SAS, 2012) with nested design. Finally, these data have been independently plotted on the study area map showing status of the distribution and infection of crenate broomrape on faba bean plants under different agro-ecologies of the surveyed zones.

Results and Discussion

During the survey, small-holder faba bean growers' fields with typical light-brown soil located in wide ranges of altitude; 2200 to 3200 meter above sea level (m a.s.l.), latitude of 11^o 07' to 12^o 75' North and longitude of 38^o 46' to 39^o 52' East were visited.

Germination and growth performance of faba bean at the surveyed area

Mean faba bean plant density recorded ranged from 24 to 72 plants per square meter (m^{-2}). Non-significantly ($P>0.05$) higher mean density of 42 plants m^{-2} was obtained in the South Wollo Zone as compared to the other zones (Figure 2). Highly significant ($P \leq 0.01$) differences observed among the surveyed districts in the regions, where the highest mean faba bean density of 50 plants m^{-2} was recorded in Dessie-Zuria and Mekdela districts followed by Enda-Mahony district (40 plants m^{-2}) as compared to the other districts (Figure 3). These results indicated more suitability of the South Wollo Zone, and its districts particularly Dessie-Zuria and Mekdela district in cultivating the faba bean crop as compared to the other zones and districts in the studied area.

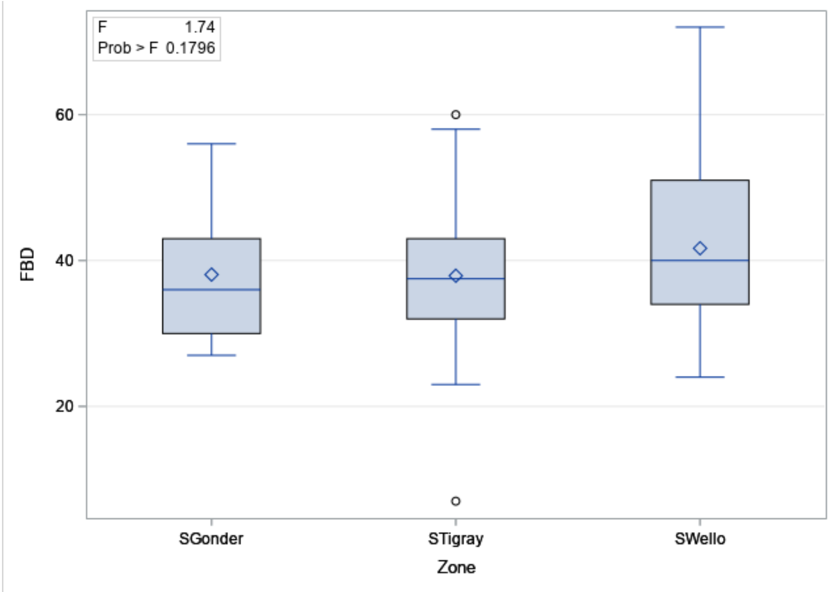

Figure 2. Mean faba bean density (FBD) across the studied zones, during 2018. Relatively highest density of 42 plants m^{-2} was recorded in South Wollo Zone as compared to the others.

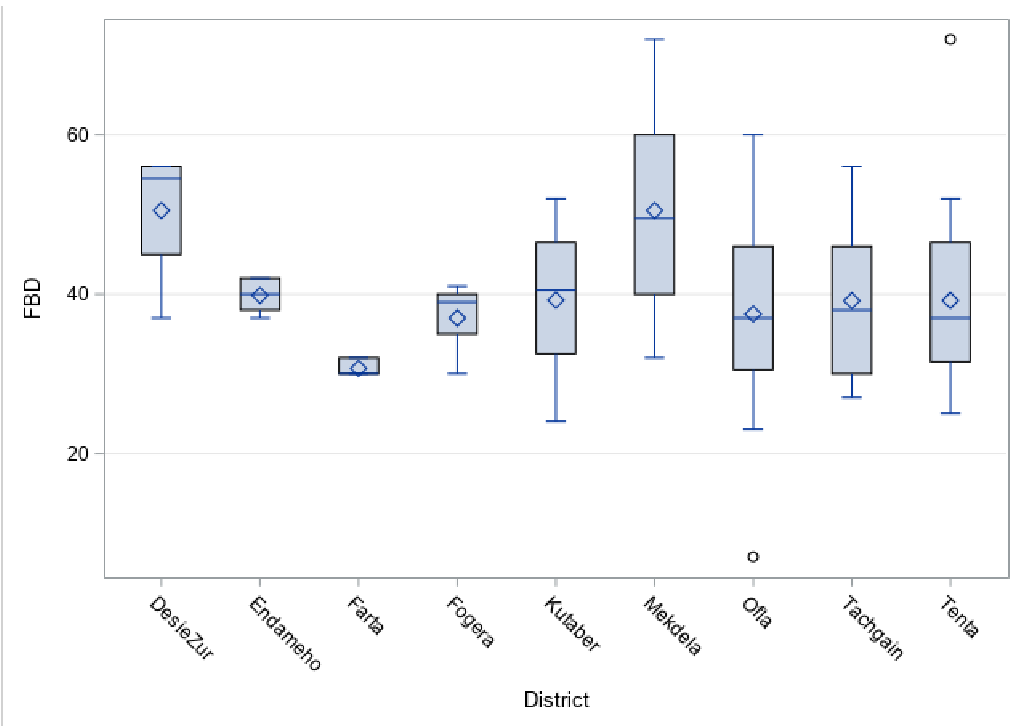

Figure 3. Mean faba bean density (FBD) across studied districts, during 2018. Significantly ($P < 0.05$) highest mean density of 50 plants m-2 was recorded in Dessie-Zuria and Mekdela districts than others.

Distribution of crenate broomrape

Crenate broomrape was recorded in faba bean fields of Amhara and Tigray National Regional States' districts. Those are Farta, Fogera and Tach-Gaint districts of South Gondar Zone; Dessie-Zuria, Kutaber, Mekdela and Tenta districts of South Wollo Zone, and Enda-Mahony and Ofla districts of Southern Tigray Zone. The prevalence of crenate broomrape in faba bean fields of South Wollo, South Gondar and Southern Tigray zones were found to be 96, 90 and 88%, respectively. Higher density levels of 134, 133, 117 and 105 shoots m^{-2} crenate broomrape were recorded from faba bean fields in Ofla, Tenta, Dessie-Zuria and Tach-Gaint districts, respectively. These districts might have been infested by the weed species earlier than other districts by two to three decades.

The recorded densities of crenate broomrape were grouped across the sampling spots as low (<10), medium (10-30) and high (>30) as indicated in Table 2 and on Figure 4. Higher mean density level of the crenate broomrape was detected more frequently in 15 and 10 fields in Tenta and Ofla districts than the other studied districts' faba bean fields. Similarly, Seid and Olivera (2016) reported density of the crenate broomrape ranging between 50 and 250 shoots m^{-2} in heavily infested districts, such as Mekdela and Tenta. The crenate broomrape mainly occurred on cool-season legumes and its infestation levels might have varied with different biophysical factors like seed bank and climatic conditions. Its occurrence was initially confined only to a few localities, but later on it has become a problem of many cool-season legumes growing in the northern part of Ethiopia, particularly in Amhara and Tigray National Regional States. Many research reports indicate the importance of crenate broomrape in the faba bean fields of the area (Besufekad *et al*., 1999; Teklay *et al.*, 2013).

Having ecological conditions suitable for such parasitic plant occurrence and infestation, Ethiopia reported as a crenate broomrape infested country many years later than the countries around the Mediterranean region. The crenate broomrape was reported for the first time in the country by Asefa and Endale (1994) as a new invader of faba bean fields in Dessie-Zuria and Kutaber districts of South Wollo Zone. Then after, Adugna *et al.* (1998) observed it infecting the same crop at Dera and Tach-Gaint districts of South Gondar Zone. Teklay *et al*. (2013) also reported the parasite infested districts of Southern Tigray Zone in Tigray Region. Similarly, Mekonnen (2016); Seid and Olivera (2016) indicated the weed infested districts such as Dessie-Zuria, Kutaber, Mekdela and Tenta in South Wollo Zone; and Tach-Gaint in South Gondar Zone of Amhara National Regional State. It has been spreading from place of introduction to other locations mainly through seed exchange among farmers, and also due to the fact that agricultural development agents and non-governmental organizations move farm inputs throughout the country without any restriction or domestic quarantine measures.

The current dense occurrence of crenate broomrape indicates that a huge number of seeds have been produced per a plant that can enrich soil seed banks by staying dormant for about two decades. Low atmospheric humidity ensures high rate of transpiration, which enhances movement of water and solute from host plants, so the weed plants' dense occurrence in the studied area might have been favored by this climatic condition besides the rich soil seed bank. Mohamed *et al.* (2006) reported that with increased temperature and drought due to climatic changes in many areas of the world, *Orobanche* species' dense infestation could pose greater threats to agriculture. Gevezova *et al*. (2012); Habimana *et al.* (2014) reported that a single crenate broomrape plant can set more than 500 000 minute seeds per season, which can easily disseminate over long distance by various mechanisms to weed-free neighboring fields, remain in soil viable for about 20 years and then heavily increase seed bank.

Analysis made on climatic requirement of *Orobanche* species suggested that very large areas of new territory of the world are at risk of invasion if no measure is taken to limit introduction of their seeds by strengthening quarantine Centre of a given weed-free country or region, and training agricultural experts and farmers to be alert on new infestations (Mohamed *et al.*, 2006; Grenz and Sauerborn, 2007). Crenate broomrape is a thermophilic plant that frequently requires dry conditions and light soils to be invasive (Negewo *et al*., 2022). These all issues hold true in the existing farming system condition of the northern highlands of Ethiopia.

Table 2. Number of faba bean fields with varying densities of crenate broomrape in the surveyed area

Region	Zone	District	Number of fields under various densities*		
			Low	Medium	High
Amhara	South Gondar	Tach-Gaint	17	9	3
		Fogera	9	0	0
		Farta	3	0	0
	South Wollo	Kutaber	2	6	4
		Dessie-Zuria	0	2	2
		Tenta	6	3	15
		Mekdela	3	1	2
Tigray	Southern Tigray	Ofla	9	9	10
		Enda-Mahony	6	0	0
Percentage			45	25	30

* Density level of low =<10, medium=10-30, high=>30 crenate broomrape shoots per m^2

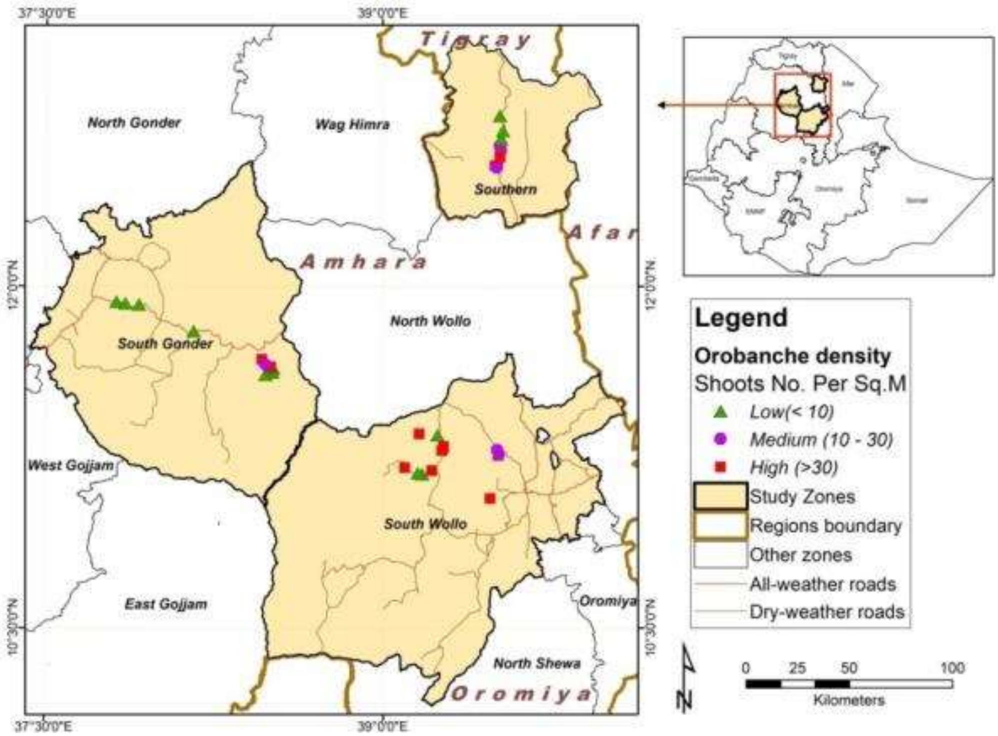

Figure 4. Mean density of crenate broomrape in faba bean fields of surveyed zones during 2018

Highly significant ($P \leq 0.01$) mean crenate broomrape density of 37 shoots m^{-2} was recorded in faba bean fields of South Wollo Zone as compared to South Gondar Zone that had only 12 shoots m^{-2} (Figure 5). Significantly ($P \leq 0.01$) highest mean crenate broomrape density levels of 60, 44 and 31 shoots m^{-2} were scored in Dessie-Zuria, Tenta and Ofla districts, respectively than the other districts (Figure 6). The highest infestation of crenate broomrape plants on such light soil dominated areas has been well expected. Thus, northern Ethiopia is currently found as an important area where crenate broomrape is a prevalent plant pest in legume crops particularly in faba bean fields. Frequent cultivation of the susceptible host crop (faba bean) seems the other main motive in aggravating spread of the crenate broomrape in the area. These limitations coupled with an ever-increasing population pressure that enhance ecological degradation and changes in climate conditions are further exacerbating the weed invasion year after year (Takele *et.al*., 2019).

Preventive measures could be effective and the most economical practices in reducing crenate broomrape infestation in agricultural fields. It is also important to consider the positive effects of cultural practices like crop rotation, intercropping, adjustment of seed sowing date and pattern, soil fertility management, and hand weeding. However, these practices were limited at large in the parasitic plant less densely infested crop fields (Kleifeld *et al*. 1994). Thus, the field survey density results need to be taken into account while planning site specific management measures on the crenata broomrape plant from the host crop fields.

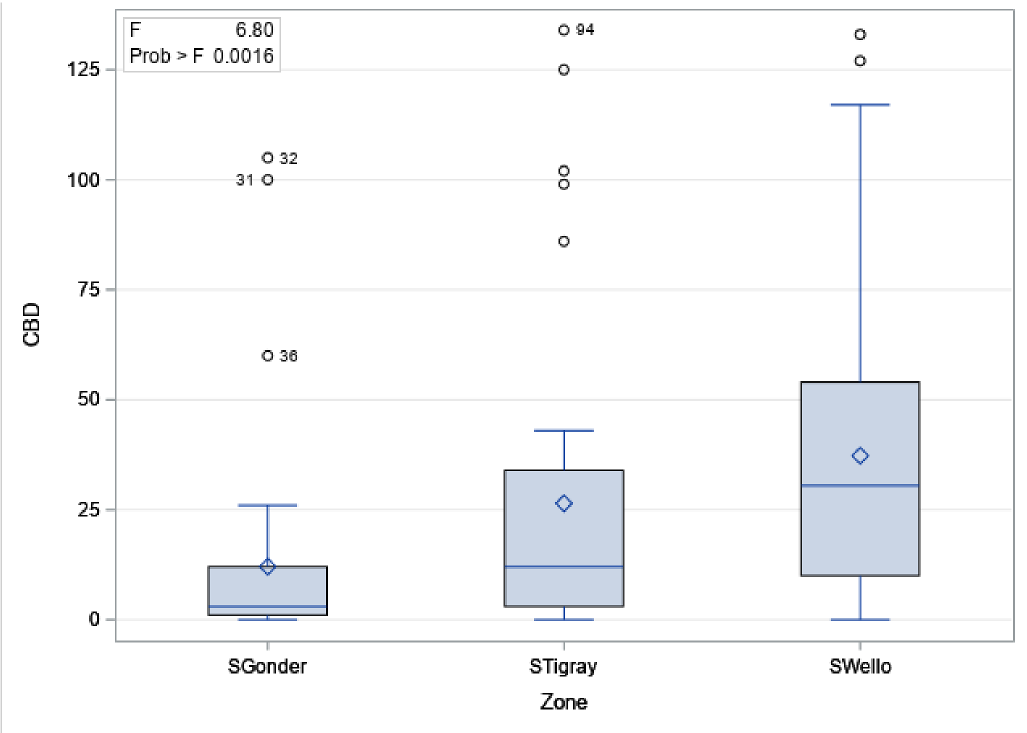

Figure 5. Mean crenate broomrape density (CBD) across the studied zones, 2018. Significantly (P < 0.01) highest mean density of 37 shoots m-2 was recorded in South Wollo Zone.

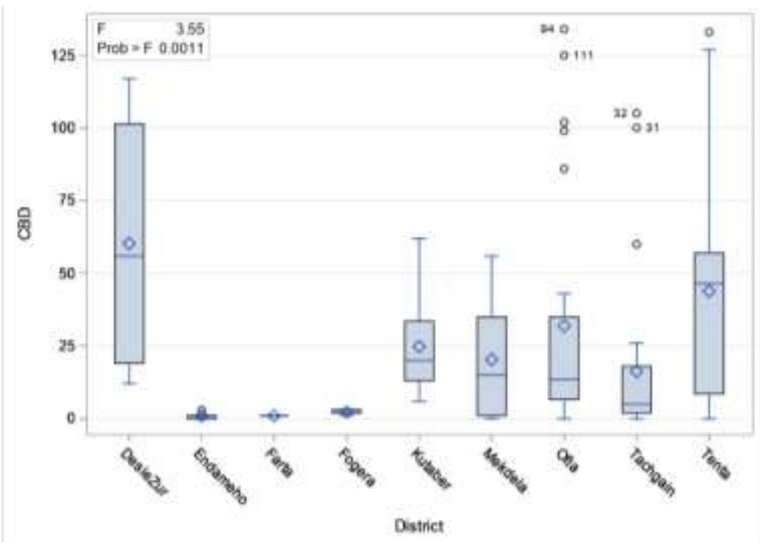

Figure 6. Mean crenate broomrape density (CBD) across the studied districts during 2018. Significantly (P < 0.01) highest mean densities were recorded in Dessie-Zuria, Tenta and Ofla districts than the others.

Infection severity of crenate broomrape

The crenate broomrape infection severity on faba beans showed considerable variation among the surveyed areas. Mean infection severities of the parasite on faba beans across the sampling spots were found ranging from low to very high (Table 3 and Figure 7). Higher infection severities of 14.14, 3.50, 3.45 and 3.16 crenate broomrape shoots per a faba bean plant were scored in Ofla, Tenta, Tach-Gaint and Dessie-Zuria districts, respectively. The mean infection severity of the crenate broomrape on faba bean across the sampling spots were grouped as low (0.01-0.09), medium (0.10-0.99), high (1.00-2.00) and very high (>2.00) parasite shoots per a crop plant. Higher levels of infection were more frequently (from about five faba bean fields) recorded in Tenta and Ofla districts than in the others.

Table 3. Number of fields with various infections of crenate broomrape on faba bean in the surveyed area

Region	Zone	District	Number of fields under various infections*			
			Low	Medium	High	Very high
Amhara	South Gondar	Tach-Gaint	13	13	0	3
		Fogera	9	0	0	0
		Farta	3	0	0	0
	South Wollo	Kutaber	0	10	2	0
		Dessie-Zuria	0	2	1	1
		Tenta	4	10	5	5
		Mekdela	3	2	1	0
Tigray	Southern Tigray	Ofla	3	18	2	5
		Enda-Mahony	6	0	0	0
	Percentage		34	45	9	12

* Infection severity of crenate broomrape shoots per a faba bean plant; low =0.01-0.09, medium=0.10-0.99, high=1.00-2.00, very high=>2.00

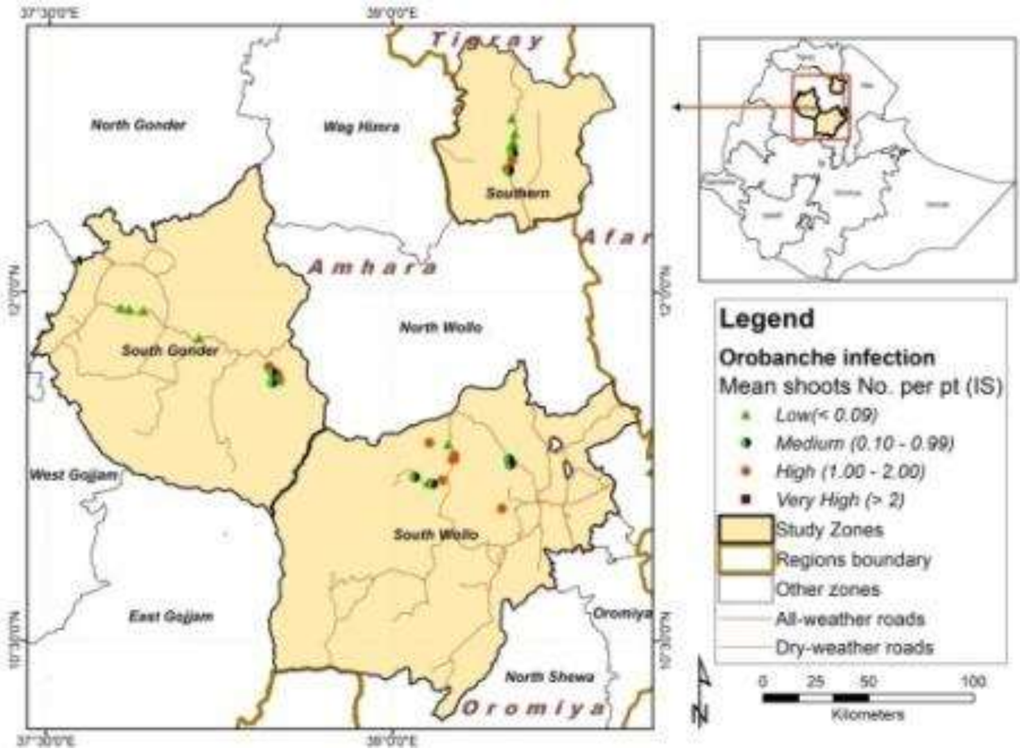

Figure 7. Mean infection severity of crenate broomrape on faba bean in surveyed zones during 2018

Crenate broomrape significantly ($P \leq 0.05$) higher mean infection severity of 1.07 shoots per faba bean plant observed in Southern Tigray Zone than South Gondar Zone (Figure 8). Significantly higher mean infection severity of 1.35, 1.29 and 1.15 scored respectively in Dessie-Zuria, Ofla and Tenta districts than Tach-Gaint and Fogera district (Figure 9). These districts also had the highest density of the faba bean crop and the crenate broomrape plants as indicated in the previous consecutive sections of this document. This strengthens the assumption that these districts had earlier infestation due to the parasitic plant than the other districts, even though more suitable for the crop plant cultivation. The possible reasons might also be due to continuous cultivation of the popular but susceptible host crop, moisture deficit and low soil fertility conditions in those districts.

