African Crop Science Journal, Vol. 32, No. 1, pp. 91 - 114 pISSN 1021-9730/2024
eISSN 2072-6589/2024

DOI: https://dx.doi.org/10.4314/acsj.v32i1.7

IMPACT OF *Korra tef* ADOPTION ON FARM HOUSEHOLD PRODUCTIVITY AND INCOMES IN CENTRAL ETHIOPIA

S. Z. LEUL[1, 2], A. A. BEKELE[3], S. T. FELEKE[4] and A.G. HAILU[3]

[1]Center for Rural Development Studies, Addis Ababa University, Ethiopia
[2]Department of Sociology, Debre Berhan University, Ethiopia
[3]Center for Rural Development Studies, Addis Ababa University, Ethiopia
[4]Center for Food Security Studies, Addis Ababa University, Ethiopia
Corresponding author: slmnzwd@gmail.com

(*Received 20 November 2022; accepted 19 December 2023*)

ABSTRACT

Tef (*Eragrostis tef*) is a major staple and income sourcing crop in the horn of Africa; that has attracted tremendous investment particularly in research. It is expected that the improved seed varieties will contribute to raising farm productivity and consequently, farmers' income. The objective of this study was to assess how the adoption of improved tef variety has influenced household productivity and incomes, with a focus on the *Korra tef* variety introduced by the Agricultural Growth Programme phase II, in Ethiopia. Cross-sectional data were collected from 479 randomly selected farm households, in two woredas in Central Ethiopia; one as an adopter and the other as a non-adopter. The Propensity Score Matching (PSM) approach was used to investigate the adoption of the *Korra tef* variety and its impacts on household production and income, over the yield obtained by the non-adopters. The PSM model's robustness was tested using regression on variables and regression on propensity scores. The adoption of the *Korra tef* variety, according to the PSM approach, increased tef productivity by 598.78 kg (nearly 6 quintals) per hectare, over the yield obtained by the non-adopters. Additionally, switching to the *Korra tef* variety raised household income by US$ 806.73 per hectare. We conclude that the adoption of *Korra tef* variety increases the productivity and incomes of adopter farm households.

Key Words: Adoption, *Korra tef*, Propensity Score Matching

RÉSUMÉ

Le Tef (*Eragrostis tef*) est une culture de base et une source de revenus majeure dans la corne de l'Afrique. Le Tef a attiré d'énormes investissements, en particulier dans la recherche. On s'attend à ce que les variétés de semences améliorées contribuent à augmenter la productivité agricole et, par conséquent, les revenus des agriculteurs. L'objectif de cette étude était d'évaluer comment l'adoption d'une variété de tef améliorée a influencé la productivité et les revenus des ménages, en mettant l'accent sur la variété de *tef Korra* introduite par la phase II du programme de croissance agricole en

Éthiopie. Les données transversales ont été collectées auprès de 479 ménages agricoles sélectionnés au hasard, dans deux Woredas du centre de l'Éthiopie; l'un en tant qu'adoptant et l'autre en tant que non-adoptant. L'approche Propensity Score Matching (PSM) a été utilisée pour étudier l'adoption de la variété *Korra tef* et ses impacts sur la production et les revenus des ménages, par rapport au rendement obtenu par les non-adoptants. La robustesse du modèle PSM a été testée à l'aide de régression sur variables et de régression sur scores de propension. L'adoption de la variété *Korra tef*, selon l'approche PSM, a augmenté la productivité du tef de 598,78 kg (à peu près 6 quintaux) par hectare, par rapport au rendement obtenu par les non-adoptants. De plus, l'adoption de la variété *Korra tef* a augmenté le revenu des ménages de 806,73 Dollars Américains par hectare. Nous concluons que l'adoption de la variété *Korra tef* augmente la productivité agricole et les revenus des ménages.

Mots Clés: Adoption, *Korra tef*, Propensity Score Matching

INTRODUCTION

Tef *(Eragrostis tef)* is one of the most important cereal crops cultivated in the horn of Africa. It is a staple food crop for millions of people and is the most important crop by area planted and value of production in Ethiopia (Assaye and Habte, 2022). Besides, it the second-most important household income generating crop in the horn of Africa. However, its productivity has remained suboptimal (Diriba, 2018); largely due to the region's smallholder farmers' characteristics of low input-output agriculture. Rural agriculture mainly relies on indigenous production techniques and is highly reliant on rainfall in general (Sisay *et al.*, 2017; Diriba, 2018; Kirchner, 2021); and the low adoption of improved technologies, including high-yielding varieties (Gebeyehu, 2016).

Additionally, the inadequate availability and lack of access to improved high-quality seeds are reportedly as the major challenges to increasing *Tef* productivity in this region (Ojiewo *et al.*, 2015; Abebe and Alemu, 2017). This has led to the need for intensification, i.e. increasing the productivity of farmland with new technologies (Koko, 2012), which in turn increase the demand for improved seeds and fertilisers (Spielman *et al.*, 2010). As a result, the Agricultural Growth Programme phase II (AGP-II) of Ethiopia aims to increase smallholders' crop production, food security, income and nutrition security, by enhancing access to crop technologies that increase yield per unit area (MoA, 2015). In light of this, the AGP-II introduced the *Korra tef* variety, a genetically modified high-yielding *Tef* variety, to enhance farmers' productivity and income. However, the impacts of the *Korra tef* variety on farmers' productivity and income have not yet been verified. The objective of this study was to determine how the introduction of *Korra tef* variety influenced household *Tef* productivity and incomes in Ethiopia.

METHODOLOGY

The study area. This study was conducted in *Wara-Jarso woreda*, located in the *Oromia* Regional State of Ethiopia. In the administrative structure of Ethiopia, *woreda* serves as the second smallest administrative unit, positioned after the *kebele* (the smallest administrative unit) and below the zone, excluding the capital city, Addis Ababa. The study site is situated at coordinates 38° 14' 60.00" East and 9° 49' 59.99" North (Fig. 1). The elevation of the area ranges from 928 to 2786 meters above sea level, and the average monthly temperature is approximately 19.80 °C. The annual average rainfall in this location is 1148.2 mm, with a range of 849.7 to 1416 mm based on the mean annual rainfall data provided by the National Meteorological Agency of Ethiopia in 2020 (NMAE, 2020).

Research design and ethical issues. A cross-sectional survey was conducted using the mixed-methods approaches, embedded in the Concurrent Embedded Strategy. In this

