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Impact of Improved Sorghum Variety Adoption (Assosa-1 and Adukara) on Gross Farm Income of Smallholder Farmers in Metekel Zone, Benishangul Gumuz Region, North Western Ethiopia

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Abstract: **Sorghum, a staple crop with significant socio-economic importance in Ethiopia, plays a critical role in the income of smallholder farmers in the humid lowlands of the Benishangul Gumuz Region. This study evaluates the impact of adopting improved sorghum varieties, Assosa-1 and Adukara, on gross farm income among smallholder farmers in the Metekel Zone. Utilizing a multi-stage sampling method, 142 households were surveyed across the Pawe and Dibate districts. Data were analyzed using Probit regression and Propensity Score Matching (PSM) models to identify factors influencing adoption and its economic effects.**

Key findings reveal that adopters of improved sorghum varieties experienced a statistically significant income increase of 11,182.39 ETB compared to non-adopters, with education, farm size, and market access being critical adoption determinants. Adopters also demonstrated higher productivity, larger land allocation for sorghum, and greater livestock ownership. However, challenges such as market distance and limited credit access negatively influenced the adoption and income outcomes. This research underscores the transformative potential of improved agricultural technologies in enhancing smallholder incomes and fostering food security in lowland agro-ecologies. Policy recommendations include strengthening extension services, improving market infrastructure, and addressing financial barriers to facilitate broader adoption.

Keywords: **Adoption; Impact; Improved Sorghum Variety; Humid lowland; PSM.**

1. INTRODUCTION

Sorghum, the fifth most significant cereal grain globally after wheat, maize, rice, and barley, is particularly important in Sub-Saharan Africa, the second most crucial cereal crop after maize (FAOSTAT/FAO, 2022). It serves as a staple food for over 100 million people in Eastern Africa and is also utilized as animal feed and raw material for industrial purposes (Agricultural Transformation Agency, 2015-2020).

Ethiopia is a key sorghum producer, ranking third in total production across the continent, following Nigeria and Sudan, and second among Common Market for Eastern and Southern Africa (COMESA) member countries. As a staple crop, sorghum is critical in ensuring stable income for millions of Ethiopians, particularly those living in humid lowland agroecological zones (Derese et al., 2018; Gizaw et al., 2017). The crop is extensively cultivated across diverse agroecological zones ranging from 400m to 2500m altitude (Abebe, 2024).

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Within the Benshangul Gumuz region, sorghum is the second most important staple crop in production and cultivated area from cereal crops, following maize (CSA, 2022). Its cultivation is particularly prominent in the Metekel and Assosa zones, where increasing productivity is seen as a pathway to improving the income of subsistence farmers. Over the past four decades, research initiatives, such as those conducted by the Assosa and Pawe Agricultural Research Center, have yielded numerous successes in enhancing sorghum productivity.

Improved agricultural technologies, including high-yielding crop varieties, present a vital opportunity for rural farmers to tackle the shortage of money, diversify their source of income, and stabilize the source of farm income. These advancements boost production, lower food prices, and foster accessibility, contributing to a shift from subsistence farming to a more productive rural economy (Asmelash, 2014). Moreover, the sustainable promotion of these technologies enhances rural livelihoods, strengthens agro-processing industries, and supports non-farm sectors (Egge, 2012; Yalew et al., 2020).

Despite the demonstrated potential of improved sorghum varieties such as Assosa-1 and Adukara, promoted extensively in the study area by Assosa and Pawe ARCs, there remains a significant gap in understanding the impact of adopting the improved sorghum variety on the enhancement of gross farm income of smallholder sorghum producers. This study aims to address this knowledge gap by examining the factors influencing the adoption of improved sorghum varieties, and their impact on gross farm income of smallholder sorghum producers in the study area.