Abandoning cultivation of faba bean by most farmers at the study area under such high infection of the parasite on the host crop seems reasonable or practical. Highly dense infection of the crenate broomrape induces acceleration of faba bean senescence, as a result the highly infected host plant dies earlier than the sparsely attacked one (Figure 10). Linke *et al*. (1991); Zaitoun *et al*. (1991) reported that the number of emerged *O. crenata* shoots are negatively correlated with productivity of infected faba bean plants. Infection severity of broomrape on the host crop is strongly related to different factors such as number of seeds in soil, and temperature and soil moisture conditions during the growing season (Manschadi *et al*., 2001; Eizenberg *et al*., 2005). Field orientation towards the afternoon sun, short time intervals while susceptible crop rotation, no irrigation and/or advancing of sowing date might also contribute to such a high level of crenate broomrape infection. Also, Trabelsi *et al.* (2017) reported that crenate broomrape dense infection tends to be associated with less fertile and moisture conditions of soil.

An increase of resources allocated within the crenate broomrape plant is concomitant to reduction of the host seed yield, indicating that the parasite growth and host reproduction compete directly for resources within a host plant. The vegetative growth and grain yield of faba bean was almost negligible at those fields with very high infection severities of the crenate broomrape. Previous studies also depicted that infection of 2.1 to 4.0 emerged crenate broomrape shoots per faba bean plant at harvest caused approximately a 50% reduction in the crop yield depending on the climatic conditions during the growing season (Mesa-Garcia and Garcia-Torres, 1984; Linke *et al.*, 1991). Likewise, Fernandez-Aparicio *et al.* (2016) reported that reductions in host aboveground biomass observed starting at low infection severity and half maximal inhibitory performance predicted at 4.5 parasites per faba bean plant.

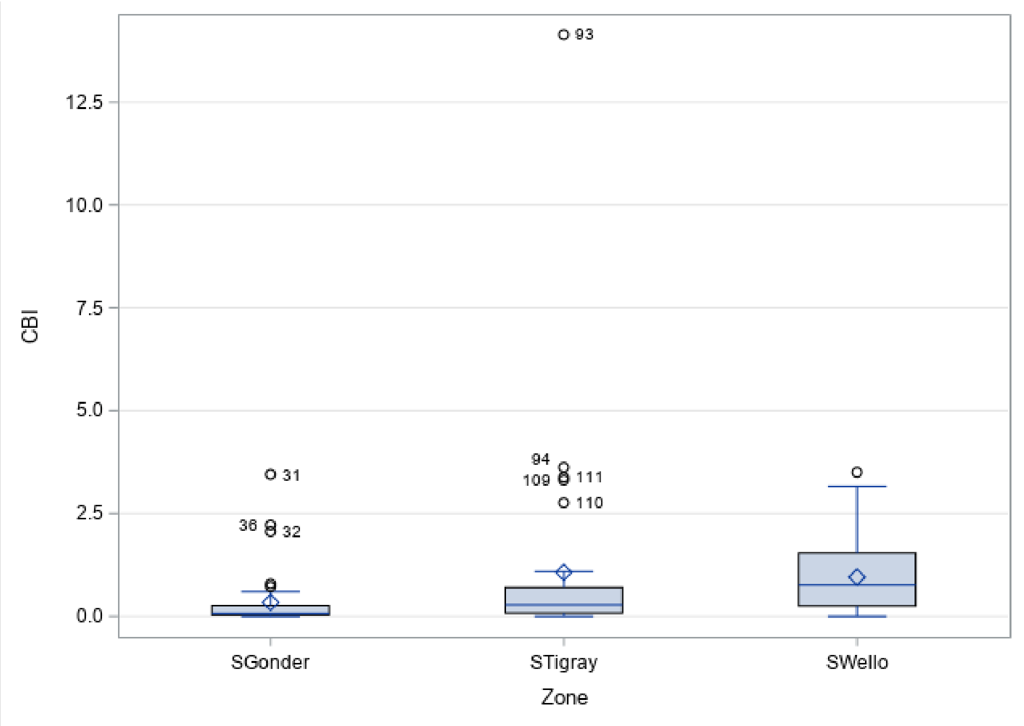

Figure 8. Mean crenate broomrape infection (CBI) on faba bean plant across the surveyed zones during 2018. Significantly ($P \leq 0.05$) higher mean infection severity of 1.07 parasite shoots per the crop plant was observed in Southern Tigray Zone than Southern Gondar Zone.

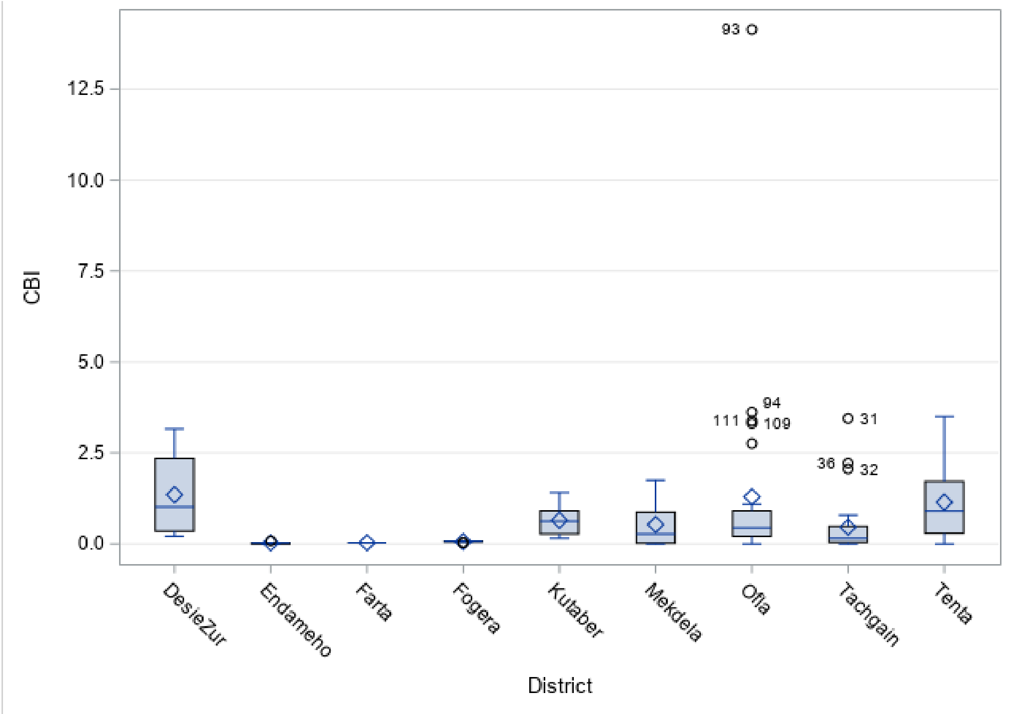

Figure 9. Mean crenate broomrape infection (CBI) on faba bean plant across the surveyed districts during 2018. Significantly ($P < 0.05$) highest mean infection severities were scored in Dessie-Zuria, Ofla and Tenta districts.

Figure 10. Crenate broomrape dense infection on faba bean in a farmer field of north Ethiopia

The crenate broomrape is a major biological constraint and also remained as continuous threat to cool-season legumes production in northern Ethiopia. In the highly affected area of North Wollo Zone, enormous growers stopped cultivating the crenate broomrape. As a result, substantial reductions in both the cultivated area and crop production occurred due to complete devastation caused by the weed (Seid and Olivera, 2016; Takele *et al.*, 2019). Thus, the high crop yield loss in the already infested area and the potential further expansion of the parasite to neighboring weed-free areas are the great concern of the country.

In the surveyed area, few growers cultivated faba beans with uncertainty just to obtain the crop grain that is much-desired for home consumption. As a result, fields planted with faba beans were very small in spite of the high concern of the farming communities to have cultivated the crop in the area. The current serious impact of crenate broomrape on specific host crops in the country might extend to other related crops in the future unless possible efforts are undertaken to restrict spread and invasion of the parasite. Moreover, it is noticed that the parasite impact on faba bean and field peas can be reduced when these host crops are intercropped with oat on infested fields, but can only be possible on soil with low seed bank condition (Fernandez-Aparicio *et al.,* 2013). Thus, the survey results of crenata broomrape plant infection severity on the host crop also need to be taken into account while planning site specific management measures.

Agricultural experts and elders in the surveyed area testified an increase in the number of crenate broomrape infested fields and occurrence of dense infection in cool-season legumes. Lack of preventive measures and awareness on biology of the parasite might have contributed to such wide distribution and an ever-increasing infection level on the host crop across the studied area. Likewise, Bulbul *et al*. (2009) reported that lack of effective countermeasure against broomrape is contributing to the continuously increasing importance of the weed species in agricultural areas. Hence, the spread of the crenate broomrape has escalated at an alarming speed putting all food legumes at jeopardy and then limitation on such valuable rotational crops indirectly lowering the productivity of cereals mono-cropped production system as reported by Teklay *et al.* (2013). Furthermore, the difficulty in containing crenate broomrape distribution in the study area is also assisting its expansion to weed-free neighboring locations including central and southern part of the country.

Conclusion

Crenate broomrape infestation in faba bean fields was recorded in nine districts of three zones in the northern highlands of Ethiopia; Amhara and Tigray National Regional States. Considerably high density and infection by the crenate broomrape were recorded in Ofla, Tenta and Dessie-Zuria districts. The crenate broomrape dense occurrence in the already infested area and further spread to the weed-free neighboring areas are of great concern in the country. Strict domestic quarantine, proper field sanitation and awareness creation among the farming communities on the biology of the weed at grass root level need to be implemented to restrict the dense infestation and further spread of crenate broomrape. Proper cropping systems and farm practices like growing resistant and/or tolerant faba bean cultivars, crop rotation systems with long time intervals between successive susceptible crops, intercropping with catch or trap crops, soil inoculation with beneficial microbes, spraying of selective herbicides, conservation of an ecology and development of integrated management strategy are mandatory to come up with reduced problem of the crenate broomrape. Thus, farmers at the parasitic weed infested area and also the weed-free neighboring areas of the country need to be advised and aware with technology and information that enable them limiting the buildup of soil seed bank and further expansion of crenate broomrape inoculum in faba bean production fields.

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Declaration of interest statement

The authors express that there is no competing interest to declare.

References

Adugna Wakjira, Amare Gizaw, Kemal Ali and Berhanu Bekele. 1998. Crop losses assessment of 1997 in Gojam and Gondar of Amhara National Regional State. *A survey report submitted to HARC*, Holetta, Ethiopia.

Asefa Admasu. 2007. Integrated Orobanche Management in Food Legumes (Faba Bean): Experience of Farmers' Field School (FFS) in Dessie-Zuria District, Ethiopia. pp. 45-49. ***In***: *Progress on Farmers Training on Parasitic Weed Management, Food and Agriculture Organization of the United Nations*, Rome.

Asefa Admasu and Endale Berhe. 1994. *Orobanche crenata:* A potential threat of food legumes in Ethiopia. *Ethiopian Weed Science Society (EWSS) Newsletter* 2:1. 75 pp.

Bendaoud F, Gunjune K, Hailey L, James H.W, Nadjia Z and David C.H. 2022. Genotyping-by-sequencing analysis of *Orobanche crenata* populations in Algeria reveals genetic differentiation. *Ecology and Evolution*. https://doi.org/10.1002/ece3.8750

Besufekad Tadesse, Legesse Admassu and Rezene Fessehaie. 1999. *Orobanche* problem in south Wollo. ***In***: *Proceeding of the Ethiopian Weed Science Workshop*, *Arem:* 5:1–10, Addis Ababa, Ethiopia.

Bulbul F, Aksoy E, Uygur S and Uygur N. 2009. Broomrape (*Orobanche* spp.) problem in the eastern Mediterranean Region of Turkey. *HELIA,* 32(51): 141-152.

CSA (Central Statistical Agency). 2021. Report on area and production of major crops-private peasant holdings, meher season 2020/21. *Statistical Bulletin* 590, Volume I, Addis Ababa, Ethiopia.

Eizenberg H, Shtienberg D, Silberbush M and Ephrath J.E. 2005. A new method for monitoring early stages of *Orobanche cumana* development in sunflower (*Helianthus annuus*) with minirhizotron. *Annals of Botany*. 96: 137–140. doi: 10.1093/aob/mci252.

Fernandez-Aparicio M, Cimmino A, Evidente A and Rubiales D. 2013. Inhibition of *Orobanche crenata* Seed Germination and Radicle Growth by Allelochemicals Identified in Cereals. *J. Agric. Food Chem*, 61: 9797–9803. doi: 10.1021/jf403738p.

Fernandez-Aparicio M, Flores F and Rubiales D. 2016. The Effect of *Orobanche crenata* Infection Severity in Faba Bean, Field Pea, and Grass Pea Productivity. *Frontiers of Plant Sciences,* 7:1409. doi: 10.3389/fpls.2016.01409.

Fick S.E and Hijmans R.J. 2017. WorldClim 2: new 1km spatial resolution climate surfaces for global land areas. *International Journal of Climatology* 37 (12): 4302-4315. https://WorldClim.org.

Gashaw Belay, Kassahun Tesfaye, Aladdin Hamwieh, Seid Ahmed, Tiegist Dejene and Jose Oscar Lustosa de Oliveira Junior. 2020. "Genetic Diversity of *Orobanche crenata* Population in Ethiopia Using Microsatellite Markers", *International Journal of Genomics*. https://doi.org/10.1155/2020/3202037.

Gevezova M, Dekalska T, Stoyanov K, Hristeva T, Kostov K, Batchvarova R and Denev I. 2012. Recent advances in broomrapes research. *Journal of Biological Science and Biotechnology,* 1(2): 91–105.

Grenz J.H and Sauerborn J. 2007. Mechanism limiting geographical range of the parasitic weed *Orobanche crenata*. *Agriculture, Ecosystem and Environment*, 122: 275–281.

Habimana S.A, Nduwumuremyi J.D and Chinama R. 2014. Management of Orobanche in field crops- A review. *Journal of Soil Science and Plant Nutrition*, 14(1): 43–62.

Kleifeld Y, Goldwasser Y, Herzlinger G, Joel D.M, Golan S and Kahana D. 1994. The effects of flax (*Linum usitatissimum* L.) and other crops as trap and catch crops for control of Egyptian broomrape (*Orobanche aegyptiaca* Pers.). *Weed Res.* 34(1):37-44.

Linke K-H, Saurborn J and Saxena M.C. 1991. Host-parasite relationships: effect of *Orobanche crenata* seed banks on development of the parasite and yield of faba bean. *Angewandte Botanik*, 65: 229-238.

Manschadi A.M, Sauerborn J and Stutzel H. 2001. Quantitative aspect of *Orobanche crenata* infestation in faba beans as affected by abiotic factors and parasite soil seed bank. *Weed Research*, 41: 311-324.

Mekonnen Misganaw. 2016. Integrated weed (*Orobanche crenata*) management on faba bean. *American Journal of Agricultural Research*, 1(1): 0029–0034. http://escipub.com/.

Mesa-Garcia J and Garcia-Torres L. 1984. A competition index for *Orobanche crenata* Forsk effects on broad bean (*Vicia faba* L.). *Weed Research*, 24: 379-382.

MoANR (Ministry of Agriculture and Natural Resource). 2016. Crop Variety Register: Issue No. 18. *Plant Variety Release, Protection and Seed Quality Control Directorate*, MoANR, Addis Ababa, Ethiopia.

MoARD (Ministry of Agriculture and Rural Development). 2006. Major Agro-ecological zones of Ethiopia, Addis Ababa.

Mohamed K.I, Papes M, Williams R, Benz B.W and Reterson A.T. 2006. Global invasive potential of ten parasitic witch weeds and related *Orobanchaceae* AMBIO. *A Journal of the Human Environment*, 35(6): 281–288.

Mounia E, Fatima ZB, Fatima G, Rabha A, Lamiae G, Loubna B, James W and Rachid M. 2017. Host differentiation and variability of *Orobanche crenata* populations from legume species in Morocco as revealed by cross-infestation and molecular analysis. *Pest Management Science*. 73: 1753-1763. https://doi.org/10.1002/ps.4536

Negewo T, Ahmed S, Tessema T and Tana T. 2022. Biological Characteristics, Impacts, and Management of Crenate Broomrape (*Orobanche crenata*) in Faba Bean (*Vicia faba*): A Review. *Frontiers in Agronomy* 4:1-15. doi: 10.3389/fagro.2022.708187

Negussie Tadesse, Seid Ahmed, Fikremariam Asargew, Cherenet Alem, Mekonnen Misganaw, Teklay Abebe, Anteneh Ademe, Gemechu Keneni, Gashaw Belay, Yohannes Ebabuye, Bogale Niger and Rezene Fessehaie. 2018. Crenate Broomrape (*Orobanche crenata* Forsk.) Problem and its Management in Food Legumes. *Ethiopian Journal of Crop Science, Special Issue*, 6(3): 377-386.

Restuccia A, Marchese M, Mauromicale G and Restuccia G. 2009. Biological characteristics and control of *Orobanche crenata* Forsk., A review. *Italian Journal of Agronomy/ Review Agronomy*, 1: 53-68.

Rezene Fessehaie and Kedir Nefo. 2006. Weed research in high land food legumes of Ethiopia, pp. 278–287. ***In**: Proceedings of the Workshop on Food and Forage Legumes*, 22-26 September 2003, Addis Ababa, Ethiopia. ICARDA, Aleppo, Syria.

Rodenburg J, Bastiaans L, Weltzien E and Hess D.E. 2005. How can field selection for Striga resistance and tolerance in sorghum be improved? *Field Crops Research*, 93: 34–50.

Rubiales D. and Fernandez-Aparicio M. 2012. Innovations in parasitic weeds management in legume crops. A review. *Agronomy and Sustainable Development*. 32: 433–449. https://doi.org/10.1007/s13593-011-0045-x

SAS (Statistical Analysis System). 2012. Statistical Analysis System, Version 9.3 computer software, SAS Institute, Cary, NC, USA.

Seid Ahmed and Olivera J.R. 2016. Narrowing the yield gap of food legumes through integrated management of parasitic weeds in the highlands of Ethiopia. Report. ICARDAEMBRAPA. Report for the period 20 Nov 2013 - 19 May 2016.

Takele Negewo, Etagegnehu Gebremariam and Rezene Fessehaie. 2019. Broomrapes (*Orobanche* and *Phelipanche* spp.) in Ethiopia: Problems and Management-*A Review*, pp. 211-230. ***In**: Proceeding of the 24th Annual Conference*, 16-17 March 2018, Haramaya University.

Teklay Abebe, Hadas Beyene and Yemane Nega. 2013. Distribution and economic importance of Broomrape (*Orobanche crenata*) in food legumes production of South Tigray, Ethiopia. *ESci Journals of Crop Production*, 02(03): 101–106. www.escijournals.net/EJCP.

Trabelsi I, Yoneyama K, Abbes Z, Amri M, Xie X, Kisugi T, Kim H.I, Kharrat M and Yoneyama K. 2017. Characterization of *strigolactones* produced by *Orobanche foetida* and *Orobanche crenata* resistant faba bean (*Vicia faba* L.) genotypes and effects of phosphorous, nitrogen, and potassium deficiencies on *strigolactone* production. *South African Journal of Botany*, 108: 15–22. www.elsevier.com/l ocate/sajb.

Wondafrash Mulugeta, Kindie Tesfaye, Mezegebu Getnet, Seid Ahmed, Amsalu Nebiyu and Fasil Mequanint. 2019. Quantifying Yield Potential and Yield Gaps of Faba Bean in Ethiopia. *Ethiopian Journal of Agricultural Science*, 29: 107-122.

Zaitoun F.M.F, Al-Menoufi O.A, Weber H and Chr. 1991. Loss assessment and forecasting work on plant diseases: 1. A new method for assessment of loss in *Vicia faba* through infection with *Orobanche crenata*. pp. 167–184. ***In***: *Progress in Orobanche Research*, Eberhard-Karls Universita ¨ t, Tu¨ bingen, FRG.

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Brewer's Spent Yeast Accessibility, Preservation, Storage and Feeding Practices of Smallholder Farmers' along Major Breweries in Ethiopia

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Abstract

Smallholder farmers often replace liquid brewer's spent yeast (LBSY) with conventionally used but costly protein sources despite associated poor management and feeding practices. This study was conducted in three purposively selected districts (Bedele and Gelan, in Oromia Regional State) and (Wereda-11, in Akaki Kality sub city in the Addis Ababa city administration) from April to June, 2022 to assess the accessibility, preservation, storage, and feeding practices of LBSY along major breweries in Ethiopia. Two peasant associations (PAs) from each district were purposively selected. Among LBSY beneficiary respondents a total of 182 household (HH) respondents were selected and individually interviewed using random sampling techniques. The study revealed that the frequency of LBSY supply was not significantly (P>0.05) varied across the study districts with 49.5% of the respondents across the study distracts accessing LBSY only once a week while 26.4, 17.6, and 6.6% of the respondents reportedly receiving it once per two weeks, once per three weeks and once per month, respectively. The farm gate purchasing price of LBSY was in the range of 1.00-1.19 birr per liter with increasing trend within the last five years across the study districts. The majority of respondents (81.3%) across the study districts responded to having obtained LBSY from local retailers. Plastic barrel was majorly used by respondents in Wereda-11 (92.2%) and Gelan (93.1%) but 93.6% of respondents in Bedele used Jeri cans of 20 liter capacity for LBSY storage. Preservation of LBSY under aqueous saline environment was a common practice to 76.6 and 60.3% of respondents in Wereda-11and Gelan districts, respectively. According to 67.5, 58.7, and 54.4% of the respondents in Wereda-11, Bedele, and Gelan districts, respectively roughage diets are treated with LBSY in mixture with salt, and water before feeding their animals. More than 82% of the respondents across all the study districts reported that mixing with feed ingredients was the major mode of offering LBSY to the diet of the animals. There were significant (P<0.05) variations in milk production performance of dairy cows across study districts with 60.2% of the respondents were able to observe incremental changes in milk production capacity of their cows when maintained on LBSY based rations. Similarly, higher proportions (71.4%) of the respondents across the study districts, reported as there were no changes in milk quality with LBSY supplementation. In conclusion, accessibility of LBSY, costs, transportation, and lack of feeding practices were the major challenges of smallholder farmers when it comes to the feeding practices of LBSY to the different livestock species in the study districts.

Keywords: brewer's spent yeast; feeding; preservation; smallholder farmers; storage

Introduction

Even though Ethiopia is a country endowed with a large cattle population and a potential for dairy development, livestock productivity is very low. Consequently, the direct contribution to the national economy so far is very limited (Dessalegn *et al*., 2016). The low productivity of the country's livestock is mainly attributed to several technical and non-technical factors, among which inadequate animal feed resources both in terms of quality and quantity (Tamirat, 2019), are hampering the sector much behind its potential.