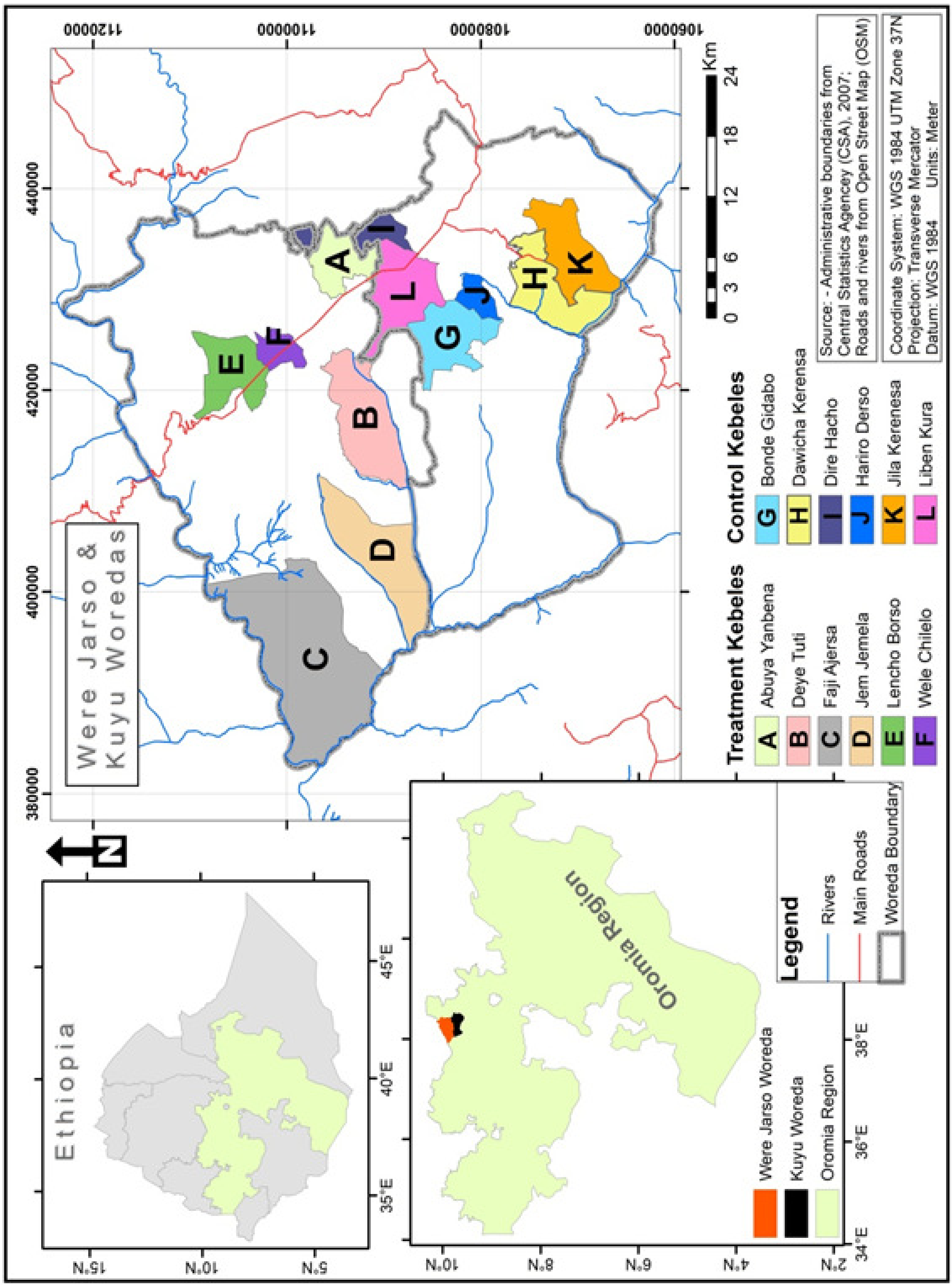

Figure 1. Map of the study areas.

approach, quantitative data are predominant, while qualitative data are embedded within the former to supplement its interpretation and for further explanation (Creswell, 2009).

As for the ethical issues, the Center for Rural Development Studies at Addis Ababa University provided clearance to certify the requirements of ethics for this study. Participants were assured that information they provided would be treated with the strictest secrecy, that only aggregate data would be released, without connecting the responses to specific participants.

Sampling and data collection. The target populations of this study were 7400 AGP-II beneficiary households, who previously participated in the *Korra tef* adoption activities promoted by the Agricultural Growth Programme phase II (AGP-II) in Ethiopia (Table 1). To get representative sample households, a multi-stage sampling procedure was employed. For the first stage, *Wara-Jarso woreda* was purposefully selected. In the second stage, with the assistance of the AGP II coordination office and the development agents (DAs) in the study *woreda*, *Korra tef* adopters were identified. The analysis focused on three primary agroecological zones found in the study areas; namely Highland (>2300 m), Midland (1500 - 2300 m), and Lowland (below 1500 m), as *tef* cultivation is prevalent across these zones. Two *kebeles* were chosen from each agroecological zone based on their accessibility and alleged level of *tef* production as high and medium growers to ensure the representativeness of the sample. Consequently, a total of six *kebeles* were included as the actual study areas.

In order to estimate the counterfactual, a control group was established using the nearby *Kuyu woreda*, which closely resembled the treatment group. The chosen control group *woreda*, *Kuyu*, shared similarities with the treatment *woreda* in terms of agroecological zones, dominant crops grown, socio-cultural, economic and institutional aspects; except for the interventions implemented by the AGP II. However, the criterion of *Korra tef* producers was replaced with the regular *tef* producers in the control group. Similar procedures to those employed in the treatment *woreda* were followed to select *kebeles* from the control *woreda*. Thus, a total of six *kebeles* were selected from the control *woreda*. By employing this sampling approach, the study aimed to ensure the representation and comparability of the target populations from both treatment and control groups, thus facilitating robust analysis and meaningful conclusions.

The sample size was computed using the Yamane (1967) sample size determination formula, on account of the finite character of the population under study (Equation 1).

$$n = \frac{N}{1 + N(e^2)} \quad \text{..................... Equation 1}$$

Overall, 479 farm households were obtained with the 95% desired level of precision. To ensure balance between the treatment and control groups in our impact assessment model, we selected 221 adopters from the treatment group and 258 non-adopters from the control group. The non-adopters from the control group were specifically non-participants in the AGP II programme, who did not grow the *Korra tef* variety.

As shown in Table 1, the sample size in each *kebele*, was calculated using the Probability Proportional to Size (PPS) of the identified number of farm households for a fair selection of samples from the *kebeles*.

A semi-structured questionnaire was used to obtain quantitative data, the main primary data of the study. The questionnaire was initially prepared in English, and then translated into *Afan Oromo* by language experts. A questionnaire pre-test was conducted to ensure that the interviewees fully comprehend the tool. Two farmers from each of the three main agroecological zones (Highland, Midland and

TABLE 1. Distribution of population and sample households across the study kebeles

Respondent type	*Kebeles*	Population size (*Korra tef* producers)	Sampled households
Adopters	Lencho Borsu	1100	70
	Wale Chilalo	540	35
	Abo Yayambana	510	33
	Dhaye Tuti	600	39
	Jemjem Mela	370	24
	Faji Ejersa	305	20
Sub-total	3425	221	
Non-adopters	Kebeles	Population size (Non-*Korra tef* producers)	Sampled households
	Liban Kura	865	56
	Bonde Gidabo	925	60
	Dire Hacho	835	54
	Hariro Derso	430	28
	Dawicha Kerensa	425	28
	Jila Kerensa	495	32
Sub-total	3975	258	
Total	7400	479	

Source: Computed from the study *woredas* (2020)

Lowland) were interviewed for the qualitative data to supplement primary data; based on the classification of high and medium adopters.

Additionally, Key Informant Interviewees (KIIs) who included the regional AGP II monitoring and evaluation officer, the zonal AGP II facilitator, the *woreda*'s AGP II coordinator, and one DA from each agro-ecology zone, were considered as from the adopter group. Secondary information was also sourced from the *kebele* agriculture offices in the study area; as well as relevant documents and website resources.

Definition of variables. The study considered two dependent variables: The first was *Korra tef* productivity measured in terms of *Korra tef* yield per hectare (Diskin, 1997):

$$\text{Productivity} = \frac{\text{Crop output (kg)}}{\text{Area planted (ha)}}$$

.... Equation 6

The second outcome variable was the annual household income, which was measured as the net income derived from the *Korra tef* farm. Household income was calculated in Ethiopian *Birr* (ETB) and described in its United States dollar (US$) equivalents. The theoretical and empirical research suggested that the factors represented in Table 2, namely demographic, socio-economic and institutional variables play critical roles in enhancing or impairing smallholder farmers' farm productivity and income. These traits were chosen based on their applicability to the characteristics of the target population and were regarded as independent variables.

Data analysis. STATA version 16 Software Package was used for the quantitative data analysis, which involved applying descriptive statistics and econometric analysis. On the other hand, transcripts of the qualitative data were used to support the interpretation of the quantitative data. The Propensity Score Matching procedures were adapted from Rosenbaum and Rubin (1983). The mean, standard deviation, proportions, frequency and percentages of respondents, were compared using statistical analysis techniques of Chi-square and t-test analysis. The qualitative data obtained from the KIIs were embedded into the quantitative data, enriching the overall analysis and providing deeper insights.

In the PSM model, the purpose was to estimate the treatment effect of using the *Korra tef* variety (d) on the outcomes of farm households, specifically their productivity and income, denoted as Y. The outcomes, Y, depend on a combination of characteristics specific to each farm household, represented as "j" for productivity and "I" for income. The equation used for estimating the treatment effect, denoted as 2, is as follows:

$$Y = \alpha + \tau d_j + \beta X_{ij} + \varepsilon \text{ .... Equation 2}$$

Where:

α represents the intercept or baseline level of the outcomes. The term τd_j captures the treatment effect of using the *Korra tef* variety (d) for each individual farm household. The coefficient β represented the effect of additional covariates or characteristics denoted as X_ij on the outcomes. Lastly, å represented the error term or unobserved factors that might influence the outcomes.

