



Determinants of improved rice seed adoption in Nepal's Terai Region: A probit analysis for sustainable agricultural development

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Abstract: *Purpose:* This study investigates the socioeconomic and institutional factors influencing improved rice seed adoption among smallholder farmers in Nepal's Terai region to inform sustainable agricultural policies and enhance food security. *Methodology:* Primary data from 347 household surveys collected over three years (2019-2021) in Bardiya district were analyzed using probit regression modeling to identify significant determinants of adoption decisions. *Results:* Results reveal that larger landholdings (coefficient 0.262, $p=0.020$) and access to agricultural training (coefficient 0.356, $p=0.022$) significantly drive adoption, while demographic factors show no statistical significance. Adoption rates declined from 82.42% (2019) to 45.4% (2021), despite 88.46% of farmers expressing willingness for future adoption. *Theoretical Contribution:* The study contributes to technology adoption literature by identifying key barriers and enablers in smallholder farming systems, providing empirical evidence for sustainable agricultural transformation in developing countries. *Practical Implications:* Findings inform targeted policy interventions including enhanced training programs, financial support mechanisms, and land tenure policies to promote sustainable agriculture and achieve SDG 2 (Zero Hunger) objectives.

Keywords: adoption, improved rice seed variety, probit model, Nepalese agriculture

Sustainable Development Goals (SDGs): **SDG 1:** No Poverty; **SDG 2:** Zero Hunger; **SDG 8:** Decent Work and Economic Growth; **SDG 9:** Industry, Innovation and Infrastructure; **SDG 12:** Responsible

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Consumption and Production; **SDG 13:** Climate Action; **SDG 15:** Life on Land

1. Introduction

Nepal is a small, landlocked country among the least developed countries in South Asia, with a geographical area of 147,181 square kilometers. It is situated in Asia between two giants,

China in the north and India in the south. The country's environmental characteristics include lowland plains in the Terai¹ area, the middle hills, and the mountainous Himalayas, which influence the country's agricultural practices (Ghimire, 2021). Nepalese agriculture is a significant pillar of the government, providing employment to approximately 62% of the population and contributing nearly 27% to Nepal's GDP (Jha et al., 2021). However, despite the agricultural sector's significance, it faces significant challenges, including low input, specifically the inadequacy of quality seeds, inadequate infrastructure, and climatic unpredictability. Subsequently, there has been a significant emphasis on pull efforts aimed at enhancing and utilizing better-quality seeds, especially rice, a staple food in Nepal (Kopp & Mishra, 2022; Vaiknoras & Larochelle, 2023).

According to the Food and Agriculture Organization (2009), In developed countries, nearly 90 percent of cereal farmers use improved seeds, while 5 to 10 percent of farmers in developing countries use improved seed varieties (FAO, 2009). The importance of rice is highlighted as both a food staple and an essential factor in the Nepalese economy and identity. It contributes about 20 percent of the agricultural and 7 percent of the total GDP (Karki et al., 2020). Rice ranks 17th in rice production and 64th in rice productivity globally (Choudhary et al., 2022). Rice is the highest-producing cereal staple crop in Nepal, accounting for 67 percent of cereal consumption. It plays a significant role in nutritional and food security (Gauchan et al., 2022; Timsina et al., 2023). Per capita rice consumption is 138 kg (Choudhary et al., 2022). Nepalese society is rooted in traditional, cultural, social, and religious values.

Rice is cultivated in three agroecological regions of the country. The Terai region accounts for about 70 percent of the country's rice production, the hills account for 26 percent, and the mountains account for about 4 percent. The Nepalese government has focused on developing new varieties and high-quality seeds due to their significant role in the country's economy and food security (MoALD, 2015). Nepal produced the largest quantity of rice in fiscal year 2023/2024, at 5,724 million metric tons, which is 5.08 percent more than the average annual production over the last four years. Although the area of rice plantations decreased, production increased due to the availability of improved seeds (MoALD, 2024). This shows that farmers are adopting technologies that boost production.

Adopting improved rice varieties helped reduce poverty by 13 percent, and the adoption of technology has a significant and positive impact on household well-being among farmers (Budhathoki & Bhatta, 2016). Improved seeds play a crucial role in agriculture, and it is indeed necessary for a country like Nepal to ensure food security and support economic growth. New high-yielding and resistant seed varieties can also increase crop yields by 20-25%, thereby enhancing farm revenues (Tiwari et al., 2023).

This study identifies key factors influencing the adoption of improved rice seeds in Nepal, emphasizing the need for targeted policies, subsidies, and farmer training to enhance adoption. The Terai region, particularly Rajapur Municipality in Bardiya District, Nepal, requires improved rice seed varieties to enhance agricultural productivity and food security (Gebre et al., 2019). Strengthening institutional support and market linkages is crucial for improving seed accessibility, reducing costs, and ensuring food security. By filling empirical gaps, the findings provide policymakers and stakeholders with actionable insights to design farmer-friendly interventions that are informed by empirical evidence. Improved seed adoption is vital for boosting yields, enhancing climate resilience, and supporting sustainable agricultural growth. Addressing the challenges faced by smallholder farmers will strengthen their livelihoods, enhance food security, and promote economic stability, making this study both academically and practically significant.

¹ Terai is the lowland (flatland) and fertile land in the southern part of country which stretches from east to west.

