



## Adoption of Rice Technology Package in Fogera District: A Multivariate Probit Approach

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### ABSTRACT

Various studies in Ethiopia have explored factors influencing rice technology adoption, primarily focusing on improved rice varieties. One study compiled from the data collected in 2018 included rice technology packages but excluded rice seed rates. Given the evolving socioeconomic landscape, this study aimed to identify factors determining the adoption of rice technology packages in the Fogera district during the 2023 cropping season. Employing a mixed-methods approach, the study selected 301 rice-farming households from three kebeles: Kidist-Hana, Kuhar-Michael, and Abuha-Kokit, using systematic random sampling. Data were collected through structured questionnaires, key informant interviews, and focus group discussions involving five informants and 15 groups. A multivariate probit model analyzed the factors influencing farmers' decisions regarding rice technology packages. Results revealed that: sex, number of oxen, income from rice sales, and membership in rice seed multiplication, mobile ownership, extension contact, and credit received positively influenced the adoption of improved varieties. Conversely, age, rice cultivation area, crop diversification, and distance to all-weather roads negatively influenced adoption. For chemical fertilizer adoption, positive influences included the number of oxen, income from rice sales, participation in rice demonstrations, and credit use, while rice cultivation area had a negative effect. Regarding recommended rice seed rates, sex, oxen number, membership in rice seed multiplication, mobile phone use, and credit access were significant positive factors, while rice cultivation area and distance to all-weather roads negatively affected adoption. It is recommended that the Amhara Credit and Saving Institution should enhance access to credit services, while district agricultural offices must improve extension services for rice technology. Maderie and Tikdem cooperatives should provide advisory support to farmers use improved varieties, and the Fogera National Rice Research and Training Centre should supply pre-basic seeds. Additionally, the government should promote labor-saving technologies, improve infrastructure, and encourage participation in demonstration events.

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## Introduction

Rice (*Oryza sativa* L.) was introduced to Ethiopia in the early 1970s, primarily to help ensure food security in the country. It was first cultivated in the Gambella and Pawe areas, primarily to provision the large number of settlers following the 1985 drought and the devastating famine it caused (Alemu et al., 2018). Improving rice cultivation in Ethiopia presents a great opportunity for enhancing food security and fostering economic development. As the nation aims to diversify its agricultural industry, rice can be pivotal in satisfying local demand, generating employment, and stimulating economic development in rural areas (Gebremariam, 2024).

The national agricultural research system has released 39 improved rice varieties for three ecosystems: 18 for rain-fed uplands, 9 for rain-fed lowlands, 3 for cold-tolerant conditions, and 9 for irrigated areas (MoA, 2020). In addition to these varieties, recommended agronomic packages including fertilizer rates, seed, and row spacing have been promoted to rice farmers. However, the adoption levels of these improved rice varieties remain low across various rice hubs in the country, with the local *X-Jigna* covering 81.69%, *Gumara* 12.76%, and *Ediget* 5.5% (Atnaf et al., 2021).

The adoption of advanced technology packages significantly enhances productivity and income, allowing farmers to achieve sustained well-being. However, the widespread adoption of multiple production technologies is not common, and the overall adoption rate remains low in Ethiopia (Guye et al., 2024; Zenbaba et al., 2024). According to Atnaf et al. (2021), the adoption rate of improved rice technology in Ethiopia is low, primarily due to limitations related to generating demand-based rice varieties. Another studies assured that poor quality and old processing machines (Tikuneh & Woldesenbet, 2024). Inadequate extension services for promoting improved technologies and packages (Dessie, 2020). Psychological, social, economic, technological, and institutional factors influence rice technology adoption decisions (Tegegne et al., 2021; Beyene et al., 2022; Assaye et al., 2023).

Fogera plain features one of the few rice-based farming systems in the country, accounting for nearly 68% of the rice area coverage and 71% of the total rice production volume in Ethiopia (ESS, 2020). In Ethiopia, the total area dedicated to rice production has increased from approximately 10,000 hectares in 2006 to 91,122.35 hectares, while production has risen from 71,316 tons in 2008 to over 280,633.3 tons in 2022 (ESS, 2022). Despite these achievements, domestic rice production still fails to meet the growing internal market demand in the country (Alemu & Thompson, 2020).

Despite numerous studies in Ethiopia on factors influencing rice technology adoption, most have focused solely on improved rice varieties. For instance, Tegegne et al. (2021) examined rice production and technology adoption in Fogera Plain, while Asmelash (2014) investigated determinants of upland rice varieties in Fogera district. Beyene et al. (2022) explored the replacement of the local cultivar *X-Jigna* with the improved variety *Shaga* in the same study area. These studies do not reflect the reality that farmers often adopt multiple technologies as a package to enhance production. Although Assaye et al. (2023) examined the adoption of improved rice technologies as a package, it did not address the new recommended rice seed rates generated afterward. This study aims to identify the factors influencing farmers' decisions to adopt newly promoted rice technologies, including improved varieties, recommended chemical fertilizer rates, and recommended rice seed rates in Fogera district.