2. METHODOLOGY

2.1 Description of the Study Area

The study was conducted in Pawe District of Benishangul Gumuz Regional State, North western Ethiopia, about 575 km from Addis Ababa. Jawi, Manudura, and Dangure encircle Pawe in the east and north, south, and west respectively. It covers a total area of 64,300 square kilometers (PDAO, 2022). Pawe district is located at Latitude; 110 09‟ N and Longitude; 36° 03‟ E. Its average Altitude of 1120 m.a.s.l. According to PARC meteorology data, Pawe has experienced an average temperature of 32.7 °C and an annual rainfall of 1582 mm over the past 30 years. Agro-ecologically most of the area in the district is classified under kola. Topographically the district is a largely gentle slope with 60% of the total area arable (PDAO, 2022). The district has a total area of 64,300 ha. From this, 50.4 % is arable land. In the 2021 cropping season, a total of 24,670 ha of land was covered by different crops. In the district 20 kebeles are available; all rural kebeles within the pawe district are potential areas to produce sorghum. The total population of the district reaches 67,862 (PDAO, 2022). The district agricultural system is characterized as a mixed-farming system dominated by grains and legumes. Crop production is the major Agricultural activity in the study area. Both cereals such as maize, finger millet, sorghum, rice, teff, and pulses like soybean, groundnut, and sesame are some of the crops produced in the study area (Assaye et al., 2023). These crops are used as a source of cash and food in the study area.

The study was conducted in the Dibate district, Metekel zone Benishangul Gumuz region, Northwestern Ethiopia. The district is located at 547 km to a northwestern direction far from Addis Ababa with a geographical location at 36^{0}12’55.57’’ longitude and latitude of 10^{0}39’00.48’’. It covers an area of 368,289 hectares with an estimated population of 67,227 (50.80% male) inhabitants (DDAO, 2022). The agricultural production practice is characterized as a mixed-farming system dominated by cereal and pulse crops. The districts are bordered in the East by the Guangua and Zigem districts, in the North by the Mandura district, in the South by the Yaso district, and in the West by the Bullen districts. It is characterized as a warm humid low land area with high rainfall. The district has 29 kebeles and it is hot humid and characterized by unimodal rainfall patterns with high and heavy rainfall which extended from May to October. The area receives a mean annual rainfall of 1175 mm and its altitude ranges between 1080 to 1700m with a mean annual temperature of 150c to 290c which ranges from 120c to 32 0c.

2.1.1 Sample size determination and sampling techniques

The study used multi-stage probability sampling methods. In the first stage, Pawe and Dibate districts were selected randomly which share similar sorghum production practices and agroecology from Metekel zones, Benshangul Gumuz Regional state. In the second stage, Sorghum producer kebeles were listed in alphabetical order with consecutive serial numbers in each district, and three kebeles were selected from Pawe and Dibate respectively using simple random sampling methods. In the third stage smallholder Sorghum producers were listed in consecutive serial numbers in each randomly

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selected kebeles. Finally, Sorghum producers were selected using a systematic sampling method and probability proportion to sample size.

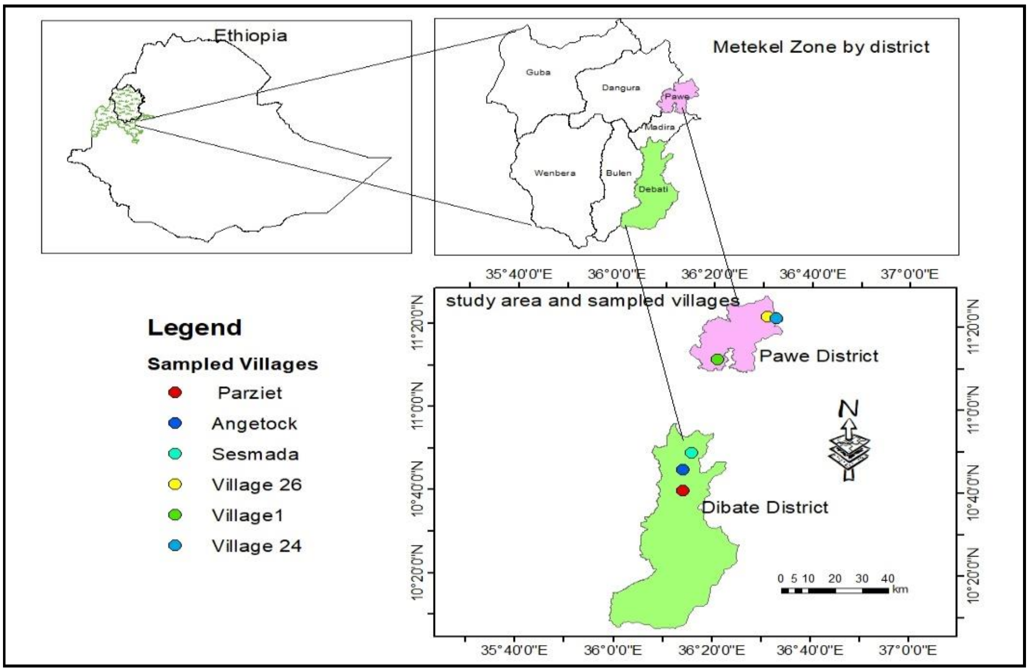

Fig. 1. Map of the study area

Table 1. Selected Sample Sorghum Producers by Districts and Kebeles

District	Kebele	Adoption Status		Total
		Adopter	**Non-adopter**	
Pawe	Village-26	13	11	24
	Village-24	9	14	23
	Village-1	11	10	21
Debate	Parziet	9	15	24
	Sesmandin	9	15	24
	Angetock	10	16	26
Metekel –zone Total Total				**142**