In Ethiopia, farmers often depend less on purchased compound feeds to maximize roughage utilization due to the rising cost of concentrate feeds caused by stiff competition with humans as food for cereal grains. Price volatility and fluctuations in the supply of raw materials to the feed industry ultimately inflate the total cost of dairy cattle feeding, often estimated to reach 70% of the total cost of animal production (Seyoum *et al*., 2018). Thus, the search for untapped, alternative, and least-cost feed supplements should remain the focal point of future research and development works. Among the feed supplements, brewery by-products could be suggested as potential candidates in the compounding of dairy rations.

Brewery industries generate large volume of by-products that can be reused as livestock feed resources (Demissie, 2021), the most common ones being brewer's spent grains (BSG) and brewer's spent yeast (BSY), both are produced from the main raw materials used for beer production (Mussatto *et al*., 2006). Currently, there are 12 beer factories in Ethiopia with annual production capacities of more than 360,758 hectoliters (hl) of LBSY (Getu *et al*., 2018). Brewer's spent yeast is obtained by the removal of yeast after the brewing process and subsequent inactivation by heat (Hertrampf and Felicitas, 2000). This by-product is used as feedstuff for pigs, ruminants, poultry and fish (Hertrampf and Felicitas, 2000; Tacon *et al*., 2009). Inactivated brewer's yeast is a highly valuable source of protein, phosphorus and B vitamins and may be fed fresh (liquid form) or dried (brewer's dried yeast). It can be generally concluded that deactivated yeast can be used as an alternative protein source in rations for ruminants because it is much cheaper than most conventionally used protein supplements in Ethiopia, with equivalent or higher nutritional value than soybean meal (Huseyin and Erol, 2003). On the other hand, brewer's yeast has a limited shelf-life and may suffer tremendous losses of total solids during storage. Related to this, however, there are very limited or no published research works on the management and animal utilization practices of LBSY in Ethiopia. Therefore, the objective of this study was to assess brewer's spent yeast accessibility, preservation, storage, and feeding practices of smallholder farmers along major breweries in Ethiopia.

Materials and Methods

Description of Study Areas

The survey study was conducted in Oromiya regional state (Bedele and Gelan districts) and Addis Ababa city administration, Akaki Kality sub-city, Wereda 11 (Figure 1), where major beer factories and their by-product beneficiaries are found.

Addis Ababa: the capital city of Ethiopia: is located in the central parts of the country and lies between 8°55´ and 9º07´North and 38º4´and 38º50´East. The altitude of Addis Ababa is 2500 meter above sea level (masl). The long rainy season extends from June to September with an annual mean rainfall of 1000 mm and an average annual daily temperature is in the range of 11-23.1^{0}C. Akaki Kality is situated in the southeast part of Addis Ababa that shares a boundary with Bole and Nefas Silk Lafto Sub-cities in the north-east and north-west directions, respectively and the rest with the Sheger City of Oromiya Regional state. The site harbors one of the biggest beer factories run by the international Heineken group with annual LBSY production potential of 36,243.5 hl (Getu *et al*., 2018).

Bedele: is a town and separate district in south-western Ethiopia, in the Buno Bedelle Zone of the Oromia Regional State. The town is located at 8°27′N latitude and 36°21′E longitude and has an altitude ranging from 2,012–2,162 masl. One of the oldest beer factories (Bedele beer factory), run by the Heineken international group has an annual LBSY production capacity of 24,853.5 hl (Getu *et al*., 2018).

Gelan: is located in Sheger City of Oromiya Regional state at a distance of 25 km south-east from Addis Ababa city administration between 7°12’- 9°14’N latitudes and 38°32’ – 39°32’ E longitudes. It lies at an altitude between 1,800 - 2,300 masl. It has an annual average daily temperature of 19 ^{0}C and an annual average rainfall of 861 mm. Due to its geographical proximity to Heineken and St. George beer factories, it harbors one of the largest numbers of LBSY beneficiaries in Oromia regional state.

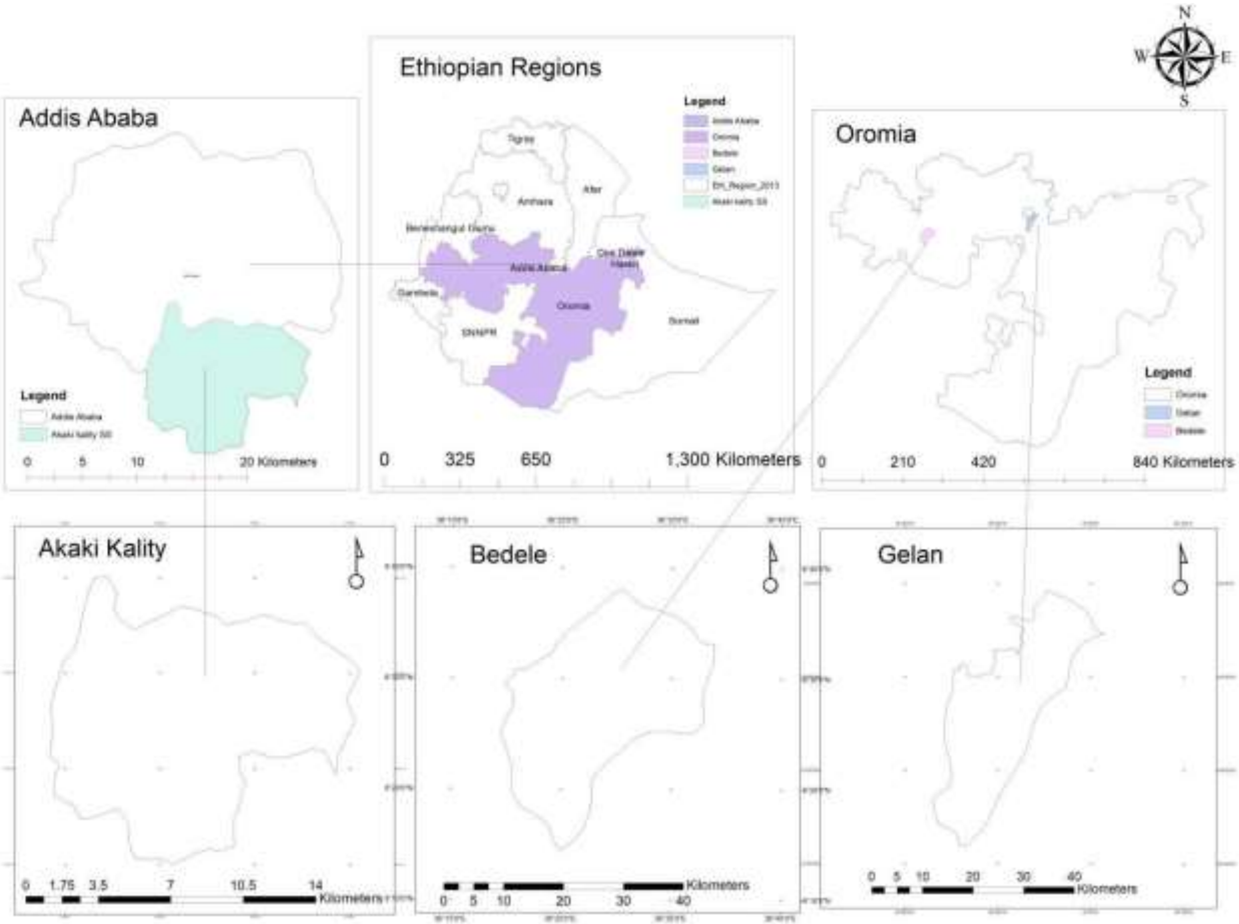


Figure 1: Map of the study locations

Sampling Procedure and Sample Size Determination

The study followed a cross-sectional study design. The three districts and two PAs from each district were purposively selected with the help of experts from the zonal and district agricultural offices. Among LBSY beneficiaries, the list of names of all HH respondents selected purposively and registered from the identified PAs in each survey district. As part of the selection criterion, all HH respondents in the PA need to have sufficient experience (≥5 years) in livestock farming and BSY feeding experience (1-3years), and above all, they should display their free willingness to participate in the survey study. The actual number of HH respondents (sample size) that was involved in the survey study was calculated using the formula developed by Arsham (2007): $N=0.25/SE^2$, where N= sample size; SE= standard error of the farms. By assuming the standard error of 3.7% at a precision level of 5% and 95% confidence interval, $N= 0.25/(0.037)^2=182$. Accordingly, 77 respondents from Wereda-11, 47 respondents from Bedele, and 58 respondents from Gelan districts were selected for a personal interview. Fully structured questionnaires and personal observations were held with HH respondents in each district as a means of data collection tool for the survey-based study.

Data Collection and Analysis

Data collected during the survey work included: basal and supplemental feed resources, feeding system, feeding practices of LBSY, amount and mode of LBSY feeding, transportation, preservation, storage and effect of feeding LBSY on the production, reproduction and health of the animals were assessed. The survey data were analyzed using Statistical Package for Social Sciences (SPSS, version 20.0). Descriptive statistics such as frequency distribution and percentages were used for categorical variables. Chi-square and one way ANOVA was use to analyze qualitative and quantitative data, respectively. Differences were considered significant at $p<0.05$.

Results and Discussion

Basal and Supplementary Feed Resources in the Districts

The major basal and supplemental feed resources across the study districts were presented in Table 1. Accordingly, the utilization of natural pasture hay across the study districts were significantly (*P<0.001*) differed with larger proportion of respondents in Bedele (78.7%) and Gelan (73.7%) depend on natural pasture hay as basal diet as compared to 29.9% in Wereda-11. The variation could be attributed to the conversion of grazing lands to crop production and encroachment of buildings to grazing lands as the city expands in Wereda-11 and the heavy dependency of most respondents on purchased natural pasture hay in Bedele and Gelan districts. Almost all (97.3%) interviewed respondents across the study districts were heavily depending on crop residue as livestock feed. Similarly, according to some studies, in the central highlands of Ethiopia, the dominant basal feed resources for livestock production in general and dairying in particular were natural pasture hay and crop residues (Ahmed *et al.*, 2010; Ararsa and Amanuel 2017). In the present study, 44.7, 54.5, 100, 67, and 63.5% of the respondents were commonly utilizing cereal and pulse screenings, brewery grain, brewer's spent yeast, local brewery waste, and concentrate mix as supplementary feeds across the study districts, respectively. In agreement to the present study, Adugna (2012) also reported that brewery by-products could be important sources of supplementary feed in commercial livestock operations. This is particularly important for farmers residing in the proximity of commercial breweries because of its moderately high crude protein and metabolizable energy contents and digestibility (Ahmad *et al.*, 2022). On the other hand, very few proportion of respondents across the study districts, depend on silage and mineral block while close to 12% and 24% of the respondents across the study districts depend on cultivated forage and molasses, respectively.

Table 1. Percentage of the respondents utilized the basal and supplemental feed resources in the study districts.

Feeds types	Wereda-11 n= 77	Bedele n=47	Gelan n=58	Over all mean	P-value
Natural pasture hay	29.9	78.7	73.7	56.4	0.000
Crop residues	96.1	95.7	100	97.3	0.298
Silage	-	-	3.6	1.1	0.107
Cereal and pulse screenings	54.5	19.6	51.8	44.7	0.000
Cultivated forages	6.5	19.1	14.5	12.3	0.095
Molasses	9.2	54.5	19.6	23.9	0.000
Brewery grain	37.3	70.2	64.3	54.5	0.000
Brewery yeast	100	100	100	100	0.236
Local brewery waste (Atela)	71.4	53.2	72.4	67.0	0.064
Concentrate mix	67.5	19.6	93.1	63.5	0.000
Mineral block	-	-	3.6	1.1	0.102

n= total number of respondents per districts; Note that percentage of feed utilization is independently calculated for each feed and sampled HHs in each district

Feeding Systems

About 87.2% of the respondents in Bedele district reported that the most prominent feeding system was cut and carry while 51.9% in Wereda-11 and 58.6% of respondents in Gelan districts were practicing both free grazing and cut and carry feeding systems, respectively (Figure 2). The variations in the feeding systems across the study districts might be attributed to the differences in less land holding size of the respondents in Bedele district as compared to respondents in Wereda-11 and Gelan districts involved in mixed crop-livestock farming systems.

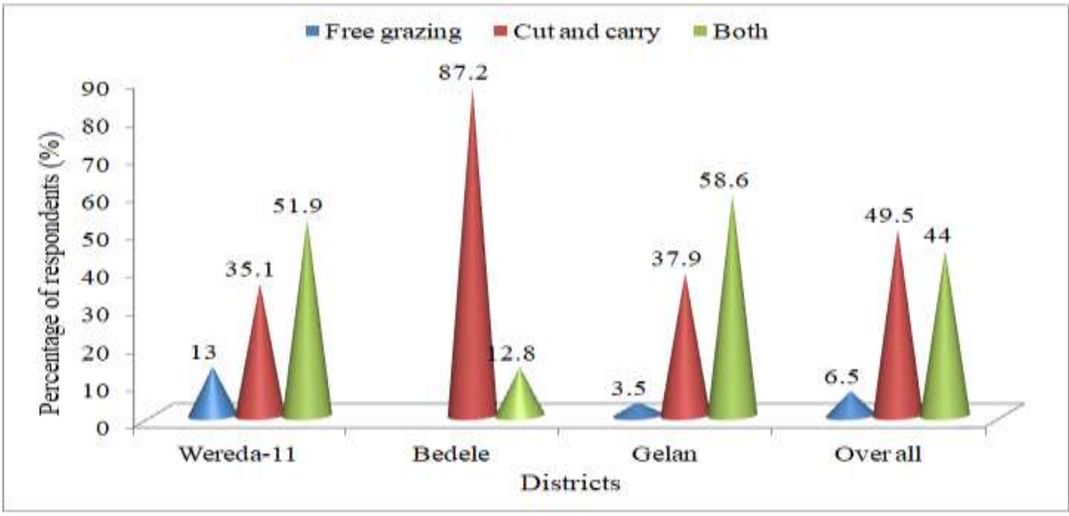


Figure 2. Percentage of respondents practicing different feeding systems across the study districts

Liquid Brewer's Spent Yeast Supply, Marketing and Transportation

The supply frequency and price of LBSY in the study districts are presented in Table 2. Accordingly, the supply frequency of LBSY was not significantly ($P>0.05$) varied across the study districts with 49.5, 26.4, 17.6 and 6.6% of the respondents across the study districts reported that the supply frequency of LBSY was once per week, once per two weeks, once per three weeks and once per month, respectively. Majority (80.4%) of the respondents in the study districts reported that the price of LBSY showed an increasing trend over the last five years. Consequently, the farm gate price of LBSY was in the range of 1.00-1.19 (overall=1.14) birr per liter and significantly ($P<0.05$) varied across the study districts. The increasing price and demand of LBSY was mostly due to the unavailability and cost of other commercial feed sources in the study districts. Even though, the demand and price for LBSY was increasing, according to Getu *et al*. (2018) the only factory supplying the autolyzed/deactivated spent yeast to the surrounding farmers was Meta Abo (at pilot level) and Heineken, Bedele and Gonder-Dashen brewery factories. The majority of the spent yeast produced by the factories each year is still subjected to disposal despite high protein feed value and costly price of other conventionally used protein supplements. A related study by Mesfin *et al.* (2014) also indicated that the majority of the food industry did not have a strategic plan to handle and market their by-products that can potentially be used as animal feed for livestock production.

Table 2. Liquid brewer's spent yeast supply frequency and price trends in the study districts (%).

Variables		Wereda-11 n=77	Bedele n=47	Gelan n=58	Overall value (182)	P-value
LBSY supply frequency	Once per week	44.2	63.8	43.1	49.5	0.424
	Once per two weeks	28.0	21.3	31.0	26.4	
	Once per three weeks	20.8	10.6	19.0	17.6	
	Once per month	7.5	4.3	6.9	6.6	
Price trends of LBSY in the last 5 years	Remains the same	-	13.2	10.7	12.8	0.000
	Fluctuating	-	5.5	-	6.7	
	Increases steadily	100	81.3	89.3	80.4	
Farm gets price of LBSY (birr/litter)		1.19[a]	1.00[b]	1.18[a]	1.14	0.005

LBSY= Liquid brewer's spent yeast; n= total number of respondents per districts

The majority of the respondents in Wereda-11 (89.6%), Bedele (87.2%), and Gelan (67.2%) responded that the LBSY was supplied by local retailers (Figure 3). According to the present study, the supply chain of LBSY was from the factory to very few retailers and finally to farmers, this would ultimately limit the distribution of the by-product to farmers in the required amount and time as it needs special transportation mechanisms. As a means of disposal mechanism, LBSY was, however, given to local retailers for free upon request after settling their bill for wet brewery spent grain. Among means of transportation, all respondents in Wereda-11 and Gelan districts reported that it was transported and supplied to them by vehicle, while 89.4% of the respondents in Bedele district reported that LBSY was transported to farmer's home stead using horse/donkey laden carts (Figure 4). The variations in the means of transportation across the study locations was due to the accessibility of transportation facilities such as tracks with tankers owned by retailers found in the former two districts. Despite the availability of better transportation services for LBSY in the former two locations, the respondents complained about the fact that they did not get LBSY on time as per their will/demand. This was because of the limited (one or two) number of retailers that deliver LBSY in a pre-scheduled regular shift to local farmers. Generally, utilization of LBSY was limited to farmers that are very close to those breweries because of higher moisture contents that requires special and costly transportation mechanisms to supply the by-product feed to stakeholders in the feed value chain found in faraway places.

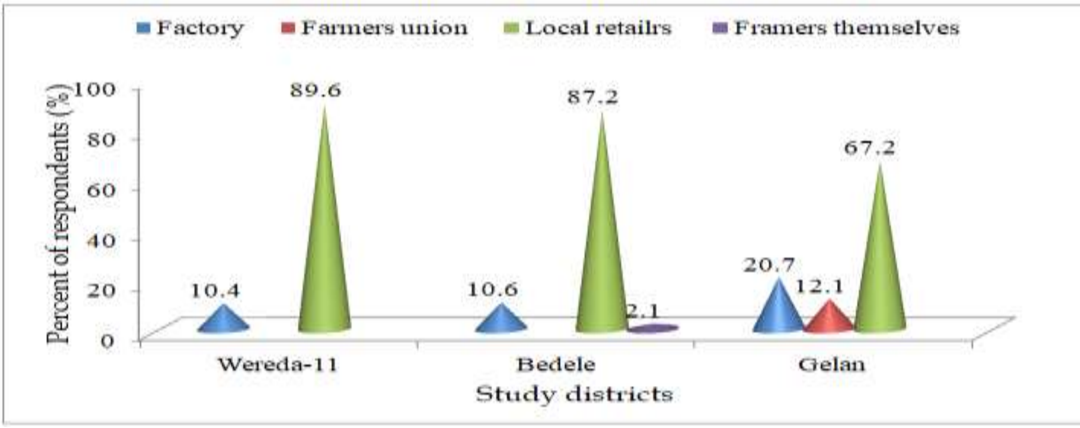


Figure 3. Actors supplying LBSY to local farmers

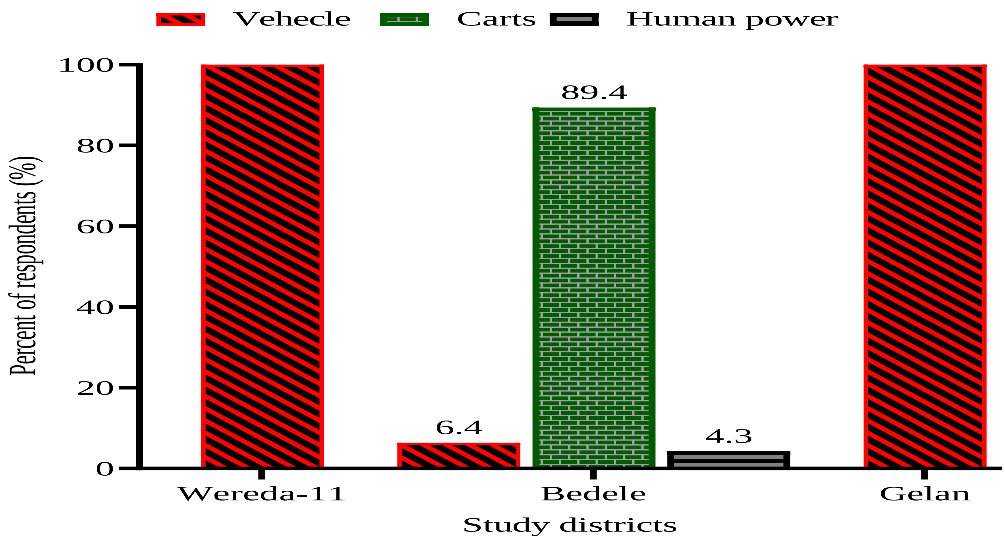


Figure 4. Means of transportation of LBSY.

Liquid Brewer's Spent Yeast Preservation and Storage Practices

The proportion of respondents using different LBSY preservation practices and storage facilities are presented in Table 3. Accordingly, almost all of the respondents across the study districts used storage facilities for LBSY storage. Among storage facilities, plastic barrels were commonly used by respondents in Wereda-11 (92.2%) and Gelan (93.1%) but 93.6% of respondents in Bedele district were using plastic Jeri cans of 20 liters capacity. A small percentage of respondents in Wereda-11 (2.6%) and Gelan (6.9%) also used concrete pits of 10,000 m^3 capacity to store LBSY. The study revealed that the majority of the respondents in Wereda-11 (76.6%) and Gelan (60.3%) reportedly observed to have practiced different types of LBSY preservation techniques for later use.

Respondents in Bedele district didn't use preservation techniques of any sort. This latter case has something to do with the relatively better frequency of fresh LBSY supply to the farmers. Among preservation techniques, adding salt to LBSY in the container was very common and mainly practiced by respondents in Wereda-11 (60.3%) and Gelan (60.0%) districts. The second commonly used preservation technique was adding saline water to the container that holds the fresh LBSY. The amount of salt and water used for preservation of brewer's spent yeast was, however, not measured but farmers make their own fair guess of the mix. According to the respondents' observation, with the above preservation techniques, LBSY can be stored for up to 22 days without deterioration. In addition to what has been mentioned, a small proportion of farmers in Gelan district exploit cold temperature (8.6%) and close the container tightly to limit the entrance of air (5.7%) to elongate shelf life of fresh LBSY. In line with this, a study by Steckley *et al.* (1979b) indicated the possibility of LBSY storage for up to two weeks under cool temperature (4^0C). Furthermore, the study by the same authors also indicated that the addition of acetic and propionic acid or a mixture including formic acid and formaldehyde is observed to have reduced changes in dry matter, crude protein, ammonia, and cell numbers of the yeast. In the current situation, chemical preservation is not advised under local conditions owing to its availability, cost, and health hazard mainly associated with handling the chemicals and technical know-how that follows it.

Table 3. Brewer's spent yeast storage facilities and local preservation practices in the study districts.