## Theoretical Framework

Several scholars have developed theories and models to explain the process of behavioural change related to the adoption of agricultural technologies. Among the most notable are the task-Technology fit theory, the technology acceptance model, and the innovation diffusion theory. This study adopts the innovation diffusion theory to address its objectives. According to Ruzzante et al. (2021), the innovation diffusion theory emphasizes that information is a critical element in farmers' decisions to adopt new technology packages and practices. The theory suggests that societies consist of different categories of adopters ranging from laggards to innovators and early adopters whose adoption patterns vary based on socioeconomic, psychological, and communication

characteristics. Consequently, farmers do not adopt new rice technologies in the same manner or at the same rate; rather, adoption takes place gradually and across different stages.

Findings from this study, supported by previous literature and practical observations, indicate that factors influencing adoption decisions may vary across different rice technology packages. A factor that significantly enhances adoption in one technology package may be insignificant or even hinder adoption in another. In the study area, adoption decisions were shaped by demographic, social, economic, and institutional factors. For instance, institutional factors such as access to credit, extension advisory services, participation in rice demonstrations, and membership in rice seed cooperatives influenced the adoption of some packages. In contrast, economic factors such as access to land, plot characteristics, rice sale income and crop diversification and ownership of oxen affects some rice technology packages. Demographic variables including sex, marital status, education level, and farming experience also affected adoption decision of some new rice technology packages and practices. Additionally, communication-related factors, such as access to mobile phones, facilitated information flow and contributed to farmers' adoption decisions. Therefore, the innovation diffusion theory is the most suitable theory for this research.

## Materials and Methods

### Description of the Study Area

This research was conducted in Fogera district, the three rice producing *Kebeles* namely *Kidist-Hana*, *Kuhar-Michael*, and *Abua-Kokit* during 2023 production season. Rice was cultivated more than 30 years. There are low-land and upland rice-producing agro-ecologies in which the prominent rice producers named those categories as *Wedek meret* and *Goba meret*, respectively (Dawit et al., 2018). The altitude ranges from 1774 to 2410 m.a.s.l with a mean annual rainfall and temperature of 1216 mm and 19°C, respectively. It is bordered on the south by Dera district, on the west by Lake Tana, on the North by Gondar Zuria district, and on the East by Farta and Ebenat districts. The district's land use pattern is made up of 59.03 % arable land, 22.73 % grazing land, 18.24% water bodies, and the remaining portion for other uses.

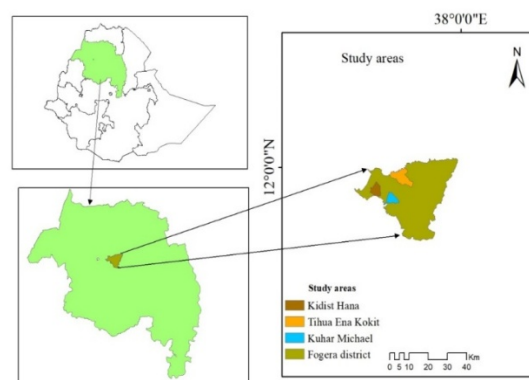


Figure 1. Map of the study area (Source: own compilation, 2023).

The district exercises mixed farming. Rice, maize, finger millet, tef, and barley are the main crops grown in the study areas (Fogera District Agricultural Office, 2024).

### Data Types, Sources and Collection Methods

For this study, both primary and secondary data were collected to address the research objectives. The primary dataset included farm family characteristics, socioeconomic factors, institutional and infrastructural elements, plot characteristics, and various components of rice production packages. This dataset was gathered through structured questionnaires for quantitative data, as well as Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) for qualitative data. Secondary data were obtained from a review of literature, including books, journals, and master's and doctoral thesis accessed from the Bahir Dar university agricultural library, as well as relevant websites. Additionally, data were sourced from annual reports of government institutions such as the Ethiopian Statistical Service (ESS), the South Gondar Zone Agricultural Office, the Fogera District Agriculture Office, and the Fogera National Rice Research and Training Center.

### Sampling Procedures and Sample Size Determination

The study primarily utilized cross-sectional data obtained from a farm household selected through a multistage sampling technique. In the first stage, the Fogera district was purposively chosen due to its high potential for rice production in the region and the zone. In the second stage, eight *kebeles* (*kebele* the smallest administrative units) were selected based on their rice production potential and the level of population participation in rice cultivation. Three *kebeles* were then chosen randomly. In the final stage, 301 rice-producing households were selected randomly using probability proportional to population size. For this study, the Yamane (1967) formula was employed, since suitable for survey research involving a limited population.

$$n = \frac{N}{1+N(e)^2} = \frac{4456}{1+4456 \times (0.06)^2} = 261 \quad (1)$$

Where  $n$  is the sample size for the study,  $N$  is the population of interest (rice-producing farmers in the production year 2023, which is 4456, and  $e$  is the precision level, which was set to 0.06 adapted from Al-Subaihi Ali (2003). Therefore, the formula is valid at a 95% confidence level. Based on this formula, 261 sample respondents were selected randomly. When determining sample size, formulas are used to identify the minimum number of samples required. Increasing the sample size beyond this minimum can enhance the precision of the data. For example, Tesfahun et al. (2022), in their study on the market participation decisions of rice producers in the Fogera district, added 19 samples to the minimum required 193. For this study 40 samples were added to the minimum sample size determined using Yamane (1967) formula and the sample size becomes 301.