Source: (Survey data, 2022)

To determine the sample size factors like research budget, time, human resources, accessibility, and availability of technology users were considered. The research considered these issues and used the (Cochran, 1977) formula the sample size is determined as follows.

$$n = \frac{Z^2\ (P\ Q)}{e^2} \qquad ----------------- \quad (1)$$

Where;

n - Is the number of sample size, Z - Is 95% confidence

p - Is 0.4 (proportion of the population to be included in the sample i.e 30%)

q – Is 0.6 proportion of the population not to be included in the sample i.e 60%)

e - Is the margin of error or degree of accuracy desired (0.05)

According to this formula, 142 sample households were taken from two districts. The sample distribution is illustrated as follows.

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Types and method of data collection: The study used primary and secondary data collected through structured questionnaires and checklists respectively. Trained enumerators collected primary data from sample households of Rice producers through face-to-face interviews. In contrast, secondary data were collected from published and unpublished documents of zonal and district administrative offices. In addition to this, personal observation, focus group discussion, and key informant interviews were conducted to support the interpretation of the results obtained from the field survey.

2.2 Method of Data Analysis

They are different impact evaluation models such as difference in difference, fixed and random effect, endogenous switching regression, and propensity score matching. The first three models were used in the panel data set whereas the endogenous switching regression and Propensity score matching were used in cross sectional data set. Especially the propensity score matching is more suitable when there is no baseline data. The researcher is also more familiar with the propensity score matching model and that is why this research chose PSM over other impact estimator models. This research used the propensity Score Matching model (PSM) to investigate the impact of improved sorghum variety adoption on smallholder farmers' gross farm income in northwestern Ethiopia. Abdukerim & Habib, (2023); Tesfay & Woundiferaw, (2024) and Bruce et al., (2014) used propensity score matching to estimate the impact of improved crop variety adoption, while Moti et al., (2015), Sisang & Lee, (2023) and Mia et al., (2024) were used to combine the propensity score matching and endogenous switching regression model. ESR is unable to estimate the counterfactual effects. Therefore, the research used PSM the only limitation is the inability to control unobservable factors. This can be treated by taking sensitivity analysis.

2.2.1 Proper scoring Matching

Rosenbaum & Rubin, (1983) defined the propensity score as the conditional probability of receiving treatment given the observable factors' vector. The propensity score signifies the probability of selecting a therapy based on observed variables. The PSM method was used to estimate the impact of improved sorghum variety adoption on the gross farm income of adopters and non-adopters of improved sorghum beneficiaries.

The propensity score matching model is expressed as follows

$$Q(x) = Pr\{ F = 1 \,|D\} = E\{F|D\} ------(2)$$

Where, Q(x) is the propensity score, F= {1, 0} is the treatment variable or the dummy adoption variable and D is a vector of farmers' characteristics. The average treatment effect on the treated (ATT) is then computed using the estimated propensity scores. An indicator of how adoption affects adopters is provided by the ATT. Farmers face two potential outcomes (Y) given their adoption status (F) such that G = G0 if F = 0 and G = G1 if F = 1. E (G1 – G0) indicates the average treatment effect on the treated (ATT). The ATT may alternatively be written as E(G1|F= 1) – E(G0|F = 1). A logit model is typically used to specify the selection equation in propensity score matching Anang, (2019). The logit adoption model used in this study was defined as an index function using Gi, an unobserved continuous variable, as shown in the equation

$$Gi = Di\beta i + \varepsilon i = Gi = \{ 1 \; if \; Gi > 0 \; other \; wise \; 0 \} \quad ------- (3)$$

Where,

Gi = Gross farm income (1 for Adopters and 0 for Non-adopters)

Di = Vector of farm and household characteristics βi = Vector of parameters to be estimated and εi = Random error.