This Equation allows us to quantify the specific impact of adopting the *Korra tef* variety (d); while accounting for other relevant factors (X_ij) that may affect productivity and income. By using the PSM method, we can establish a more robust estimate of the treatment effect by matching farm households based on their propensity to adopt the *Korra tef* variety, minimising the potential bias that can arise from self-selection or confounding variables. Overall, Equation 2 provides a clear and structured framework for analysing the treatment effect of using the *Korra tef* variety

TABLE 2. Definition and measurements of the independent variables used in the study

Notation	Name of the variables	Type	Unit/Measurement	Expected sign
SEXHH	Gender of household head	Dummy	1 for male, 0 for female	±ve
MARSTATUSHH	Marital status of household head	Categorical	Scores from 1 - 6	±ve
FARMEXPHH	Farming experiences of household head	Continuous	Farm experience of household head (in years)	+ve
HHSIZE	Family size of household	Continuous	Total number of household members	+ve
TOTLAND	Total farmland	Continuous	Household's total farmland (ha)	+ve
TLU	Livestock owned by household	Continuous	Tropical Livestock Unit	+ve
RADIOOWN	Functional radio	Dummy	1 for yes, 0 for none	+ve
CREDUSE	Access to credit services	Dummy	1 for yes, 0 for none	+ve
FTCDIST	Distance household travels from home to Farmers Training Centers (FTC), where AGP II focal personnel resides	Continuous	Km	-ve
MAINPARTCCOOP	The cooperative and/or association households largely engaged in	Categorical	Scores from 1-10	+ve
MRKTDIST	A distance from home to the main market (to input and output market)	Continuous	Km	+ve
INONFARMACT	Income from non-farm activities	Continuous	ETB	+ve
REMIT	Remittances, money transferred both from inside the country and abroad	Continuous	ETB	+ve

on farm household outcomes, incorporating the PSM methodology and relevant covariates.

The mean productivity difference between the treatment (*Korra tef* adopters) and the control group (non-adopters) can be viewed in Equation 3 (τATE). Since there could have been unobservable factors that may be correlated with the adoption of *Korra tef,* as well as with omitted factors that affect its productivity and income, it is practically difficult to determine the impacts of *Korra tef* utilisation on productivity and incomes, with accurate comparison of the productivity and incomes of households with and without *Korra*, which is responsible for the fundamental difficulties associated with the counterfactual situation. As a result, we turn in to determining the average treatment effect on the treated (ATT) than the average treatment effect (ATE). The yield and net income impacts of the *Korra tef* on its producers *versus* non-producers are referred to by ATT in this study and are outlined as follows:

$\tau ATE = E[Y|X, d = 1] - E[Y|X, d = 0]$ .... Equation 3

Where:

Y1 and Y0 in Equation 4 represent the productivity and income of *Korra tef* adopters against non-adopters; and [Y0|d=1] represents the counterfactual result for the treated groups if they had not used *Korra*.

Due to self-selection into *Korra* use, switching E [Y0|d=1] by E [Y0|d=0], observable may not correctly estimate Y0 for the treated and non-treated can systematically differ.

$ATT = [Y_1|d=1] - [Y_0|d=1]$ .... Equation 4

To compare farm households that had used *Korra,* with those that had not, but had similar characteristics, the matching process that followed was employed. A propensity score is the probability of *Korra tef* variety utilisation, p(x) conditional on a set of characteristics, x:

$p(x) = P_r[d = 1|x] = E[d|x]$ .... Equation 5

Yet, it is important to take into account the Conditional Independence Assumption (CIA) requirements, which states that the outcome variables (Y0) are independent of the treatment (adoption of *Korra*) conditional on a set of observable variables (x), as well as the common support that enables appropriate comparison.

RESULTS AND DISCUSSION

Demographic characteristics. The descriptive results of the study revealed that male-headed households constituted a significant majority, accounting for 90.81% of the population. Among adopters, male-headed households represented 89.14%, while among non-adopters; the figure was slightly higher at 92.25% (Table 3). These findings align with the statistics reported by the Ethiopian Rural Household Survey (ERHS), which indicated that approximately one-quarter of households in Ethiopia were headed by women (World Bank, 2016). The similarity in the proportion of male-headed households between the adopter and non-adopter groups is an important observation for the upcoming impact evaluation section of the study. It ensures that meaningful comparisons can be made between the two groups when analysing the impacts of adopting the *Korra tef* variety. The fact that the study areas closely reflect the national average in terms of the proportion of female and male-headed households further enhances the generalisability of the study's findings.

Understanding the gender composition of households is crucial for agricultural development interventions, as it allows for a more nuanced analysis of the impacts on different household types. In the context of this study, the high representation of male-headed households indicates that the findings

TABLE 3. Statistical summary of χ^2-test distribution for dummy and categorical variables

Explanatory variables	Categories	Total sample (%)	Non-adopters (%)	Adopters (%)	χ^2 (P-value)
SEXHH	Male	435 (90.81%)	238 (92.25%)	197 (89.14%)	1.3782 (0.240)
	Female	44 (9.19%)	20 (7.75%)	24 (10.86%)	
MARSTATUSHH	Married, Single Spouse	442 (92.28%)	241 (54.52 %)	201 (45.48%)	11.3183
	Married, more than one spouse	5 (1.04%)	2 (40.00%)	3 (60.00%)	(0.045**)
	Single	4 (0.84%)	3 (75.00%)	1 (25.00%)	
	Divorced	9 (1.88%)	4 (44.44%)	5 (55.56%)	
	Widowed	10 (2.09%)	1 (10.00%)	9 (90.00%)	
	Not together for any reason	9 (1.88%)	7 (77.78%)	2 (22.22%)	
RADIOOWN	Yes	215 (44.89%)	104 (40.31%)	111 (50.23%)	4.7314
	No	264 (55.11%)	154 (59.69%)	110 (49.77%)	(0.030**)
CREDUSE	Yes	271 (56.58%)	113 (43.80%)	95 (42.99%)	0.0319 (0.858)
	No	208 (43.42%)	145 (56.20%)	126 (57.01%)	
MAINPARTCCOOP	Agricultural cooperative	275 (57.41%)	128 (49.61%)	147 (66.52%)	24.6069 (0.003***)
	Village saving and loan association	35 (7.31%)	26 (10.08%)	9 (4.07%)	
	RUSSACO	47 (9.81%)	23 (8.91%)	24 (10.86%)	
	Iddir	12 (2.51%)	8 (3.10%)	4 (1.81%)	
	Equub	9 (1.88%)	6 (2.33%)	3 (1.36%)	
	Kebele council	20 (4.18%)	9 (3.49%)	11 (4.98%)	
	Youths' association	27 (5.64%)	19 (7.36%)	8 (3.62 %)	
	Women's association	8 (1.67%)	6 (2.33%)	2 (0.90%)	
	Local representative	22 (4.59%)	16 (6.20%)	6 (2.71%)	
	Religious organization	24 (5.01%)	17 (6.59%)	7 (3.17%)	

***, ** indicates significant at 1 and 5%; Standard errors in parenthesis. Source: Computed from own survey data (2020) regarding the adoption of the *Korra tef* can be generalised to a significant portion of the farming population in Ethiopia. However, it is important to note that gender dynamics and roles within households can influence the adoption and impact of agricultural innovations. Further research and analysis are necessary to explore how gender factors may interact with the adoption of the *Korra tef* and its impacts on household productivity and income. Such insights can inform targeted strategies to promote gender-equitable agricultural development and maximise the benefits of improved *tef* seed varieties for all household members.

The chi-square test conducted on the treatment groups revealed that gender and credit availability do not exhibit significant differences (P>0.05) in the context of the impact of *Korra tef* adoption on farm household productivity and incomes in central Ethiopia (Table 3). The non-significance of gender and credit availability in relation to the impact of *Korra tef* adoption suggests that these factors are not major barriers that influence the outcomes of interest in this study, thereby enabling a meaningful comparison. However, the analysis demonstrated significant disparities (P<0.05) between the two groups regarding marital status, ownership of radio sets, and participation in various cooperatives and/or organisations. These findings suggest that these factors could potentially introduce imbalances between the groups. Therefore, it is crucial to acknowledge that additional balancing mechanisms are necessary to ensure the creation of groups with comparable characteristics.

The t-test results revealed significant differences (P<0.05) between the treatment and control groups across various factors, including farming experience, household size, total farmland, livestock ownership, market and Framers Training Center (FTC) distances, and remittances received (Table 4). These findings indicate that there are notable variations among the comparison groups, which need to be carefully balanced. In other words, to ensure a meaningful comparison between the treatment and control groups, it is crucial to carefully address and balance these significant differences.