Variables		Wereda-11 n=77	Bedele n=57	Gelan n=48	Overall mean (182)	P-value
Do you use storage facilities (yes)		98.7	100	100	99.5	0.504
Storage facilities (%)	Plastic barrel	92.2	6.4	93.1	70.3	0.000
	Jeri can	3.9	93.6	-	24.2	
	Concrete pit	2.6	-	6.9	3.3	
	Clay pot	1.3	-	-	0.5	
Do you practice preservation of LBSY (yes)		76.6	-	60.3	51.6	0.000
How long do you preserve LBSY (days)		22.1	-	21.1	21.7	0.560
Preservation techniques (%)	Adding salt	60.3	-	60.0	60.2	0.049
	Adding water	5.2	-	2.9	4.3	
	Adding salt and water	34.5	-	22.9	30.1	
	Store in a cool place	-	-	8.6	3.2	
	Closing the container tightly	-	-	5.7	2.2	

LBSY= liquid brewer's spent yeast; n= total number of respondents per districts

About 61% of the respondents in Wereda-11 and 58% in Gelan districts got firsthand information about the different LBSY preservation techniques from their neighbor and their own experiences, respectively (Figure 5). As sources of information, extension workers and research centers have been also cited by the respondents to a limited extent in that order of importance.

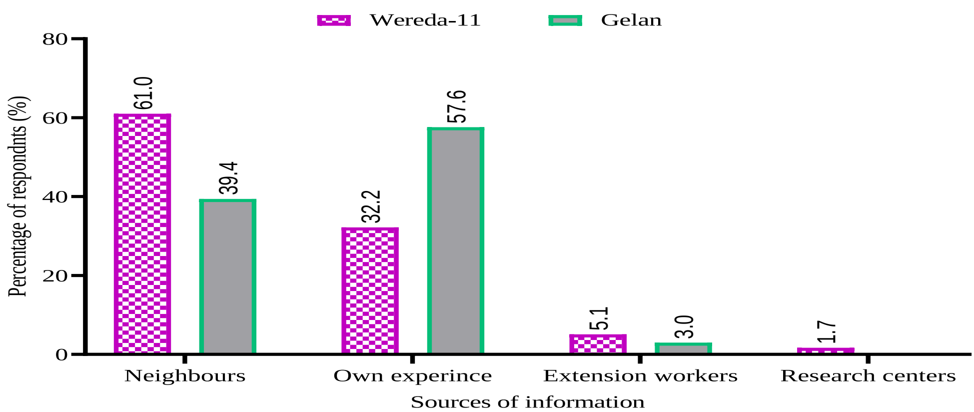


Figure 5. Sources of information for LBSY preservation techniques

Factors Responsible for Deterioration of Liquid Brewer's Spent Yeast

The major factors responsible for deterioration and hygienic conditions of LBSY upon storage are presented in Table 4. Districts varied in their response ($P<0.05$)

with 58.4% of the respondents in Wereda-11 claiming hygienic conditions of the storage facilities as being the major factor responsible for quality deteriorations while for 68.1% and 56.9% of respondents in Bedele and Gelan districts, respectively claimed storage temperatures, high moisture contents of LBSY were more important than other factors. In agreement to the present study, Alphonce *et al.* (2018) and Getu (2019) reported that deterioration of brewery by-products were mostly caused by moisture, temperature, microorganisms (mold and yeast) and local relative humidity conditions. Peter (2019) also reported that temperatures between 10 - 30 °C would favor growth of a wide range of fungal species that may possibly contribute to contamination of LBSY. Moreover, according to Boateng *et al.* (2015), excessive contamination of animal diets with molds and yeast have been reported to increase the incidence of diarrhea that causes heavy loss in production and health performances of farm animals. Once quality deteriorations encountered, majority (65.9%) of the respondents in study districts prefer to dispose spoiled BSY and/or opt to feeding only fresh LBSY while relatively few (6.4 and 3.4%) of the respondent households in Bedele and Gelan districts, respectively continued feeding of LBSY regardless of the extent of deteriorations they are faced with the stored LBSY. Among LBSY deterioration symptoms, 46.3% of the respondents across all study districts claimed to have observed smell change as a major sign followed by surface mold growth (23.4%) in the storage facilities where the LBSY is stored (Figure 6).

Table 4. Hygiene and management of Deteriorated LBSY expressed as the percentage of total respondents.

Variables		Wereda-11 n= 77	Bedele n=47	Gelan n=58	Overall mean	P-value
Factors responsible for deterioration of LBSY	Hygienic condition of storage facility	58.4	31.9	25.9	41.2	0.000
	Hygienic condition during transportation	1.3	-	15.5	5.5	
	Storage tem, moisture and RH	37.7	68.1	56.9	51.6	
	Hygienic condition of feeding troughs	2.6	-	1.7	1.6	
Fate of spoiled LBSY	I will dispose deteriorated LBSY	71.4	57.4	65.5	65.9	0.208
	I will maintain hygienic condition of materials	28.6	36.2	31.0	31.3	
	I will continue feeding whatsoever the extent of spoilage in the LBSY	-	6.4	3.4	2.7	

LBSY= liquid brewer's spent yeast; RH= relative humidity; tem= temperature; n= total number of respondents per districts

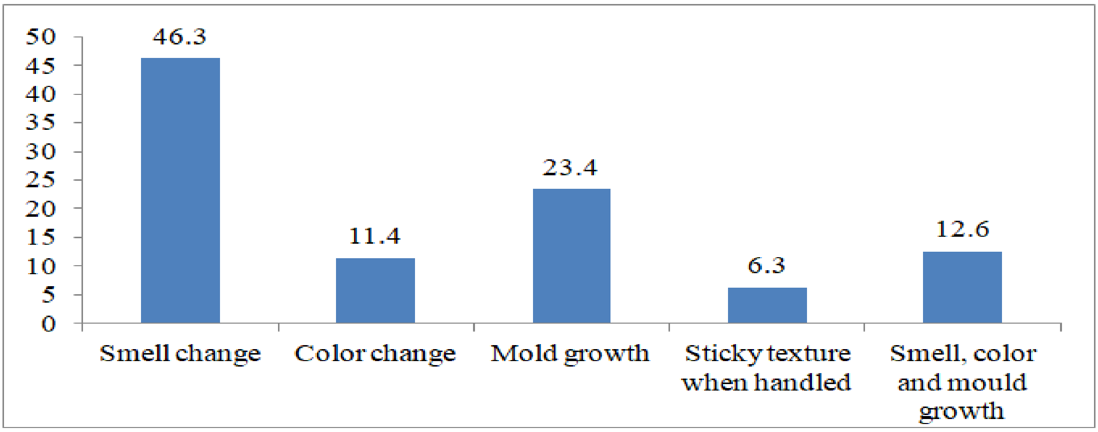


Figure 6. Liquid brewer's spent yeast deteriorations signs

Farmers' Source of Information and Feeding Priorities of LBSY

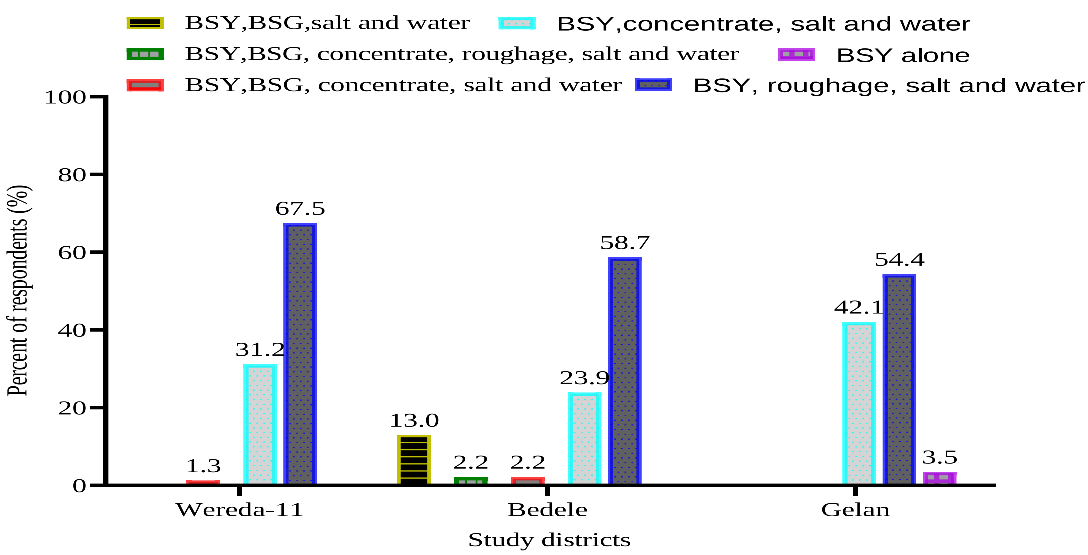
There were substantial differences (*P<0.05*) in the feeding experience of farmers across study districts when it comes to feeding practices of LBSY for the different livestock species (Table 5). This was 1.53 years for HH respondents in Gelan and 3.76 years for those in Bedele districts. The majority of the respondents in Wereda-11 (83.1%) and Gelan (81.0%) got firsthand information about the feeding values of LBSY from their neighbors while 46.8% of the respondents in Bedele district secured the information from their friends. Similarly, Getu *et al*. (2018) reported that the majority (83%) of respondents in Sebeta, Bedele, and Debre Birhan towns got information about the feeding value of brewery spent-grain from their neighbors and/or family members. According to 67.5, 58.7, and 54.4% of the respondents in Wereda-11, Bedele, and Gelan districts, respectively roughage diets are treated with LBSY in mixture with salt, and water before it is fed to their animals (Figure 7). More than 82% of the respondents across all the study districts reported that mixing with feed ingredients (roughage and/or concentrate) was the major mode of offering LBSY to the diet of the animals followed by top dressing (7.9%) over the roughage and/or concentrate (Figure 8). According to the present study, farmers formulate LBSY based diets traditionally by themselves without having any scientific knowledge in feed formulations and/or prior LBSY based feeding recommendations. In general, feed formulation and the way it should be fed to the different livestock groups remained an important research gap in the efficient utilization of LBSY by smallholder farmers in the study districts. Overall, 66.9% of the respondents in the survey areas claimed to have prioritized their animals when feeding LBSY to their animals (Table 5). Dairy cows are usually given priority in Bedele according to 95% of the HH respondents whereas 86.1 and 54.8% of the respondents in Wereda-11 and Gelan districts, respectively give more priority for fattening cattle than the rest of their animals. The relatively small number of crossbred dairy animals in Wereda-

11 and Gelan districts gave fattening animals a comparative advantage over remaining livestock species in getting access to LBSY based ration. According to those respondents, the major reason as to why dairy and fattening cattle has been prioritized over remaining livestock species across the study districts could be attributed to the higher response obtained from these same animals to a LBSY supplementation. However, earlier studies by other scholars (Peter, 2019) also revealed the use of LBSY as a feed supplement in diets of ruminants, poultry, swine, and fish for the production of milk and meat.

Table 5. Farmers' access to information and prioritization of LBSY to animals (%).

Variables		Wereda-11 n=77	Bedele n=47	Gelan n=58	Overall value	P-value
Experience of feeding LBSY (Years)		2.9[b]	3.7[a]	1.5[c]	2.6	0.000
Sources of information about feeding value of LBSY	Neighbor	83.1	31.9	81.0	69.2	0.000
	Friends	13.0	46.8	5.2	19.2	
	Family	2.6	4.3	1.7	2.7	
	Beer factory	1.3	4.3	3.4	3.0	
	Market place	-	12.8	8.6	6.0	
Prioritization of LBSY	Yes	47.4	95.7	69.0	66.9	0.000
	No	52.6	4.3	31.0	31.1	
Animals get priority	Dairy cattle	13.9	95.6	45.3	51.6	0.000
	Fattening cattle	86.1	4.4	54.8	48.4	
Major reasons for priority	Availability of LBSY	16.7	-	19.0	11.4	0.009
	Response of LBSY	83.3	100	69.0	84.6	
	Availability and response	-	-	9.6	3.2	
	Health related factors	-	-	2.4	0.8	

LBSY= liquid brewer's spent yeast; n= total number of respondents per districts



BSG= brewery spent grain; BSY= brewer's spent yeast

Figure 7. Types of feed ingredients mixed with BSY during animal feeding

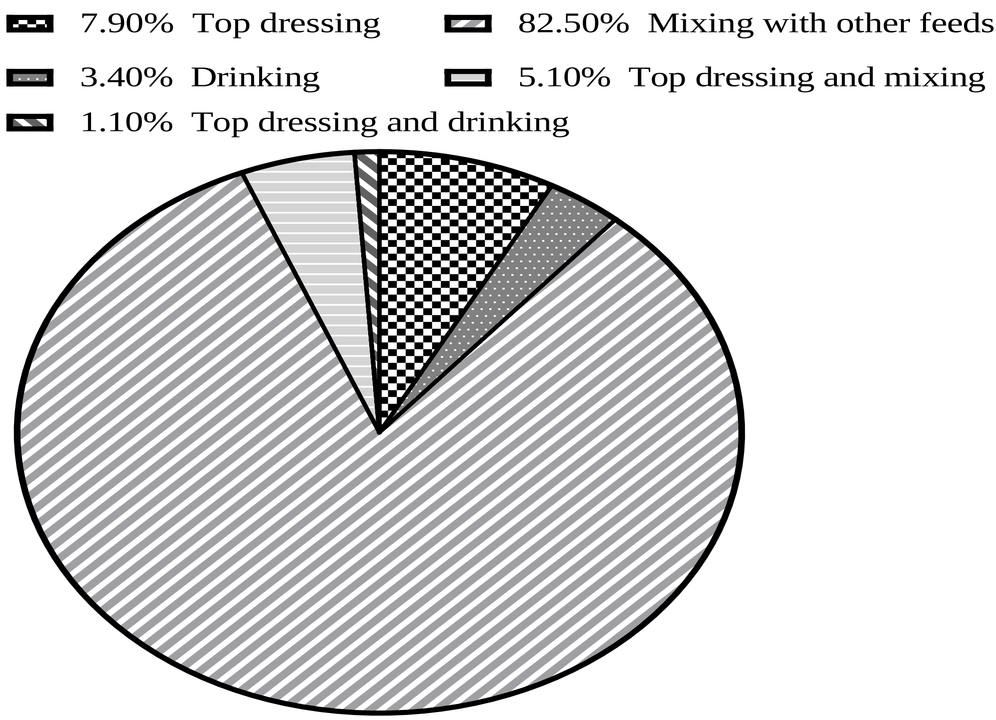


Figure 8. Mode of LBSY offer to the animals' diet

Amount of Liquid Brewer's Spent Yeast Supplemented to the Animals

The amount of LBSY supplemented to the animals is presented in Table 6. Accordingly, the majority (67.6%) of the respondents across the study districts did not weigh/estimate the amount of LBSY supplemented to their animals while only 31.9% weigh or estimate the daily amount of LBSY fed to their animals with locally available measurement units. According to those farmers' estimation the amount of LBSY when fed alone is estimated to 1.62-3.75 liters per animal per day with significant ($P<0.05$) variation across study districts. When LBSY mixed with other feed ingredients (roughages and/or concentrate feeds), the amount would range from 3.25-5.33 liters per animal per day with no significant ($P>0.05$) variation across study districts. According to respondents' perceptions, feeding too much LBSY alone will cause bloating and death to the animals. In agreement to the present survey, Peter (2019) reported that lactating dairy cows could be fed with 4 liters of LBSY per day as a supplemental diet while other remaining adult cattle stocks are usually supplemented with 2 liters per day.

Table 6. Proportion of respondents (%) who estimate the amount (kg) of LBSY supplemented to the animals across the study districts.

Variables		Wereda-11 (N=77)	Bedele (N=47)	Gelan (N=58)	Overall mean	P-value
Do you weigh/estimate the daily amount of LBSY supplemented	Yes	18.2	25.5	55.2	31.9	0.000
	No	80.5	74.5	44.8	67.6	
Estimated amount of LBSY supplemented	Alone	1.6[b]	1.8[b]	3.7[a]	2.1	0.004
	With other feeds	3.2	5.3	4.2	4.2	0.242

LBSY= liquid brewer's spent yeast; n= total number of respondents per districts

Farmer's Perceptions on the Effects of Feeding Brewer's Spent Yeast on Milk Production, Reproduction and Health of Animals

The long-term effects of feeding LBSY on production, reproduction, and health conditions of animals are presented in Table 7. Accordingly, there were significant (*P<0.05*) variations in milk production performance of dairy cows with the overall, 60.2% of the respondents across the study districts reported to have observed increased milk production because of feeding LBSY based diets. Similarly, West *et al.* (1994) also reported an increase in milk production when LBSY was added to the diet of the animals, the increase was attributed to a possible enhanced ruminal environment and the numerical boost in dry matter intake. Steckley *et al.* (1979a) also reported that brewer's yeast slurry had a similar feeding value to soybean meal in supporting milk production of dairy cows due mainly to its superior effect on ration digestion coefficients, and rumen acetate production. Significantly higher proportions of (overall,71.4%) the respondent households across the study districts (*P<0.001*), weren't able to observe changes in the milk quality as a result of feeding a LBSY based diet. On the other hand 25.9% of respondents in Gelan district were able to note fatty milk while a considerable proportion of the household respondents in Bedele (40.4%) reported to have observed watery milk (less fatty) upon feeding LBSY based diet to their milking cows. The latter case might be attributed to the water contents of the LBSY (88-90%). The majority (93.9%) of the respondents across the study districts (*P<0.05*), responded as depressed feed intake and metabolic disorder like blotting could be sometimes encountered upon feeding LBSY based diet to the animals. The metabolic disorder (blotting) might be linked to the higher nitrogen concentration or higher crude protein (63.8%) contents of LBSY (Podpora *et al.*, 2016). Close to 5.3% of the respondents in Wereda-11 encountered death loss in the animals that often drink too much LBSY especially when consumed too hot. More than 33% of the respondents in Bedele district observed reproductive problems (stillbirth, delay in estrous, extended calving intervals, abortions) when LBSY based diets were frequently fed to their animals. Similarly, reproductive problems were also observed in those animals fed on wet brewery spent grain (Getu *et al.*, 2018) but it should be confirmed with animal experimentation.

Table 7. Farmer's perceptions (%) towards the effect of feeding LBSY on animal performances.

Variables		Wereda-11 n= 77	Bedele n=47	Gelan n=58	Overall Mean	P-value
Milk production change	No change	42.3	-	32.5	34.0	0.002
	Increase milk yield	57.7	72.7	60.0	60.2	
	Decrease milk yield	-	27.3	5.0	4.9	
Milk quality change	No change	87.0	55.3	63.8	71.4	0.000
	Milk becomes fatty	2.6	4.3	25.9	10.4	
	Milk becomes watery	9.1	40.4	10.3	17.6	
	I do not know	1.3	-	-	0.5	
Health problems encountered	Reproductive problems	-	33.3	-	11.1	0.026
	Depressed intake and metabolic disorder	94.7	66.7	100	93.9	
	Death of the animals	5.3	-	-	3.0	

Reproductive problems= stillbirth, delay in estrous, extended calving intervals, abortions etc; Depressed intake and metabolic disorders= bloating and Acidosis; n= total number of respondents per districts

Challenges in Liquid Brewer's Spent Yeast Accessibility and Animal Utilization

The major challenges associated with LBSY accessibility and feeding practices in the study districts are presented in Table 8. Notably higher proportions of the respondents that amounted to 51.9 and 72.4% in Wereda-11 and Gelan districts, respectively, responded that they are faced with multiple challenges including LBSY accessibility, cost, transportation problems, and lack of animal feeding practices. Fifty per cent of the respondents in Bedele district claimed transportation problems and lack of animal feeding practices as being the major bottlenecks to the efficient utilization of LBSY. In agreement to the present study, Boateng *et al.* (2015) also reported that cost of transportation, availability, tedious processing process, and rapid deterioration of BSY were the major challenges in the utilization process of brewery by-products in Ghana.

Table 8. Major challenges of LBSY accessibility and feeding utilization practice (%).

Variables	Wereda-11 (n=77)	Bedele (n=47)	Gelan (n=58)	Overall mean	P-value
Accessibility	39.0	17.0	19.0	26.9	0.000
Cost/affordability	7.8	8.5	5.2	7.1	
Lack of feeding practice	-	23.4	-	6.0	
Transportation problem	1.3	34.0	-	11.7	
Multiple challenges*	51.9	17.0	72.4	49.5	
No challenges	-	-	3.4	1.1	

* Multiple challenges= availability, cost, lack of utilization practices, and transport problems; n= total number of respondents per districts

Conclusion and Recommendations

Liquid brewer's spent yeast was found to be traditionally used as livestock feed in the study districts by smallholder farmers both for dairying and animal fattening. The main suppliers of LBSY to local farmers were few local retailers who were unable to fill the demand gap of the by-product. The demand and purchasing price of LBSY was increasing from time to time due to less accessibility and soaring price of conventionally used protein sources. Inaccessibility, cost, lack of transportation mechanisms, and lack of feeding practice were cited to be the major challenges for proper utilization of LBSY by households across the study districts. Therefore, in order to utilize these untapped protein sources, LBSY supply mechanisms, storage, preservation and standard feeding recommendations shall be developed for the different livestock species.

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References

Adugan Tolera. 2012. Feed Resources Availability and Quality vs. Animal Productivity. *Sources in Ethiopia Livestock Feed: Challenges, Opportunities the Need for Transformation*, 37–46.

Ahmed Hassen, Abule Ebro, Mohammed Kurtu & Treydte, A. C. 2010. Livestock feed resources utilization and management as influenced by altitude in the central highlands of ethiopia. *Livestock Research for Rural Development, 22(12).*

Ahmed, N., Aranguiz, A. A., Vernooij, A., & Mohammed, D. 2022. Potential use of liquid spent brewer ' s yeast for animal feed in Ethiopia. Public report 1392.

Alphonce, P., Alaru, O., Shitandi, A., & Mahungu, M. 2018. Effect of Handling Practices of Liquid Brewer's Yeast on Microbial Growth During Storage and Risk Unit Suitability as Feed Supplement in Smallholder Dairy Farms. *Journal of Animal and Veterinary Sciences 2018; 5(4): 26-30.*

Ararsa Derara and Amanuel Bekuma. 2017. Evaluation of Livestock Feed Nutritional Composition in Weliso District, South West Shoa Zone, Central Ethiopia. *Int. J. Adv. Res. Biol. Sci*, *4*(4), 37–43. https://doi.org/10.22192/ijarbs

Arsham, H. 2007. Questionnaire Design and Surveys Sampling.

Boateng, M., Okai, D. B., Frimpong, Y. O., & Zeebone, Y. Y. 2015. Wet brewers' spent grains and wet brewers' spent yeast: Problems associated with their usage and suggested solutions: A case study of the Ejisu-Juaben Municipality of Ghana. *Livestock Research for Rural Development*, *27*(1).

Demissie Negash. 2021. Use of Brewery By-Products as Animal Feeds. *Journal of Nutrition & Food Sciences*, *4*(1), 1–5.

Dessalegn Genzebu, Berhan Tamir& Gebreyohannes Berhane. 2016. Study of Reproductive and Production Performance of Cross Breed Dairy Cattle under Smallholders Management System in Bishoftu and Akaki Towns. *Int. J. Adv. Res. Biol. Sci. (2016). 3(2): 118-123.*

Getu Kitaw, Berhan Tamir, Getnet Assefa & Getnet Animut. 2018. Production , Preservation , and Utilization Patterns of Brewery Spent Grain in Ethiopia. *EJAS*. *28*(3), 1–17.