3. RESULT AND DISCUSSION

3.1 Characteristics of Humid Lowland Improved Sorghum Variety Producers in Northwestern Ethiopia

Smallholder farmers in Metekel Zone, Benshangul regional state, used sorghum as the main source of food, income, and feed for their livestock. Sorghum requires little nutrients to grow and produces an output. Smallholder farmers prefer to produce sorghum that needs little nutrients, has high productivity relative to other cereals, is used as an alternative source of income, and its straw is used as animal feed. Hence, this research tried to identify the impact of adopting humid lowland-improved sorghum variety on income among smallholder-improved sorghum adopters and non-adopters. For this purpose,

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43.66% and 56.34% of adopters and non-adopters of sample households were taken from the whole sorghum producers in Metekel Zone Benishangul Gumuz regional state.

3.2 Demographic and Institutional Characteristics of Humid Lowland Improved Sorghum Variety Producers for Dummy Variables

The majority of sample households are male-headed (92.25%) and the rest 7.75% are female-headed households. This is a reality most of the rural households in Ethiopia are married and male-headed households. There is no single woman in rural Ethiopia except, the divorced for short periods and windowed women. The divorced female also marries again to access the labor force from his husband. Only 9.68% and 6.25% of the female-headed households are adopters and non-adopters respectively (Table 3).

Development Agents (DA) are the grassroots experts designed to create awareness, and demand for agricultural technologies, and fill the skill gap among smallholder farmers. They trained and followed their farmers in their Keble center and on a field basis. They trained and created awareness on the advantages of improved agricultural inputs like improved seed, and inorganic fertilizer as well as improved farm tools. The DA contacted their smallholder sorghum producers weekly, twice per month, and monthly. 38.73% of the sample households were got extension contact with the DA in the survey period. 53.33% and 28.75% of the Adopters and non-adopters of the sample households got extension contact with the DA. The chi2 statistics showed, that there is an association between extension contact and adoption of improved sorghum variety and statistical significance at a 1% probability level.

Table 2. Adopters' Status of Improved Sorghum Variety in Northwestern Ethiopia

Characteristics of Respondents	Frequency	%
Adopter	62	43.66
Non-Adopter	80	56.34
Total	142	100

Source: (Survey data, 2022)

Table 3. Demographic and Institutional Characteristics of sample households

Variable	Adopter	Non-Adopter	Whole	Chi^2
	Frequency	Frequency	Frequency	
Sex HH	62	80	142	0.57
Male	56	75	131	
Female	6	5	11	
Credit Access				0.25
Yes	14	21	35	
No	48	59	107	
Number of Extension Contact				13.74***
Weekly	5	4	9	
Twice per Month	15	16	31	
Once per Month	12	3	15	

Source: (Survey data, 2022)

Table 4. Demographic and Institutional Characteristics of Respondents for Continuous Variables

Variable	Adopter		Non-Adopter		Whole		T-Value
	Mean	Std. Err	Mean	Std. Err	Mean	Std. Err	
Age HH	42.45	1.28	40.13	1.24	41.14	0.90	-1.29
Edu HH	6.40	0.39	4.51	0.44	5.34	0.31	3.14***
Family Size	3.34	021	2.99	0.17	3.14	0.13	-1.32
Sorghum Farm Experience	9.27	0.95	6.78	0.56	7.87	0.53	2.39***
Distance to Cooperative	18.18	3.49	28.58	4.48	24.04	2.97	-1.75*

Distance to FTC	12.64	2.12	14.14	1.47	13.49	1.24	0.59
Distance to Main Market	6.61	0.40	7.59	0.34	7.16	0.26	1.86*
Land Size	4.26	0.16	4.23	0.13	4.24	0.10	-0.16
Sorghum Farm land	1.73	0.15	1.07	0.06	1.35	0.08	4.36***
Total Sold	5.42	0.69	3.16	0.32	4.15	0.36	3.18***
TLU	5.18	0.64	3.82	0.36	4.41	0.35	1.96**
Yield	16.26	2.00	8.94	0.83	12.13	1.03	3.68***

3.3 Demographic and Institutional Characteristics of Humid Lowland Improved Sorghum Variety Producers for Continuous Variables

According to the survey result, Adopters of humid lowland Improved sorghum varieties were older, educated, and had more family-size than non-adopters in Northwestern Ethiopia during the survey period. The T-value showed there is a statistical difference between adopters and non-adopters at a 1% probability level (Table 4).