### Methods of Data Analysis

#### Simple Descriptive Analysis

The measure of central tendency was employed, utilizing the mean to describe the data collected from the sampled rice respondents. Additionally, frequency distribution and standard deviation were used to further characterize the data. Furthermore, a t-test and chi-square test were conducted to compare the means between

adopters and non-adopters of rice technologies, as well as to examine the relationship between categorical independent variables and the adoption decision, respectively.

### Model Specifications for Econometric Analysis

The Multivariate Probit (MVP) model was employed to identify the determinants of rice technology package adoption by smallholder farmers. The MVP model is a generalization of the probit model, which is used to estimate several correlated binary outcomes simultaneously. Our research examined whether the decisions to adopt improved rice varieties, recommended rice seed rates, and chemical fertilizer rates are correlated, as all three are binary outcomes. Therefore, the multivariate probit model is appropriate for jointly predicting these three choices on an individual-specific basis (Dageye & Mengistu, 2015). Adapted from Assaye et al. (2023) stated that the multivariate probit econometric approach used for this study is characterized by a set ( $n$ ) of binary dependent variables  $y_{hpj}$ , such that

$$Y^*_{hpj} = X'_{hpj} \beta_j + \mu_{hpj} \quad j = 1, 2, 3, \dots, m \quad (2)$$

$Y_{hpj} = 1$ , if  $y^*_{hpj} > 0$  or (if the farmer adopts)  $0=$ , otherwise (3).

Where  $j=1,2, 3, \dots, m$  represent improved rice technology packages available;  $X'_{hpj}$  is a vector of explanatory variables,  $\beta_j$  denotes the vector of the parameter to be estimated, a multivariate normal distribution with zero means and unit variance. It is assumed that a rational  $h$ th farmer has a latent variable,  $y^*_{hpj}$  which captures the unobserved preferences or demand associated with the  $j$ th choice of technology packages. This latent variable is assumed to be a linear combination of observed households and other characteristics that affect the adoption of improved rice technology packages, as well as unobserved characteristics captured by the stochastic error term. The dependent variable in the empirical estimation for this study is the adoption from the set of adoption of rice technologies such as improved rice varieties (*Gumara*, *Ediget*, *Shaga*, and *Wanzaye*), chemical fertilizer rate (350 Urea and 121 NPS kg hectares and using the recommended rice seed rate (100 kg- hectares).

## Results and Discussion

### Summary of Continuous Explanatory Variables

The summary statistics of the variables that are believed to influence the adoption of improved seeds, chemical fertilizer rates, and rice seed rates are included. The mean age of adopters was approximately 42.61 years, while that of non-adopters was around 46.72 years. This suggests that, on average, the ages of rice-producing farmers are adequate for them to have gained sufficient experience in adopting rice technology packages. This is comparable to the findings reported by Guye et al. (2024). The average educational level of adopters and non-adopters was 2.66 and 1.18 years of schooling, respectively. This indicates that adopters tend to be more educated than non-adopters.

Table 1. Definition, measurement, and expected influence of variables used in the analysis.

Variable	Description and unit	ES
Adoption	Adoption in this study refers to rice farm households that adopted rice technology packages (improved rice variety, chemical fertilizer, and rice seed rate) on rice farming plots. These variables are represented as dummy variables, with a value of 1 indicating adoption and 0 indicating non-adoption for each technology.	
Gender	Gender of the household head (1=male)	±
Age	Age of the household head ( years)	±
Marital status	Marital status household heads(1=married)	+
Household size	Number of family members	±
Education	Education level of the head of household (years of schooling)	+
Rice experience	Experience of the household in rice farming ( years)	+
Rice land	Cultivated area covered by rice in ha	+
Crop diversification	Households that participate in diversified crop	±
Rice income	Income from sale of rice in birr	+
Oxen	Number of oxen in the household	+
Distance to all weather road	Distance to the all-weather road in walking minutes	-
Market distance	distance to main market in walking minutes	-
Rice seed multiplication membership	Household heads membership in rice seed multiplication (1=member)	+
Mobile phone	Mobile phone ownership (1=yes)	+
Rice demonstration	Household participate in rice demonstration (1=yes)	+
Extension	Frequency of extension contact in a year (count)	+
Receive credit	Household heads use credit (1=yes)	+

ES: Expected sign

Consequently, the educational attainment of household heads plays a significant role in facilitating access to information, which is essential for understanding and effectively implementing rice production practices. This study is consistent with a study done by Assaye et al. (2023), which stated that education plays an important role in getting rice farming households' access to basic information that helps decision-making

The average rice farming experience of adopters and non-adopters was 16.38 and 18.10 years, respectively, suggesting that non-adopters have more extensive experience in rice farming than adopters. This result is comparable to the study done by Beyene et al. (2022), which reported that experience in rice farming was statistically significant at the 5% level and negatively affected farmers' decisions to adopt improved rice varieties. The most experienced rice-growing farmers preferred the local *X-Jigna* over the improved rice varieties due to their desire to maintain and protect their saved seeds.