Getu Kitaw. 2019. Assessment on the Production, Conservation and Utilization Practices of Brewery Spent Grain across Selected Destricts in Ethiopia, and its Supplementary Value for Dairy Cows. A dissertation submitted to the College of Veterinary Medicine of Addis Ababa University.

Hertrampf, J., Felicitas, P. 2000. Handbook on Ingredients for Aquaculture Feeds

HÜSEYİN, N., EROL B. 2003. The Effects of Baker ' s Yeast (Saccharomyces cerevisiae) in Dairy Cow Diets on Milk Yield , Some Rumen Fluid Parameters and Blood Metabolite of dairy cows diet. *Turk J Vet Anim Sci 27(1).*

Mesfin Dejene, Seyoum Bediye, Dawit Alemu, Getu Kitaw, Aemiro Kehaliw, Getnet Assefa and Getaw Tadesse. 2014. Livestock feed marketing in Ethiopia: challenges and opportunities for livestock development. *Journal of Agricultural Science and Technology A*,*4*(2),155–168. http://search.ebscohost.com/login.aspx?direct=true&db=lah&AN=20143178612&site=ehost-live%5Cnhttp://www.davidpublishing.com/show.html?16124%5Cnemail.

Mussatto, S. I., Dragone, G., & Roberto, I. C. 2006. Brewers' spent grain: Generation, characteristics and potential applications. *Journal of Cereal Science*, *43*(1), 1–14. https://doi.org/10.1016/j.jcs.2005.06.001.

PETER, A., ALPHONCE, O. 2019. Evaluation Of Appropriate Storage Conditions Of Liquid Brewer's Yeast As Feed Supplement For Lactating Dairy Cows And Its Effect On Milk Quality. *A Thesis Submitted to the Graduate School in Partial Fulfilment for the Requirements of the Master of Science Degree in Food Science of Egerton University*.

Podpora, B., Swiderski, F., Sadowska, A., Rakowska, R., & Wasiak-Zys, G. 2016. Spent brewer's yeast extracts as a new component of functional food. *Czech Journal of Food Sciences*, *34*(6), 554–563. https://doi.org/10.17221/419/2015-CJFS

Seyoum Bediye, Nemi, G., & Makkar, H. 2018. Ethiopian feed Industry: current status, challenges and opportunities. *Broadening Horizons Number 50. Feedipedia*.

SPSS. 2008. Programming and Data Management for SPSS Statistics 17.0. A Guide for SPSS Statistics. 576. http://www.spss.com/sites/dm-book/legacy/ProgDataMgmt_SPSS17.pdf

Steckley, J. D., Grieve, D. G., Macleod, G. K., & Moran, E. T. 1979a. Brewer's Yeast Slurry. II. A Source of Supplementary Protein for Lactating Dairy Cattle. *Journal of Dairy Science*, *62*(6), 947–953. https://doi.org/10.3168/jds.S0022-0302(79)83353-6

Steckley, J. D., Grieve, G. D., Macleod, G. K., & Moran, E. T. 1979b. Brewer's Yeast Slurry, I. Composition as Affected by Length of Storage, Temperature, and Chemical Treatment. *Journal of Dairy Science*, *62*(6), 941–946. https://doi.org/10.3168/jds.S0022-0302(79)83352-4

Tacon, G. J., Metian, M., & Hasan, M. R. 2009. Feed ingredients and fertilizers for farmed aquatic animals: Sources and composition. In *FAO Fisheries and Aquaculture Technical Paper* (Vol. 540).

Tamirat Dinkale 2019. Review on Milk Production : Recent Trends and Future Prospects in Relation to Past Trends in Ethiopia. https://doi.org/10.7176/FSQM

West, J. W., Ely, L. O., & Martin, S. A. 1994. Wet Brewers Grains for Lactating Dairy Cows During Hot, Humid Weather. *Journal of Dairy Science*, *77*(1), 196–204. https://doi.org/10.3168/jds.S0022-0302(94)76942-3

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Influence of Treated Wheat Bran, with Effective Microorganisms- on an *In vitro* Digestibility and *In sacco* Degradability of a Mixed Ration

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Abstract

This study assessed the impacts of including a treated wheat bran, with effective microorganisms (EMWB), in a mixed diet on the chemical composition, in vitro digestibility, and in sacco degradability of the dry matter (DM) and crude protein (CP). The treatment consisted of 70% native pasture hay (NPH) and 30% concentrate mixtures (wheat bran (35%), maize (20%), rice bran (21%), molasses (3%), niger seedcake (4%), sunflower cake (11%), salt (3%), and limestone (3%)). This concentrate mixture was substituted with different levels (0, 33, 66 and 100%) of treated wheat bran forT_1, T_2, T_3 and T_4, respectively. The CP content was increased (7.2, 9.1, 9.2 and 12.2% DM (SEM = 0.214), while the neutral detergent fiber (NDF) content was decreased with an increasing level of EMWB (66.2, 64.3, 63.7 and 62.1 % DM (SEM = 0.117) for T_1, T_2, T_3 and T_4 respectively). Similarly, the contents of both acid detergent fiber (ADF) and acid detergent lignin (ADL) showed a declining trend with an increasing EMWB in the diet. The in vitro DM digestibility (IVDMD) was in the order of $T_4 > T_3 > T_2 > T_1$ (54.9, 56.2, 59.7 and 74.4% (SEM = 0.169), respectively. An inclusion of EMWB, in the diet enabled to improve the rapidly degradable (a) and insoluble but potentially soluble (b) fractions of the diets. Furthermore, the in sacco potential (PD) and effective degradability (ED) of DM and CP increased with increasing levels of EMWB in the diet. The PD and ED for DM ranged from 55 to 70% and 37 to 48%, respectively. Similarly, the PD and ED for CP ranged 25 to 48% and 16 to 22%, respectively. The treatments with EMWB for example T_4 showed the most significant impact on enhancing the nutritive values and degradability. Consequently, EMWB can completely substitute a commercial concentrate mixture used in the current study, yielding better results.

Keywords: *In sacco* degradability, *in-vitro* digestibility, crude protein, dry matter

Introduction

The livestock sector of Ethiopia plays a crucial role in the country's economy and the livelihoods of the majority of its people, with significant potential for meat and milk production (CSA 2017/18). However, feed supply (in quantity and quality) have been a major hindrance to livestock production and productivity in the country (FAO, 2019). The primary sources of livestock feed in Ethiopia are natural pasture and crop residues, which are characterized by poor nutritional quality and insufficient year-round supply (Seyoum et al., 2007). Dried forages and roughages are deficient in crude protein (CP), minerals, and vitamins and their high-lignin content restricts their use as sole feed for ruminants (ILRI, 1999).

To enhance the utilization of low-quality roughages, various strategies, including supplementation, biological treatment, and manipulation of the rumen ecosystem, are well-known and widely used in the sector (Lettat et al., 2012; FAO, 2019; Bimrew et al., 2020). Microorganisms have been effectively employed as biological treatments in ruminant production to increase productivity, prevent digestive disorders like acidosis, and reduce pathogenic load (Lettat et al., 2012). Generally, the use of combinations of microbial strains in ruminants has shown synergetic beneficial effects (Collado et al., 2007), leading to improved animal performance (Krehbiel *et al.,* 2003).

Effective Microorganisms (EM) are a mixed culture of aerobic and anaerobic microbes that live symbiotically with each other. These microorganisms are beneficial, natural, free-living, and safe. EM comprises selected species of microorganisms, including predominant populations of lactic acid bacteria and yeasts, as well as smaller numbers of photosynthetic bacteria, actinomycetes, and other types of organisms (Higa, 1994).

The use of EM in animal husbandry is widely accepted in many parts of the world. In a study conducted in Russia by Alexey et al. (2019), EM was successfully used as a feed supplement in cattle rations to increase the productivity and meat quality of calves. Similarly, studies conducted in Egypt by Yacout et al. (2021) showed that the use of EM as a feed supplement improved digestibility in sheep. Likewise, several studies have been conducted in Ethiopia to investigate the effect of EM on enhancing the nutritive value of crop residues. For instance, research findings of Bimrew et al. (2020) and Daniel et al. (2017) indicated that treating rice straw and sorghum stover with EM improved their quality by reducing fiber content and enhancing CP. However, to date, the effects of a mixed ration containing different proportions of EM- treated wheat brans on chemical composition, *in-vitro* digestibility, and *in sacco* degradability of a mixed ration have not been investigated. Therefore, the objective of this study was to assess the effects of different levels of EM-treated wheat bran on the chemical composition, *in vitro* digestibility, and *in sacco* degradability of DM and CP of a mixed ration.

Materials and Methods

Study Site and Treating the Wheat Bran, with Effective Microorganisms

The study was conducted at the Holetta Agricultural Research Center of the Ethiopian Institute of Agricultural Research (EIAR).

A sufficient quantity of activated EM packed in plastic bottles was purchased from Weljeji PLC (Bishoftu, Ethiopia) and molasses was purchased from Ethiopian Sugar Corporation Wenji branch. EM was diluted by mixing 1 liter of EM, 1 liter of molasses and 18 liter of water in a ratio of 1:1:18. Then, 20 liters of the diluted EM solution was poured gradually onto a 50 kg of wheat bran and then thoroughly mixed. The mixture was placed in a concrete hole/silo-type that was prevented from air entry, maintaining anaerobic conditions, and it was protected from direct sunlight. Finally, it was left to ferment for 21 days. After 21 days, the treated wheat bran was ready for use when it emitted a sweet fermented smell.

Experimental Treatments

In a companion feeding trial with lactation dairy cows, the animals were fed a mixture of 70% native pasture hay and 30% concentrate mixture (consisting of wheat bran 35%, maize 20%, rice bran 21%, molasses 3%, niger seed cake 4%, sunflower cake 11%, salt 3%, and limestone 3%). The composition and proportions of the concentrate mixture were provided by the formulating company. The aim of this study was to determine the effects of EM-treated wheat bran on performance parameters of lactating dairy cows. The concentrate mixture was replaced by 0, 33, 66 and 100% EM-treated wheat bran for T_1, T_2, T_3 and T_4, respectively. A mixed ration with that of proportionally similar to the feeding trial was also prepared and used to evaluate the chemical composition, *in vitro* digestibility and *in sacco* degradability of the experimental feeds. Thus, a 200 g mixed ration was prepared by mixing 140 g of native pasture hay plus 60 g concentrate mixture for T_1. The same amount of native pasture hay was combined with 33 % (20 g), 66% (40 g) and 100 (60 g) of the concentrate mixtures being replaced by an EM-treated wheat bran for T_2, T_3 and T_4, respectively. Samples of these feeds were dried at 65 °C for 48 hours. Then, these samples were divided into two halves, with one half was ground using a Wiley mill to pass through a 1 mm screen for chemical analysis and *in vitro* digestibility determination. The other half was ground to pass through a 2 mm screen for *in sacco* degradability measurement.

Experimental Measurements

Chemical Composition

The DM, ash and CP contents in the treatment samples were analyzed following the AOAC (1990) method. The organic matter (OM) content was calculated as 100 − ash content. The CP content was calculated by multiplying nitrogen content by a factor of 6.25. The acid detergent fiber (ADF), acid detergent lignin (ADL) and neutral detergent fiber (NDF) of the samples were determined using the method of Van Soest and Robertson (1985).

In vitro Digestibility

The *in-vitro* dry matter digestibility (IVDMD) of the treatments was determined as described by Van Soest and Robertson (1985). Rumen fluid was obtained from three rumen fistulated Boran × Holstein Frisian crossbred steers, fed on a basal diet of natural pasture hay and supplemented with 2 kg of concentrate mixture (wheat bran 35%, maize 20%, rice bran 21%, molasses 3%, niger seed cake 4%, sunflower cake 11%, salt 3%, limestone 3%). This fluid was used for *in vitro* incubation of the treatment samples. The same natural pasture hay used in this study served as the source of hay fed to the rumen content of the donor animals.

In sacco Degradability

The *in sacco* DM and CP degradability were determined by incubating about 3 g of each treatment sample in a nylon bag (40 to 60 μ pore size and 4.5 × 18 cm dimension) in three rumen fistulated Boran × Friesian crossbred steers. Duplicated samples were incubated for 0, 6, 12, 24, 48, 72, and 96 hours. The bags were inserted sequentially and removed at the same time (Osuji et al., 1993). After removal from the rumen, the bags were washed in running tap water while rubbing gently between thumb and fingers until the water became clear. Zero-time disappearances (washing losses) were obtained by washing un-incubated bags in the same manner. The washed bags were then dried in an oven at 100 °C for 24 hours. After cooling in desiccators, the bags were weighed immediately to determine the dry weight of the incubation residues. The residues were also analyzed for CP contents. Dry matter and CP disappearances were estimated using the following equations:

$$Dry\ Matter\ Disappearance\ (DMD) = \frac{((BW+S1)-(BW+RW))}{S1}\ X\ 100$$

$$Crude\ Protein\ Disapperance\ (CPD) = \frac{((S1\ X\ CP1)-(RW\ X\ CP2))}{S1\ \ X\ CP1}\ X\ 100$$

Where; BW = bag weight; RW = residue weight; S1 = sample weight; CP1 = crude protein content of the original sample; CP2 = crude protein content of the residue.

The DMD and CPD data were fitted to the equation $Y = a + b\ (1 - e^{-ct})$ described by Ørskov and McDonald (1979) using the Naway Excel program (Chen, 1995), where; Y = the potential disappearance of DM at time t; a = the rapidly degradable fraction; b = the potentially, but slowly degradable fraction; c = the rate of degradation of b; e = the natural logarithm; t = time after incubation. The potential degradability was determined by the equation PD = a + b. Effective degradability (ED) was calculated assuming a passage rate of 4%/h using the equation described by Ørskov and McDonald (1979) as $ED = \frac{a+bc}{k+c}$; where k = passage rate.

Statistical Analysis

The data were analyzed using analysis of variance (ANOVA) following the general linear model (GLM) procedure of SAS statistical program (2010). Means were separated using LSD. The model used for analysis was $Y_{ij} = \mu + T_i + ß_j + e_{ij}$, where; Y_{ij} = response variable; μ = overall mean; T_i = treatment effect; $ß_j$ = replication effect; and e_{ij} = the random error.

Results and Discussion

Chemical composition and *in-vitro* digestibility

The chemical composition and IVDMD of treatment rations used in this study are given in Table 1. The OM content of T_4 was greater ($P < 0.05$) compared to the other treatments. The diets in T_4 had the greatest CP content, while T_1 had the lowest, and the other two treatments showed intermediate values. Generally, there was an increasing trend in CP content as the level of EM-treated wheat bran inclusion increased. This increase in CP content with rising levels of EM-treated wheat bran may be attributed to enhanced microbial growth and proliferation during the treatment process, which is consistent with the findings of Bimrew et al. (2020) and Daniel et al. (2017) regarding greater CP values in EM-treated rice straw and sorghum stover compared to untreated ones.

The NDF contents of treatment diets followed the order of $T_1 > T_2 > T_3 > T_4$ ($P < 0.05$). The ADF and ADL contents were higher for T_1 and T_2 compared to T_3 and T_4. These findings align with previous studies that have reported deceased levels of structural carbohydrates such as NDF, ADF and lignin with EM inoculation on fibrous feedstuffs (Yonatan et al., 2014; Daniel et al., 2017; Bimrew et al., 2020).

The IVDMD in the current study ranged from 54.9 to 74.4%. There was a significant increase ($P < 0.05$) in IVDMD with increasing levels of EM-treated wheat bran inclusion in the diet. Previous research has shown a negative correlation between digestibility and NDF, ADF and ADL contents, as well as a positive correlation with CP content (Solomon et al., 2010; Bimrew et al., 2020). Therefore, the observed increase in CP and decrease in NDF and other fiber contents of the treatment diets with increasing levels of EM-treated wheat bran inclusion likely contributed to an improved value of IVDMD. Similar improvements in IVDMD have been reported by Yonatan et al. (2014) for EM-treated coffee husk silages and Yacout et al. (2021) for different sheep feeds treated with EM. Based on the results of this study, the inclusion of EM in animal feeds appears to improve feed quality by reducing structural carbohydrates and increasing CP content and IVDMD.

Table 1. Chemical composition and *in-vitro* dry matter digestibility (IVDMD) of mixed diets containing different levels of EM-treated wheat bran replacing concentrate mixture

Treatments	DM (%)	Ash (% DM)	OM (% DM)	CP (% DM)	NDF (% DM)	ADF (% DM)	ADL (% DM)	IVDMD (%)
T1	92.9	9.9[a]	90.0[b]	7.1[c]	66.1[a]	21.2[a]	4.9[a]	54.9[d]
T2	93.2	9.9[a]	90.0[b]	9.1[b]	64.3[b]	21.1[a]	4.9[a]	56.2[c]
T3	92.8	9.7[a]	90.3[b]	9.2[b]	63.6[c]	20.2[b]	4.4[b]	59.7[b]
T4	92.5	8.4[b]	91.6[a]	12.2[a]	62.1[d]	20.1[b]	4.3[b]	74.4[a]
SEM	0.182	0.108	0.108	0.214	0.117	0.126	0.099	0.169
p-value	0.13	< .0001	< .0001	< .0001	< .0001	0.0004	0.004	< .0001

DM = dry matter; CP = crude protein; OM = organic matter; NDF = neutral detergent fiber; ADF = Acid detergent fiber; ADL = acid detergent lignin; Concentrate mixture (CM) = (wheat bran 35%, maize 20%, rice bran 21%, molasses 3%, niger seedcake 4%, sunflower cake 11%, salt 3%, limestone 3%); T_1 = 70% native pasture hay (NPH) plus 30% CM; T_2 = 70% NPH plus 33% of the 30% CM replaced by EM-treated wheat bran; T_3 = 70% NPH plus 66% of the 30% CM replaced by EM-treated wheat bran; T_4 = 70% NPH plus 100% of the 30% CM replaced by EM-treated wheat bran; SEM = standard error of mean

In sacco Dry Matter and Crude Protein Degradability

The *in sacco* degradation of DM and CP at different incubation hours are presented in Table 2 and Table 3, respectively. Generally, the degradation of DM and CP increased with the incubation time. Differences in the degradability of DM and CP were observed at all incubation periods. In most incubation hours, the degradability of DM and CP increased with increasing levels of EM-treated wheat bran inclusion in the diet. Therefore, the inclusion of EM-treated wheat bran in the diet has improved the ruminal degradation of the mixed diet, indicating an improvement in nutritional value of feeds with EM treatment. Consistent with the current results, other studies have noted that treating feed with EM increased ruminal DM degradability and improved the nutritive value of feeds (Syomiti et al., 2010; Daniel et al., 2017).

The improved CP content and reduced content of structural carbohydrates with increasing levels of EM-treated wheat bran noted in this study might have contributed, in part, to the improvements in the ruminal degradability of DM and CP (Solomom et al., 2010; Bizelew et al., 2021). Moreover, Syomiti et al. (2010) reported that EM treatment increased *in sacco* DM degradability of cellulose and highly fibrous feeds and suggested that this could be due to the yeasts and bacterial species in EM.

It has been suggested that the microbes in EM may stimulate the activity of beneficial microbes, especially cellulolytic organisms and their associated enzymes in ruminants (Aramble and Kent, 1990; Yoon and Stern, 1995). Maurya (1993) highlighted that the yeast cells remain active in the rumen and have a stimulatory effect on cellulose-degrading bacteria. Yeasts in the rumen also convert available oxygen and sugar into carbon dioxide and usable energy for efficient bacterial cell growth, thereby maintaining the rumen environment anaerobic and favorable to ruminal cellulolytic microbes (Knapp et al., 2014). Thus, the effect of including dietary probiotics in enhancing ruminal degradation of nutrients could be a consequence of multiple factors, such as improvements in chemical composition of the diet, enhanced degradation of structural carbohydrates, changes in the profile of ruminal microbes that stimulate degradation of fibrous feeds, and the maintenance of favorable anaerobic ruminal environment for the microbes, among others. These positive attributes of EM on the chemical composition and ruminal degradability of nutrients can increase animal productivity and feed efficiency.

Table 2. *In-sacco* dry matter degradability at different incubation hours of mixed diets containing different levels of EM-treated wheat bran replacing concentrate mixture

Treatments	Incubation hours						
	0	6	12	24	48	72	96
T1	12.7^{c}	26.3^{d}	33.1^{c}	36.1^{d}	42.7^{d}	51.2^{c}	55.6^{d}
T2	14.3^{c}	30.9^{c}	35.9^{b}	39.5^{c}	47.2^{c}	55.6^{b}	58.4^{c}
T3	17.6^{b}	33.5^{b}	39.2^{a}	43.4^{b}	52.9^{b}	58.2^{b}	65.6^{b}
T4	19.8^{a}	36.1^{a}	41.1^{a}	47.2^{a}	59.8^{a}	64.4^{a}	70.4^{a}
SEM	0.537	0.496	0.655	0.834	0.483	0.794	0.656
p-value	< .0001	< .0001	< .0001	< .0001	< .0001	< .0001	< .0001

$^{a-d}$Mean values in a column without common superscripts differ (P < 0.05); Concentrate mixture (CM) = (wheat bran 35%, maize 20%, rice bran 21%, molasses 3%, niger seedcake 4%, sunflower cake 11%, salt 3%, limestone 3%); T1 = 70% native pasture hay (NPH) plus 30% CM; T2 = 70% NPH plus 33% of the 30% CM replaced by EM-treated wheat bran; T3 = 70% NPH plus 66% of the 30% CM replaced by EM-treated wheat bran; T4 = 70% NPH plus 100% of the 30% CM replaced by EM-treated wheat bran; SEM standard error of mean

Table 3. *In-sacco* crude protein degradability at different incubation hours of mixed diets containing different levels of EM-treated wheat bran replacing concentrate mixture

Treatments	Incubation hours						
	0	6	12	24	48	72	96
T1	6.4^{d}	10.4^{b}	13.6^{c}	17.2^{d}	20.4^{c}	21.3^{d}	26.3^{d}
T2	8.1^{c}	13.0^{ab}	14.3^{c}	19.3^{c}	23.2^{b}	24.2^{c}	29.1^{c}
T3	10.9^{b}	13.4^{a}	16.6^{b}	20.1^{b}	23.0^{b}	25.5^{b}	31.8^{b}
T4	12.5^{a}	14.7^{a}	19.1^{a}	23.3^{a}	24.3^{a}	29.6^{a}	35.5^{a}
SEM	0.247	0.822	0.248	0.205	0.275	0.189	0.342
p-value	< .0001	0.032	< .0001	< .0001	< .0001	< .0001	< .0001

$^{a-d}$Mean values in a column without common superscripts differ (P < 0.05); SEM standard error of mean; Concentrate mixture (CM) = (wheat bran 35%, maize 20%, rice bran 21%, molasses 3%, niger seedcake 4%, sunflower cake 11%, salt 3%, limestone 3%); T1 = 70% native pasture hay (NPH) plus 30% CM; T2 = 70% NPH plus 33% of the 30% CM replaced by EM-treated wheat bran; T3 = 70% NPH plus 66% of the 30% CM replaced by EM-treated wheat bran; T4 = 70% NPH plus 100% of the 30% CM replaced by EM-treated wheat bran; SEM = standard error of mean

Degradability Parameters of Dry Matter and Crude Protein

The parameters for *in sacco* degradation of DM and CP in the treatment diets are presented in Tables 4 and 5, respectively. Except for parameter c/rate of degradation for DM, all degradation parameters differed among the treatments ($P < 0.05$). The rapidly degradable fraction (a) for DM was greater for T_3 and T_4 compared with T_1 and T_2. The insoluble but potentially degradable DM fraction (b) tended to increase with an increasing inclusion of EM-treated wheat bran in the diet. The PD followed the order of $T_1 = T_2 < T_3 <$ T4 and the ED followed the order of $T_1 < T_2 < T_3 < T_4$ ($P < 0.05$). The fraction a for CP increased with an increasing level of EM-treated wheat bran inclusion in the diet. The fraction b for CP was greater in T_3 and T_4 compared to T_1 and T_2. The rate of degradation of CP decreased with an increasing level of EM-treated wheat bran in the diet. The PD and ED of CP showed a similar trend to that observed for DM, and both increased with increasing levels of EM-treated wheat bran in the diet.

