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The Impact of Improved Dairy Cow Adoption on Smallholders' Food Security in Northern Ethiopia: An Endogenous Switching Regression Approach

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ABSTRACT

Background: Increased adoption of dairy cows is a significant factor in lowering food insecurity, but in northern Ethiopia, it is still overlooked. Therefore, this study aims to evaluate the impact of adapting improved dairy cows on smallholders' food security in Northern Ethiopia. **Methods**: This study used a total of 360 sample households, of which 176 and 184 were adopters and non-adopters, respectively. An Endogenous Switching Regression approach was used to address the potential selection biases of improved dairy cow adoption. Besides, the food security status for the adopters and the non-adopters was estimated using a Foster-Greer-Thorbecke index approach. **Results:** The results indicated that compared to the non-adopters, adopters had an increased calorie intake of 3.89%, and dietary diversity was increased by 10.5%. Moreover, compared to the adopters, food insecurity among the non-adopters was more prevalent and severe, with a higher gap in all Foster-Greer-Thorbecke index. **Conclusions:** Notably, this study calls upon policymakers to focus on the dissemination of improved dairy technologies within rural areas of Northern Ethiopia as a strategic intervention for addressing food insecurity.

Introduction

Livestock production is among the fundamental components of agricultural production, and it provides globally about 40% of the total agricultural GDP . Furthermore, the livestock industry in Africa accounts for close to 30% of the continent's agricultural GDP (Abbasi and Nawab, 2021). In a similar manner, livestock rearing in Ethiopia plays a major role and contributes to almost 40% of agricultural GDP and about 20% of whole GDP (Abbasi and Nawab, 2021). In Ethiopia, dairy production is the main part of livestock production and contributes to 8.5 to 10.5% of the total agricultural production (Central Statistics Agency, 2020).

Food security and the distribution of agricultural technology are interrelated concepts (Feder *et al.*, 1985). Despite enormous potential for dairy cows, robust development efforts and impact studies on improved dairy cows are limited. As a result, the Tigray region faces severe food insecurity, with up to 30% of the population facing extreme food shortages (United Nations Office for the

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Coordination of Humanitarian Affairs, 2024). Few empirical studies have been conducted in Ethiopia and globally to assess the impact of adopting dairy cows on food security. Some researchers argue that the adoption of dairy cows significantly improves food security. Few empirical studies have been conducted in Ethiopia and globally to assess the impact of adopting dairy cows on food security. Some researchers argue that the adoption of dairy cows significantly improves food security (Hana, 2019, Lemma *et al.*, 2023). Conversely, others argue that improved dairy cow adoption has no significant impact on the food security of farm households (Feyisa *et al.*, 2023).

Notably, the adoption of improved dairy cows has been shown to improve food security for smallholders. Given this, the Ethiopian government has determined that the use of dairy production technology can help smallholder farmers become more food secure and less impoverished (Hana, 2019, Jebessa *et al.*, 2023). The Ethiopian Institute of Agricultural Research (EAIR) and the International Livestock Research Institute (ILRI) are the primary initiators of this program (Hana, 2019). As a result, during the past 20 years, dairy cows have been distributed, but there is limited evidence of its impact. In addition, previous empirical studies utilized traditional methodological approaches, such as propensity score matching, which fail to address selection bias during adoption (Ashagrie, 2017, Hana, 2019). As a result, smallholder farmers miss robust information about the impact of improved dairy cow adoption on food security. Moreover, most of the empirical studies used a single measurement outcome of food security status. For instance, Ashagrie Y used the Household Food Insecurity Assessment Scale (HFIAS) (Ashagrie, 2017); and Hana used Household Net Available Food (HNAF) (Hana, 2019). Thus, a single measurement may not provide a robust conclusion.

To the authors' knowledge, no appropriate impact evaluation method is applied, and no consistent findings are found from the studies done so far. Thus, this study aims to address the lack of consistent findings on the impact of improved dairy technology adoption regarding food security in Ethiopia. It resolves divergent empirical effects of improved dairy cows, employs an endogenous switching regression approach to account for selection biases, and analyzes food insecurity between those adopting and not adopting improved dairy cows.

Materials and Methods

Study area, sample size and sampling technique

The study area is the Tigray Region, which is situated in northern Ethiopia. With their enormous potential and subsistence level of output, livestock play a central part in supporting the Ethiopian economy (Tigray Bureau of Planning and Finance, 2018). A multi-stage sampling process was used to get samples from the households. In the first phase, two districts were specifically selected based on their potential for dairy milk production. Subsequently, four kebelles were proportionately chosen at random from each area. Third, a total sample 360 households, including 176 improved dairy adopters and 184 non-adopters were selected. Basically, this study was used a cross-sectional study with both numerical and qualitative data.