The average number of contacts a farm household had with extension workers was 3.09 for adopters and 1.20 for non-adopters. This indicates that adopters of the rice technology package engage more frequently with extension services, suggesting more effective utilization compared to non-adopters this finding aligned with Geda et al. (2024). The average number of oxen among adopters and non-adopters was 1.97 and 1.71, respectively. This indicates that oxen serve as the primary power source for many rice production activities in the study area, and they are a key determinant in the adoption of rice technology packages. This result is confirmed by Siyum et al. (2022).

The average annual rice income for adopters and non-adopters was found to be 131,239.3 ETB and 92,444.19 ETB, respectively. This indicates that adopters of the rice technology package have higher rice sales income compared to non-adopters, this study consistent the study done by Assaye et al. (2023) the study assured that adopter

have get better rice sale income in the counter factual non adopters. The average distance to an all-weather road for adopters and non-adopters was measured at 11.83 walking minutes and 28.60 walking minutes, respectively. This suggests that adopters have superior road access compared to non-adopters. Additionally, the average distance to the market for adopters and non-adopters was 108.72 walking minutes and 118.68 walking minutes, respectively. This further implies that adopters of the rice technology package enjoy better market access than non-adopters, this study comparable study done by Zegeye et al. (2022) non adopters' larger market distance than adopters (Table 2).

#### Categorical Explanatory Variables

Among the sampled household heads, 13.29% were female headed and 86.71% were male-headed households, this showing that a strong male dominance. About 86.71% of total male headed households, on average 94.77% male headed, and among 13.29% of female-headed households, about 5.23% were adopters of rice technology packages respectively. Descriptive findings, supported by focus group discussions, revealed that female-headed households reported limited access to extension services and lower participation in rice production training. This disparity is primarily attributed to the tendency of extension agents to engage more frequently with male-headed households, thereby restricting female farmers' access to vital information and awareness of improved rice varieties and farming practices, study is consistent with the research conducted by Guye et al. (2024), which argued that adoption decision-making is predominantly skewed toward male-headed households.

From the total sampled households, 6.31% were members of rice seed multiplication cooperatives, while the majority 93.69% were not. Among non-members, 89.53% adopted new rice technology packages, compared to only 10.47% of members.

Table 2. Description of Continuous explanatory variables by adoption decision.

Variables	Adopter category		Std. err	t value	P value
	Non-adopters	Adopters			
	(129)	(172)			
Age	46.72	42.61	.609	3.3966	0.0004***
Household size	5.82	5.74	.1038	0.3688	0.356ns
Educational level of HH	1.18	2.66	.1338	-5.7689	0.0000***
Rice farm experience	18.10	16.38	.3677	2.3380	0.0100***
Rice cultivated land (ha)	.91	.93	.0214	-0.3892	0.3487ns
Number of oxen owned	1.71	1.97	.0292	-4.6020	0.0000***
Rice income (ETB)	92444.19	131239.3	3949.3	-5.0563	0.0000***
Distance to all-weather road	28.60	11.83	.9453	10.1701	0.0000***
Distance to market	118.68	108.72	2.539	1.9498	0.026**
Extension contact	1.20	3.09	.11658	-9.0811	0.0000***

Note: ns insignificant: \*\*\*, \*\*, \* significant at 1, 5, and 10% respectively. Source: own survey data (2023)

Table 3. Dummy variables by adoption decision.

Variables	Category	Non adopters (n=129)		Adopters (n=172)		Total (n=301)		χ <sup>2</sup>
		Freq	Percent	freq	Percent	Freq	Percent	
		Gender	Male	98	75.97	163	94.77	
	Female	31	24.03	9	5.23	40	13.29	
Marital status	Unmarried	36	27.9	15	8.3	51	16.94	0.0084***
	Married	93	72.1	157	91.3	250	83.06	
Mobile phone	No	64	49.62	9	5.23	73	24.25	0.000***
	Yes	65	50.38	163	94.767	228	75.75	
Rice seed multiplication	Non-members	128	99.22	154	89.53	282	93.69%	0.001***
	Member	1	0.78	18	10.47	19	6.31%	
Crop-diversification	No	57	44.2	72	41.86	129	42.87	0.788ns
	Yes	72	55.8	100	58.14	172	57.14	
Credit received	No	125	96.9	92	53.49	217	72.09	0.000*
	Yes	4	3.10	80	46.51	84	27.91	
Demonstration participation	No	100	77.5	109	63.4	209	69.44	0.008***
	Yes	29	22.5	63	36.6	92	30.56	

Note: ns insignificant: \*\*\*, \*\*, \* significant at 1, 5, and 10% respectively. Source: own survey data (2023)

This suggests a notable association between cooperative membership and rice technology adoption decisions. Farmers reported that membership in rice seed multiplication groups enhanced their access to training, improved rice varieties, agronomic demonstrations, and a consistent supply of quality seeds, which in turn influenced their adoption decisions. This result is consistent with Mihretie et al. (2022), who found that membership in tef seed multiplication groups was positively associated with the intensity of tef technology adoption.

