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Unlocking the potential of smallholder dairy farm: Evidence from the central highland of Ethiopia

Abraham Abera Feyissa [a,*], Feyera Senbeta [a,b], Adugna Tolera [c], Dawit Diriba Guta [a,d]

[a] College of Development Studies, Center for Environment and Development, Addis Ababa University, Ethiopia
[b] Department of Biological Sciences Faculty of Sciences, University of Agriculture and Natural Resources, Gaborone, Botswana
[c] School of Animal and Range Sciences, Hawassa University, Hawassa, Ethiopia
[d] Department of Forest Management, University of British Colombia, Canada

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ABSTRACT

Sustainable livestock farming practices have the potential to improve productivity and high income, reduce greenhouse gases, and improve household food security. Despite previous efforts to disseminate these technologies, the rate of adoption has remained very low in Ethiopia. In this study, we investigate the determinants of adoption and the impact of improved dairy farming practices (IDFP), which include improved breed, improved feed, and improved feeding conditions, on household food security in the central highland of Ethiopia.
Methods: A multi-stage stratified random sampling technique was used to select 480 smallholder farmers from four districts. The study employed principal component analysis (PCA) to group IDFPs, and the endogenous switching regression model (MESR) was used to examine household food security status.
Results: Our findings showed that IDFP adoption had a significant and positive impact on per capita food consumption and increases the likelihood of smallholder farmers being food secure compared to non-adopters. The adoption of integrated IDFP had a greater impact on household food security when smallholder farmers used a package that incorporates improved breeds, feeds, and feeding systems ($B_1F_1S_1$). The implementation of this package increased food security by 31% in terms of household food consumption score (HFCS) and 26% in terms of household diet diversity score (HDDS). Additionally, the size of livestock holdings, off-farm income, extension services, and milk collection centers all influenced the adoption decision of this package.
Conclusions: It has been confirmed that improving dairy farming practices for sustainable development can significantly contribute to the food security of smallholder farmers when used in combination. Interventions that address access to farm resources, the supply chain for technological inputs and services, and output markets may assist in the adoption of dairy technologies.

1. Introduction

Global livestock production is at a crossroads in terms of adapting to climate change and reducing greenhouse gas emissions while ensuring sustainable development goals [1]. To achieve food security, reduce poverty, and address climate change without depleting natural resources, livestock production must undergo a major transformation in the coming decades. The sector is a significant source of livelihood and employment opportunities for millions of smallholder farmers around the world. For instance, in sub-Saharan Africa (SSA), livestock is a primary source of livelihood for many low-income rural farmers [2]. Livestock is an integral part of agriculture in Ethiopia, accounting for about 45% of the total value of agricultural production and supporting the livelihoods of a large share of the population [3]. About 70% of the Ethiopian population rear livestock, including many poor people, for their source of livelihood [4]. On the other hand, livestock supply chains are significant sources of global greenhouse gas (GHG) emissions, accounting for up to 14% of total GHG emissions [5]. In addition to land and forest degradation effects [6], animal products are often less efficient at utilizing nutrients and have a large water footprint than other foods [7,8].

The growing demand for livestock products as a result of population growth and diet changes will allow smallholder farmers (SHFs) to improve animal productivity by improving breeds, improving feed and

* Corresponding author.Addis Ababa, P.O .box 1176, Ethiopia.
E-mail addresses: dhiro2009@gmail.com, dhiro2009@gmail.com (A.A. Feyissa), feyeras@yahoo.com (F. Senbeta), adugnatolera3@gmail.com (A. Tolera), davdiriba@ahoo.com (D.D. Guta).

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feeding conditions, improving animal health services, and using animals as a vehicle to escape poverty. Smallholder dairy farming is one of the leading agricultural industries in Ethiopia. A sector is a viable option for improving farmers' household income and food security [4,9]. Ethiopia possesses one of the most diverse and distinct livestock production systems in Africa. About 65 million cattle are estimated to be found and kept under different farming systems and production objectives [3]. Despite Ethiopia's large cattle population and favorable development environment, per-animal productivity is significantly lower than its potential owing to inadequate feed quality and quantity, the low genetic potential of indigenous breeds, poor animal health services, and poor management practices [10,11]. The national average daily milk yield per cow is 1.49 L [3], and per-capita consumption of beef and cow milk is 6.5 kg and 43.3 L per year, respectively [4], lower than the per-capital consumption of most African countries [12]. As a result, Ethiopia is a net importer of dairy products to satisfy the increasing demand for dairy products [12].

Recently, sustainable intensification of the agricultural system has been proposed as a strategy to increase agricultural productivity and resource efficiency [13,14]. In light of this, several technologies that involve the use of improved technologies in breeding (e.g., artificial insemination, selection, and cross-breeding), feeding (e.g., planting improved forage and fodder trees and using agro-industrial by-products), and management (e.g., vaccination and anti-parasitic medicaments) have been promoted [15,16]. These improved dairy technologies can be viewed as sustainable strategies for increasing animal productivity, productive capacity, and farmers' food security, thereby improving smallholder farmers' resilience and adaptation to climate variability and change. Furthermore, improved dairy farming practices are important in reducing greenhouse gas emissions and degrading ecosystem services [5,17]. Despite the multiple benefits of improved dairy technologies and deliberate efforts of the government and development partners to encourage smallholder farmers, the uptake rate of dairy technologies is very low and varies significantly across the country [[15,16,18]].

While numerous proven agricultural technologies, products, and models have been successfully piloted, scaling them up through expansion, adoption, and replication has proved challenging, particularly in the livestock sector due to incompatibility with local farming [18,19]. Understanding why smallholder farmers do not adopt improved technologies and what motivates people to select a specific package from the options is a critical area of inquiry and policy development. According to Loevinsohn et al. [20], the dynamic interaction between a technology's characteristics and varying conditions and circumstances influences farmers' decisions about whether and how to adopt a new technology. Individual decisions often result from comparing the uncertain benefits and costs of adopting a new technology [21]. Similarly, smallholder farmers often have varying access to basic services, information, and basic knowledge of the market system, all of which limit their ability to invest, expand their market surplus, and add value to their produce [22,23].