The sample size was determined by using a single population proportion formula. The sample size was determined using the following formula.

$$n = \frac{(Z_{\alpha/2})^2(pq)}{\varepsilon^2} \qquad (1)$$

The required sample size, denoted as n, is calculated based on the proportions of households that adopt improved dairy cow (p) and those that do not-adopt (q) within the total population. The acceptable error level is represented by Ɛ, while Z corresponds to a 95% confidence level (1.96). In this context, since specific proportion data is available, the authors set both p=0.35 and q= 0.65 for adopters and non-adopter households. Consequently, a total sample size of n=360 households was established, accounting for a 3% non-response rate.

Data types, sources, and methods of data collection

Both primary and secondary data were used for this study. The primary data was collected from the sample respondents using face-to-face interviews. A pre-tested well-structured questionnaire was designed to collect data regarding the socioeconomic factors affecting improved dairy cow adoption and other outcome variables. Secondary data were also collected from the agriculture and rural development office and other published and unpublished sources to support the primary data.

Inclusion and exclusion criteria

In the methods section, the inclusion criterion was smallholder farmers adopting improved dairy cows, while the authors excluded those who were not engaged in farming or those who were without agricultural resource access.

Data analysis

Descriptive statistics and econometric models were used in this analysis. The data were analyzed using descriptive statistics and econometric models. The collected data was analyzed by Stata 17 software. The effect of adopting dairy cows on food security of farmers was estimated using an endogenous switching regression (ESR) technique. Two procedures have been used in the estimating process. The selection equation is defined as follows:

In the first step,

$$C^* = \alpha Z_i + \eta_i, C_i = 1 \quad \text{if } C_i = 1 (\text{Adopter})$$

$$C_i = 0 \quad \text{if } C_i \leq 0 \ (\text{Non} - \text{adopter}) \qquad (2)$$

where, Z_i is a vector of household characteristics; and η_i is a random error

In the second step, two separate groups of food security functions are defined. Therefore, food security functions are given by:

$$\text{Regime 1}: Y_{1i} = \beta_1 X_i + \epsilon_{1i} \text{ if } C_i = 1 \ (\text{Adopters}) \qquad (3)$$

$$\text{Regime 2}: Y_{2i} = \beta_2 X_i + \epsilon_{2i} \text{ if } C_i = 0 \ (\text{Non} - \text{Adopters}) \qquad (4)$$

Where Y_{1i} and Y_{2i} represent food security (outcome) for improved dairy cow adopters and non-adopters, respectively; X_i represents the vector of covariates of producer i; β_1 and β_2 are parameters to be estimated; and ϵ_{1i} and ϵ_{2i} are error terms.

Measuring food security status

Food security status is typically examined by means of reference to four dimensions including: food availability, accessibility, utilization, and stability (Food and Agriculture Organization, 2013). In this study, food utilization is given a priority since it examines the calorie intake and dietary diversity. Additionally, food utilization is vital since food access alone is not a guarantee for food and nutritional security (Barrett, 2010). Thus, two food utilization parameters were used to measure food security status of the households. The first measurement is the calorie intake within seven days. This is done by listing and estimating the bundle of food items consumed by the sample households in terms of 100 grams of solid food using conversion factors for liquid and semi-liquid food items (Ethiopian Health and Nutrition Research Institute, 1998) After this, 2100 kcal is the minimal criteria for Ethiopia's food security status (Federal Democratic Republic of Ethiopia, 1996). The second measurement is the dietary diversity score, which is divided into seven food groups (These food groups are (1) cereals, roots and tubers, (2) pulses and legumes, (3) dairy products (4) meats, fish and eggs (5) oils and fats (6) fruits, and (7) vegetables) based on the number of food items consumed (Food and Agriculture Organization, 2013).

Ethical considerations

The study was approved by Ethical Review Committee of Adigrat University in College of Agriculture and Environmental Sciences research, Ethiopia (Consent Ref Number AGU/CAES/ 045/2023). Moreover, the research followed clear ethical consent and did not include any human experimentation. Every participant was coded and anonyms to everyone.

Results

Socio -economic characteristics of respondents

Table 1 presents the demographic and socio-conomic characteristics of the study participants using p-value (which measures the statistical mean difference between adopters and non-adopters). There is a significant difference in all variables between adopters and non-adopters at (*P*<0.01), except of the variable of farm size. For instance, 83% and 57% of the respondents were headed by men for adopters and non-adopters, respectively. For adopters an average educational level included 4 years of schooling, while for non-adopters, it was 2 years of schooling. In addition, adopters consumed an average calorie intake of 2408.88 kcal per day, while non-adopters consumed 1734.66 kcal. In addition, adopters consumed an average dietary diversity of 4.87 food groups, while non-adopters consumed an average of 3.96. This result justifies that the adoption of improved dairy cow is essential to enhance food security status.