The mean household size was 7 people, indicates a relatively large family size. This finding aligns closely with the 2016 Demographic and Health Survey (DHS) report for Ethiopia, which reported an average of 4.6 children per family (CSA, 2017). The size of a household can have diverse impacts on its productivity and income. If effectively

TABLE 4. Statistical summary of t-test for continuous variables

Explanatory variables	Mean values			t (P-value)
	Non-adopters	Adopters	Combined	
FARMEXPHH	17.00388	18.70136	17.78706	-2.0607 (0.0399**)
HHSIZE	6.589147	7.235294	6.887265	-2.9413 (0.0034***)
TOTLAND	1.805075	1.871136	1.871136	-2.0189 (0.0441**)
TLU	4.546046	3.000905	3.833152	4.8607 (0.0000***)
FTCDIST	2.907558	2.316742	2.634969	4.9171 (0.0000***)
MRKTDIST	10.46047	11.50362	10.94175	-4.1677 (0.0000***)
INONFARMACT	83.22 US$	97.73 US$	89.92 US$	-0.8295 (0.4072)
REMIT	52.87 US$	32.00 US$	43.24 US$	2.0512 (0.0408**)

****P<0.01; **P<0.05; Standard errors in parenthesis. Source: computed from own survey data (2020) harnessed as a source of family labour, a large household size can lower labor costs and production expenses, potentially leading to positive outcomes. Conversely, having a significant number of dependents within a household can potentially limit income and productivity. Furthermore, enhancing farmers' knowledge and skills through training programmes, promoting access to credit, and improving infrastructure are crucial for the successful adoption of improved *tef* varieties (Assaye and Habte, 2022). In terms of non-farm activities, the earnings of both groups did not significantly differ from each other. The absence of significant differences in non-farm earnings between the treatment and control groups is essential for the study's objective of assessing the specific impact of the *Korra tef* variety. It suggests that factors related to non-farm activities, such as alternative income sources or employment opportunities, are not major drivers of variations in outcomes between the two groups.

During the 2020 production season, both the adopters and non-adopters of the *Korra tef* variety utilised a range of inputs for *tef* production. These inputs comprised seeds, fertilisers, various soil fertility reclamation methods, herbicides, and insecticides. These inputs were considered colossal costs and were included in the analysis. The total amount of labour, both family and hired labour, was also taken into account for the two study groups. All input costs were converted into the prevailing market price in United States Dollars (USD), using the average exchange rate of 36.65 Ethiopian Birr (ETB) per 1 USD, as reported in September 2020.

Data presented in Table 5 indicate a significant difference ($P < 0.01$) in the amount of *tef* seed used per household, with non-adopters utilising more seeds compared to their adopter counterparts. It is important to note that this difference in seed usage is not directly related to seeding rate or resulting planting density. However, understanding the underlying reasons for this difference is crucial in assessing the overall benefits of adopting the *Korra tef*. According to the KIIs, the adoption of the *Korra tef* leads to a reduction in the amount of seed sowed per hectare. This phenomenon can be attributed to several factors. Firstly, improved *tef* varieties often possess superior genetic characteristics, such as higher yield potential and better resistance to pests and diseases. These traits enable farmers to achieve comparable or even higher yields with a reduced amount of seed. Although these factors may not directly impact seeding

TABLE 5. Mean input use for *tef* production by respondent types (kg ha^{-1})

Input item	Mean values			t (P-value)
	Non-adopters	Adopters	Combined	
Seed (*Korra tef* variety for adopters and other than *Korra* for non-adopters)	27.17338	16.90991	22.43804	73.0644 (0.0000***)
DAP	90.40628	93.71516	91.93292	-3.9723 (0.0001***)
Urea	108.0736	110.737	109.3024	-2.5934 (0.0098***)
Herbicide	0.958217	1.04669	0.999039	-2.1322 (0.0335**)
Insecticide	1.050039	1.093484	1.070084	-2.3060 (0.0215**)

***P<0.01; **P<0.05; Standard errors in parenthesis. Source: computed from own survey data (2020) rate or planting density, they play a significant role in optimising space utilisation for optimal yield outcomes. By leveraging the advantages of improved varieties, farmers can avoid unnecessary costs associated with excessive seed usage while increasing the efficiency of their farming practices (Assefa *et al*., 2013).

While it is true that these factors may not directly influence seeding rate or resulting planting density, they contribute to the overall rationale behind adopting the Korra tef variety. The benefits of reduced seed usage and optimised space utilisation are essential considerations for farmers seeking improved yield outcomes and cost-effectiveness in their agricultural practices.

Therefore, despite not directly relating to seeding rates or resulting planting density, these factors are significant in assessing the value and potential of adopting the Korra tef variety. By adopting this improved variety, farmers can achieve comparable or even higher yields while optimising the use of seeds and field space. This understanding reinforces the importance of considering these factors when evaluating the benefits and feasibility of adopting the *Korra tef* variety. Additionally, improved *tef* varieties are typically bred and selected for their desirable agronomic traits, such as uniform height, tillering capability, and better stand establishment. These traits contribute to better plant spacing and distribution, thus allowing for optimal resource utilisation, including sunlight, water, and nutrients. As a result, farmers can achieve adequate plant populations and attain desired yields with a lower amount of seed per hectare (Mihretie *et al*., 2021; Desta *et al*., 2022).

Additionally, a significant difference was observed between the mean costs of *tef* seed utilised by the groups, as illustrated in Table 6. This difference can likely be attributed to the significant variance in prices between the *Korra tef* variety and other *tef* varieties. Qualitative data revealed that the price range for 1 kg of *Korra tef* variety was between US$ 1.3 and 1.41; whereas that for an equivalent amount of other *tef* varieties ranged from US$ 1 to 1.3. Comparable significant differences were also evident in the groups' utilisation of other agricultural inputs, including Diammonium phosphate (DAP), urea, herbicides, and pesticides, with adopters surpassing non-adopters in this regard (Table 5). This finding aligns with the insights gathered from KIIs, which suggested that the cultivation of *Korra tef* necessitates a higher application of fertilisers, herbicides, and pesticides than alternative *tef* varieties. Furthermore, the active involvement of the AGP II, which extensively engaged in awareness-raising initiatives related to agriculture, may have played a role in encouraging adopters to adhere more closely to recommended dosages of agricultural inputs. As a result, adopters exhibited a higher usage of agricultural inputs compared to their non-adopter counterparts. The idea that a higher-yielding variety takes more labour, for it yields more output per unit of labour (Bekele *et al*., 2019) may also explain the difference in mean labour costs (Coelli *et al.*, 2005; Abate *et al.*, 2015). The qualitative finding in which the KIIs stated that the *Korra tef* farms required more labour than other types of *tef,* supports labour-related findings.

The analysis of data presented in Table 6 reveals that there are no significant differences in the use of compost and soil erosion protection measures between the treatment and control groups. This finding indicates that a considerable number of farmers from both groups have actively employed compost and implemented soil erosion protection practices to enhance the maximum yield potential of their land. The insignificant differences in the use of compost and soil erosion protection measures between the treatment and control groups imply that both groups utilised these technologies to enhance their land's productivity, regardless of the seed varieties they adopted. This in turn enables a meaningful comparison between the two groups regarding the specific yield and income impacts of adopting the improved *tef* variety.

TABLE 6. Mean input costs of *tef* production by respondent types (US$ ha^{-1})

Inputs	Mean values			t (P-value)	Remark
	Non-adopters	Adopters	Combined		
Seed (*Korra tef* variety for adopters and other than *Korra* for non-adopters)	29.46	22.51	26.26	40.9736 (0.0000***)	
DAP	37.00	38.36	37.63	-3.9731 (0.0001***)	
Urea	39.81	40.79	40.26	-2.5933 (0.0098***)	
Soil erosion protection	0.98	1.08	1.02	-0.2819 (0.7781)	
Compost	36.63	36.37	36.51	0.1827 (0.8551)	
Herbicide	4.71	5.14	4.91	-2.1270 (0.0339**)	
Insecticide	7.16	7.46	7.30	-2.2999 (0.0219**)	
Labor	305.77	465.14	379.30	-37.1498 (0.0000***)	
Land rent	(125.65) 14 respondents	(27.29) 1 respondent	(119.5089) 15 respondents	-	This variable is excluded from the estimation of cost due to the lack of representative sample observations from both categories
Total production cost	468.78	633.65	544.85	-29.8676 (0.0000***)	

***P<0.01; **P<0.05; Standard errors in parenthesis. Source: computed from own survey data (2020)

Although respondents and KIIs from both adopters and non-adopters of the *Korra tef* variety did not allude to using irrigation for their *tef* farms, there could be potential for greater yields of *tef* under supplementary irrigation. Previous studies highlighted the significance of irrigation in increasing agricultural productivity, including for *tef* cultivation (Diriba, 2018).