Several studies have been conducted to evaluate the effects of improved dairy technology on farmers' food security and the factors that determine adoption [24–26]. Some of these studies, however, either ignored the scale of technology adoption, which is potentially inter-related and may provide better outcomes when adopted jointly [25,27]; or the analytical model failed to account for differences in welfare outcomes between adopters and non-adopters of improved dairy technologies caused by unobservable differences among smallholder farmers [24,28]. Ignoring the unobservable difference between adopters and non-adopter smallholder farmers could lead to wrong conclusions [29]. Furthermore, using logit or probit models to assess factors influencing the adoption of dairy technology fails to control for unobserved heterogeneity effects on farmers' technology adoption decisions. When subjects in non-experimental studies cannot be randomly assigned to "treatment" and "control" groups, these regression methods may be less effective in dealing with the sample selection problem [30,31]. Hence, we use a multinomial endogenous switching regression approach to control for selection bias while considering the impact of IDFPs on food security.

The present study attempts to fill this knowledge gap by using an endogenous switching regression model to identify factors that influence the choices of improved dairy technologies and investigate the impact of improved dairy technologies on farmers' food status.

2. Literature review

2.1. Dairy farming system and technology use in Ethiopia

Recent data estimates 65 million cattle, of which 97.76% are local breeds with low genetic potential for milk production, and the remaining are hybrid and exotic [3]. Approximately 97% of cattle milk is produced by indigenous cattle, while 3% is produced by pure exotics and crossbreds [12]. The vast majority of the cattle are kept by smallholder farmers who raise low-productivity indigenous breeds and feed them with natural pastures and crop residues. They also follow an underdeveloped market for inputs and outputs [10,11]. By-products from the flour and oil industries, as well as brewery residues, are the main supplementary feeds. Smallholder farmers who keep improved dairy cows also cultivate improved forage crops such as elephant grass, oats, vetch, and alfalfa to supplement grazing [[10,11,32]].

In Ethiopia, three smallholder dairy farming systems (urban, peri-urban, and rural) are identified and characterized based on agroecology, production objectives, sources of feed and feeding system, breeds and genotypes kept, and integration with crop production [10,11]. Dairy farming systems distinguish between breeds and genotypes kept and the feeding conditions [10]. Urban and peri-urban smallholder farming systems are more likely to keep medium-high grade cows with exotic blood and use stall feeding and semi-grazing. Rural smallholder farmers keep low-grade cross-bred cows with exotic blood levels and multi-purpose local zebu breeds [10].

In response to the growing demand for animal-sourced foods, SHFs are anticipated to make investments that increase production and productivity [12]. Various dairy technology packages have been identified and introduced to optimize the production and reproduction performance of both local and cross-bred dairy animals. These improved packages, which focus on breeding, feed and feeding management, and improved husbandry, can increase animal productivity while also improving smallholder livelihoods, household income, and improving nutrition. Despite many years of effort, smallholders do not use these technologies widely, and dairy cow productivity remains low [16,33].

We identified and classified the existing improved dairy farming practices based on their relative economic and environmental importance, as well as their interdependence and complementarity of practices. The technologies were categorized using principal component analysis into three categories (IDFPs): improved breed, improved feed and forage, and improved feeding system.

Improved Breeds (cross and highbred): Increased milk production is one of the leading dairy breeding goals worldwide [34]. However, new breeding goals, particularly in milk composition, have recently been identified in response to the demands of a healthier human diet [33]. An efficient, systematic, and operational breeding strategy is necessary to improve the dairy sector and increase milk production. Initial dairy development efforts focused on introducing high-yielding dairy cattle (Friesian and Jersey) to the highlands and around major urban areas, where they were crossed with indigenous breeds to improve the production potential of local breeds [35–37]. Crossbreds have longer lactation periods, and shorter calving intervals and calves are younger than indigenous breeds [38]. This has encouraged farmers to adopt improved breeds, resulting in higher milk yields and economic returns. Hence, SHFs with a cross or highbred dairy cows are considered an indicator of dairy technology adopters.

Improved feed and forage utilization: Feed is the primary input in milk production, and the performance of the dairy industry is primarily hampered by low quality and quantity, as well as seasonal fluctuations of feed resources in the central highlands [32,39]. Without the adoption of improved feed and forage production for livestock-rearing households in the highlands of Ethiopia, grazing land shortages and degradation will have devastating effects on food security and the environment [40]. Improved forage, feed conservation practices, and industrial by-products have been promoted to alleviate the shortage of livestock feed. Using improved feed and forage by SHFs is considered an adopter of improved practices.

Stall feeding/zero-grazing (ZG): this management practice is believed to have economic and environmental importance compared to extensive grazing systems. It improves animal performance and fodder productivity and minimizes land degradation, disease prevention, and manure management [25,41]. Recent studies in Ethiopia's highlands indicated that farmers benefit by earning a higher income from milk and meat and having higher traction power under ZG than traditional grazing [25,42]. Hence, the use of stall feeding by SHFs is considered an adoption of improved practices.

3. Materials and methods

3.1. Description of the study area

The study was conducted in the Salale milk shed in the central highlands of Ethiopia (Fig. 1). The Salale milk shed encompasses a large area, stretching from Suluta, Addis Ababa's outskirts, to Kuyu districts, heading north along the road to Bahirdar, the capital city of Amahara regional state. It is the major supplier to Ethiopia's most affluent urban market, Addis Abeba, the capital city of Ethiopia. The study area lies at 38° 07′ 60″ E longitude and 9° 40′ 60″ N latitude and has an elevation of 1250 to greater than 3000 m above sea level [43,44]. The average annual rainfall in the area is 1200 mm, with average minimum and maximum temperatures of 6 °C and 21 °C, respectively [39]. Livestock, particularly dairy farming, is the dominant agricultural enterprise and source of income in the Salale highlands [43]. The subsistence mixed crop-livestock farming system dominates the smallholder agricultural production system in the study area [43]. Smallholder dairy farms dominate the dairy industry in the area [39], and three smallholder dairy farming systems (urban, peri-urban and rural) were identified and characterized by Tegegn et al. [10], and Gizawu et al. [11].