Findings from the focus group discussions revealed that farmers who own mobile phones can easily communicate with agricultural experts regarding rice production techniques and share information with peers without the need for physical travel. From the total sample respondents, about 75.75% of the household heads in the sample owned a mobile phone, while the remaining 24.25% did not have mobile phone ownership. The research report by Gebremariam et al. (2024) confirmed that owning a mobile phone facilitates access to extension services, resources, and platforms through calls, enabling the implementation of multiple rice technology packages.

Among the total sample households about credit received by respondents, 27.91% was obtained on average. Among the sample households, approximately 3.10% were non-adopters of improved rice technology packages. Of the

total households that did not receive credit, 72.09% were rice farming households, and about 96.9% of these sampled households were non-adopters of rice technology packages. Among the 72.09% who did not receive credit, approximately 53.49% of the sample respondents adopted improved rice technology packages. Conversely, among the 27.91% of households that received credit, about 46.51% of respondents adopted rice technology packages. This finding aligns with Oparaojiaku et al. (2025), who noted that increased access to credit significantly enhances farmers' ability to adopt a broader range of climate-smart agricultural practices.

From the sample households about 83.1% were married and 16.9% were unmarried. Moreover, out of the 83.1% of married sample households, 72.1% of the sample households were non-adopters of rice technology packages. Out of 16.9% of unmarried households, about 27.9% of sample households did not adopt rice technology packages. Out of the 83.1% of married households, about 91.3% of the sample households use improved rice technologies. Further, 16.9% of unmarried sample households, or about 8.3%, use rice technology packages. There is association among adopters and non-adopters in terms of marital status of the household heads. Spouses play a crucial labor role in crop production procedures, mostly helping with weeding and sowing transportation,

land preparation, this study consistent a study (Fikire & Emeru, 2022).

Out of the total sample, 30.56% of households participated in rice demonstration activities, while about 69.44% which is not participation on rice technology demonstration. This event is an extension activity designed to help farmers learn both the technical details and practical skills of a new technology. These findings are consistent with the study by Mihretie et al. (2022), which showed that attending demonstrations positively influences farmers' decisions to adopt tef technology packages (Table 3).

### ***Econometrics Analysis***

#### ***Determinants of Adoption Improved Rice Technology Packages***

Various factors can affect rice growing farmers' choices to implement a specific technology packages. We have modeled three binary dependent variables: (improved rice varieties, recommended chemical fertilizer rates (Urea and NPS), and recommended rice seed rate. Given the likelihood that these decisions are interrelated, we employ a multivariate probit (MVP) model to jointly estimate the probabilities of these correlated binary outcomes. A total of 17 explanatory variables are included to capture the range of potential influences on these adoption decisions. Before model estimation, we conducted diagnostic checks to ensure the reliability of our analysis, including tests for multicollinearity among the independent variables and the identification of outliers. The correlation between explanatory variables in this research study is less than 0.8, and the variance inflation factor (VIF) is 1.39. Therefore, there is no multicollinearity problem among the explanatory variables. According to Tay (2017), multicollinearity becomes a concern when the correlation coefficient exceeds 0.8, and when the VIF values of explanatory variables are higher than the recommended thresholds of 5 to 10.

As indicated below in Table 4, the MVP model is significant; the rationale is that the null hypothesis that the three rice technology packages' probabilities of adoption decision are independent rejected at the 1% significance level. The MVP model result indicated that Wald test (LR test of indep. eqns.  $\rho_{21} = \rho_{31} = \rho_{32} = 0$ :  $\chi^2(3) = 21.8351$  Prob >  $\chi^2 = 0.0001$ ) estimations at the 1% significance level This result suggests that the decisions to adopt improved rice varieties, apply the recommended rates of chemical fertilizers (urea and NPS), and use the recommended rice seed rates are not made independently. Instead, these decisions are interrelated and complementary, occurring at the household level.

Therefore, the adoption of these rice technologies tends to happen jointly, underscoring the importance of considering their interdependence in policy and extension interventions. This research finding is consistent with a study conducted by Assaye et al. (2023), which utilized a multivariate probit model. The results confirmed that improved rice production technology packages are complementary.

The results indicate that the three rice technology packages are interdependent and complementary. Households tend to adopt improved rice varieties in conjunction with other recommended practices. Findings from the Focus Group Discussions (FGDs) support the

econometric results: farmers reported that the availability of improved seeds positively influences their decision to utilize the recommended rice seed rate. This is because the appropriate seed rate often depends on the establishment potential of the seed variety. Farmers also noted that when they use improved seed varieties, they are more likely to apply the recommended rates of chemical fertilizers. This suggests that promoting the use of improved seed varieties can lead to a broader adoption of the complete rice technology package, as these decisions are mutually reinforcing. This finding consistent a study done by Martinez et al. (2021), said that the adoption of multiple technologies is interrelated, with shared factors affecting both their adoption and extent.