Proper irrigation management enhances crop growth by optimising water use efficiency, and mitigates water stress on *tef* plants (Tsegay *et al*., 2015). Nevertheless, the exact response of *Korra tef* to supplementary irrigation in Ethiopia needs to be established to avoid possible under performance of this variety due to the various types of bio- and abio-stress prevalent in this environment.

The analysis of total variable costs incurred for tef production revealed significant differences between adopters and non-adopters. The average cost for adopters was US$ 633.65, while non-adopters incurred an average cost of US$ 468.77. The observed difference in costs between the two groups was statistically significant at $p < 0.01$ (Table 6). The findings of this study are supported by qualitative evidence, which indicates that adopting improved *tef* varieties, such as *Korra tef*, entails a greater financial investment compared to local *tef* varieties. However, despite the higher costs, adopters are able to achieve relatively better yields. A case study conducted in North-Eastern Ethiopia revealed that farmers who embraced the *Boset tef* variety experienced higher input costs, including expenditures on fertilisers and seeds, as well as increased production costs (Natnael, 2019). Another study highlighted that labor and fertiliser were the major production costs for *Korra* and *Boset tef* varieties, accounting for 58 and 22% labour costs. Respectively, compared to local *tef* varieties (Bekele *et al*., 2019).

The observed cost disparity between adopters and non-adopters of improved *tef* varieties carries significant implications for enhancing productivity and incomes in the study area. The higher input and production costs associated with adopting improved *tef* varieties can create barriers for farmers, limiting their ability to access and benefit from these varieties. To overcome this challenge and promote wider adoption, targeted support and interventions are crucial. These could include: Access to Subsidies, Extension Services, Farmer-to-Farmer Knowledge Sharing and Research and Development:

By implementing targeted support and interventions, policymakers, agricultural organisations, and stakeholders can work together to address the cost disparity and encourage wider adoption of improved *tef* varieties. This, in turn, can contribute to enhancing productivity and increasing incomes for farmers in the study area.

The existing literature highlights the importance of addressing the financial burden associated with adopting improved *tef* varieties, as well as providing capacity building and extension services on cost-effective farming practices (Assefa *et al*., 2013; Shiferaw *et al*., 2014). However, it is important to note that these measures alone may not directly bring down the overall production costs of improved varieties compared to conventional *tef* varieties while maintaining superior yields, because reducing the cost of production of improved *tef* varieties while maintaining superior yields is a complex and multifaceted challenge as it requires a combination of research and development, capacity building, market access, policy support, and collaboration among various stakeholders. Additionally, research and development efforts should focus on developing sustainable and resilient *tef* production systems, optimising resource utilisation, reducing production costs, and enhancing productivity.

The adopters generated a mean annual income of US$ 1,754.71, whereas non-adopters earned US$ 946.43 per hectare (Table

7). Importantly, this income disparity is statistically significant, as indicated in Table 7. These findings suggest that adopters exhibited higher levels of productivity and achieved greater income from *tef* production. The observed productivity and income disparity between adopters and non-adopters can be attributed to a combination of factors, including the adoption of the *Korra tef*. To comprehensively analyse the underlying reasons behind the observed differences in productivity and income, an econometrics model is employed. This model takes into account various factors, including the adoption of the *Korra tef* variety, as well as other relevant variables. By considering these additional factors, the model aims to provide a more comprehensive understanding of the productivity and income disparities between adopters and non-adopters of *Korra tef*.

Figure 2 shows a comparison of the mean variations in *tef* productivity and net income between adopters and non-adopters.

Estimation of Propensity Score. In order to thoroughly examine the observed differences between adopters and non-adopters, a model was employed in the study. Prior to implementing the model, precautionary measures were taken to address the issue of multicollinearity. This was done by conducting tests on the Variance Inflation Factor (VIF) for continuous variables and the Contingency Coefficient for dummy/categorical variables. The results of these tests revealed that all continuous variables exhibited VIF values below 1.21, with a mean value of 1.09 (Table 8). Additionally, the Contingency Coefficients for the dummy/categorical variables were found to be close to zero (Table 9). These findings indicate that the model is devoid of multicollinearity, which is an important consideration in regression analysis.

By addressing the issue of multicollinearity, the study ensures that the independent variables included in the model are not overly correlated with each other. This allows for more reliable and accurate regression analysis, as multicollinearity can lead to biased coefficient estimates and inflated standard errors.

The decision to conduct tests for multicollinearity and ensure the absence of this issue in the model instills confidence in the subsequent regression analysis. By taking these precautionary measures, the study establishes a solid foundation for investigating the relationship between the adoption of *Korra tef* and the observed differences in productivity and income.

The STATA results in Table 10 reveal significant differences between the treatment and control groups in several variables, including household size, farming experience, total farmland, livestock ownership,

TABLE 7. Level of productivity and income of *tef* producers in 2020

Outcome variables	Obs	MeanStd.	Dev.	Min	Maxt	(P-value)
Productivity (ha^{1})	479	1712.639	336.5133	1058.823	2575.758	-43.7648 (0.0000***)
	258	1434.254	132.4452			
	221	2037.632	169.0124			
Income (US$ ha^{-1})	479	1319.36	439.05	576.87	2244.82	-28477.43 (0.0000***)
	258	946.44	141.26			
	221	1754.71	204.99			

***P<0.01; Standard errors in parenthesis. Source: computed from own survey data (2020)

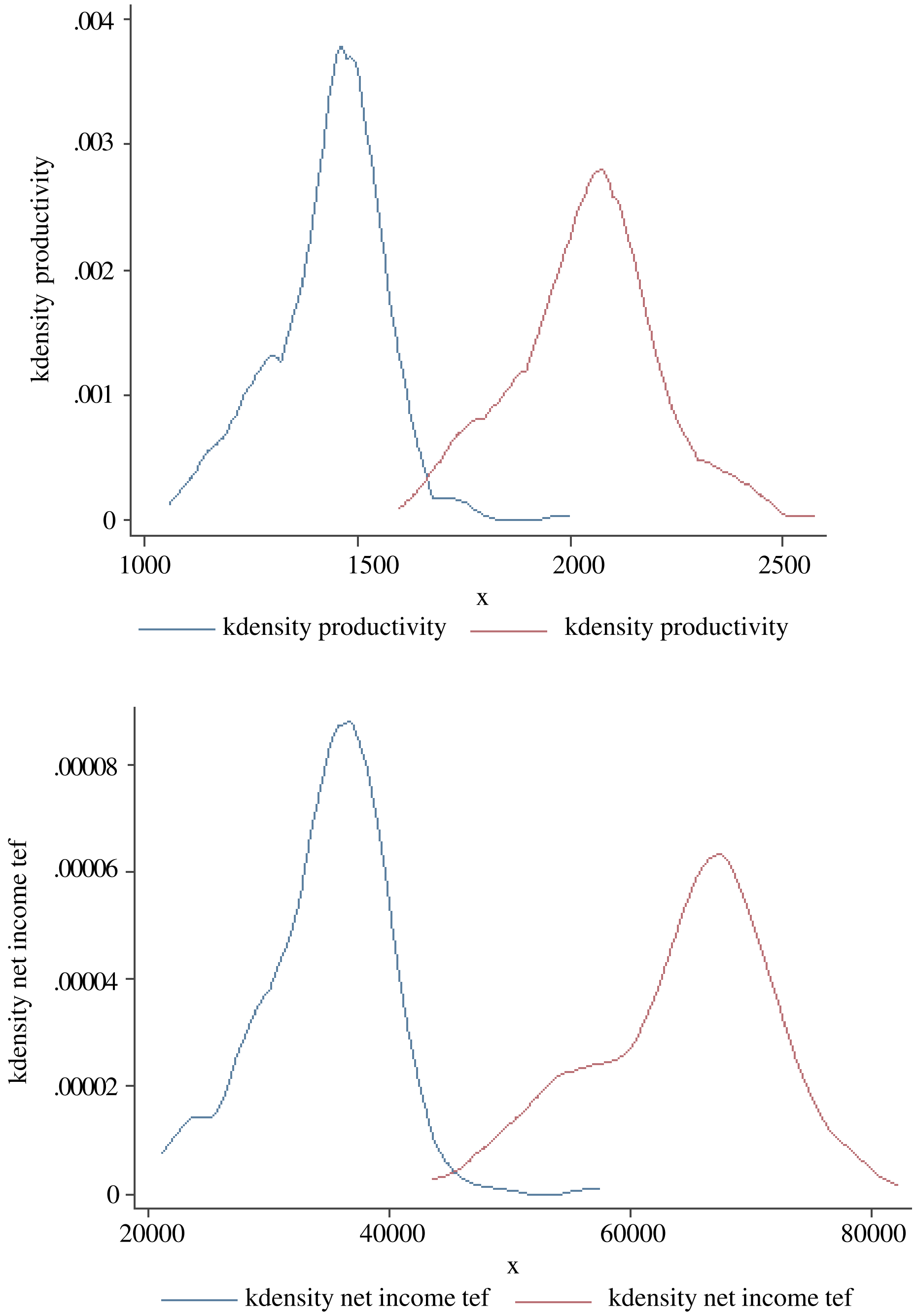

Figure 2. Comparisons of productivity and income differences. Source: STATA output.