The study area was selected due to its high milk production potential and the importance of dairy farms in the local economy as a subsistent agriculture. The Selale milk shed, the leading dairy development in the country, and is known for having a long history of dairy development ever since the introduction of modern dairy cows some 60 years ago [11, 45]. Besides, the region/area is known to have suitable conditions for fodder production and the use of agricultural by-products. Farmers have a high percentage of specialized dairy breeds and better access to artificial insemination [3,45]. CSA's [3] annual report shows that the region/area holds the largest cross-bred dairy cow population.

3.2. Sampling and data collection

This study employed a multi-stage stratified random sampling technique to select SHFs. The first four districts (Sululta, Wuchale, Girar Jarso, and Degem) were purposively selected from Salale milk shed to represent the mixed crop-livestock farming system and suitability for dairy farming. Four kebeles (the smallest administrative units in Ethiopia) were purposively selected from each district by considering dairy cattle potential and road accessibility. In each kebele, SHFs were

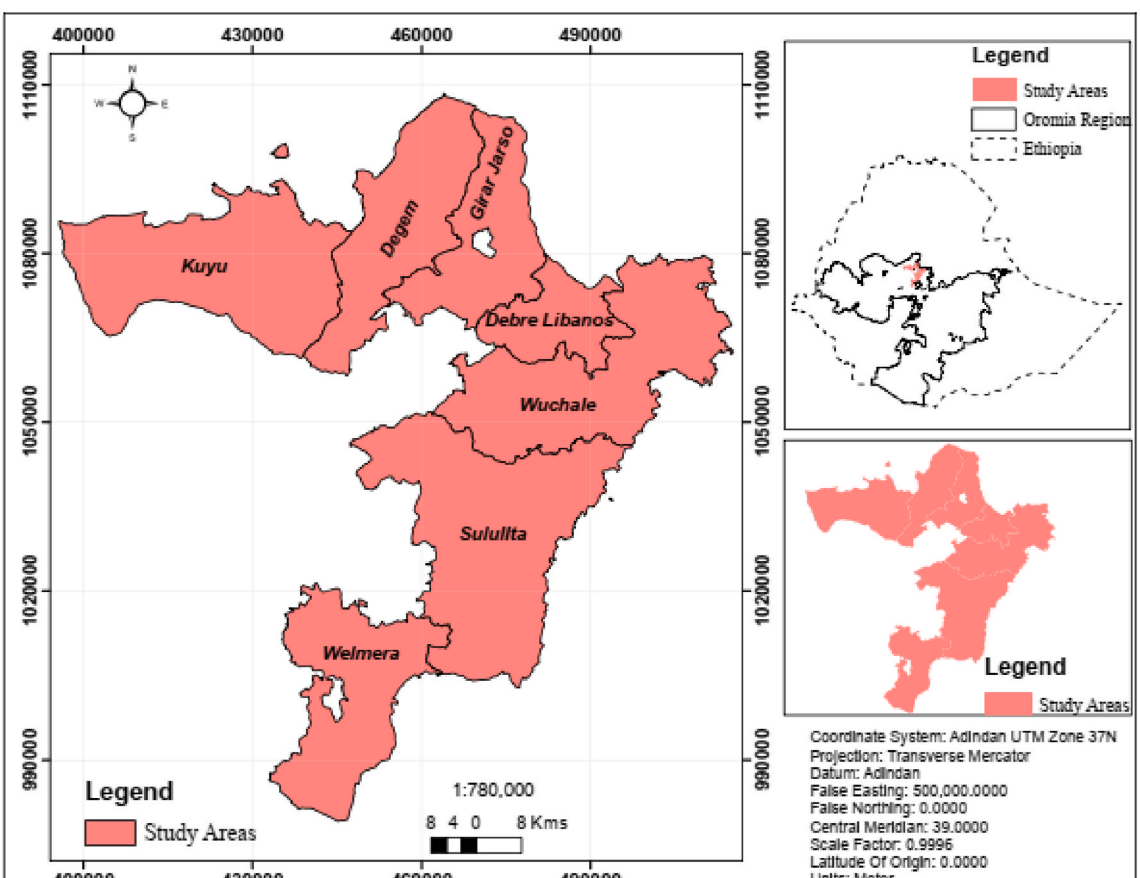

Fig. 1. Location map of the study area.

stratified into adopters and non-adopters of improved farming practices based on dairy technology adoption indices, such as improved breed, improved feeds and forage production, and feeding conditions (stall feeding, free grazing) promoted through the extension system.

A total of 480 SHFs were randomly selected to represent adopters and non-adopters based on [46]. A survey questionnaire was designed to collect data on farm household characteristics, farm input-output, feed sources, feeding practices, and productive and reproductive performance. Three enumerators, experts in livestock production, were selected from each district and were given orientation and refresher training on the household survey. Data collection was held between July 2020 and February 2021. The first author supervised the survey. The survey data was triangulated using a transect walk and group discussion.

3.3. Analytical framework

This study used the methodology of [47,45], which used a multinomial endogenous switching regression model to assess how individual and alternative combinations of improved dairy farming practices (IDFP) affect household food security. Specifically, this study examines the impacts of multiple IDFPs, such as improved breeding, improved feeds and forage, and feeding systems, on farmers' livelihoods.

First, Principal Component analysis was employed to group improved dairy farming practices into heterogeneous principal clusters. The components were rotated using the orthogonal rotation (varimax method) [48] so that a smaller number of highly correlated practices were put under each component for easy interpretation and a generalization about a group. Principal Component Analysis is a type of factor analysis that can reduce dimensions or uncover latent variables by extracting linear combinations that best describe the covariance among all elements [49].