In general, the inclusion of EM-treated wheat bran in the diet improved the degradability parameters. The improvement in the fraction a for both DM and CP with the inclusion of EM-treated wheat bran was apparently associated with changes in chemical composition of the treatment diets noted in this study. Other researchers also noted that the increase in CP and decrease in structural carbohydrate content with EM treatment increased the rapidly degradable fraction of the diets (Solomon et al., 2010; Syomiti et al., 2010). Similarly, the values of fraction b, PD and ED were greater with the inclusion of EM-treated wheat bran in the diet, which is supported by previous finding of Daniel et al. (2017) and Syomiti et al. (2010) who showed the use of EM as a feed additive increases the DM degradability parameters of sorghum stover and forages. The values for PD and ED parameters also align with the *in vitro* digestibility values noted in this study. Solomon et al. (2010) also observed that *in sacco* DM and CP degradation parameters have a positive correlation with IVDMD and a negative correlation with NDF, ADF and ADL contents. Similarly, Bezelew et al. (2021) indicated that greater levels of NDF and lignin could lead to lower levels of PD and ED. Based on the *in sacco* PD and ED parameters of DM and CP in the treatment diets, the treatments can be ranked as $T_4 > T_3 > T_2 > T_1$.

Table 4. *In-sacco* dry matter degradability parameters of mixed diets containing different levels of EM-treated wheat bran replacing concentrate mixture

Treatments	a (g/kg DM)	b (g/kg DM)	c (%/h)	PD (g/kg DM)	ED (g/kg DM)
T1	16.4[b]	38.5[c]	0.03	54.9[c]	36.6[d]
T2	18.2[b]	38.9[bc]	0.04	57.2[c]	40.3[c]
T3	21.5[a]	42.1[b]	0.03	63.6[b]	44.2[b]
T4	23.3[a]	46.8[a]	0.03	70.1[a]	48.2[a]
SEM	0.552	0.954	0.003	1.316	0.269
p-value	0.0004	0.003	0.64	0.0007	< .0001

[a-d]Mean values in a column without common superscripts differ ($P < 0.05$); a = rapidly degradable fraction; b = slowly, but potentially degradable fraction; c = rate of degradation; DM = dry matter; ED = effective degradability; PD = potential degradability; Concentrate mixture (CM) = (wheat bran 35%, maize 20%, rice bran 21%, molasses 3%, niger seed cake 4%, sunflower cake 11%, salt 3%, limestone 3%); T1 = 70% native pasture hay (NPH) plus 30% CM; T2 = 70% NPH plus 33% of the 30% CM replaced by EM-treated wheat bran; T3 = 70% NPH plus 66% of the 30% CM replaced by EM-treated wheat bran; T4 = 70% NPH plus 100% of the 30% CM replaced by EM-treated wheat bran; SEM = standard error of mean

Table 5. *In-sacco* crude protein degradability parameters of mixed diets containing different levels of EM-treated wheat bran replacing concentrate mixture

Treatments	a (g/kg DM)	b (g/kg DM)	c (%/h)	PD (g/kg DM)	ED (g/kg DM)
T1	7.1[d]	18.1[b]	0.03[a]	25.29[c]	16.36[d]
T2	9.0[c]	20.1[b]	0.02[b]	29.07[c]	18.48[c]
T3	11.9[b]	29.3[a]	0.01[c]	41.27[b]	19.61[b]
T4	13.7[a]	34.4[a]	0.01[c]	48.14[a]	22.02[a]
SEM	0.375	1.865	0.001	1.808	0.191
p-value	< .0001	0.0024	< .0001	0.0004	< .0001

[a-d]Mean values in a column without common superscripts differ (P < 0.05); a = rapidly degradable fraction; b = slowly, but potentially degradable fraction; c = rate of degradation; DM = dry matter; ED = effective degradability; PD = potential degradability; SEM standard error of mean; Concentrate mixture (CM) = (wheat bran 35%, maize 20%, rice bran 21%, molasses 3%, niger seed cake 4%, sunflower cake 11%, salt 3%, limestone 3%); T1 = 70% native pasture hay (NPH) plus 30% CM; T2 = 70% NPH plus 33% of the 30% CM replaced by EM-treated wheat bran; T3 = 70% NPH plus 66% of the 30% CM replaced by EM-treated wheat bran; T4 = 70% NPH plus 100% of the 30% CM replaced by EM-treated wheat bran; SEM = standard error of mean

Conclusion

Treating feed with EM, as used in the present study, showed improvements in the chemical composition through an increased CP and reduced structural carbohydrates. It also increased the degradability of DM and CP, indicating the high potential of EM treatment for enhancing the nutritive values of the feeds. The current results suggested that EM-treated wheat bran can fully replace the concentrate mixture used in the current study with better animal performance results.

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References

Alexey B., B. Oksana, Vitaliy, Z., Svetlana, G., Irina, B., Evgenia, E., Sergey, E., Yulia, M., Maksim, R. and Evgeny, P. 2019. Using of EM-technology (effective microorganism) for increasing the productivity of calves. Int. J. Eng and Adv. Tech 8 (4): 1058-1061.

AOAC (Association of Official Analytical Chemists). 1990. Official methods of analysis (15th edition), Washington, DC.

Aramble M. J., and B.A. Kent 1990**.** Effect of yeast culture on nutrient digestibility and milk yield responses in early to mid-lactation in dairy cows. J. Dairy. Sci 73: 1560-1563.

Bimrew A., Fentie B., and Teshome G. 2020. On-farm evaluation of the effective microbes and urea treated rice straw on performance of local dairy cows and farmers' perception in Ethiopia. AgroLife. Sci. J. 9 (2):35-44.

Bizelew G., Ajebu N., Getnet A. and Getahun A. 2021. Chemical Composition and *In sacco* Dry Matter Degradability of Selected Browse and Grass Species in Abobo District, Gambella Regional State, Ethiopia. Acad. J. Nutr 10 (1): 24-35.

Central Statistical Agency of Ethiopia (CSA). 2017/18. Report on "livestock and livestock characteristics" agricultural sample survey volume II.

Chen, XB. 1995. Neway excel: an excel application program for processing feed degradability data. International Feed Resources Unit, Rowett Research Institute, Aberdeen, UK.

Collado M.C., Grzeskowiak, L. and Salminen, S**.** 2007. Probiotic strains and their combination inhibit in vitro adhesion of pathogens to pig intestinal mucosa. Curr Microbiol 55:260–265.

Daniel T., Mengistu U., Gebeyehu G. and Zemelak G. 2017. *In sacco* Dry Matter Degradability of Urea and Effective Microorganism (EM) Treated Sorghum (Sorghum biclor L. Moench) Stover. Advan. Biol. Res., 11 (1): 41-50.

FAO. 2019. Ethiopia. Availability and utilization of agroindustrial by-products as animal feed 2018. Rome. 64 pp.

Higa T. 1994. Effective microorganisms: A new dimension for nature farming. p. 20-22. *In.* Proc. of the Second International Conference on Kyusei Nature Farming. U.S. Department of Agriculture, Washington, D.C, USA.

International Livestock Research Institute (ILRI). 1999. Farmers, their animals and the environment. Feed and nutrition. P 29.

Knapp G. L., P.A. Laur, W.P. Vadas, Weiss, J. M. Tricarico. 2014. Review: Enteric methane in dairy cattle production: Quantifying the opportunities and impact of reducing emissions. J. Dairy Sci. 97:1–31.

Krehbiel C.R., Rust, S.R., G. Zhang, and S.E. Gilliland. 2003. Bacterial direct-fed microbials in ruminant diets: performance response and mode of action. J. Animal Sci. 81(14): 120-132.

Lettat A., Nozière, P., M. Silberberg., D.P. Morgavi., C. Berger,, & C. Martin. 2012. Rumen microbial and fermentation characteristics are affected differently by bacterial probiotic supplementation during induced lactic and subacute acidosis in sheep. BMC Microbiol 12: 142

Maurya M.S. 1993. Effect of Feeding Live Yeast Culture (*Saccharomyces cerevisiae*) on rumen fermentation and nutrient digestibility in goats. A *PhD* Thesis. Indian Veterinary Research Institute, Deemed University, Izotnager. India.

Ørskov E.R. and I. McDonald. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J. Agric. Sci., Camb. 92: 499-503.

Osuji P.O., I.V. Nsahlai, and H. Khalili. 1993. Feed evaluation. P. 40. *In* ILCA Manual 5. ILCA, Addis Ababa, Ethiopia.

SAS (Statistical Analysis System). 2010. Statistical Analysis System, Version 9.0, SAS Institute, Inc., Cary, NC, USA.

Seyoum B., Zinash S., and Dereje F. 2007. Chemical composition and nutritive values of Ethiopian feeds. Research Report 73, 24pp. Inst. Agric. Res., Addis Ababa.

Solomon M., Teferi A. and Lisanework N. 2010. Chemical composition, *in vitro* dry matter digestibility and *in sacco* degradability of selected browse species used as animal feeds under semi-arid conditions in Northern Ethiopia. J. Agroforest Syst. 80:173–184.

Syomiti M., M. Wanyoike, R.G. Wahome, and J.K.N. Kuria. 2010. In saccoprobiotic properties of effective microorganisms (EM) in forage degradability, Livest. Res. Rural Develop. 22(1): 8-14.

Van Soest P.J. and J.B. Robertson. 1985. Analysis of Forages and Fibrous Foods a Laboratory Manual for Animal Science. Cornell University, Ithaca, New York, USA.

Yacout M.H., EL-Badawi. A.Y., Khalel. M.S., Atia. S.E., and A.A.M. Hassen. 2021. Impact of effective microbes (em) bokashi supplementation on nutrients digestibility, rumen fermentation and gas volume production in diets of sheep. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Animal Sci and Biotech. 78 (2):66-75.

Yonatan K., Solomon D., Taye T., and Yehenew G. 2014. Effect of Effective Microorganism (EM) on the nutritive quality of coffee husk silage. Int. J. Sci and Tech. Res 3(7): 13-20.

Yoon, I. K., and M.D. Stern. 1995**.** Influence of direct-fed microbials on ruminal microbial fermentation and performance of ruminants: A review: Anim Bio Sci 8(6):533-555.

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Production System Characterization of Coffee in Amhara Region, Ethiopia: Implications for Research and Development Intervention

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Abstract

Although coffee has historically been grown as a garden crop in different areas of the Amhara Region, there is no complete documentation about the coffee production system for research and development interventions in the region. This article was intended to characterize the main socio-economic and biophysical constraints and opportunities of coffee growing areas in the Amhara region. A combination of qualitative and quantitative methods was used to generate data. A multi-stage sampling technique was employed to select a total of 344 target coffee growers. Descriptive statistics such as mean, standard deviation, frequency, percentage, SWOT analysis and narration were used. Around 85.50% of the coffee growers produce coffee as a garden crop. The Region's coffee cropping calendar, which runs from planting to harvesting, is influenced by the rainfall season and farmers' access to irrigation. The study found that among the main factors limiting coffee production in the area are lack of improved coffee varieties, diseases, pests, drought, farmers' low level of knowledge and skill on pre- and post-harvest management, limited access to irrigation water, and the growth of unlicensed traders. The main potential for coffee production in the region, however, were the emerging primary coffee cooperatives and unions, the presence of NGOs investing in coffee production, the strong interest of the regional government, and the availability of coffee nursery sites. The agronomic practice and management methods used by coffee growers in the area were traditional. Despite different challenges faced in production and marketing of Amhara region coffee, primary coffee cooperatives and unions were established. Therefore, there needs to be a holistic approach to improve the coffee production system, and there needs to be an improvement in the management skills of cooperatives and unions.

Keywords: Amhara region; Coffee grower; Cooperative and Union; SWOT analysis

Introduction

Ethiopia is the largest producer of Arabica coffee in Africa and the fifth-largest producer of the crop in the world (Beza, 2014). About 15 million people in Ethiopia depend directly or indirectly on coffee for their livelihood, making it an essential component of the country's economy (Alemayehu, 2014). Ethiopia's primary export product and economic mainstay is coffee (Bizualem, 2018).

Arabica coffee has been grown, traded, and consumed for generations and continues to be an important part of most Ethiopians' everyday lives as well as the country's overall economy. About 95% of the total coffee output is produced by over 4 million small-scale producers (Jiga et al., 2017). The relationship between Ethiopians and coffee is deep-rooted, and coffee production and consumption are closely intertwined with Ethiopian history, culture, and economy (Fekadu and Gosa, 2015; Akalu et al., 2009). Besides, to economy coffee plays a vital role both in the cultural and social life of the nation.

Like other coffee growing regions such as Oromia and Southern Nations and Nationalities and People’s Region (SNNPR), Amhara Region has got favorable agro-ecology for coffee production (HNSE, 2015). However, the federal and regional governments and other concerned stakeholders have not given recognition and attention to coffee production and marketing in this region. Because of this, coffee in the Amhara region has been produced only as a garden crop in some pocket areas for a long time (Sintayhu, 2000). The western part of the Amhara region is the leading producer of coffee in the region, particularly the west Gojam and Awi zone. Despite the region has the potential to produce quality and organic coffee, the production level is still nil to date even coffee produced for consumption is covered by traditionally managed fields. Nevertheless, according to a report from the region's agriculture office in the recent past, a strong emphasis has been given to coffee production by the regional government to exploit the existing ecological potential and socio-economic opportunities.

Thus, the coffee farming system study is important for further research and development intervention in the region. Because farming systems in Ethiopia generally and Amhara region particularly are highly diverse in terms of biophysical and socioeconomic characteristics (Workineh et al., 2020). Biophysical and socioeconomic factors affect agricultural farming systems due to rapid changes in climate variability, an outbreak of diseases and pests, infrastructural development, farmers' preference, and new technology generation (Moat, et al., 2017; Mekuria et al., 2004). These factors are among the major ones affecting coffee development and research and influence the production systems characterization in Ethiopia as well as the Amhara region at different dimensions and extents. Some studies have been conducted to characterize coffee farming in other coffee potential regions in Ethiopia (Jiga Degaga *et al.*, 2017; Fekadu Gemechu, and Gosa Alemu, 2015; Tadesse Woldmariam, 2015; Alemayehu Asfaw, 2014; Mekuria et al., 2004).

Production of coffee as a country is an increasing trend where the current production is estimated to be about 449,229.8 tons with the productivity of 0.612 t ha−1 clean coffee (Central Statistical Agency, 2018). Like other potential regions Amhara region also possesses conducive agro-ecological and socio-cultural conditions for coffee production (Yigzaw, D., 2005). In recent years, however, coffee production in the region is increasing from time to time (Melese Wale, 2020). According to the Central Statistical Agency (2018), currently, about 3,006.8 tons of green coffee beans are produced on 9,961.2 hectares of land with 0.302 t ha−1 productivity. Productivity and quality of coffee production remained low relative to the national average. This might be because, the Amhara Region is considered as a modest production region compared to the main coffee growing areas such as Oromia Region and Southern Nations, Nationalities, and Peoples' Region (SNNPR), (ECFF 2017). This led to development not intervening in coffee production. Besides there has not been a study conducted to characterize Amhara regions coffee production and marketing system. Mainly, the current coffee production system, agronomic practice, coffee pre and post harvesting management, drying process, coffee farmers' perception, production challenges and opportunities faced at the household level are important topics of investigation.

Hence, assessing and characterizing the coffee production system in Amhara region is helpful for further research and development intervention. In the first section, the introduction part of the study was explained. In the second section, the methodology is provided. In the third section, the result and discussion are provided and finally, the conclusion and policy implications are presented.

Methodology

This section describes the data and data collection methods. First, the context of the study including the location of the research site was presented. Second, quantitative and qualitative data collection methods including focus group discussion, and key informant interviews were provided. Third, the method of quantitative data collection was explained. Finally, a method of data analysis was described.

Description of the study area

Most coffee-growing zones are in the western part of the Amhara region. The specific study areas are found in east and west Gojjam, Awi, south Gondar, and Bahir Dar city administration areas. Totally nine districts and one city administrative (Zege) were selected for the coffee survey. The districts are the major coffee growing belts in terms of area coverage. The areas fall within the altitude ranging from 1300–2150 mters above sea level. The study areas did not have major physiographic differences from other crop-producing areas of the region. The coffee growing districts of the region have a homogenous topographic feature, which are flat to gentle slope except for Zege which rise up to 10% slope (BoEPLAU, 2015). The soil group is categorized as nitosol, and vertisol. Nitosol is the dominant soil type mostly found in coffee producing sites and vertisol is dominantly observed in the other crop field suitable for production of cereals and pulses. In general, the soil type of the selected districts is fertile and has good potential for coffee production.

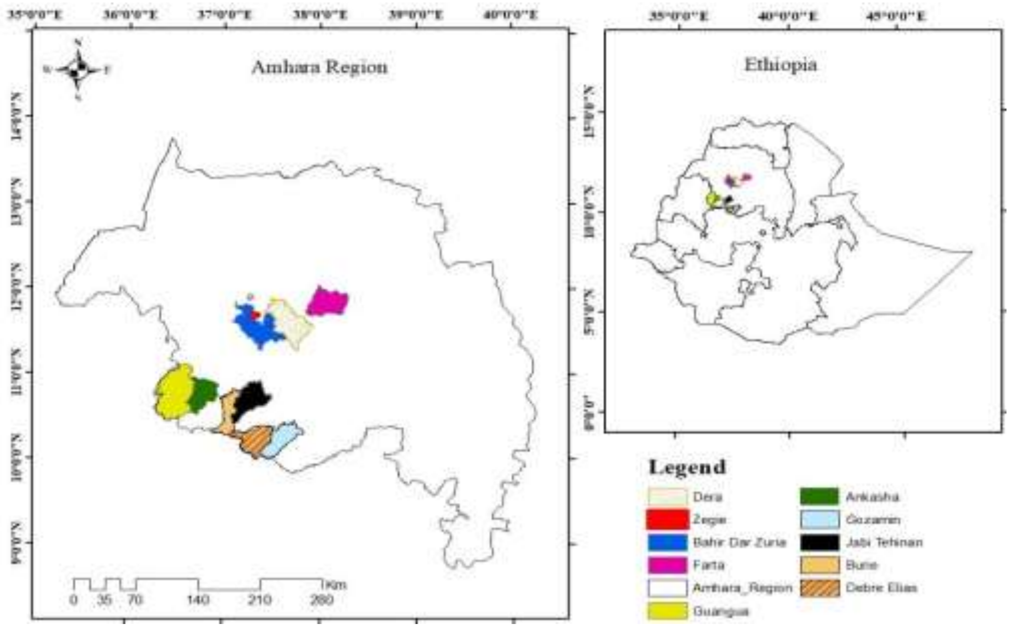

Figure 1. Map of the study districts.

Sampling techniques and sample size

A multi-stage sampling technique was employed to select representative districts and coffee growers. First, four zones and one town administration were selected purposively based on the potential of producing. Secondly, two districts in each zone and three in west Gojjam were selected purposively based on the potential. Thirdly, two kebele per district were selected based on production potential and agro-ecology. Finally, a total sample size of 344 smallholder coffee growers was selected randomly using the probability of proportional probability sampling technique (PPS) on each district.

Data source and method of data collection

The data were collected both from primary and secondary sources. A mixed-method strategy combining qualitative and quantitative data collection techniques was used. Primary quantitative data were gathered using a cross-sectional survey design. The primary data were collected using a pretested structured questionnaire by trained enumerators with a good knowledge of coffee farming systems and fluency in local languages. The variable of interest included information on demographic, socioeconomic characteristics, coffee grower farm resources, institutional variables, and biophysical constraints and opportunities for coffee growing.

Moreover, we held focus group discussions (FGD) in all study districts to gain more insights into coffee production and related issues. The FGD participants were drawn from farmers groups with different wealth status, gender, and age composition. Each FGD group consisted of 8–12 participants. The group discussions were guided by a semi-structured checklist. Similarly, a key informant interview (KII) was used to complement the data collected with structured questionnaires. KII was held with agricultural experts, coffee cooperatives, Amhara farmer's coffee producers' cooperatives union, Amhara national regional state cooperative agency, and district cooperatives. Semi-structured checklist was used as a tool focusing on the coffee farming system, production areas, and several trees on a household level, trends of cultivation system, land allocation, opportunity and constraints, and before and post-harvest management. Secondary data was also collected from the Office of Agriculture on the production, land allocation, and distribution of coffee seedlings planted in the past three years. Besides, secondary data was sourced from coffee cooperatives, the Amhara farmer coffee producers' cooperative union and the HARNS Ethiopia project.

Method of data analysis

A mixed-method data analysis was used to analyze collected data through structured questionnaires and key informant interviews. The quantitative data collected from the sample respondents were encoded into SPSS version 20 and analyses were done with STATA version 14. Descriptive statistics employed such as percentage, mean, standard deviation, frequency, and cross-tabulation to characterize the socio-economic situation and constraints of coffee production. In this study SWOT analysis was also employed to capture the internal and external analysis of coffee production in the region. This enables to identify of the strengths and weaknesses, possible opportunities, and potential threats to sustaining coffee production and markets.

Results and Discussion

This section presents the results and discussion of coffee production characterization. The results presented demographic and socioeconomic profiles of the coffee growers based on selected socio-economic variables; the next subsections provided about the coffee plantation system including agronomic practice and cropping calendar; coffee management such as shade tree management, pruning practice, drying process, disease, and insect pest occurrence was discussed; finally, irrigation and type of water lifting technologies to coffee field and irrigation water use association function for the coffee growers were presented.