TABLE 8. Result of Variance Inflation Factor (VIF)

Variables	VIF	1/VIF
HHSIZE	1.06	0.943059
FARMEXPHH	1.21	0.824110
TOTFARMLAND	1.20	0.830737
TLU	1.07	0.931316
FTCDIST	1.05	0.953237
MRKTDIST	1.02	0.979941
INONFARMACT	1.07	0.934798
REMIT	1.05	0.952393
	1.09	

Source: computed from own survey data (2020)

TABLE 9. Contingency coefficients test for discrete variables

Variables	(1)	(2)	(3)	(4)	(5)
(1) SEXHH	1.000				
(2) MARSTATUSHH	-0.397	1.000			
(3) MAINPARTCCOOP	-0.114	0.086	1.000		
(4) CREDUSE	0.086	-0.068	0.026	1.000	
(5) RADIOOWN	0.025	0.012	-0.071	-0.031	1.000

Source: computed from own survey data (2020)

membership in agricultural cooperatives and/or associations, radio ownership, distances from the FTC and market, and remittances. While these variables may not initially appear directly pertinent to the study's objectives of estimating the impacts of *Korra tef* adoption on adopters' productivity and income, they do have relevance when considered in the context of the study's overall thrust.

These variables, despite not being directly related to *tef* adoption, are important factors that have the potential to influence productivity and income outcomes. By identifying significant differences in these variables between the treatment and control groups, the study acknowledges the existence of initial imbalances that could introduce bias in the estimation of the impacts of *Korra tef* adoption.

The matching process, guided by the objective of creating a homogeneous group, intends to reduce or eliminate the effects of these confounding variables. By striving for covariate balance through matching, the study aims to ensure that any observed differences in productivity and income outcomes between the adopters and non-adopters can be more confidently attributed to the treatment (*Korra tef* adoption) rather than the imbalances in the covariates. This is because the matching process helps create comparable groups by balancing the distribution of these relevant covariates, thereby mitigating the potential confounding effects of the imbalanced variables.

Through the matching process, the study seeks to achieve a higher degree of

TABLE 10. Probit regression of adoption

Variables	Coef.	Std.Err.	P>z
SEX	-0.3809371	0.2389731	0.111
HHSIZE	0.1157336	0.0282889	0.000
MARSTATUSHH	0.0106221	0.0695231	0.879
FARMEXPHH	0.0161557	0.007943	0.042
TOTFARMLAND	0.4486467	0.2001243	0.025
TLU	-0.1182213	0.0233214	0.000
MAINPARTCCOOP	-0.0745842	0.0203583	0.000
RADIOOWN	0.4734555	0.1324159	0.000
CREDUSE	0.0021285	0.1321177	0.987
FTCDIST	-0.2699168	0.0512259	0.000
MRKTDIST	0.1143858	0.0239768	0.000
INONFARMACT	7.41e-06	9.33e-06	0.427
REMIT	-0.0000329	0.0000164	0.045
_cons	-1.775279	0.5628004	0.002
Log-likelihood	-265.18831		
Number of obs	479		
LR chi2(13)	130.80		
Prob > chi2	0.0000		
Pseudo R2	0.1978		

Source: computed from own survey data (2020)

comparability between the adopters and non-adopters, reducing the likelihood of spurious associations and enabling a more accurate estimation of the impacts of *Korra tef* adoption. By addressing the initial imbalances and striving for covariate balance, the study aims to provide stronger evidence regarding the relationship between *tef* adoption and productivity and income outcomes.

Therefore, even though the variables showing significant differences may not seem directly related to the study's objectives at first glance, they are indeed relevant when considering the broader context of the study's objectives and the potential influence of these variables on productivity and income outcomes. By addressing these imbalances through the matching process, the study can provide more reliable and robust estimates of the impacts of *Korra tef* adoption, enhancing the validity of the findings.

Testing the balance of Propensity Score and Covariates. The Ps-test was employed to achieve covariate balance between the two groups. Initially, there was noticeable bias in the distribution of covariates, with bias percentages ranging from 1.6 to 45.6. However, after matching, the bias percentages significantly decreased to a range of 0.2 to 6.8 (Table 11). This reduction in bias indicates that the imbalance between the treatment and control samples was effectively minimised, strengthening the validity of the subsequent estimation processes. The achievement of covariate balance through matching is crucial in addressing the study's objective. By reducing the bias in the distribution of covariates, the study ensures that any observed differences in outcomes between the adopters and non-adopters can be more confidently attributed to the treatment (*Korra tef* adoption)

TABLE 11. Propensity score and covariate matching

Variables	Unmatched Matched	Mean		% bias	% reduction |bias|	P>|t|
		Treated	Control			
Sex	U	0.8914	0.92248	-10.7		0.241
	M	0.89302	0.89233	0.2	97.8	0.981
HHSIZE	U	7.2353	6.5891	27.0		0.003
	M	7.1488	7.1951	-1.9	92.8	0.832
MARSTATUSHH	U	1.2986	1.2287	7.2		0.434
	M	1.2884	1.3218	-3.4	52.2	0.744
FARMEXPHH	U	18.701	17.004	19.0		0.040
	M	18.428	18.295	1.5	92.2	0.875
TOTFARMLAND	U	1.8711	1.8051	18.5		0.044
	M	1.8696	1.8773	-2.2	88.3	0.818
TLU	U	3.0009	4.546	-45.5		0.000
	M	3.0254	3.0633	-1.1	97.5	0.870
MAINPARTCCOOP	U	2.5158	3.5891	-32.8		0.000
	M	2.5349	2.6681	-4.1	87.6	0.634
RADIOOWN	U	0.50226	0.4031	20.0		0.030
	M	0.49302	0.50055	-1.5	92.4	0.876
CREDUSE	U	0.57014	0.56202	1.6		0.859
	M	0.57209	0.58049	-1.7	-3.4	0.861
FTCDIST	U	2.3167	2.9076	-45.6		0.000
	M	2.3498	2.438	-6.8	85.1	0.446
MRKTDIST	U	11.504	10.46	38.6		0.000
	M	11.476	11.582	-3.9	89.8	0.686
INONFARMACT	U	3581.9	3050.2	7.6		0.407
	M	3542.3	3496.9	0.6	91.5	0.948
REMIT	U	1172.9	1937.6	-19.0		0.041
	M	1178.6	1235.9	-1.4	92.5	0.859

Source: computed from own survey data (2020)

rather than the initial imbalances in the covariates.

Additionally, the fact that the bias percentage remained well below the 20% critical threshold cutoff point is significant. This threshold is often used as a guideline to determine the extent of covariate imbalance that can affect the accuracy of treatment effect estimation (Rosenbaum and Rubin, 1983). By keeping the bias percentage below this threshold, the study ensures that the estimated treatment effect of using the *Korra tef* variety is more reliable and less prone to confounding. Based on this information, the way forward would involve utilising the improved covariate balance achieved through matching in subsequent estimation processes. The successful balance achieved between the covariates of the treatment and control groups through the Ps-test allows for more accurate estimation of the treatment effect. It strengthens the study's findings and provides a solid foundation for drawing meaningful conclusions about the impact of adopting the

Korra tef variety. In light of this, the next procedure is the choice of an appropriate matching algorithm.