In the model below, IDFP practices were grouped based on PCA with iteration and varimax rotation [50].

$$Y_1 = a_{11}x_{12} + a_{12}x_{12} + \ldots + a_{1n}x_n$$

$$Y_j = a_{j1}x_{j1} + a_{j2}x_2 + \ldots + a_{jn}x_n \tag{1}$$

where $Y_1, \ldots Y_j$ = principal components which are uncorrelated, a_1-a_n = correlation coefficient, $x_1, \ldots x_j$ factors influencing choices of a particular strategy. The output of previous studies guided the selection of these practices in the study area [25,51].

Multinomial endogenous switching regression (MESR) was used to model determinants of IDFPs' adoption and effects of improved practices after grouping them into "n" heterogeneous groups. Then household food consumption scores (HFCS) and household dietary diversity scores (HDDS) were used to measure a household's food security status.

Modeling the adoption of multiple technologies

In a multiple-adoption framework, the adoption of a combination of IDFPs may not be random. Decisions about adoption or non-adoption are likely influenced by unobservable characteristics that are correlated with the outcomes of interest rather than observable characteristics [47]. The MESR model framework has the advantage of evaluating combinations and individual practices while controlling for self-selection bias caused by both observed and unobserved heterogeneity and the interactions between choices of combinations of practices [52,51]. This can be done simultaneously in two steps. In the first stage, farmers' choices of individual and combined IDFPs are modeled using a multinomial logit selection model while recognizing their inter-relationships. In the second stage, the MESR econometric model is used to investigate the effect of different IDFP practices on food security status.

Stage 1: A multinomial adoption selection model

A multinomial logistic model was used to assess the determinants of the choice of IDFP practices. The model is the analytical approach that is commonly used in an adoption decision study involving multiple choices [49,53]. This method can also be used to examine crop and livestock [53] choices as a means of adapting to the negative effects of climate change. The MNL has the advantage of allowing the analysis of decisions across more than two categories and determining choice probabilities for different categories [54,55], as well as being computationally simple [55].

Farmers are assumed to maximize their food security status, Y_i by comparing the revenue provided by "M" alternative IDFPs. The requirement for farmer *i* to choose any strategy *j* over other alternatives *M* is that Yij > YiM M ≠ j, that is, *j* provides higher expected food security than any other strategy. Y_{ij}^* is a latent variable that represents an expected food security level influenced by observed household characteristics, and unobserved characteristics expressed as follows:

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

Where ***Xi*** captures the observed exogenous variables (household and institutional characteristics), while the error term ϵij captures unobserved characteristics. Covariate vector X_i is assumed to be uncorrelated with the unobserved stochastic component ε_{ij}, so $E(\varepsilon_{ij}/X_i) = 0$, with error terms ε_{ij} assumed to be similarly Gumbel distributed and independent, under the independent irrelevant alternatives hypothesis (IIA).

The selection model (2) leads to a multinomial logit model (McFadden, 1973) where the probability of choosing strategy *j* (p_{ij}) is:

$$p_{ij} = p\left(\varepsilon_{ij} < 0|x_i\right) = \frac{\exp\left(X_i\beta_j\right)}{\sum_{k=1}^{j} \exp\left(X_i\beta_m\right)} \tag{3}$$

Stage 2: multinomial endogenous switching regression model

To determine the impact of a combination of improved livestock farming practices on the outcome variable (food security), endogenous switching regression (ESR) is used by applying the selection bias correction model [56]. Farm households face a total of "M" regimes j = 1 being the reference category (non-adopter). The food security status equation for each possible regime j for j = 1 … 6 is defined as follows:

$$\begin{cases} Regime\ 1\ Q_{i1} = z_i\alpha_1 + \mu_{i1}\ if\ i = 1 \\ \quad\quad\quad . \\ \quad\quad\quad . \quad\quad\quad j = 2, \ldots, 6 \\ \quad\quad\quad . \\ Regime\ 2\ Q_{ij} = z_i\alpha_j + \mu_{ij}\ if\ i = j \end{cases} \tag{4}$$

Where $Q_{ij}{'}s$ represents the food security status, Z_i represents a set of exogenous variables (household xis, resources and market access, and institutional variables), and the *i*th farmer in regime *j,* and the error terms μ_{ij}'s are distributed with

$E\ (\mu_{ij}|x, z) = 0\ and\ var\ (\mu_{ij}|x, z) = \delta_j^2$. Q_{ij} is observed if, and only if, IDFP practices j are used, which occurs when $Q_{ij}^* > {}^{max}_{M\neq 1}(Y_{im})$, if the error term in Eqs (3) and (4) are not independent, the OLS estimates for Eq (4) be biased. Consistent estimation of α_j requires the inclusion of the selection correction terms of the choices in Eq. (3). MESR assumes the following linearity assumption:

$E(\mu_{ij}|\varepsilon_{i1} \ldots \varepsilon_{ij}) = \delta j \sum_{m\neq j}^{r} r_j(\varepsilon_{im} - E(\varepsilon_{im}))$. By construction, the correlation between the error terms in (3) and (4) will be zero.

Using the above assumption, Eq. (3) can be expressed as follows:

$$\begin{cases} Regime\ 1\ Q_{i1} = z_i\alpha_1 + \delta_1\Lambda_1 + w_{i1}\ if\ i = 1, \\ \quad\quad\quad . \\ \quad\quad\quad . \\ \quad\quad\quad . \\ Regime\ 2\ Q_{ij} = z_i\alpha_j + \delta_j\Lambda_j + w_{ij}\ if\ i = j \end{cases} \tag{5}$$

δ_j is the covariance between $\mathcal{E}$'s and μ's, while Λ_j is the inverse Mills ratio computed from the estimated probabilities in Eq. (5) as follows:

$$\Lambda_j \sum_{m \neq j}^{j} p_j \left[\frac{p_{mi} \ln (p_{im})}{1 - p_{im}} + \ln (p_{ij}) \right] \tag{6}$$

P in the above equation represents the correlation coefficient of $\mathcal{E}$'s and μ's, while w_{ij} are error terms with an expected value of zero. In the multinomial choice setting, there were j-1 selection correction terms, one for each alternative IDF practice. The standard errors in Eq. (5) are bootstrapped to account for the heteroskedasticity arising from the generated regressor given by λ_j.