Table 1. Socio-economic summary of sample households (n=360).

Variables	Adopters(n=176)	Non-adopters (n=184)	P-value[a]
Sex of household head (1=male, 0= female)	0.83(0.38)[b]	0.57(0.50)	<0.01
Family size in adult equivalent	4.9 (1.8)	5.11 (3.2)	<0.01
Education (years)	4.27(2.56)	2.2(2.24)	<0.01
Farm size (hectares)	0.52 (0.13)	0.48(0.12)	<0.10
Experience in dairy farming (year)	9.16(5.17)	5.14(4.2)	<0.01
Extension service (1=yes, 0= no)	0.73(0.45)	0.29(0.46)	<0.01
Distance to market (km)	1.54(0.67)	2.77(0.79)	<0.01
Market information (1=yes, 0= no)	0.97(0.16)	0.16(0.37)	<0.01
Calorie intake (kcal)	2408.88 (574)	1734.66 (516)	<0.01
Household dietary diversity	4.87(1.0)	3.96(0.89)	<0.01
Ln of off/non farm income (ETB)	7.54(0.33)	6.99(0.54)	<0.01

[a]: Student t-test; [b]: Mean (SD).

The incidence, gap and severity of food insecurity between adopters and non-adopters

Based on the Foster-Greer-Thorbecke (FGT) indices results, the overall incidence of food insecurity or head count ratio of the sample households was 52.77% (**Table 2**). Of these, 22.72% and 81.13% were adopters and non-adopters of improved dairy cows, respectively. This result highlights the adoption of improved dairy cows, which helps to increase food security in rural households. In addition, the food insecurity gap and severity of food insecurity are also higher among non-adopters than adopters at 1% level. The results show that the average aggregate consumption shortfall relative to the minimum subsistence daily allowance among adopters and non-adopters of improved dairy cows was 12.54 and 21.12%, respectively. The severity of food insecurity among adopters and non-adopters was 3.4% and 9.78%, respectively. In addition, 5.8% of the total respondent household members were living in a precarious situation (**Table 2**).

Household dietary diversity score between adopters and non-adopters

The most precise measure of food security is dietary diversity (Food and Agriculture Organization, 2011). Basically, 71.4% of the sampled households have a low degree of dietary variety. Of these, 40.4% were improved dairy cow adopters and 78.80% were non-adopters. As a result, adopters had a significantly greater household dietary diversity score than non-adopters (**Table 3**). This suggests that adopting cow milk increases revenue, which enables one to buy a wider variety of foods

Determinants of improved dairy cows' adoption

The determinants of improved dairy cow adoption were estimated by probit model estimation (**Table 4**). The significant determinant factors of improved dairy cow adoption were sex of the household head (28.5%.), education level (13%), experience in dairy farming (4.8%), distance to market (62%), extension contact (50.5%), access to information (24%), and off-farm income (127%).

Table 2. Incidence, gap and severity of food insecurity between adopters and non-adopters.

Food insecurity indices	Adopters (n=176)		Non adopters (n=184)		Total (n=360)	
	n	%	n	%	n	%
Incidence ($\alpha = 0$)	40	22.72	149	81.13	190	52.77
Gap ($\alpha = 1$)	22	12.54	39	21.12	61	32.10
Severity ($\alpha = 2$)	6	3.40	15	9.78	21	5.80

Table 3. Household dietary diversity score between adopters and non-adopters.

Household dietary diversity score	Adopters (n=176)		Non adopters(n=184)		Total (n=360)	
	n	%	n	%	n	%
< 4.5 (low dietary diversity)	71	40.40	145	78.80	216	71.40
4.5-6 (medium dietary diversity)	98	55.68	39	21.2	137	38.05
6 and above (good dietary diversity)	7	3.98	0	0.00	7	3.98

Impact of dairy cow adoption on food security

Table 5 shows the full information maximum likelihood (FIML) technique, which jointly generates the outcome and selection equations. Since determinant of adoption result has already been estimated in **Table** 4, the first stage of the Endogenous Switching Regression (ESR) estimation is disregarded. In this case, only the second stage of the ESR estimation, which involves estimating the outcome equations for dairy cow adopters and non-adopters, is reported. Thus, show the findings of household calorie consumption and household dietary diversity.