Choice of matching algorithm. To determine the best estimation model, the four main matching estimators were tested. Table 12 lists the STATA outputs of these estimators. The Nearest Neighbor Matching (with 2, 3, 4, and 5-Nearest Neighbors); as well as all Radius and Kernel matching estimates, have all met the (Rubin, 2006) criterion that states that for the overall balance to be sufficient, a value of B should lie below 25 and a value of R should lie between 0.5 and 2. However, we chose the Kernel estimator with a Bandwidth of 0.1 as it has shown the lowest mean bias (2.3) and B value (11.0). The values of Ps R2 and LR chi2 were also used as indicators for the completion of the balancing criteria. The assumption that both groups have a similar distribution in covariates after matching is verified by the relatively low Ps R2 (0.002 in the estimate we selected) and the insignificant LR chi2 (1.30) after matching.

According to the Minima and Maxima criterion, those observations whose propensity score is both smaller than and larger than that of the opposing group were eliminated while determining the common support region (Caliendo and Kopeinig, 2008). As a result, the range of common support is between 0.065 and 0.893 (Table 13), and any households outside of this range were excluded from the matching process. Fortunately, in all matching estimators, only six observations were shown outside of the common support zone.

Figure 3 depicts the propensity score of the density of distribution of the treatment and control groups. This indicates that the balance has been successfully attained because the p-score is fairly distributed between the treatment and control groups.

Estimation of treatment effect on the treated. Tables 14 and 15 show the results of the impacts of the adoption of *Korra tef* on

TABLE 12. Comparison of the matching estimators for both productivity and income

Performance criteria	Un matched	Matching estimates													
		Nearest Neighbour					Caliper			Radius caliper			Kernel		
		NN (1)	NN (2)	NN (3)	NN (4)	NN (5)	0.01	0.05	0.1	0.01	0.05	0.1	Band width 0.01	Band width 0.05	Band width 0.1
Ps R^2	0.198	0.009	0.009	0.007	0.005	0.004	0.009	0.009	0.009	0.006	0.003	0.003	0.008	0.003	0.002
LR chi2	130.80	5.57	5.08	4.10	2.86	2.61	5.57	5.57	5.57	3.75	1.97	1.57	4.77	1.74	1.30
P>chi^2	0.000	0.96	0.973	0.990	0.998	0.999	0.960	0.960	0.960	0.994	1.000	1.000	0.980	1.000	1.000
MeanBias	22.5	5.7	4.9	4.2	3.1	3.2	5.7	5.7	5.7	3.5	3.0	2.5	4.3	2.7	2.3
MedianBias	19.0	5.5	4.9	4.3	2.8	3.6	5.5	5.5	5.5	2.4	2.2	1.9	5.1	2.6	1.7
B	112.4*	22.8	21.8	19.5	16.3	15.5	22.8	22.8	22.8	18.7	13.5	12.1	21.1	12.7	11.0
R	0.50*	0.86	0.97	0.98	0.92	0.90	0.86	0.86	0.86	0.88	0.61	0.71	0.95	0.65	0.68
%Var	60	40	40	40	40	40	40	40	40	40	50	40	40	30	40

Source: computed from own survey data (2020)

TABLE 13. Distribution of estimated propensity scores

Variable pscore	Groups	Obs.	Mean	Std. dev.	Min	Max
	Total HH	479	0.4580324	0.2474228	0.0007765	0.9636034
	Treated	221	0.5884689	0.1892896	0.0653953	0.9636034
	Control	258	0.346302	0.2366982	0.0007765	0.8932305

Source: computed from own survey data (2020)

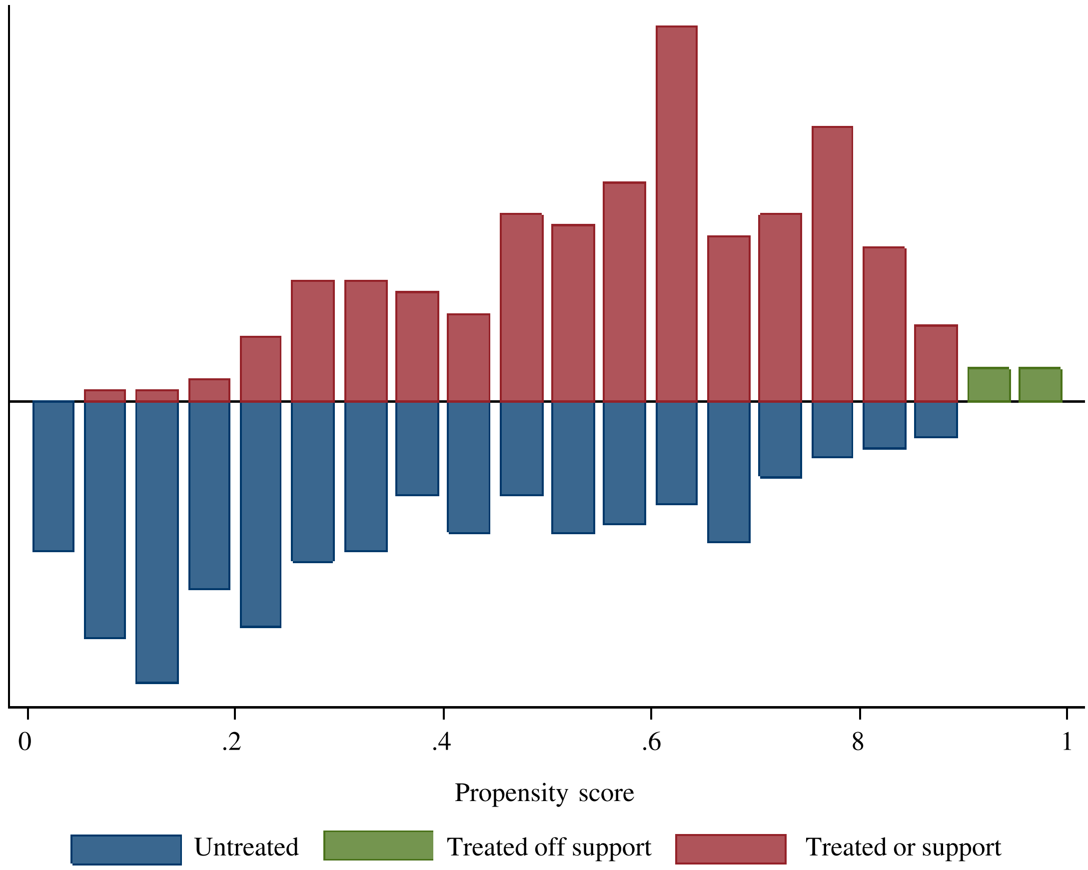

Figure 3. Distribution of propensity score generated from Kernel matching. Source: STATA output (2020).

TABLE 14. Productivity result of mean treatment effect on the Treated (ATT)

Variable	Sample	Treated	Controlled	Difference	S.E	T-stat
Productivity (ha)	Unmatched	2037.63235	1434.25385	603.378504	13.7868468	43.76
	ATT	2037.22512	1438.44577	598.779347	16.3709648	36.58

Source: Computed from own survey data (2020)

TABLE 15. Income result of mean treatment effect on the treated (ATT)

Variable	Sample	Treated	Controlled	Difference	S.E	T-stat
Net income(USD$)	Unmatched		946.44	808.27	15.91	50.80
	ATT	1753.93	947.20	806.73	18.64	43.27

Source: computed from own survey data (2020)

the outcome variables of productivity and income.

CONCLUSION

The results from this study indicate that the adoption of the *Korra tef* variety led to significant improvements in both *tef* productivity and household income. According to the PSM model used in the analysis, *tef* productivity increased by approximately 598.78 kg (nearly 6 quintals) per hectare among adopter farm households compared to non-adopters. This demonstrates the positive effect of the improved variety on crop yield. Furthermore, adopting the *Korra tef* variety resulted in an increase in household income by US$ 806.73 per hectare. This suggests that the improved variety not only enhances productivity but also contributes to the income of farm households. The findings highlight the potential of the *Korra tef* variety as a means to improve the livelihoods of adopter smallholder farmers in Ethiopia. The study underscores the importance of promoting the adoption of high-yielding varieties like *Korra tef* to enhance agricultural productivity and income generation. These findings have significant implications for policymakers, agricultural extension services, and development organisations working in the region. Encouraging the adoption of the *Korra tef* can be an effective strategy to address the challenges of low productivity and inadequate access to high-quality seeds in the region. However, it is essential to ensure the availability and accessibility of improved seeds to farmers, especially smallholders, to maximise the potential benefits. Additionally, further research are needed to assess the long-term sustainability and scalability of the adoption of the *Korra tef* variety, as well as its potential impact on other aspects such as soil type, biodiversity, agroecological zones, the amount of farmland set aside for *tef* production, and/or the degree of adoption, etc.