Estimation of average treatment effects

At this stage, a counterfactual analysis is used to examine average treatment effects (ATT) by comparing the expected outcomes of adopters with and without the adoption of a particular IDFP package. ATT in the actual and counterfactual scenarios is determined as follows [49,53]:

Food security status with adoption/usage

$$E(Q_{i2}|i=2) = z_i\alpha_2 + \delta_2\Lambda_2 \tag{7a}$$

$$E(Q_{ij}|i=j) = z_i\alpha_1 + \delta_1\Lambda_j \tag{7b}$$

Food security status without adoption (counterfactual)

$$E(Q_{i1}|i=2) = z_i\alpha_1 + \delta_1\Lambda_2 \tag{8a}$$

$$E(Q_{i1}|i=j) = z_i\alpha_1 + \delta_1\Lambda_j \tag{8b}$$

ATT can be defined as the difference between (7a) and (8a) which is given by:

$$\text{ATT} = E(Q_{i2}|i=2) - E(Q_{i1}|i=2)$$

$$= z_i(\alpha_2 - \alpha_1) + \Lambda_2(\delta_2 - \delta_1)$$

Measurement of food security

WFP [57] developed the Household Food Consumption Score (HFCS) and Household Dietary Diversity Scores (HDDS), which are widely used to measure farmers' food security status [45]. HFCS is a weighted score based on dietary diversity, food frequency, and the nutritional importance of food groups consumed. HFCS and HDDS are similar, with slight differences in the food cluster components. HDDS considers food items consumed within the last 24 h, while HFCS takes into account food items consumed within the last 7 days.

Empirical specification

The model specification and selection of explanatory variables were based on researchers' knowledge of a review of theoretical work and previous similar empirical adoption and impact studies [[25,45,58]]. In this regard, 16 explanatory variables that are believed to influence and explain farmer technology adoption and, therefore, food security were identified and explained. These factors were broadly categorized under household, institutional, resource, and market access factors (Table 1).

4. Results and discussions

4.1. Improved dairy farming practices

The principal component analysis (PCs) and the coefficients of linear combinations (loadings) is presented in Table 2. The result indicated that the three PCs showed 69.4 of the total variability in the data set. The first component showed 32.75%, while the second and third explain 25.34% and 11.31% of the total variation in the data of improved dairy technology adoption, respectively. The first component was associated with concentrate feed, supplementary feed (local feed), and improved forage and was named feed-related intervention. These improved practices were the most commonly adopted, with 79.19% of smallholder farmers (SHF) using at least one of these components. The second PC was improved dairy cows and artificial insemination, used by 53% of SHF. The last PC was associated with the feeding system, using stall feeding and semi-grazing/seasonal grazing, which were only used by 29.79% of SHF (Table 3). Following MacCallum et al. [59], the total

Table 1
Explanatory variables and expected sign.

Variable	Description and variable type	Variable type	Sign
Household characteristics			
Age	Age of household head: Years	continuous	+
Gender	Sex of household head: Female = 1, Male = 0	Dummy	+/−
Family size	NA number of a family:	continuous	+
Education	Educational status (illiterate = 1, Literate = 0)	Dummy	+
Dependency ratio	The ratio of non-active/active family member	dummy	-
Resource and market access			
Farm size	Total land size (ha)	continuous	+
TLU	Number of Livestock in TLU	continuous	+
Credit access	Access to credit (No = o, Yes = 1)	Dummy	+
Social network	Social network (No = 0, Yes = 1)	Dummy	+
DNM	Distances to a nearby market	Continuous	−/+
Off-farm income	Off-farm income (none = 0, yes = 1)	Dummy	+/−
Institutional factors			
Ext. services	Access to extension services (No = 0, Yes = 1)	Dummy	+
Frequency of exte	Frequency of extension: no	Continuous	
Cooperative memb	Member of social cooperatives (No = 0,Yes = 1)	Dummy	+/−
Health	Animal health facilities (No = 0, Yes = 1)	Dummy	+/−
Access to inf	Access to climate information	Dummy	+

Table 2
Loading of the three components for IDFP.

Farming practices	Comp 1	Comp 2	Comp 3	Communalities
Highbred	0.736	0.370	−0.286	0.769
Crossbred	0.020	0.835	−0.22	0.838
Artificial insemination	0.731	0.495	0.105	0.784
Use of concentrate feed	0.708	0.636	0.124	0.912
Improved forage	0.172	0.781	0.144	0.620
Supplementary feed (local)	0.100	0.450	−0.46	0.277
Stall feeding	0.825	−0.197	−0.051	0.768
Semi-grazing/Seasonal grazing	0.122	8.460	0.154	0.765
Eigenvalues	2.947	2.280	1.018	
Eigenvalues % contribution	32.75	25.34	11.31	
Cumulative %	32.745	58.081	69.394	

Table 3
Lists of improved dairy farming practices.

Group	Percentage of users	Components
Improved breed & AI	53.13	Use of highbred cow Crossbred cow Use of AI
Feed related intervention	79.17	Use of concentrate feed Supplementary feed Improved forage
Feeding condition	29.79	Stall feeding Semi-grazing (seasonal)

AI: Artificial Insemination.

amount of each variance in the three components was over 0.60, or an average commonality of 0.7 for a small sample size to undertake a PC analysis (Table 2). The use of PCA is justifiable given the sample size of 480 and the commonalities reported in (Table 3) as it fulfills the minimum criterion. For the interpretation of PCs, variables with high factor loading and communalities were taken from the maximum likelihood method [60,61].