The result of the MVP model revealed that among the 17 explanatory variables incorporated in the analysis, namely, gender, oxen number, sale of rice income, membership rice seed multiplication, mobile ownership, extension contact, and credit received, were found to have a statistically significant effect on the decision to adopt improved rice varieties positively. Age, rice cultivated land, crop diversification, and distance to all-weather road negatively and significantly affect the adoption of improved rice seed. Oxen number, sale of rice income, participation rice demonstration and use credit were found to have a statistically significant effect on the decision to adopt chemical fertilizer rate positively, whereas rice cultivated land was negatively and statistically significant. Gender, oxen number, membership rice seed multiplication, use mobile phone, and credit use were found to significantly affect the choice to use the suggested rice seed rate. Whereas rice cultivated land and distance to all-weather road negatively affects the use rice seed rate. This research report aligns with the study conducted by Zegeye et al. (2022), which found that the distance to the main road negatively affects farmers' adoption of packages.

#### ***Gender of the Household Head***

Gender of the household head the adoption of improved rice varieties and recommended rice seed rates are positively and significantly influenced by the gender of the household head, at the 5% and 10% significance levels, respectively. Households headed by males are more likely to adopt both improved rice varieties and recommended seed rates. Specifically, the probability of adopting improved rice varieties and rice seed rates increases by 1.47% and 1.0%, respectively, when the household head is male, holding all other variables constant. This suggests that male-headed households are more inclined to embrace these technologies compared to female-headed ones, likely due to better access to agricultural information and management practices. This finding is consistent with the study by Fikire & Emeru (2022), which also reported that female-headed households face limited access to extension services and participate less frequently in rice production training. Evidence from focus group discussions in the study area supports this explanation, highlighting that extension agents often prioritize male-headed households when disseminating information. As a result, female-headed households are disadvantaged in accessing knowledge about improved rice varieties and associated technology packages.

### **Number of Oxen Owned**

The number of oxen owned is positively correlated with the adoption of three rice technology packages: improved rice seed, chemical fertilizer, and rice seed rate. The coefficients for the impact of oxen ownership are 1.06, 0.63, and 0.46 for improved rice seed, chemical fertilizer, and rice seed rate, respectively. This indicates that an increase in oxen ownership would raise the probability of adopting improved seed, chemical fertilizer, and rice seed rate by 1.06%, 0.63%, and 0.46%, respectively. Owning oxen provides a solution to the challenges of financial constraints and labor shortages. Farm households that possess oxen can plow a significantly larger area of farmland, prepare their land more efficiently, and plant on time. These advantages contribute to higher crop yields, increased income, and enhanced food security. Consequently, these households are more likely than their competitors to adopt superior agricultural practices. This result is consistent with the findings of (Guye et al., 2024).

### **Sales of Rice Income**

Income generated from rice sales (in ETB) has a positive and significant effect on the adoption of improved seed varieties and the use of recommended rates of chemical fertilizers, with significance levels of 1% and 5%, respectively. This suggests that rice sales enable farmers to implement rice technology packages by easing financial limitations and supplying the funds needed to buy urea and NPS fertilizers, along with improved rice seeds. This result is consistent with the findings of Assaye et al. (2023), which state that income positively influences farmers' decisions to apply fertilizers at the recommended rates.

### **Membership in Rice Seed Multiplication**

Membership in rice seed multiplication is positively associated with the adoption of improved rice seed varieties and the recommended rice seed rate, with significant levels at 10% and 1%, respectively. The coefficients for rice seed cooperative membership are reported as 1.58% and 1.2%, assuming other variables remain constant. This indicates that households participating in rice seed growing groups gain access to institutional services, including market access, agricultural inputs, credit, and agricultural services such as training and participation in demonstrations. Consequently, this involvement positively influences the likelihood of making adoption decisions. Another critical issue is that each seed producer implements planting activity based on agronomic recommendations. This finding is consistent with the results of studies conducted by Mihretie et al. (2022 and Cholo et al., 2023). Improved seed sources are key determinants influencing rice farming households' adoption of the recommended rice seed rate. Strengthening and supporting rice seed multiplication initiatives is critical for ensuring a sustainable supply of quality seed sources, which contributes to adoption decisions. Therefore, when households have access to pure and high-quality seeds, they are more likely to utilize the recommended rice seed rate. Consequently, the quality of the seed source and adherence to the recommended rice seed rate are directly related (FGD from the respective *kebeles*).