Demographic and socio-economic characteristics

Survey findings revealed that 63.95% of the sampled households were non-literate and the remaining 36.05% were literate. Table 1 showed that the average age for respondents in the sample was 47.76 years, ranging from 20 to 87 years. The family size of the sampled households varied between 2 and 12, with an average and standard deviation of 5.84 and 2.084, respectively. The survey result indicated that the average landholding size per household was 1.5 ha with a standard deviation of 1.35. On average, 0.15 hectares have been allocated to coffee plantations. A household had 14.39 years of experience in coffee production with a standard deviation of 10.90. The number of mother coffee trees owned ranged from 10 to 6000 with a mean of 634.85.

Table 1. Demographic and socioeconomic profiles of the coffee growers

Number of observations = 344					
Variable	Min	Max	Mean	Std. Dev	Percent (%)
Sex (Male)					89.90
Educational status (illiterate)					63.95
Age (years)	20	87	47.76	12.26	
Family size (number)	2	12	5.84	2.08	
Total cultivation land (ha)	0.25	5.5	1.5	1.35	
Coffee land allocation (ha)	0.0025	2.5	0.15	0.27	
Coffee farm experience (year)	2	50	14.39	10.90	
Number of trees (number)	10	6000	634.85	561.39	

Note: Min = Minimum, Max= Maximum, Std.Dev = Standard deviation

Coffee plantation and production systems

Gardens coffee production system is the dominant coffee-growing culture in the Amhara region. In a coffee-growing zone of the Amhara Region, the coffee field is a little bit far from the vicinity of the farmers. The characteristic of garden coffee is commonly planted on small parcels of less than five hectares that generate good cultural management. In the Amhara's National Regional State, the coffee production culture is not as categorized in the main crop production system as cereals, fruits, and vegetables. However, the region is known for its avid coffee consumption culture, being the highest in terms of domestic consumption within the country.

Table 2. Types of coffee production system

Production system	Percent (%)
Garden	85.50
Plantation	8.70
Forest	3.50
Semi-forest	2.30

Although the garden production system is a major plantation, forest (around Zege), and semi-forest coffee production systems are also present. Forest coffee is self-produced and naturally cultivated in the wild under full forest cover (Anteneh and Aman, 2017). Semi-forest coffee is also grown under forest canopy and has limited human intervention (Dessalegn and Solomon, 2014). Plantation coffee is grown on large state-owned or commercial farms, representing 5% of production, and garden coffee refers to the bulk of Ethiopian coffee more than 50% (USAID, 2012).

In recent years, growing coffee production has become the main preoccupation of coffee farmers in the region as one of the main sources of cash income. This is especially the case in the western part of the region where coffee performs better than other crops in terms of area and productivity per unit area. Farmers' awareness of coffee production, quality and commercial demand in the coffee producing areas of western Amhara has also shown a certain positive development.

Cropping calendar and agronomic management

In the region, the ripened coffee harvest began towards the end of October and continues into February. But in the Zege area harvesting began late and governed by community law and harvesting activity was started at the end of February when it was announced by the community chief and district administration. Community law was fully agreed by all coffee producers. The purpose of this community law was to keep from animal pests and theft during drying.

Table 3. Cropping calendar of coffee in the study districts

Coffee management	Cropping calendar and management frequency	Remark
Time of planting	June-July (rainy season) November–December (irrigation coffee)	Coffee plantations using irrigation are developing in certain regions of the study districts.
Plowing frequency	1-2 and digging by hand	
Weed frequency	1-3 per year	
Digging frequency	0-2 per year	Some farmers practice ‘zero’ tillage for coffee planting
Flowering time	May-June	Yet it depends on the rainy season and farmers' access to irrigation.
Harvesting time	October end-February	The districts of Zege and Dera commenced late February.
How long does it take to be the first harvested?	3-6 years from planting	If irrigation is not used , the first harvesting time would become a six year long

Source: Collected from districts and kebele agriculture office

Application of inputs and management practice

Table 4 shows that 89% of respondents used organic fertilizers like manure and compost. Ethiopian coffee farmers used organic coffee, not inorganic. The result of this study is consistent with study by (GAIN, 2014). The study reported that 2%

of interviewees applied chemical fertilizers and 98% did not. This indicates that almost all farmers do not use inorganic fertilizers on their coffee plantations. A recent survey reported that only 2% of smallholder farmers apply chemical fertilizers on their coffee plantation in Ethiopia (Tadesse, 2015). Coffee produced in the area is the more organic coffee which is in line with the ministry of agriculture and natural resource management which does not encourage the application of chemical fertilizers.

Ethiopia is the primary center of origin and genetic diversity of Arabica coffee; there are wide ranges of variability among coffee types. As a result, there are distinct coffee types known by different vernacular names in the region. According to the farmers, a local named *Enaria* coffee is found in west Gojam, south Gondar, and Zegie. The local name of cultivars *Welelo, Ginjar,* and *Derso* coffee are called around in Burie and Ankasha districts. About 62.5% of respondents responded that improved varieties are not demonstrated in the area. This indicated that the availability of improved coffee varieties and extension services on coffee technologies promotion is very low which has hindered coffee production and productivity in the region. Similarly, a study conducted by GAIN (2014) argued that the major reason for the low production of coffee in Ethiopia is the inadequate use of improved seed technologies.

Table 4. Input applications and management practice by respondents'

Inputs used	Frequency	Percent (%)
Inorganic fertilizer (applied)	7	2.00
Organic fertilizer (applied)	306	89.00
Improved coffee varieties (Yes)	129	37.50
Inter-crop coffee (Yes)	148	43.00
Seedling source (District agri. Office)	267	77.60
Planting materials (seedling)	316	91.90
Shade tree (used)	316	91.90
Pruning (practiced)	75	21.8

The introduced coffee variety was 74110 in most study districts and it was distributed by extension agents. The rest of the coffee grown by most coffee growers was local cultivar. The farmers preferred 74110 because of its high yielding, uniform maturity, and early maturing feature. According to the farmer's response, disease sensitivity, short life span and drought tolerance were among the main challenges in maintaining the 74110 variety. The coffee produced in the Zege region comes from local cultivar.

The finding also indicated that 43% of respondents intercropped coffee with other horticulture crops and spices. The most common intercropping crops with coffee in the study districts were mango, papaya, spices, pepper, tomato, and potato. The majority of coffee growers are still traditionally managed. Especially post-harvest activities are not yet progressing to new technological levels (EIAR, 2008). This traditional agricultural practice is similar across all coffee farming districts, where the use of improved cultural practices and agricultural inputs is very limited. Overall, it can be generalized that appropriate and timely use of irrigation water, regular rejuvenation of old coffee trees, pruning, cultivating with the use of mulching as well as shade tree regulation is not common farming practices in the region.

All shaded trees in the surveyed districts exhibit different tree types and densities. The common shade trees found in the coffee garden are Sesbania, Cordia Africana (Wanza), Vernonia Africana (Girawa), Albizia Gummifera (Sessa), Croton Macrostachi (Misana), M. Fergunia (Birbira), Ficus Vasta (Shola), Kawa, Szgium Guineense (Dokima), and fruit trees such as avocado, papaya, and banana. According to the response of coffee growers, Cordia Africana (Wanza) is not a desirable coffee shade tree because of its shallow roots and hence adds uproot thickness which will push up the root of coffee. Moreover, it competes with humidity, and its leaves do not break down. Permanent shading is a standard practice in all study districts except for some farmers. The advantages of shade trees were to reduce high sunshine, reduce natural hazards such as snow and wind, increase soil fertility, and be used for fencing purposes. Generally, there is no scientific pruning practice in the Amhara region and farmers do not have the know-how of pruning practice. Mulching is practiced by a few farmers using fallen leaves of coffee and some shade trees. It is required practice, especially in lands where irrigation is used, but most farmers do not seem concerned or do not have the know-how on mulching practice.

Major coffee diseases and insect-pest occurrence

In our country, the most economically important pathogenic coffee diseases are coffee berry disease, coffee wilt disease, coffee leaf rust, and physiological disorders like coffee branch dieback are caused by pseudomonas syringae and non-pathogenic agents (Jiga, et al 2017; Mohammedsani, 2017; Weldemariam et al., 2016). Similarly, coffee berry disease and branch dieback were causing the higher yield loss of coffee production in Amhara region. The study area coffee wilt disease, coffee berry diseases, rust, and leaf minor are observed during the survey. Particularly coffee wilt diseases are highly observed in Zege area where the farmers used plant materials sourced from local landrace.

Insect pests are also considered to limit coffee production in both quality and quantity. Insect pests such as coffee berry borer, hypothalamus hampei, coffee thrips, diarthrothrips coffea, green scale, coccus alpinus, coffee cushion scale, stictococcus formicarius, are potentially important pests (Weldemariam et al., 2016). Likewise, the result of the study indicated that the major insect pests affecting coffee production in the study area were termites, tip borer, root rot, green scale, and stem borer. Termites pose serious problems to coffee production by feeding on the bark or skin of the tree and also by making tunnels or passageways of other fungal and bacterial diseases and causing considerable harm.

Coffee dry processing

The coffee processing method in Amhara's region is not different from any other major coffee-growing areas in the country, except that sund dried or natural processing is the only method that is being practiced by all farmers in the region. In the Awi zone, there is a privately owned large-scale plantation (Ayehu farm) for the coffee processing facility, and Ankasha Guagusa, Burie, and Jabithnan districts start the process with vouchers. Selective picking only matured red cherries is a well-accepted and common practice in the Amhara region, but in most study districts the processing of red cherries is carried out traditionally. Farmers dry this red cherry on the ground simply prepared by cow dung and bare ground. Besides, coffee farmers used wooden and bamboo-made drying beds and plastic materials as shown from the image (annex).

Irrigation water source and water user association

The role of water in the development and yield of the coffee crop is great. The need for irrigation, and its role in controlling the timing of flowering, varies depending on the rainfall distribution, the severity of the dry season, and soil type and depth. Based on the focus group discussion and key informant interview irrigation was a promising technique that may provide both yield increase and expansion of coffee plantations in areas considered unsuitable due to the occurrence of water shortage. Coffee farmers were planting around rivers to use the water nearby. Besides, some coffee farmers used cultural practices using human labor and donkeys to irrigate their coffee.

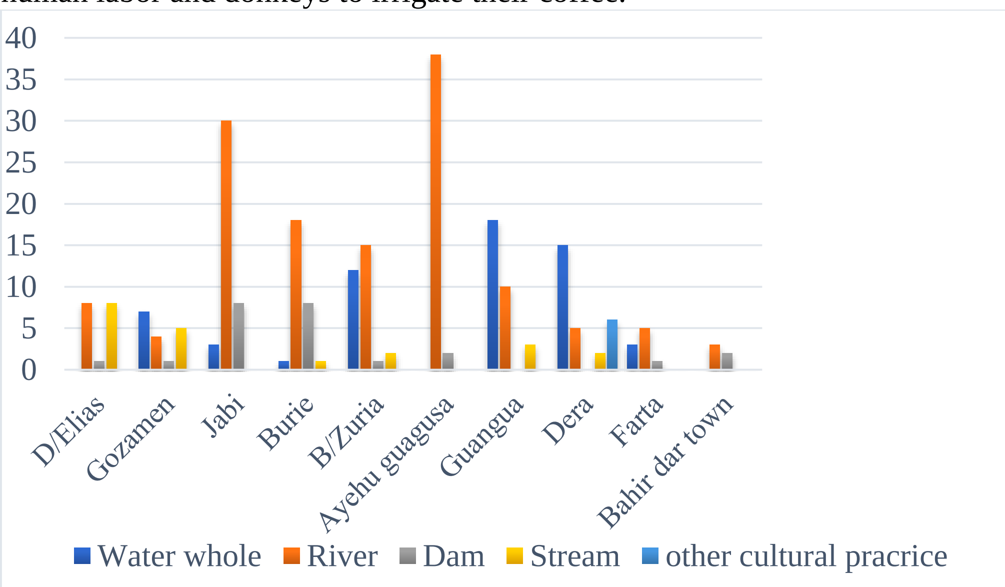

Figure 2. Water source in each study district by respondents.

Figure 3 showed that the most coffee growers are taking water from source to coffee field by river diversion. Some coffee farmers used water lifting technologies such as water pumps, rope and washers, and human and donkey labor to coffee farmland. In Zege almost all respondents did not have irrigation access.

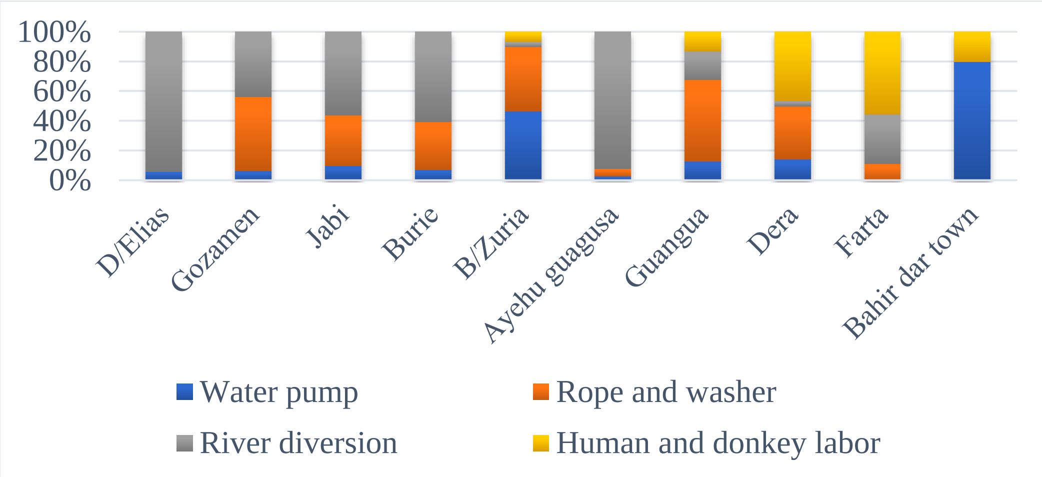

Figure 3. Water lifting technologies by respondents.

Irrigated water user associations are informal organizations created to bring together farmers for managing a shared irrigation system (Chuchird et al., 2017). In all the study districts irrigated water user associations are self-governed local organizations of irrigators who pool their financial, technical, and human resources for the use and maintenance of irrigation production of coffee (Tadesse et al., 2019). According to focus group discussion information, the coffee grower's irrigation water user association had its own functions. The current status of the irrigated water user association is an informal, user-based organization, and only association members were using water from an irrigation system. Users also had their governance and representatives led the association who were elected by members and they are called the father of water. The selected committee keeps irrigation water from damage such as from animals and silt. Water allocation between members also used the program sequentially in his/her coffee field. Based on the key informant interview response, father of waters monitors and evaluates their bylaws of rights and duties of water user association members, procedures, calling meetings, and efficiencies all about.

Coffee marketing in Amhara region

The main actor includes a network of coffee growers, assemblers, retailers, wholesalers, primary coffee cooperatives, unions, and consumers operating at different levels in the coffee production value chain of the study districts. The behavior and functional role of the different participants in the determination of the structure and performance of the coffee marketing system is described as follows;

Coffee farmer: Farmers supply their coffee around their local markets both clean and/or jenfel coffee for different actors. Some farmers also sell their coffee to local customers through local measurements such as Melekia and Bicherie. As such, farmers provide coffee to cooperatives and local traders. The local traders illegally purchased from coffee growers by adding the price of the margin price set by the primary coffee cooperatives.

Consumers: Individual consumers are one of the players in the coffee production and consumption value chain in the areas covered. They purchase coffee from the coffee producer and traders on the market. Coffee consumption has been rising in both rural and urban areas, mainly in jebena coffee, which has spread like a culture and users used after a launch.

Retailers: Most coffee retailing in urban and rural areas is characterized by non-specialized activities. They buy smaller quantities from producers and/or wholesalers and sell them to consumers on particular market days in one week with local measurements like Melekia and Bicherie.

Assembler/collector: Rural assemblers play a significant role in collecting products from small producers on the farm and delivering them to wholesalers at different levels. These are unlicensed/illegal rural and urban assemblers of pulp/red cherry coffee collected during main market day at local or village markets and grinding dry coffee cherries from producers and to deliver for retailers illegally.

Wholesalers: Wholesalers gather from small farmers and assemblers and distribute them to retailers in their districts and areas of the region.

Primary coffee cooperatives: Primary cooperatives in Ethiopia are significant participants in the country's coffee value chain. Most coffee cooperatives in the area were established in 2015 in each potential coffee districts and kebeles. These newly emerged primary cooperatives buy dried cherries mainly from their members for processing and market supply. When it was established, the main objective was for coffee producers to cooperate to gain better access to resources, take advantage of better marketing and business opportunities, provide training, Control unlicensed coffee dealers and more. In addition, local coffee growers cannot produce enough volume to attract a market individually, requiring them to sell special quality coffee at commodity prices to intermediaries. They may also lack resources to showcase themselves through creating social media accounts, spending time meeting prospects and attending coffee events around the world. Those reasons contributed to the establishment of cooperatives. However, the capacity of these newly emerged primary coffee cooperatives in the region is not yet well developed and needs to be supported for efficient management and marketing of coffee for member coffee growers. These cooperatives were purchased from growers and supplied to the established union.

Amhara farmers coffee producers' cooperatives union: Amhara coffee farmers' cooperative unions were established following the issue of Proclamation No. 220/2007 E.C article 11 with the name of Amhara farmers coffee producer cooperatives union plc. The union was established and recorded in November 22/2008 E.C on Ref.No 01/1436 with 22 primary coffee cooperatives. This Union was a new institution that organized the primary cooperatives in the region. Cooperatives purchased coffee from farmers at the market price. The price is determined based on competition between cooperatives and private traders. The payment system by the cooperative is made immediately or around one week after the farmers deliver the coffee. The timing of the payment depends on the financial status of the cooperatives. The coffee growers did not agree on the price fairness, because the local traders were bought with a better price than cooperatives. And some member coffee growers were not providing to the cooperative due to the lower price of coffee. The coffee purchased by the cooperative was delivered to a union. The union purchases coffee from cooperatives at a price equivalent to the domestic auction price at that time. The payment was usually made immediately or after a couple of weeks following coffee delivery; the exact payment time depends on the financial status of the union.

The biggest problem of the union and cooperatives were the shortage of funds to purchase coffee from growers. They financed their transactions using credit from banks. In cases in which they are unable to repay the credit, they are not granted new credit. Some past purchased records of cooperatives have shown some years without any purchases because of the failure to repay the banks. Financial constraints limit the amount of coffee purchased. Human capacity problems such as leaders, marketing experts, office and necessary facilities and poor extension systems were the major problems facing both unions and cooperatives.

Conclusion and Implication

Despite the potential, current production, and agronomic practice coffee at the household level are traditional. This is an attribute to some internal and external factors among which poor agricultural practice, lack of the extension service, lack of access to good planting materials, improved seed varieties, absence of adequate milling and storage facility at a household level, weak coffee cooperative/union and expansion of unlicensed traders. Generally agronomic management of coffee production is too poor. Since coffee production system characterization was extremely important for the research and development intervention. Then, the following recommendations are formulated based on findings for policymakers, development intervention activities, and future research.

Research institutes should pay particular attention to developing adaptable and disease-resistant coffee varieties so that farmers can maintain sustainable coffee production. The management system for coffee plantations and the agronomical practices of growers were traditional. As a result, the focus should be on improving extension services in all ways to improve coffee growers' skills and knowledge of the coffee production system.

Improving the marketing conditions of coffee was also an important issue as farmers in the study area pointed out that that low coffee price limits coffee production. The effects of the cooperatives and unions appear positive for coffee growers. So, the concerned body should be improving the management capabilities and accounting skills of coffee primary cooperatives and unions is critical for the development and sustainability. Improving institutional infrastructures such as access to irrigation, market information, roads and transportation, were also a key to motivating coffee producers and increasing coffee production and productivity.

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References

Akalu Teshome, Wale, M., Fentahun Mengistu, Biru Yitaferu, and Dar, B. (2009). Agricultural potentials, constraints and opportunities in the Megech and Ribb rivers irrigation project areas in the Lake Tana Basin of Ethiopia Federal Democratic Republic of Ethiopia Ministry of Water Resources Ethiopian Nile Irrigation and Drainage Pro. December.

Alemayehu Asfaw. 2014. Coffee Production and Marketing in Ethiopia. *European Journal of Business and Management*, 6(37): 109–122.

Anteneh Temesgen and Aman Tufa. 2017. Analysis of Coffee Farm Productivity in Darolabu District. *American Journal of Environmental and Resource Economics*, 2(5): 158–161.

Beza Erko. 2014. Maize and Faba bean value chains: the Case of BakoTibe and GobuSeyo Districts in Central Western Ethiopia. MSc Thesis, Haramaya University, Haramaya, Ethiopia. 7(8): 626–632.

Bizualem Assefa. 2018. Exploration of Structure-Conduct-Performance of Coffee Market System in Exploration of Structure-Conduct-Performance of Coffee Market System in Ethiopia The Case of Jimma Zone. *Marketing and Consumer Research*, 44(4): 1–11.

BoEPLAU (Bureau of Environmental Protection, Land Administration and Use), 2015. Amhara National Regional State Bureau of Environmental Protection, Land Administration and Use Tana sub basin integrated Land Use Planning and Environmental impact Study Project Technical Report: Land Use Land Cover and Change Detection (ADSWE , LUPESP). 058.

Central Statistical Agency. (2018, April). The Federal Republic of Ethiopia central statistical Agency. Agricultural sample survey report on Area and Production of major crops, 2017/18

Chuchird, R., Sasaki, N., and Abe, I. 2017. Influencing factors of the adoption of agricultural irrigation technologies and the economic returns: A case study in Chaiyaphum Province, Thailand. *Sustainability (Switzerland)*, 9(9).

Dessalegn Gachena, and Solomon Kebebew. 2014. Analysis of Coffee Marketing Cost and Margins in South West. *Journal of Economics and Sustianable Development*, 5(15): 10–18.

ECFF (Environment and Coffee Forest Forum) and Kew garden (2017) Coffee farming and climate change in Ethiopia; Summary report on impacts, Forecasts, resilience and opportunities. https://www.kew.org/sites/default/files/Coffee%20Farming%20and%20Climate%20Change%20in% 20Ethiopia.pdf

EIAR (Ethiopian Institute of Agriculture Research). 2008. Proceeding of a national workshop four-decade of coffee research and development in Ethiopia 14-17 August 2007, Addis Ababa (Ghion Hotel), Ethiopia.

Fekadu Gemechu, and Gosa Alemu. 2015. Opportunities and constraints of coffee production in West Hararghe , Ethiopia. *Journal of Agriculral Economics and Rural Develpoment*, 2(4): 54–59.

GAIN (Global Agricultural Information Network). 2014. Coffee annual report, ET 1402.

HNSE (Hanns R.Neumann Stiftung). 2015. Baseline survey of western coffee-growing zones of Amhara region national regional state of Ethiopia. January.

Jiga Degaga, Tadesse Melka, Birhanu Angasu, Gosa Alemu, Asfaw Zewdu, Mohammedsani Amin. 2017. Constraints and Opportunities of Coffee Production in Arsi Zone: The Case of Chole and Gololcha Districts. *European Journal of Business and Management*, 9(10), 8-17–17.