4.2. Determinants of adoption of improved dairy farming practices

Determinants of improved dairy farming technologies can be categorized in a variety of ways, which have an impact on a household's food security. In the study, SHF adoption choices were influenced by various demographic, socioeconomic, and institutional factors. Table 4 presents a combination of different packages, of which SHFs used 6 out of 8 possible packages/combinations. The majority of SHFs (21%) used a package ($B_1F_1S_0$) with the improved breed and feed management. About 20% of households used package $B_1F_1S_1$, containing all three groups of improved dairy farming practices, whereas non-adopters of package $B_0F_0S_0$ comprise 21% of SHF in the study area. The MNL results show six sets of parameter estimates, one for each mutually exclusive combination of practices (Table 5). Non-adoption ($B_0F_0S_0$) of all practices was the base category for comparing the other five packages used by farmers. The wald test, that all regression coefficients are jointly equal to zero, is rejected [x^2 (65) = 255.34; P = 0.000].

Age of Household Head: The age of the household head was positively and significantly ($p < 0.05$) associated with the use of $B_1F_0S_0$ and $B_0F_1S_0$ (Table 5). This means that an increase in the age of the household head by one year increases the likelihood of the household's decision to use $B_1F_0S_0$ by 1.26% and 1.3% more than a non-adopter, respectively. In other words, as the age of the household heads increases by one year, the likelihood of the household heads choosing a smaller package increases. It is most likely that older farmers are more experienced and thus less risk-averse than younger SHFs. In support of this finding, previous studies indicated that older farmers are assumed to have gained knowledge and experience, may have accumulated more physical and social capital over time, and are better able to evaluate technical information than younger farmers [[45,61,62]]. On the contrary, a negative relationship has been found between age and technology adoption, which can be explained by the fact that as farmers get older, their risk aversion increases, and their interest in long-term farm investment decreases [63].

Education: The education level of the household was found to positively and significantly influence farmers' decision to adopt improved breeds only ($B_1F_0S_0$). As the educational level of the household increased, the probability of using $B_1F_0S_0$ and $B_0F_1S_1$ increased significantly. The level of education of farmer improves his ability to obtain, process, and apply information relevant to adopting a new technology [20,62] and tends to build farmers' innovativeness and ability to assess risks for proper farm adjustments [64]. Similarly, a study by Okunlola et al. [65] on fish farmers' adoption of new technology and Ajewole [66]on organic fertilizer adoption found that the level of education significantly influenced adoption. Education influences respondents' attitudes and thoughts [67], easing the introduction and adoption of innovations [68]. On the other hand, some authors have reported an insignificant or negative effect of education on the rate of technology adoption [49,69]. Wekesa et al. [45] argue that a higher level of education enables farmers to avoid using improved practices that do not offer risk-reduction measures.

The dependency ratio: is used as a measure of labor availability. Many working age groups in the family could positively influence the adoption of labor-intensive new technologies. The dependency ratio positively and significantly explained the adoption of $B_1F_0S_0$ and $B_0F_1S_0$. This is because households with a higher dependency ratio have a lower workforce to apply the intensive work of improved dairy practices. A low dependency ratio within a household may increase labor availability [69], easing labor constraints when introducing new technologies [61]. This shows that SHF with a low dependency ratio is more likely to adopt than non-adopters.

Farm size: Having a large farm size negatively and significantly explains the use of the improved package $B_1F_1S_1$. This means that as farmland size increases, the likelihood of using $B_1F_1S_1$ decreases by 26.9% more than non-adopters. This is most likely due to households with small farm sizes adopting land-saving and labor-intensive technologies such as small numbers of productive animals and stall feeding/zero grazing to increase animal productivity. According to key informants, due to urbanization and cropland expansion to vast grazing land, farmers are switching from traditional dairy production systems to improved ones to increase dairy profitability. Several studies, however, have found a positive relationship between farm size and agricultural technology adoption [49,62]. Farmers with larger farm sizes are more likely to adopt new technology because they can afford to devote a portion of their land to experimenting with new technologies and influence the use of large packages as opposed to those with smaller farm sizes [49,70]. Other studies have found an insignificant or neutral relationship between adoption and farm size [26,69]. Kebebe [18] found no significant effect of extensive farm holdings on adopting improved dairy technologies.

Livestock holding (TLU): having a large livestock holding had a negative and significant impact on the adoption decisions of all $B_1F_1S_1$, $B_1F_1S_0$, $B_0F_1S_1$, $B_1F_0S_0$, and $B_0F_1S_0$ improved practices. This is most likely due to adopters of improved dairy technology reducing the number of low-yielding animals and keeping a few improved breeds for milk production. According to Moll et al. [70], due to limited grazing land, farmers cannot maintain a large number of livestock holdings, so they keep only a few productive animals. In contrast, Wekesa et al. [45] stated that resource-endowed farmers can absorb the risks associated with failure and the time it takes before realizing the meaningful effects of using CSAs.

Off-farm income: Off-farm income had a positive and significant

Table 4
Specification of improved dairy farming practices.

Choices	Binary quadruplicate	Improved breeds		Improve feeding		Feeding system		Frequency	Percentage
		B_1	B_0	F_1	F_0	S_1	S_0		
1	$B_1F_1S_1$	✓		✓		✓		100	20.83
2	$B_1F_1S_0$	✓		✓			✓	102	21.25
3	$B_0F_1S_1$		✓	✓		✓		43	8.96
4	$B_1F_0S_1$	✓			✓	✓		0.00	0.00
5	$B_1F_0S_0$	✓			✓		✓	58	11.04
6	$B_0F_1S_0$		✓	✓			✓	82	17.08
7	$B_0F_0S_1$					✓		0.00	0.00
8	$B_0F_0S_0$		✓		✓		✓	100	20.83
Total									100

The binary quadruplicate defines the IDFP packages. For each IDFP combination, each element in the quadruplicate is a binary variable: improved breed (B), enhanced feeding (F), and feeding condition (S), with subscript 1 indicating adoption and 0 indicating non-adoption.

Table 5
Marginal effects estimates for the determinants of IDFPs packages by MNL.