Table 6 presents a thorough analysis of the impact of improved dairy cow adoption using Average Treatment Effect on the Treated (ATT) and Average Treatment Effect on the Untreated (ATU). The statistical method employed is ESR, which is robust for estimating treatment effects in situations where treatment assignment is not random, thereby accounting for potential biases due to self-selection into treatment groups. The results of ATT and ATU for dairy cow adoption suggest a significant improvement in the household calorie intake and dietary diversity score of adopters as compared to non-adopters. The mean consumed calorie intake for the adopters was 7.74 kcal per day on a natural logarithmic basis or 2298 Kcal/day in standard basis, with an increase in ATT of 0.29 points or 3.89%. Conversely, non-adopters' food consumed in calorie intake of 7.25 kcal per day on a natural logarithmic basis or 1408 Kcal/day in standard basis was below the minimum food security threshold in Ethiopia (2100 Kcal/day). Furthermore, the average dietary diversity score for the adopters was 4.2, with an incredible ATT of 0.4 (10.5%), whereas for non-adopters, an average score of 2.96 was found with an ATU of 0.24 (8.1%). This huge difference in diet diversity among adopters further signifies some nutritional benefits related to the improved dairy cow adoption.

Table 6 also shows the base heterogeneity effect of dairy cow adoption on calorie intake ($BH_{1LnCalv}$ and $BH_{2LnCalv}$) and on dietary diversity (BH_{1HHdd} and BH_{1HHdd}). Thus, the heterogeneity effect of dairy cow adoption for the outcome of calorie intake was estimated by subtracting (a-c) - (d-b) or (ATT-ATU=0.50) and for dietary diversity, by (a_1-c_1) - (d_1-b_1), which was 0.64.

Discussion

The study found that 22.72% and 81.13% of rural households adopt improved dairy cows, with food insecurity levels of 3.4% and 9.78%, respectively (**Table 2**). Adopting cow's milk increases food security and household dietary diversity, indicating that it can boost revenue and food variety. This result was similar to the results by Bacha (Bacha *et al.*, 2011), who found that the impact of small-scale irrigation significantly and positively affects household food security in Ambo district, Ethiopia.

The probit model result indicated that as expected, the probability of adoption was higher in households headed by men than women by 28.5%. This is because male household heads have greater access to knowledge and social networks which can increase their willingness to adopt better dairy cows (Ashagrie, 2017). On the other hand, there is a divergent empirical finding by Jodlowski *et al*. in Zambia (Jodlowski *et al.*, 2016), who found that the sex of household head negatively affected the adoption of dairy technology.

Farm households that receive education are more equipped to gather, analyze, and apply knowledge necessary for implementing new technologies. Therefore, at 1%, it became apparent that the household's educational attainment had a favorable and significant impact on farmers' decisions to adopt improved dairy cows. A consistent result was found by Jebessa et al. (2023), who revealed that experience with dairy farming has a positive and significant impact on crossbred dairy cow adoption in southwestern Ethiopia.

Table 4. Probit model estimation result.

Variable	Marginal effect (dy/dx)
Sex of household head	0.285(0.17)[b]
Family size in adult equivalent	0.02(0.035)
Education in years	0.13(0.03) [a]
Farm size in hectares	0.25(0.32)
Experience in dairy farming	0.048(0.01) [a]
Extension service	0.505(0.10) [a]
Distance to market in kilometer	-0.62(0.1) [a]
Log of livestock ownership in TLU	0.05(0.07)
Log of off-farm or non-farm income	1.27(0.27) [a]
Market information	0.24(0.14) [a]
Liklihood Ratio chi2 (13)	388.25
Prob > chi2	0.00

[a] and [b] are statistically significant at <0.01 and <0.10, respectively; Standard errors are in parentheses; Probit model estimation

Table 5. Endogenous Switching Regression (ESR) results for household calorie intake and household dietary diversity score.