Mekuria Taye, Neuhoff D, and Kopek U. 2004. The Status of Coffee Production and the Potential for organic conversion In Ethiopia: *Conference on International Agricultural Research for Development*, Berlin, October 5-7, 2004.

Melese Wale Mengistu, Melkamu Alemayehu Workie & Abrar Sualeh Mohammed. 2020 Biochemical compounds of Arabica coffee (Coffea arabica L.) varieties grown in northwestern highlands of Ethiopia, Cogent Food & Agriculture, 6:1, 1741319, DOI: 10.1080/23311932.2020.1741319

Moat, J., Williams, J., Baena, S., Wilkinson, T., Demissew, S., C., and Z.K., Gole, T. W. and D. A. . (2017). Coffee Farming and Climate Change in Ethiopia: Impacts, Forecasts, Resilience and Opportunities. - Summary. *Royal Botanic Gardens, Kew (UK)*, 37.

Mohammedsani Amin. 2017. Influence of harvesting and postharvest processing methods on the quality of Arabica coffee (Coffea arabica L.) in Eastern Ethiopia. *ISABB Journal of Food and Agricultural Sciences*, 7(1), 1–9.

Sintayhu. 2000. Coffee production and marketing in Amhara region Bureau of agriculture and rural development P.O box Bahir Dar, Ethiopia. Field survey report BOA.

Tadess Tolera, Blaineh Legesse, and mohammed Aman. 2019. Determinants of Farmers ' Willingness to Pay for Improved Irrigation Water Use : The Case of Woliso District , Ethiopia. 10(July).

Tadesse Woldmariam. 2015. Coffee production systems in Ethiopia: environment and coffee forest forum, Addis Ababa, Ethiopia.

USAID (United states Agency of International Development). 2012. Ethiopian Coffee Industry Value Chain Analysis Profiling of the Actors, Their Interactions Costs Constraints and

Opportunities Chamois International.

Weldemariam Seifu, G., Belay, S., Mideksa, D., and Solomon, G. 2016. Factors Affecting Coffee (Coffea Arabica L.) Quality in Ethiopia: A Review. *Journal of Multidisciplinary Scientific Research,* 4(1), 27–33.

Workineh Mossie, Tayech Lakew, and Haile Kirstos. 2020. Agricultural technology adoption and its impact on smallholder farmers welfare in Ethiopia. *African Journal of Agricultural Research,* 15(3), 431–445.

Yigzaw, D. (2005). Assessment of cup quality, morphological, biochemical and molecular diversity of C. Arabica L. genotypes of Ethiopia [Ph.D. dissertation]. University Free State.

Annex

Table A1. SWOT analysis of coffee production

Internal analysis of coffee production	
Strengths	**Weaknesses**
• Committed farming community • Favorable weather condition • Attention of the regional government • Positive global reputation of coffee from the region (Zege coffee) • A strong culture of domestic consumption	• Poor pre- and post-harvest management • Lack of coffee extension services • No adequate milling and storage facility • Absence of centralized institution leading the coffee sector at the regional level • Inconsistency of the quality • Inadequate improved seedlings of coffee to overcome drought, disease, and pest
External analysis of coffee production	
Opportunities	**Threats**
• Potential to expand the coffee • Diverse climate condition • Strong regional government interest to promote coffee production • Establishment of cooperatives and union • Availability of NGOs and projects working on coffee development • Potential to establish market linkage	• Climate fluctuation and soil erosion • Fluctuation of international quality standards • Other food crops competing such as khat and other horticultural crops • Disease and pest's occurrence • Absence of strong irrigation access • Fluctuating world coffee prices

Source: Survey (2018)

Fig. A.1. Coffee grower dried their coffee on the ground

Fig. A.2 Coffee grower dried their coffee with the plastic shera.

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Short Communication

Noug Seed Cake Quality and Safety

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Abstract

*Niger (***Guizotia abyssinica***) is an oil-seed crop cultivated in the highland areas of Ethiopia. It is known locally as noug, and its seed is a major source of edible oil. The by-product that remains after extraction of oil from noug seed is called noug seed cake and serves as the main protein supplement and as a moderate source of energy for livestock production in Ethiopia. Noug seed cake has a high concentration of protein which varies from 25.2 to 38%. However, its nutritional contents are highly variable depending on the environmental factors, variety of the seed, extraction methods, etc. In addition, different physical, chemical, and biological factors were reported to affect the nutritional quality and feed safety of noug seed cake. A visible fungal growth is an indicative of spoilage of noug seed cake, and noug seed cake contamination and moulding are the main source of aflatoxin contamination. Some of the common malpractices that cause the accumulation of moulds and aflatoxin production in noug seed cake include storage of noug seed cake indoors in plastic bags or on the floor without bags, in bags stacked without aeration, absence of raised platforms and store for longer time. It is therefore very important to protect mycotoxin production and contamination and keep the feeding value of noug seed cake safe. Furthermore, adulteration of noug seed cake with other types of oil seed cakes is also a common feed safety issue. Prevention of noug seed cake aflatoxin contamination and keeping it safe requires an on-going and thorough sampling and testing program and strict adherence to guidelines since its contamination is critical to animal health and productivity and also to public health. This is because animal feed is an essential channel for transmission of contaminants to the human food chain. A key area of attention is awareness creation using different tools such as media outlets, public gatherings, and social medias about the dangers of aflatoxin B1 contamination of noug seed cake and its adverse effects on animals and humans. It is also especially important to strengthen nationwide surveillance, increase frequent feed inspections to ensure feed safety, and to increase local education and assistance to ensure that animal feeds are harvested and processed correctly, dried completely, and stored properly.*

Keywords: Noug seed cake, feed safety, mould, aflatoxin

Introduction

Niger (*Guizotia abyssinica*) is an oil-seed crop cultivated in the highland areas of Ethiopia and locally known as noug. It is a strong, upright annual herbaceous plant with hairy stems reaching up to a height of 2 m (**Figure 1**). The stems are soft, hollow with a diameter of up to 2 cm, and branched. Its root system is well developed, with a taproot that has many lateral roots, particularly in the upper 5 cm (Getinet & Sharma, 1996; Wayessa, 2007). The color of the plant is pale green, often stained or dotted with purple, and becomes yellow with age. Noug leaves are usually dark green, but the lower ones have a distinct yellow color.

Figure 1. Noug plant

Noug is a variable species adapted to different environments. It can be grown from sea level up to an altitude of 2500 m above sea level where average daily temperatures range from 13°C to 23°C. It requires optimal annual rainfall of about 1000 - 1300 mm, but more than 2000 mm of rainfall depresses its seed yield (Wayessa, 2007). Noug does well on a wide range of soils, from poor sandy soils to heavy black cotton soils, at a pH varying from 5.2 –7.3. Noug can withstand waterlogged areas where there is poor oxygen supply. Noug plants also have some tolerances to soil salinity (Getinet & Sharma, 1996). Noug flowers are capitulate, ranging from 15 to 50 mm in diameter, bright yellow (**Figure 1**) and becoming golden yellow as they mature.

Noug seeds resemble other oil crop seeds such as sunflower seeds. However, noug seed is smaller in size and black in color, angular and elongated (**Figure 2**). The seeds have a thick, adherent seed coat and can be stored for up to a year without deterioration under appropriate dry conditions. Noug seed contains proteins, oil and soluble sugars. In Ethiopia, noug seed is a major source of edible oil. Oil from noug seed is pale yellow, with a nutty taste and a pleasant odor and mostly used for cooking.

Figure 2. Noug seeds

The by-product that remains after extraction of oil from noug seed is called noug seed cake and serves as the main protein supplement and as a moderate source of energy for livestock production (dairy, beef cattle and small ruminants) in Ethiopia. However, different physical, chemical, and biological factors were reported to affect its feed safety and nutritional quality. These factors were also shown to be used to assess the quality and safety of noug seed cake.

Characteristics of Noug Seed Cake

Physical attributes

Noug seed cake (**Figure 3**) is the by-product obtained after the extraction of most of the oil from noug seeds. It is one of the oil seedcakes commonly used as a protein supplement in the diet of different farm animals (dairy, beef cattle and small ruminants). Because of its high nutrient content noug seed cake is increasingly used in Ethiopia for its effect on animal productivity in small- or large-scale livestock production systems. Noug seed cake produced in fine form is preferred as compared to coarse form. It is popular because users think it is easy to mix with other feed ingredients like wheat bran and does not need to be ground for immediate feeding or mixing with other ingredients like wheat bran.

Users assess the quality of noug seed cake by visual observation. Fresh noug seed cake is shiny but turns greyish or dull as it is exposed to moisture. Fresh noug seed cake has a pleasant odor, but it turns rancid as it ages, especially under poor storage conditions. In addition, visible mould (fungal growth) is indicative of spoilage of noug seed cake. Recent studies have identified noug seed cake contamination and moulding as the main source of Aflatoxin contamination in feeds. A level of contamination of Aflatoxin B1 up to 290-397 µg/kg has been detected in noug seed cake samples collected from farms and feed millers around

Addis Ababa (Gizachew *et al*., 2016). It is, therefore, important to recognize the characteristics of a contaminated noug seed cake to avoid feeding aflatoxin contaminated diets to animals.

Figure 3. Noug seed cake

Chemical composition

Noug seed cake has a high concentration of protein which varies from 25.2 to 38%, with most values lying between 30 and 35%, as well as non-starch polysaccharides, fat content varying from 2.1 to 12.6% with an average of 8.4% and a metabolizable energy value of 2.37 Mcal/kg DM (**Table 1**). However, as indicated in Table 1 the nutritional contents of noug seed cake are highly variable mainly due to environmental factors, variety of the seed, extraction methods, etc. For instance, noug seed cake produced by mechanical extraction of the oil from the seeds is reported to contain more fat (7-14% DM) than those produced by solvent (chemical) extraction leaving only around 1-2% in the cake but with a higher NDF content (31.6 - 51.8 %). Noug seed cake also has a moderate *in vitro* DM digestibility of 61.7 - 67.3% (**Table 1**).

Table 1. Chemical and nutritional value of noug seed cake

Nutritional parameter	Value	References
Dry matter (g/Kg)	91.9 – 92.3	Gashaw & Defar, 2017; Feyissa *et al*., 2015; Mekuriaw *et al*., 2018; Gebermariam *et al*., 2016; Yigzaw *et al*., 2019; Mengistu et al., 2020
CP (%)	25.2 – 38.0	Tolera, *2008*; Mekuriaw *et al*., 2018; Gebermariam *et al*., 2016; Yigzaw *et al*., 2019; Mengistu *et al*., 2020
NDF (%)	31.6 – 51.8	Gashaw & Defar, 2017; Mekuriaw *et al*., 2018; Gebermariam *et al*., 2016; Yigzaw *et al*., 2019; Mengistu *et al*., 2020
ADF (%)	22.7 – 35.6	Gashaw & Defar, 2017; Feyissa *et al*., 2015; Mekuriaw *et al*., 2018; Gebermariam *et al*., 2016; Yigzaw *et al*., 2019; Mengistu *et al*., 2020
Fat (%)	2.1 – 12.6	Tolera, 2008; Feyissa *et al*., 2015
DM digestibility (%)	61.7 - 67.3	Tolera, 2008; Mekuriaw *et al*., 2018
ME (Mcal/Kg DM)	2.37	Tolera, 2008

Biological features

Noug seed cake needs proper storage and transportation. The cake should be aerated when stored, as its shelf life is shortened when it becomes too damp. A study by Gizachew *et al*., (2016) suggest that the optimal storage conditions for avoiding growth of aflatoxin producing fungi on noug seed cakes would be a dry well aerated room with average room temperature less than 20°C and equilibrium relative humidity of 86%.

Common storage malpractices that cause the accumulation of moulds and aflatoxin production in noug seed cake include storage of noug seed cake indoors in plastic bags or on the floor without bags, in bags stacked without aeration, absence of raised platforms (**Figure 4**), storage for more than 3 months, etc. These storage conditions can cause heating and shorten its shelf-life. Noug seed cake should be packed in moisture-proof bags or in similar suitable moisture-proof clean and pathogen/contaminant-free containers. Moisture contamination during transportation or storage can allow fungal growth which can predispose noug seed cake to contamination with mycotoxins, particularly aflatoxins. Mycotoxins are poisonous chemical compounds produced by fungus or moulds. Those mycotoxins that occur in feedstuffs have great significance in the health and productivity of livestock. Since they are produced by fungi, mycotoxins can be associated with diseased or mouldy crops, although they can also be present in visually healthy crops and grains.

Figure 4. Poor storage conditions that are favorable to the accumulation of moulds and production of aflatoxins

Mycotoxin Production and Safety of Noug Seed Cake

Factors that affect mycotoxin production and contamination can be categorized as physical, chemical, and biological factors. Physical factors include environmental conditions favorable for fungal colonization and mycotoxin production such as temperature, relative humidity, and insect infestation. In general, moulds can grow at a temperature range of 10 - 40°C, under high moisture, and oxygen (above 20% dry matter and above 70% equilibrium relative humidity), and a pH range of 4.0 - 8.0 (Negash, 2020). Because feedstuffs can be contaminated during pre- or post-harvest, control of additional mould growth and mycotoxin formation is dependent on storage management such as poor air circulation. After harvest, temperature, moisture content, and physical damage (by insects, rodents) and/or the stress of hot dry conditions are the major factors influencing mycotoxin contamination of noug seeds. Chemical factors include the use of fungicides and/or fertilizers. Biological factors are based on the interaction between the colonizing toxigenic fungal species and substrate. In addition, like chemical properties, the biological quality of noug seed cake is affected by type of oil extraction method and adulteration.

Aflatoxin in animal feedstuffs has been a growing concern in the dairy industry due to the prevalence of aflatoxin M1 (hydroxylated form of AFB1) in dairy products from animals consuming AFB1-contaminated feed. Concentrate animal feedstuffs can have elevated levels of mycotoxin contamination. For instance, the highest level of aflatoxin B1 contamination detected in noug seed cake was 419 μg/kg (De Boevre *et al*., 2012). In fact, noug seed cake has been found to be the main source of aflatoxin contamination among animal feeds by different studies (Tola and Kebede, 2016). It is important to note, however, that there is a difference between aflatoxin B1 which is the aflatoxin in feeds, with aflatoxin M1 which is the one excreted in the milk of a cow that consumed a feed contaminated with aflatoxin B1 (Gizachew *et al*., 2016). Aflatoxin M1 is considered a detoxified by-product of Aflatoxin B1 and, therefore, has only 10% of the toxicity and mutagenicity of Aflatoxin B1 (Wogan and Paglialunga, 1974).

In addition, adulteration of noug seed cake with other types of oil seed cakes is also a common feed safety issue. In Ethiopia it is quite common that diverse types of oil seed cakes are mixed for livestock feeding. For instance, noug seed cake can be adulterated with rapeseed, mustard seed, or safflower seed during extraction and yet the mixture can be sold as pure noug seed cake. When adulterated with rapeseed the mixture often reduces DM intake, weight gain and may cause health problems for animals because of the toxic glucosinolates (and their derivative) in rapeseed that causes physiological changes in the thyroid gland, liver, spleen, and other organs (Lajolo *et al*., 1991; Knutsen *et al*., 2016).

Control and Prevention of Mould Growth in Noug Seed Cake

Animal feed is an essential channel for transmission of contaminants to the human food chain; therefore, hazards present in animal feeds pose a threat to human health. Prevention of mycotoxin contamination of feed, particularly noug, is critical to animal health and productivity and public health. A combination of technology solutions, effective regulations, and standards could bring about mitigation and prevention of aflatoxin contamination of feeds. The latter includes prevention of mould or fungus growth on feedstuffs, decontamination of mycotoxin contaminated feeds as a secondary strategy, and continuous surveillance for mycotoxins in animal feedstuffs. Prevention can be achieved by following strict hygienic safety measures during harvesting, threshing, storage, and processing of noug seeds. In addition, proper drying, and storage of seeds and noug seed cake are effective tools for reducing mould growth and mycotoxin production.

Decontamination of mycotoxin can be attained by physical, chemical, and biological techniques. Mycotoxin binders mainly used as feed additives could be a reliable option for sequestering mycotoxin in feeds and preventing their absorption after ingestion. Adsorbents/binders that are usually added to compound animal feed have been confirmed to reduce mycotoxins, and examples include naturally occurring specific clays (e.g., bentonite) as well as activated charcoal, and certain yeasts, bacteria, and enzymes (Ogunade *et al*., 2018; Vila-Donat *et al*., 2018). Physical approaches include sorting out contaminated grains and de-hulling. Chemical approaches include applying fungicides that inhibit mould growth, and biological approaches depend on the development of atoxigenic fungi that compete with toxigenic fungi in the environment.

Preventing noug seed cake aflatoxin contamination requires an on-going and thorough sampling and testing program and strict adherence to the following guidelines:

- Purchase noug seed cake from reputable persons and companies with a proven record of properly monitoring the quality and safety of their feed products.
- Do not buy poor quality noug seed cake as it is likely to have been adulterated.
- Noug seed cake should be packed in moisture proof bags or in similar suitable moisture-proof clean and pathogen/contaminant-free containers.
- Store noug seed cake at proper moisture levels (70% equilibrium relative humidity), temperature of 10 - 40°C with adequate aeration for no longer than 3 months.
- Feed processors and sellers should develop a systematic inspection and clean-up program to keep bins, delivery trucks and other equipment free of adhering or caked feed ingredients.
- Minimize dust accumulation in milling and mixing areas.
- Keep all feed equipment free of caked feed.
- Check feed storage bins for leaks.
- Implement effective rodent and insect control programs in storage areas.

Summary

Adverse animal health can result from consumption of aflatoxin-contaminated feeds, particularly noug seed cake and handling of such feeds by humans may pose additional health risks. However, risks of cancer from human consumption of milk from cows fed aflatoxin-contaminated noug seed cake are likely overstated as recent findings have challenged the notion that milk aflatoxin M1 is carcinogenic (Turna *et al*., 2022). A key area of need is awareness creation about the dangers of aflatoxin B1 contamination of feed and its adverse effects on animals and humans. It is also especially important to strengthen nationwide surveillance, increase feed inspections to ensure feed safety, and to increase local education and assistance to ensure that animal feeds are harvested correctly, dried completely, and stored properly. These could be achieved through awareness creation using tools such as media outlets, public gatherings, and social learning. However, equal attention should be paid to correcting the myth that milk from different places including Ethiopia is unsafe due to aflatoxin contamination (typically due to consumption of aflatoxin-contaminated noug seed cake), given the recent publication (Turna *et al*., 2022) showing that US FDA and EU standards for safe levels of aflatoxin in milk are probably misleading.

References

De Boevre, M., Di Mavungu, J. D., Landschoot, S., Audenaert, K., Eeckhout, M., Maene, P., Haesaert, G., & De Saeger, S. 2012. Natural occurrence of mycotoxins and their masked forms in food and feed products. World Mycotoxin J. 5:207-219.

Feyissa, F., Kitaw, G., & Assefa, A. 2015. Nutritional qualities of agro-industrial by-products and local supplementary feeds for dairy cattle feeding. Ethi. J. Agric. Sci. 26(1):13-26.

Gashaw, M., & Defar, G. 2017. Livestock feed resources, nutritional value, and their implication on animal productivity in the mixed farming system in Gasera and Ginnir districts, Bale zone, Ethiopia. Int. J. Livest. Prod. 8(2):12-23.

Getinet, A., & Sharma, S. M. 1996. Niger (*Guizotia abyssinica,* L. f.) Cass. Promoting the conservation and use of underutilized and neglected crops. 5. Institute of Plant Genetics and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute, Rome.

Gizachew, D., Szonyi, B., Tegegne, A., Hanson, J., & Grace, D. 2016. Aflatoxin contamination of milk & dairy feeds in the greater Addis Ababa milk shed, Ethiopia. Food Control. 59:773-779.

Knutsen, H. K., Alexander, J., Barregård, L., Bignami, M., Brüschweiler, B., ... & Vleminckx, C. 2016. Erucic acid in feed and food. EFSA J.

Lajolo, F. M., Marquez, U. M. L., Filisetti-Cozzi, T. M. C. C, & Ian McGregor, D. 1991. Chemical composition and toxic compounds in rapeseed (*Brassica napus*, L.) cultivars grown in Brazil. J. Agric. Food Chem. 39(11):1933-1937.

Mekuriaw, S., Hunegnaw, B., Aamane, A., Molla, L., Yitayew, A., & Yeheyis, L. 2018. Tree lucerne (*Chamaecytisus palmensis*) leaves substitution of noug (*Guizotia abyssinica*) seed cake as protein supplementation on growth performance of Washera sheep in Awi zone, Amhara region, Ethiopia. In: Proceeding of the 10th Annual Regional Conference on Completed Livestock Research Activities. pp. 13-16.

Mengistu, G., Assefa, G., & Tilahun, S. 2020. Noug seed (*Guizotia abyssinica*) cake substituted with dried mulberry (*Morus indica*) and *Vernonia amygdalina* mixed leaves' meal on growth performances of Bonga sheep at Teppi, Ethiopia. J. Nutr. Metab. 5:1-10.

Negash, D. 2020. Animal feed safety: Cases and approaches to identify the contaminants and toxins. ANAFS-176.

Ogunade, I. M., Martinez-Tuppia, C., Queiroz, O. C. M., Jiang, Y., Drouin, P., Wu, F., Vyas, D., & Adesogan, A. T. 2018. Silage review: Mycotoxins in silage: Occurrence, effects, prevention, and mitigation. J. Dairy Sci. 101(5):4034-4059.

Tola, M. & Kebede B. 2016. Occurrence, importance and control of mycotoxins: A review. Cogent Food Agric. 2:1191103.

Tolera, A. 2008. Feed resources and feeding management: A manual for feedlot operators and development workers (Ethiopia Sanitary and Phyto-sanitary Standards and Livestock and Meat Marketing Program [SPS-LMM]). United States Agency for International Development.

Turna, N. S., Havelaar, A., Adesogan, A., & Wu, F. 2022. Aflatoxin M1 in milk does not contribute substantially to global liver cancer incidence. Am. J. Clin. Nutr. 115:1473-1480.

Vila-Donat, P., Marín, S., Sanchis, V., & Ramos, A. J. 2018. A review of the mycotoxin adsorbing agents, with an emphasis on their multi-binding capacity, for animal feed decontamination. Food Chem. Toxicol. 114:246-259.

Wayessa, B. 2007. *Guizotia abyssinica* (L.f.) Cass. Record from PROTA4U. van der Vossen, H.A.M. and Mkamilo, G.S. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l’Afrique tropicale), Wageningen, The Netherlands.

Wogan, G. N., & Paglialunga, S. 1974. Carcinogenicity of synthetic aflatoxin M1 in rats. Food Cosmetics Toxicol. 12(3):381-384.

Yigzaw, D., Berhanu, A., & Asnakew, A. 2019. Effect of different levels of lentil (*Lens culinaries*) hull and noug seed (*Guizotia abyssinica*) cake mixture supplementation on feed intake, digestibility and body weight change of Farta sheep fed hay as basal diet. Acad. Res. J. Agri. Sci. Res. 7(2):75-86.

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Book

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