### **Mobile Ownership**

Mobile ownership is positively associated with the adoption of improved rice seed and the use of the recommended rice seed rate. The estimated marginal effects indicate that owning a mobile phone increases the likelihood of adopting improved rice seed and the recommended seed rate by 1.05% and 1.1%, respectively, assuming all other factors remain constant. Mobile phones serve as a key channel for accessing agricultural information, exchanging ideas, and receiving advisory services related to rice production and productivity. They also enable farming households to obtain market information and learn about improved production techniques without requiring the physical presence of development agents in their communities. This increased access to timely and relevant information empowers households to make informed decisions about adopting improved rice technologies. Moreover, mobile phone use reduces transaction costs, saves time, and facilitates decision-making processes related to the adoption of new agricultural technology packages. This study aligns with previous research conducted by (Siyum et al., 2022; Assaye et al., 2023).

### **Credit Received**

Credit received has a positive and significant association with the adoption of improved seed, use of recommended chemical fertilizer rate, and rice seed rate at the 1%, 10%, and 1% level of significance, respectively. When farmers receive credit, the likelihood of adopting improved rice seed, chemical fertilizer, and rice seed rate increases by 1.69%, 0.4% and 0.55% respectively, assuming all other factors remain constant. The underlying rationale is that access to credit alleviates financial constraints for farmers, enabling them to purchase agricultural inputs, which subsequently facilitates the timely use of these improved farm inputs. Because credit increases farmers' income, enabling them to purchase superior seeds, fertilizers, and other essential inputs. This finding is consistent with (Ayenew et al., 2020; Obisean et al., 2016).

### **Extension Contact**

Extension contact positively and significantly influenced the likelihood of adopting improved rice varieties at a 5% level of significance. The coefficient indicated that each additional contact with an extension worker would increase the probability of adoption of improved rice varieties by 0.13%, holding all other factors constant (*ceteris paribus*). This suggests that development agents play a crucial role in providing essential information, skills, and innovative methods related to rice cultivation. This study is similar to the one conducted by Beyene et al. (2022). A household attending on rice demonstration has a positive and significant effect on adopting chemical fertilizer packages. The model result showed that a unit increase in attending rice demonstration employing the recommended rate of chemical fertilizer increased by 0.29%. The main reason rice-growing household adopts chemical fertilizer packages by upgrading their agricultural production skills through demonstration. Households attending demonstrations are more likely than other growers to adopt new and enriched technologies. This finding correlated with (Cholo et al., 2023).

**Age of the Household Head**

Age of the household head has a negative and statistically significant effect on the likelihood of adopting improved rice varieties, at the 5% significance level. Specifically, each additional year in the household head's age is associated with a 0.03% decrease in the probability of adopting improved rice varieties, holding all other factors constant. This finding suggests that older farmers are less inclined to adopt modern agricultural technologies and practices compared to their younger counterparts. This may be due to older farmers' lower willingness to take risks, limited exposure to new technologies, or reduced adaptability to change. This finding aligns with the results of a study conducted by Ayenew et al. (2020).

**Rice Cultivated Land**

Rice cultivated land area dedicated to rice was negatively and significantly associated with the adoption of improved rice varieties, recommended chemical fertilizers, and suggested seed rates at the 1%, 5%, and 5% significance levels, respectively. The marginal effects indicate that for each additional hectare of rice land, the likelihood of adopting improved rice varieties, chemical fertilizers, and recommended seed rates decreases by 1.5%, 0.95%, and 0.7%, respectively, while holding other explanatory variables constant. This negative relationship may arise from farmers spreading their limited resources, such as labor, inputs, and capital, too thinly across larger plots or facing competition for these resources from other agricultural enterprises or businesses. Consequently, farmers with larger rice fields may find it challenging to fully implement the recommended technology packages across all their land; this finding is consistent with a study done by Assaye et al. (2023).

**Crop Diversification**

Crop diversification was negatively and significantly associated with the adoption of improved rice varieties at

the 10% significance level. The coefficient indicates that a one-unit increase in crop diversification decreases the likelihood of adopting improved rice varieties by 0.37%, assuming all other explanatory variables remain constant. A possible explanation is that households engaged in diversified cropping may have larger cultivated land and can achieve higher overall productivity by allocating resources across multiple crops. Consequently, these households might be less inclined to focus solely on improved rice varieties, as diversification offers alternative means of risk management and income generation.

**Distance to All-Weather Road**

Distance to all weather roads had a negative and significant effect on the adoption of improved rice seed and recommended rice seed rate at the 1% significance level respectively. This indicates that households located farther from the main road are less likely to adopt proven agricultural technologies. A possible explanation for this is that improved agricultural seeds are often demonstrated based on road accessibility; thus, farmers living in remote areas have limited information about these innovations, resulting in a lower likelihood of adoption. Additionally, rice-producing farmers may struggle to understand new technologies and practices, leading to increased transaction costs. A one-unit change in the distance of all-weather road decreased the probability of adoption of improved rice seed and recommended rice seed rate by -0.26%, keeping all other explanatory variables unchanged. The reason might be that if the distance is far, the soil fertility is low because farmers didn't apply organic fertilizers like green manure or compost, so the probability of rice seed adoption will have decreased because soil fertility and seed rate are positively correlated. If the soil fertility is higher, households would have to use a lower amount of grain seed. This finding is aligned with a study by Fikire & Emeru (2022).