Variables	household calorie consumption		household dietary diversity	
	Adopters	Non-adopters	Adopters	Non-adopters
Sex of household head	0.09(0.035)[a]	-0.05(0.08)	0.33(0.28)	0.17(0.15)
Family size in adult equivalent	-0.0008(0.06)	-0.05(0.08)	-0.062(0.04)	-0.015(0 .019)
Education in years	0.014(0.007)[b]	0.013(0.006) [b]	0.08(0.041) [b]	0.015(0.001) [a]
Farm size in hectares	-0.07(0.07)	0.29(0.14) [b]	0.23(0.13)	0.65(0.37) [c]
Experience in dairy farming	0.003(0.002)	0.009(0.06)	0.02(0.01) [b]	0.013 (0.016)
Extension service	0.036(0.02) [c]	0.06(0.035)[c]	0.15(0.17)	-0.26(0.11) [b]
Distance to market in kilometer	-0.05(0.015) [a]	0.025(0.73)	-0.05(0 .13)	-0.08(0.02) [a]
Log of livestock ownership in tropical livestock unit	0.01(0.02)	0.056(0.04)	0.31(0 .13) [b]	-0.03(0.09)
Log of off-farm income	0.62(0.06) [a]	0.55(0.07) [a]	0.63(0.05) [a]	0.29(0.19)
Constant	2.90(0.43) [a]	3.14(0.53) [a]	1.25(1.01)	1.14(1.06)
ρ_{1i}	-1.33 [a]	0 .31	-0.77[a]	0.26
ρ_2	-0.21	0.16	-0.07	0.26
Number of observations	176	184	176	184

[a]: P<0.01; [b]: P<0.05; [c]: P<0.1; Standard errors are in parentheses.

Table 6. Average Treatment Effect on the Treated (ATT) and Average Treatment Effect on the Untreated (ATU) of improved dairy cow adoption: Endogenous Switching Regression (ESR) estimates.

Variables	Mean outcomes ESR			
	Adopters	**Non-adopters**	**Treatment Effect**	**Effect (%)**
Household calorie intake				
Adopters	(a) 7.74	(c) 7.45	(a-c) = ATT= 0.29[a]	3.89
Non-adopters	(d) 7.25	(b) 7.46	(d-b) = ATU =-0.21[a]	2.90
Heterogeneity effects	$BH_1LnCalv = 0.49$	$BH_{2nCalv} = -0.01$	0.50[a]	
Dietary diversity score				
Adopters	(a_1) 4.2	(c_1) 3.8	(a_1-c_1)= ATT=0.4[a]	10.5
Non-adopters	(d_1) 2.96	(b_1) 3.2	(d_1-b_1) =ATU=-0.24[a]	8.1
Heterogeneity effects	BH_{1HHdd} =1.24	$BH_{2HHdd} = 0.6$	0.64[a]	

[a]: *P<0.01*

In **Table 6**, the ESR results suggest that improved dairy cow adoption in Tigray, Northern Ethiopia, is effective at enhancing food security in both parameters (household calorie intake and dietary diversity). This result was consistent with the study done by Hana and Ashagrie (Ashagrie, 2017, Hana, 2019) who revealed that dairy technology adoption facilitates household food security and welfare, respectively. Additionally, a study done by Jodlowski *et al.* in Zambia (Jodlowski *et al.*, 2016) found that the adoption of improved dairy cows has a significant impact on improving food security. This finding was also consistent with the result of Kabunga (Kabunga, 2014) in Uganda, who found that the adoption of improved cow breeds has a positive impact on household welfare and child nutrition. In Table 6, the positive sign of transitional heterogeneity effects indicates that improved dairy cow adopters are more better-off in both outcomes of calorie intake and dietary diversity, compared to non-adopters at (P<0.01). In summary, the outcome of this result suggests that adopting dairy cows is important in enhancing overall food security.

The present study had several advantages. This study used a relatively large sample size (360), which included both sexes and adopters and non-adopters. This study also used a robust methodological approach like an ESR approach for assessing the selection bias in the impact evaluation. In addition, this paper provides context-specific insights for policymakers aiming to enhance food security in dairy farming through targeted intervention. This study also had some limitations. For instance, the research does not fully capture external factors such as climate variability, market fluctuations, and policy influences that can greatly affect food security outcomes. Additionally, this research used a cross-sectional data; future studies should aim to address these limitations through longitudinal designs and a broader exploration of contextual factors influencing food security.

Conclusion

Food insecurity is a widespread problem in Northern Ethiopia, and the gap is bigger among the non-adopters. Improved adoption of dairy cows could therefore ease this situation. Factors such as household head's sex and education, dairy farming experience, and market distance positively influence adoption. Developmental agents' capacity building, gender empowerment (as sex is a significant determinant of dairy cow adoption), and improvement in road facilities would encourage improved adoption of dairy cows. Therefore, this study favors policymakers to focus on the dissemination of improved dairy technologies within rural areas of Ethiopia as a strategic intervention for addressing food insecurity effectively.

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Conflict of interest

The authors declared no conflict of interest.

Authors' contributions

S Kahsay, K Gebrehiwot and M Hadush designed the research. S Kahsay, A Hailu and A Tefera participated in data collection and analysis. S Kahsay, K Gebrehiwot and M Hadush wrote the manuscript. S Kahsay had primary responsibility for the ultimate content. Finally, all authors read and confirmed the final article.

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