ACKNOWLEDGMENT

This study was funded by the Debre Berhan University and the Ministry of Education, Federal Democratic Republic of the Ethiopian, to whom we are heartily grateful.

REFERENCES

Abate, Shiferaw, B., Menkir, A., Wegary, D., Kebede, Y., Tesfaye, K., Kassie, M., Bogale, G., Tadesse, B. and Keno, T. 2015. Factors that transformed maize productivity in Ethiopia. *Food Security* 7: 965-981. https://link.springer.com/article/10.1007/s12571-015-0488-z

Abebe, G. and Alemu, A. 2017. Role of improved seeds towards improving livelihood and food security at Ethiopia. *International Journal of Research-Granthaalayah* 5(2):338-356.

Assaye, A. and Habte, E. 2022. Adoption of improved tef technology packages in northern Ethiopia: A multivariate probit approach. *Ethiopian Journal of Agricultural Sciences* 32(3):78-109. ajol-file-journals_560_articles_241710_submission_proof_241710-6601-584013-1-10-20230305.pdf

Assefa, K., Chanyalew, S. and Tadele, Z. 2013. Achievements and prospects of tef improvement. Proceedings of the Second International Workshop, November 7-9, 2011, Debre Zeit, Ethiopia. Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia. https://boris.unibe.ch/73185/1/tef_improvement.pdf

Bekele, A., Chanyalew, S., Damte, T., Husien, N., Genet, Y., Assefa, K., Nigussie, D. and Tadele, Z. 2019. Cost-benefit analysis of new tef (*Eragrostis tef*) varieties under lead farmers' production management in the Central Ethiopia. *Ethiopian journal of Agricultural Sciences* 29(1):109-123. ajol-file-journals_560_articles_183056_submission_proof_183056-6601-466091-1-10-20190205.pdf

Caliendo, M. and Kopeinig, S. 2008. Some practical guidance for the implementation of Propensity Score Matching. *Journal of Economic Surveys* 22(1), pp. 31-72. doi: 10.1111/j.1467-6419.2007.00527.x

Coelli, T.J., Rao, D.S.P., O'Donnell, C.J. and Battese, G. E. 2005. An introduction to efficiency and productivity analysis. 2nd ed. New York, NY, United States: Springer. https://doi.org/10.1007/b136381

Creswell, J.W. 2009. Research design: Qualitative, quantitative, and mixed methods approaches. Sage publications. http://www.ceil-conicet.gov.ar/wp-content/uploads/2015/10/Creswell-Cap-10.pdf

Central Statistical Agency (CSA). 2017. 2016 Ethiopia demographic and health survey key findings. Addis Ababa, Ethiopia, and Rockville, Maryland, USA. CSA and ICF. https://dhsprogram.com/pubs/pdf/SR241/SR241.pdf

Desta, B.T., Mekuria, G.F and Gezahegn, A.M. 2022. Exploiting the genetic potential of tef through improved agronomic practices: A review. *Cogent Food & Agriculture* 8:1. https://doi.org/10.1080/23311932.2022.2083539

Diriba, G. 2018. Agricultural and rural transformation in Ethiopia: *Ethiopian Journal of Economics* 27(2):51–110. ajol-file-journals_316_articles_207582_submission_proof_207582-3769-516487-1-10-20210525.pdf

Diskin, P. 1997. Agricultural productivity indicators measurement guide. Food Security and Nutrition Monitoring (IMPACT) Project. https://statistics.kilimo.go.ke/files/bookpage/Agricultural_Productivity_Measurement_Guide_WulaeL3.pdf

Gebeyehu, M.G. 2016. The impact of technology adoption on agricultural productivity and production risk in Ethiopia: Evidence from rural Amhara household survey. *Open Access Library Journal* 3(2):1-14. 10.4236/oalib.1102369

Kirchner, S. 2021. The World Bank aids smallholder farmers in Ethiopia. The Borgen Project. - Google Search.

Koko, I.S. 2012. Effects of migration of farmers on sustainable livelihood in Nigeria. *IOSR Journal of Business and Management* 3(3):10-14. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=e785a788d035d40b8824bce16a8de509b15538b6

Mihretie, F. A., Tsunekawa, A., Haregeweyn, N., Adgo, E., Tsubo, M., Masunaga, T., Meshesha, D. T., Tsuji, W., Ebabu, K. and Tassew, A. 2021. Tillage and sowing options for enhancing productivity and profitability of teff in a sub-tropical highland environment. *Field Crops Research* 263: 1-9. https://doi.org/10.1016/j.fcr.2020.108050.

MoA. 2015. FDRE Ministry of Agriculture. Agricultural Growth Program II (AGP-II) Program Design Document. https://eeas.europa.eu/archives/delegations/ethiopia/documents/financing_agreement/1._agp_ii_design_doc.docx.

National Meteorological Agency of Ethiopia [NMAE]. (2020). Meteorological Grid

Data. [Accessed 21 June 2022]. Available from: https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=National+Meteorological+Agency+of+Ethiopia.+Meteorological+Grid+Data&btnG=.

Natnael, A.B. 2019. Impact of technology adoption on agricultural productivity and income: A case study of improved teff variety adoption in north eastern Ethiopia. *Agricultural Research & Technology* 20(4). https://juniper publishers.com/artoaj/pdf/ARTOAJ.MS. ID.556139.pdf

Negussie, F.A. 2020. Impact of row planting teff technology adoption on the income of smallholder farmers: The case of Hidabu Abote District, North Shoa Zone of Oromia Region, Ethiopia. *International Journal of Agricultural Science and Food Technology* 6(2):195-203.

Ojiewo, C.O., Kugbei, S., Bishaw, Z. and Rubyogo, J.C. 2015. Community seed production. In: *Community Seed Production Addis Ababa, Ethiopia, 9-11 Dec 2013*. FAO/ICRISAT. https://www.fao.org/3/a-i4553e.pdf

Place, F. and Otsuka, K. 2002. Land tenure systems and their impacts on agricultural investments and productivity in Uganda. *Journal of Development Economics* 67(2): 287-311. https://doi.org/10.1080/00220380412331322601

Rosenbaum, P.R. and Rubin, D.B. 1983. The central role of the propensity score in observational studies for causal effects. *Biometrika* 70(1):41-55. https://doi.org/10.1093/biomet/70.1.41

Shiferaw, B., Kassie, M., Jaleta, M. and Yirga, C. 2014. Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy* 44: 272-284. https://doi.org/10.1016/j.foodpol.2013.09.012

Rubin, D.B. 2006. Matched sampling for causal effects. Cambridge University Press. 10.1017/CBO9780511810725

Sisay, D.T., Verhees, F.J. and Van Trijp, H.C. 2017. Seed producer cooperatives in the Ethiopian seed sector and their role in seed supply improvement: A review. *Journal of Crop Improvement* 31(3):323–355. https://doi.org/10.1080/15427528.2017.1303800

Spielman, D.J., Byerlee, D., Alemu, D. and Kelemework, D. 2010. Policies to promote cereal intensification in Ethiopia: The search for appropriate public and private roles. *Food policy* 35(3):185-194. https://doi.org/10.1016/j.foodpol.2009.12.002

Tefera, T., Tesfay, G., Elias, E., Diro, M. and Koomen, I. 2016. Drivers for adoption of agricultural technologies and practices in Ethiopia: A study report from 30 woredas in four regions. CASCAPE Project Report No. NS_DfA_2016_1, Addis Ababa/Wageningen.

Teferi, A., Philip, D. and Jaleta, M. 2015. Factors that affect the adoption of improved maize varieties by smallholder farmers in Central Oromia, Ethiopia. *Developing Country Studies* 5(15):50-59.

Tsegay, A., Vanuytrecht, E., Abrha, B., Deckers, J., Gebrehiwot, K. and Dirk Raes, D. 2015. Sowing and irrigation strategies for improving rainfed tef (*Eragrostis tef* (Zucc.) Trotter) production in the water scarce Tigray region, Ethiopia, Agricultural Water Management 150:81-91. https://doi.org/10.1016/j.agwat.2014.11.014

World Bank. 2016. Ethiopia ET: Female Headed Households | Economic Indicators | CEIC. https://www.ceicdata.com

Yamane, T. 1967. Statistics: An Introductory Analysis, 2nd Edition, New York: Harper and Row. https://www.gbv.de/dms/zbw/252560191.pdf