Table 4. Multivariate probit simulation results for the adoption of rice technology packages

Explanatory variables	Improved Seed Coef. (Rob. S.E)	Urea&NPS Coef. (Rob. S.E)	Rice seed rate Coef.(Rob.S.E)
Sex (1= male)	1.469 (0.654)**	0.285 (0.576)	1.013 (0.575)*
Age (years)	--0.032 (0.015)**	-0.009 (0.011)	-0.006 (0.011)
Marital status (1= married)	-0.586 (0.586)	-0.023 (0.511)	--0.335 (0.483)
Household size (number)	0.039 (0.066)	-0.042 (0.051)	-0.027 (0.052)
Educational level (years)	0.001 (0.052)	0.053 (0.040)	-0.016 (0.045)
Rice farm experience (years)	0.014 (0.024)	0.014 (0.019)	0.029 (0.019)
Rice Cultivated land ha	-1.579 (0.441)***	-0.957 (0.388)**	-0.704 (0.326)**
Number of oxen owned	1.064(0.257)***	0.632 (0.195)***	0.467 (0.191)**
Crop diversification (1=yes)	-0.370 (0.223)*	-0.202 (0.174)	--0.011 (0.177)
Rice income	0.000 (0.000)***	0.000 (0.000)**	-0.000 (0.000)
Distance to all-weather road (minutes)	-0.026 (0.007)***	-0.002 (0.007)	-0.026 (0.008)***
Distance to market (minutes)	0.001 (0.003)	0.002 (0.002)	0.003 (0.002)
Rice seed cooperative membership (1=yes)	1.583 (0.817)*	0.132 (0.341)	1.189 (0.376)***
Mobile ownership (1=yes)	1.058 (0.281)***	0.391 (0.266)	0.844 (0.306)***
Rice demonstration 1= yes	-0.089 (0.254)	0.297(0.180)*	-0.027 (0.190)
Extension contact (number)	0.134 (0.060)**	0.056 (0.049)	-0.027 (0.051)
Credit received (1=yes)	1.694 (0.360)***	0.401 (0.207)*	0.554 (0.212)***
Cons	-1.908 (0.791)	-2.217 (-0.655)	-2.125 (0.678)

LR test of indep. eqns. rho21 =rho31 = rho32 = 0: chi2(3) = 21.8351 Prob > chi2 =0.0001

Note 1: \*\*\*, \*\*, \* are significant at 1%, 5%, and 10% levels respectively; Note 2: Standard errors are given in the parentheses; Source: own survey result (2023).

## Conclusion

The adoption of multiple rice technology packages in Fogera district was analysed using a Multivariate Probit (MVP) model, focusing on improved rice varieties, chemical fertilizer rates, and rice seed rates. Key findings revealed that factors such as sex, number of oxen, income from rice sales, membership in rice seed multiplication, mobile ownership, extension contact, and credit use positively influenced the adoption of improved rice varieties. Conversely, age, rice cultivation area, crop diversification, and distance to all-weather roads hindered adoption. Similarly, the number of oxen, income from rice sales, participation in rice demonstrations, and credit use encouraged the adoption of recommended chemical fertilizer rates, while rice cultivation area negatively impacted this decision. For rice seed rates, factors like sex, number of oxen, membership in rice seed multiplication, mobile phone ownership, and credit use significantly affected the choice, whereas rice cultivation area and distance to all-weather roads had negative effects.

Based on these findings, several recommendations are made: the Amhara Credit and Saving Institution (ACSI) should enhance access to credit services; district agricultural offices must strengthen extension services for rice technology packages; Maderie and Tikdem rice seed multiplication cooperatives should provide advisory services on improved varieties and seed rates; and the Fogera National Rice Research and Training Centre should supply pre-basic seeds to cooperatives. The government should develop and promote the labour-saving technologies like weeder and row planter. Additionally, government infrastructure development, particularly roads, is necessary, along with promoting participation in demonstration events by the district agricultural office and providing timely rice market information by the market development office.

## Declarations

### *Ethical Publication Approval Committee Certificate*

The Directorate of Knowledge Management and Scientific Communication (KMSC) approve research publications under the Ethiopian Institute of Agricultural Research (EIAR). Approval is granted by the head of the department responsible for a given research topic, the director of the research center or research sector director, the Deputy Director General for Research, and the KMSC Director. Accordingly, the procedures for this study were approved by the College of Agriculture and Environmental Sciences at Bahir Dar University. Correspondingly, the publishing of this work has been allowed with decision number RDAE/55/015 on March 16, 2023.

### *Conflicts of Interest*

There are no conflicts of interest related to the authorship and publication of this research manuscript.

### *Author contributions*

The corresponding author, E. M., contributed to the survey design, data collection, data cleaning, data analysis, conclusion writing, and the first draft of the manuscript. G. S., supervised the research, authored the literature review,

and contributed to the manuscript writing. A.T., contributed to the writing of the introduction, designed the study, wrote the materials and methods, and contributed to the descriptive statistics.

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