Adopters are more experienced in sorghum farming, allocated larger land for sorghum production, and travel fewer minutes to cooperative offices, Farmer Training centers, and main markets than the non-adopters. They also hold more livestock in TLU than the non-adopters. Furthermore, Adopters produced more sorghum yield than non-adopters and sold more sorghum surplus from their sorghum production (Table 4). The T-value showed there is a static difference between adopters and non-adopters in terms of sorghum farm experience, land allocated to sorghum, Total yield produced and total sold at 1% probability level, distance to FTC and Cooperative at 10% and animal holding in TLU at 5% of probability level (Table 4).

3.3.1 Econometrics analysis

Factors affecting the decision to Adopt Improved sorghum Variety and its Impact on Sample Households Income: The research identified both factors affecting the decision to adopt an improved sorghum variety and its impact on the Gross Farm Income of improved sorghum producers. The Propensity score matching model (PSM) determined these factors. The PSM revealed that the education level of the household head, and the cultivated land size allocated for sorghum production were affected positively by a 1% of probability the decision to adopt an improved sorghum variety whereas the distance to the main market from sorghum producers was affected the decision-making to improve sorghum variety negatively at 10% probability level (Table 6).

The outcome variable derived due to adopting an improved sorghum variety was influenced by total animal holding in TLU positively at a 1% probability level whereas it was affected by access to credit negatively at a 10% probability level (Table 5). Animal holding affects positively because sample households used animals also as additional source of income by selling some amount of their livestock. However, Access to credit affects the outcome variable (Gross Farm Income), because some part of the respondent's gross farm income is dedicated to paying the credit and interest rate associated with the use of credit.

Number of Observations 142

F(15,126) = 4.97

Prob>F = 0.0000

R-Square = 0.3719

Adjusted R Square = 0.2971

Table 5. Covariates affecting the Gross farm Income of Sample Households

Gross Farm Income	Coefficient	Std. Err	T-Value	P>|Z|
Adoption Status	7395.85	4968.30	1.49	0.14
Age	49.87	376.23	0.13	0.90
Sex	7654.35	8797.97	0.87	0.39
Education	-139.12	693.67	-0.20	0.84
Family Size	-220.39	2311.73	-0.10	0.92

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Sorghum Farm Experience	42.78	482.40	0.09	0.93
Distance to FTC	-96.27	165.48	-0.58	0.56
Distance to Cooperative	-88.28	165.48	-0.58	0.56
Distance to the main market	321.51	714.39	0.45	0.65
Land Size	56.77	1854.17	0.03	0.98
Sorghum farm Size	809.97	2830.12	0.29	0.78
Market Access	3612.74	3106.66	1.16	0.25
TLU	**3581.95**	**581.27**	**6.16**	**0.000**
Access to Credit	**-9566.88**	**5113.10**	**-1.87**	**0.06**
Extension Contact	-7150.12	5033.87	-1.42	0.16
Constant	21909.77	18580.44	1.18	0.24

Source: (Survey data, 2022)

Probit Regression

Number of observations 142

LR $Chi^2(14) = 42.87$

Pro> $Chi^2 = 0.0001$

Pseudo $R^2 = 0.2204$

Table 6. Covariates affecting the decision to adopt the improved sorghum Variety

Adoption Status	Coefficient	Std. Err	T-Value	P>|Z|
Age	0.007	0.026	0.27	0.79
Sex	0.1950	0.473	0.41	0.68
Education	**0.103**	**0.039**	**2.63*** **	**0.009*** **
Family Size	-0.004	0.138	-0.03	0.98
Sorghum Farm Experience	0.059	0.053	1.12	0.26
Distance to FTC	0.0001	0.009	0.01	0.99
Distance to Cooperative	-0.003	0.005	-0.72	0.47
Distance to the main market	**-0.068**	**0.04**	**-1.68***	**0.09***
Land Size	-0.086	0.101	-0.86	0.39
Sorghum farm Size	**0.474**	**0.174**	**2.73****	**0.006****
Market Access	-0.033	0.179	-0.18	0.85
TLU	0.019	0.345	0.54	0.59
Access to Credit	-0.240	0.287	-0.84	0.40
Extension Contact	0.430	0.277	1.54	1.23
Constant	-1.60	1.11	-1.45	0.15

Source: (Survey data, 2022)

Table 7. Description of the estimated propensity Score in the Region of Common Support

Range of percentiles	Estimated Propensity Score	
	Adopters	**Non-Adopters**
1%	0.1396	0.1434
5%	0.0.1434	0.1698
10%	0.1522	0.2056
25%	0.1595	0.2559