Variables	$B_1F_1S_1$		$B_1F_1S_0$		$B_0F_1S_1$		$B_1F_0S_0$		$B_0F_1S_0$	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Gender	0.603	0.122	0.325	0.276	0.016	0.205	0.0564	0.220	0.215	0.180
Age	0.012	0.010	0.049	0.084	0.096	0.074	0.0126*	0.010	0.013*	0.007
Education	0.285	0.290	0.284	0.186	0.28**	0.130	0.415**	0.140	0.1869	0.123
Family size	−0.260	0.100	0.126	0.063	−0.110	0.058	−0.150	0.060	0.185	0.057
Dependency Ratio	0.760	0.752	0.591	0.426	−0.036	0.372	0.701**	0.374	0.99***	0.315
Farm size	0.049	0.086	0.085	0.063	0.075	0.049	0.026	0.052	0.099**	0.047
TLU	−0.16**	0.060	−0.057**	0.025	−0.065**	0.021	−0.066**	0.020	−0.58*	0.195
Off-farm income	1.772**	2.626	1.32**	2.530	2.387	2.326	2.202	2.400	1.77	2.288
Extension service	0.79**	0.260	0.462**	0.157	0.266*	0.122	0.286**	0.126	.233**	0.118
Cooperative member	0.900	2.820	0.32**	0.810	0.100	0.365	1.18**	0.570	0.235	0.341
Credit access	0.214	0.223	0.456***	0.143	0.34**	0.115	0.34**	0.120	0.294*	0.111
District market	−1.18***	0.570	−0.376***	0.072	−0.234**	0.055	−0.31***	0.057	−0.23***	0.054
Milk collection	−0.221***	0.640	−0.0284	0.018	0.010	0.008	0.011	0.087	0.02**	0.083

$B_0F_0S_0$ = base category.
Number of obs = 480.
Prob > chi2 = 0.0000.
Log pseudo likelihood = 362.284.
Pseudo R^2 (McFadden) = 0.784.

impact on technology adoption ($B_1F_1S_1$, $B_1F_1S_0$). This is because off-farm income diversifies income sources and serves as an essential strategy for overcoming financial constraints, allowing farmers to invest in technology adoption. Similarly, a growing body of evidence indicates that employment in off-farm occupations positively impacts agricultural technology uptake and adoption [71,72]. Diro [71] states that off-farm income provides farmers with liquid capital for purchasing productivity-enhancing inputs like fertilizer and seeds.

Access to extension services positively and significantly influenced the usage of almost all dairy farming technologies. The service would help farmers be better informed about the existence of new technologies and how to use and benefit from them. Several authors have reported a positive relationship between extension services and technology adoption [49,73]. The diffusion of new technologies may also be influenced by agricultural extension agents' visits to farmers [26]. Similarly, Wekesa et al. [45] suggest that extension services play a crucial role in implementing development technologies by farmers.

Access to credit: This positively and significantly explained the likelihood of using dairy technologies such as $B_1F_1S_0$, $B_0F_1S_1$, $B_1F_0S_0$, and $B_0F_1S_0$. Credit access allows SHF to cover the costs of implementing expensive technologies that require a large initial investment, such as improved dairy breeds. Several similar results reported a positive correlation between credit access and agricultural technology adoption [26, 73]. Credit availability, according to Mohamed and Temu [73], has stimulated and increased technology adoption. In addition, Shiferaw et al. [74] reported that households experiencing credit constraints are less likely to adopt CSA technologies requiring cash expenditures.

Member of a cooperative: Similarly, agricultural group membership positively and significantly explained the usage of $B_1F_1S_0$ and $B_1F_0S_0$. Membership in a social group allows for the exchange of ideas, information, and trust [61], facilitating technology adoption. Members of group networks can exchange ideas, get market information, handle farm demonstrations, and connect to the dissemination of important research findings [45]. Ward and Pede [75] also noted that learning from peers' experience increases the likelihood of technology adoption because farmers trust the practical experiences demonstrated by their peers because they share many things in common, including shared labor.

Distance to the nearest district market: Distance negatively influences the likelihood of SHF usage of all improved dairy technologies. This is possible because access to markets allows the household to purchase inputs and sell their goods. Proximity to the market is an essential determinant of technology adoption, presumably because the market serves as a means of exchanging information with other farmers and facilitating buying and selling activities. Teklewold et al. [76] observed that, in addition to affecting market access, the distance could also affect the accessibility of new technologies, information, and credit institutions, resulting in a negative relationship. Similarly, distance to the milk selling point had a negative and significant influence on the adoption of $B_1F_1S_1$ but a positive influence on the use of $B_0F_1S_0$. This is possible due to a lack of or weak linkage between producers and consumers, exacerbated by poor road infrastructure to transport fluid milk to the selling point. Lack of well-established market linkage, infrastructure, transportation facilities, and the value chain for collecting, cooling, processing, and marketing milk and milk products are the main limiting factors for dairy development in Ethiopia [16].

4.3. IDFP impact on household food security

This section presents the conditional effects of adopting improved dairy production technology on rural household food security (Table 6). Following the identification of factors influencing IDFP package selection in the first stage, treatment effects were determined in the second stage to investigate the impact of package usage on household food security. The predicted outcomes of the ESR models were used to calculate the average treatment effect on the treated (ATT) and the average treatment effect on the non-treated (ATU). Then the ordinary least squares regression of the households' food consumption scores (HFCS) and household diet diversity scores (HDDS) was estimated for each combination of improved practices, taking into account the selection bias correction terms from the first stage (Table. S_1, S_2). For interpretation and comparison with existing literature, HFCS was preferred over HDDS because the latter only captures meals consumed within 24 h, which may exclude occasional meals consumed on specific days such as market days within a week (Table 6).

Table 6 depicts the average adoption effects of HFCS and HDDS in actual and counterfactual conditions. The result showed that adopting either individual IDFPs or a combination of them provides a significant food security effect compared to non-adopters. The SHFs that adopted the entire technology package, namely improved breed, forage, and stall feeding ($B_1F_1S_1$), had a more significant overall effect on HFCS and HDDS than the others. This is most likely due to the complementarity between the adoption of improved breeds and the feed and feeding system, which are crucial in boosting dairy productivity and the farmer's income. In all combinations of adoptions, the adopters' average per capita food consumption would have decreased if they had not adopted.