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50%	0.4381	0.4381
75%	0.9567	0.6506
90%	0.9832	0.8495
95%	0.9964	0.9211
99%	0.9997	0.9964

Source: (Survey data, 2022)

Table 8. The inferior bound the number of adopters and non-adopters for each block

Inferior block of Propensity score	Adoption Status		
	Adopters	Non-Adopters	Total
0.1396	1	11	12
0.2	14	28	42
0.4	18	17	35
0.6	14	9	23
0.8	15	1	16
Total	62	66	128

Source: (Survey data, 2022)

Table 9. Selection of the Best algorithm

Algorithm Method	Number of Adopter	Number of Non-Adopters	Average impact on Gross Farm income in ETHB		T-Value
			Mean	Std. Err	
Nearest Neighborhood	62	30	5,617.39	8411.06	0.67
Radius bandwidth 0.01	39	46	2,840.94	7184.58	0.395
Radius bandwidth 0.1	**62**	**66**	**11,182.39**	**5498.72**	**2.034**
Radius bandwidth 0.25	62	66	11,043.11	5504.27	2.01
Radius bandwidth 0.5	62	66	11,064.15	5457.26	2.03
Kernel	62	66	7,036.39	-	-
Kernal bstp	62	66	7,036.39	7668.57	0.92

Source: (Survey data, 2022)

3.3.2 Identification of common support

The first step in impact estimation using the PSM model is estimating of propensity scores of adopters and non-adopters. Next identify the lowest and the maximum of propensity scores in both cases. After identifying the minimum and maximum propensity scores, select from the minimum and maximum propensity scores. Based on this evidence the common support area lies between 0.1396 to 0.9997 for both adopters and non-adopters (Table 7).

In this common support area 62 adopters and 66 non-adopters are included for further estimation of the impact of adopting improved sorghum variety on the Gross Farm Income of smallholder sorghum producers in Northwestern Ethiopia (Table 8).

3.3.3 Identifying algorithm best Algorithm to estimate the Impact

After identifying the common support, the next step is identifying of best algorithm to estimate the real impact of adopting improved sorghum variety on the Gross Farm Income of smallholder sorghum Producers. The criteria to select the best algorithms are a large number of observations included in the common support, the smallest R square, and the number of insignificance variables. So according to these criteria radius bandwidth 0.1 is the best algorithm to estimate the impact of adopting improved sorghum variety on the Gross Farm Income of smallholder sorghum producers in Northwestern Ethiopia (Table 9). According to the PSM model output using the radius algorithm, adopters earned a Gross Farm Income of

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11,182.39 ETHB on average over the non-adopters from the adoption of improved sorghum varieties (Table 9). The difference in Gross Farm Income earned between adopters and non-adopters is statistically significance at a 5% probability level. The result is in line with (Tesfay & Woundiferaw, 2024)

4. CONCLUSION

This research was conducted in the Metekel Zone, Benishangul Gumuz Region, Northwestern Ethiopia. The study, which utilized data from 142 smallholder farmers across the Pawe and Dibate districts, applied Probit regression and Propensity Score Matching (PSM) models to analyze adoption determinants and economic impacts. The study highlights the significant impact of adopting improved sorghum varieties (Assosa-1 and Adukara) on the gross farm income of smallholder farmers in the Metekel Zone of the Benishangul Gumuz Region, Northwestern Ethiopia. Key findings demonstrate that adopters of these improved varieties earned substantially higher incomes compared to non-adopters. This income growth is attributed to increased productivity, better land utilization, and enhanced livestock holdings among adopters.

The adoption of improved sorghum varieties was influenced by factors such as education level, farm size, and proximity to markets, while constraints like market distance and limited access to credit negatively impacted adoption rates and income outcomes. These findings emphasize the transformative role of improved agricultural technologies in enhancing rural livelihoods and promoting food security.

The study underscores the need for policies aimed at scaling up the adoption of improved crop varieties. Recommendations include enhancing farmer education, improving market access through better infrastructure, and addressing financial barriers by increasing access to affordable credit. Strengthening extension services to promote awareness and provide technical support is also crucial for maximizing the benefits of agricultural innovations.

Overall, the adoption of improved sorghum varieties offers a promising pathway for smallholder farmers to transition from subsistence farming to more sustainable and profitable agricultural practices, thereby contributing to broader socio-economic development in Ethiopia's rural communities.

DATA AVAILABILITIES

The data set for this manuscript is in the hand of the corresponding author and sent with the reasonable request

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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