On the other hand, if non-adopters had adopted IDFPs, their HFCS would have increased significantly higher than the benefit adopters

Table 6
Impact of use and non-use of CSA packages on food security estimated using HFCS of farmers by ESR.

Package	Status	HFCS		HDDS	
		adoption status		adoption status	
		Adopting	Non-adopting	Adopting	Non-adopting
$B_1F_1S_1$	Adopting	71.71 (0.92)	75.6 (0.52)	10.92 (0.45)	11.51 (0.034)
	Non-adopting	49.79 (0.27)	50.81 (0.33)	8.1 (0.15)	7.81 (0.89)
	Effect	21.92 (0.3) ***	24.79 (0.61)***	2.82 (0.031) ***	3.7. (0.11)
$B_1F_1S_0$	Adopting	65.380 (0.792)	68.59 (0.52)	10.62 (0.017)	10.1 (0.073)
	Non-adopting	50.4 (0.4)	51.0 (0.33)	8.057 (0.011)	8.05 (0.045)
	Effect	17.98 (0.85)***	17.79 (0.61)***	2.56 (0.033)***	2.05 (0.086)***
$B_0F_1S_1$	Adopting	51.23 (0.26)	52.38 (0.53)	8.12 (0.012)	8.24 (0.14)
	Non-adopting	49.20 (0.33)	50.81 (0.39)	7.18 (0.031)	6.86 (0.035)
	Effect	2.03 (0.41) ***	1.57 (0.62)***	0.94 (0.034)***	1.38 (0.14) ***
$B_1F_0S_0$	Adopting	57.51 (0.62)	56.28 (0.43)	8.62 (0.017)	8.23 (0.039)
	Non-adopting	54.44 (0.48)	50.81 (0.33)	7.83 (0.034)	7.12 (0.024)
	Effect	2.75 (0.26) ***	5.47 (0.54)***	0.79 (0.036)***	1.10 (0.045)***
$B_0F_1S_0$	Adopting	49.47 (0.15)	52.48 (0.14)	7.62 (0.012)	7.9 (0.087)
	Non-adopting	47.85 (0.47)	50.81 (0.33)	4.54 (0.11)	5.26 (0.036)
	Effect	1.72 (0.5) ***	1.68 (0.36)***	3.1 (0.055) ***	2.64 (0.094)***
Pairwise correlation					
	HFCS	HDDS			
HFCS	1	0.918***			
HDDS	0.918 ***	1			

would have lost due to non-adoption. For non-adopters, for example, the average probability of food security increases by 40% if the entire package is implemented ($B_1F_1S_1$). These findings are consistent with previous technology adoption studies, showing that adopting new technologies can improve farmers' food security and reduce poverty. These include the adoption of improved agronomic practices on net crop income and agrochemical use in Malawi [47]; the adoption of improved breeds of dairy cows and improved forages on household nutrition and income [26]; the adoption of improved maize varieties on household food security [58]; and the adoption of stall feeding on household welfare in Mekele milk shed [25]. This is because improved agricultural technology is expected to increase farmer income while decreasing food insecurity and poverty. Along with food security effects, improved dairy farming technologies have biophysical and environmental benefits in mitigating greenhouse gas emissions and grazing land management [17, 25].

5. Conclusions

Enhancing food production without compromising a healthy agro-ecosystem has become an increasingly global challenge. An improved smallholder dairy farming system aims to enhance livestock productivity and resilience, reducing food insecurity and poverty while improving natural resource management. The study investigated the adoption of improved dairy technology and its effects on household food security as factors influencing its uptake using the multinomial endogenous switching regression approach in a counterfactual framework, where selectivity is modeled as a multinomial logit model.

It was found that households adopting dairy technologies have better off-farm income, better access to complementary inputs and services, and broader market opportunities than households not adopting dairy technologies. Agricultural research, extension services, and credit access appear to be successful in disseminating improved dairy technologies. The distance to the nearest market and milk collection center had a negative ($P < 0.05$) impact on adopters of improved technology.

The empirical results indicated that adopting either individual IDFPs or a combination of them provides a significant food security effect compared to non-adopters. Whereas, a larger package comprised of improved breed, improved feeding, and feeding condition ($B_1F_1S_1$) had the highest overall effects in HFCS and HDDS than the others. This package is comprehensive as it addresses a wider spectrum of breed improvement, improved feed and forage, and improved feeding conditions. The economic impacts of improved dairy technology suggested in this study would be an input for the ongoing efforts in transforming livestock production, and efforts aimed at enhancing widespread adoption in Ethiopia will generate significant benefits.

Resource constraints, supply chain bottlenecks, an incomplete value chain for input and output, and institutional barriers have been hindering improved dairy technology adoption. Interventions that overcome the constraints related to access to farm resources and the supply chain for IDF practice inputs and services and output markets could facilitate the uptake of dairy technologies. Improved infrastructure and targeted institutional arrangements for the distribution of technological inputs and services could alleviate market access constraints and improve dairy productivity.

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Ethics approval

Not applicable.

Consent to participate

Before the survey began, farmers were asked if they would be willing to participate.

Consent to publish

Not applicable.

The author's contribution

The first author, Abraham Abera Feyissa, a Ph.D. student at the Center for Environment and Development, Addis Ababa University, generated the research idea, designed the study, designed and carried out data collection and analysis, interpreted the result, drafted the manuscript. The second author, Feyera Senbeta, professor of ecology, center for environment and development, Addis Ababa University, participated in the study design, data collection, analysis, and manuscript write-up. The third author, Adugna Tolera, professor of animal nutrition at Hawasa University, participated in the whole process of research design and analysis. The final author, Dawit Diriba, economist (Ph.D.), center for environment and development, Addis Ababa

University, was also involved in the analysis and write-up. All authors read and approved the final manuscript.

Data and model availability statement

Data and models will be available upon request. The software used is available online for reviewers.

Declaration of competing interest

We wish to declare that there are no conflicts of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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