2. Understanding the adoption of improved rice seeds in Nepal: Insights from literature

2.1. Improved rice seed adoption and its impact in Nepal

Adopting improved seeds significantly enhances food security and economic stability for farmers, two critical aspects deeply intertwined in agricultural development. According to Ghimire et al. (2022), improved seeds are engineered to be more efficient and reliable, characteristics that directly contribute to enhanced food security. These seeds typically yield more abundant, consistent, and resilient crops that are less susceptible to environmental stresses such as pests, diseases, and fluctuating weather patterns. As a result, food production becomes more predictable and sufficient to meet the demands of growing populations. This reliability is crucial in regions where food scarcity is a threat and agricultural outputs are directly tied to the well-being of communities.

Areas of Improved, Hybrid, and Local rice varieties are 82 percent, 7.4 percent, and 10.2 percent, respectively (MoALD, 2015). It is mainly grown in the Terai region due to the good soils and favorable climate for rice production. Nevertheless, due to the use of traditional varieties, the practice of old cultivation methods, and limited access to improved seed varieties, the country's rice yields are sometimes far below potential (Choudhary et al., 2022). To respond to these problems, the Nepalese government, with assistance from organizations like the International Rice Research Institute (IRRI), has promoted some high-yielding rice varieties like 'Sabitri and Radha-4, which were drought-tolerant and the most adopted improved in Nepal (Witcombe et al., 2017; Adhikari et al., 2019; Poudel, 2023) and preferred by farmers due to its higher production, better taste, and market price (Dixit et al.,

2017). Swarna Sub-1 and Sawa Mansuli Sub-1 were stress-tolerant varieties (Joshi et al., 2023), and 'Makwanpur-1', which was developed to overcome productivity constraints and factors such as pests, diseases, and climate-related stresses (Vaiknoras and Larochele, 2023).

Nepal's government has established a Seed Quality Control Centre (SQCC) to enhance seed quality and ensure farmers have easy access to high-quality seeds, which are vital for improving food security and promoting sustainable agricultural development in Nepal. The SQCC makes plans and programs, performs quality assessments, performs varietal registration and seed certification, and regulates seed production and distribution by collaborating with the public and private sectors (Sah, 2014). Community seed banks, commercial seed businesses, government agencies, and farmer-to-farmer exchanges in Nepal provide improved seeds. Farmers who have adopted improved varieties often share seeds with their neighbors, and such a sharing system among farmers has been a long-standing tradition in rural areas, an integral part of their culture. Nepalese farmers not only share seeds but also exchange technologies collectively.

According to the author's survey data, collected from three different reference years, seventy percent of the rice-growing area consisted of improved varieties, while 30 percent consisted of hybrid varieties. This demonstrates the significant impact of Improved varieties in the Terai region, as also noted by various researchers (Witcombe et al., 2017; Joshi et al., 2023). In the study area, Makwanpur-1 was the most preferred variety for the primary rice planting season, followed by Sabitri and Sarju-52. In contrast, Hardinath-1 was the most popular for the spring season, followed by Chaite-5. In some situations, farmers in the study area have also planted imported Indian and Chinese varieties in the Terai regions, as noted by Ghimire et al. (2015). Some farmers in the study area continue to grow traditional varieties, such as IR-22, due to their preference for household consumption. The Sabitri variety in several Nepalese districts has been successfully adopted and is popular due to its cultural preferences, better taste, and cooking quality (FAO, 2024). IR-8, Sarju-52, Radhan-4, and Mansuli are old, improved rice varieties that remain popular in the Terai region of Nepal (MoALD, 2015).

Climate change influences the adoption of improved seeds and crop productivity (Chandio et al., 2021). The Terai is prone to droughts, floods, and irregular rainfall. Farmers with high climatic variability are more likely to use climate-resilient seed varieties (Tharu, 2021).

Begho's (2021) study on Nepal reveals that many rural farmers lack the expertise and resources to utilize climate-resilient, improved seed varieties. Thus, smallholder farmers can be risk-averse due to climate change, and fluctuations in climate affect their production. Climate change adaptation on rice varieties has increased significantly (Khanal et al., 2018). This hinders 'smallholders' livelihoods, revenue, and productivity.' Nepal's agro-climatic variation makes it diverse in its cultivated rice varieties (Begho, 2021). Improved seeds are designed to be more resilient to the effects of climate change, such as temperature fluctuations and unpredictable rainfall patterns, thus ensuring more stable yields.

The farmer's seed system in Nepal is fundamental for ensuring food security, as farmers produce seeds for the next planting according to their requirements (Devkota and Shrestha, 2020). This system remains predominant for about 90 percent of the country's major staple crops (Joshi et al., 2017). The rice seed system is complex due to its multiple actors and components, as it is still in the development stage in Nepal (Shrestha and Gauchan, 2020). Furthermore, the current seed system is insufficient for farmers to access quality seeds (Gauchan, 2019). Currently, rice seed production in Nepal is conducted through both public and private sectors, with a significant role played by government institutions, particularly the Nepal Agricultural Research Council (NARC), which develops new seeds, conducts quality testing, and provides seed certification (Timsina et al., 2024). To continue delivering improved seed varieties to growers across Nepal's diverse agroecological zones, research remains crucial in developing seed varieties best suited to the country's environment (Chable et al., 2020).

Government policies have played a key role in promoting the conditions necessary to support such technologies. As stated by Ghimire et al. (2022), the Government of Nepal, in its strategic framework for the National Seed Vision 2013-2025, has outlined key interventions aimed at encouraging the use of improved rice varieties, which include increasing and improving seed production and strengthening the seed system. The implementation of this policy is expected to have a significant impact on food security and poverty reduction. Ghimire et al. (2020) have reviewed the policy's progress and found a significant impact on varietal research and development. Recently, private seed businesses in Nepal have developed and distributed more modified rice cultivars (Thapa et al., 2024).

The government provides subsidies on seeds to help reduce farmers' production costs while also testing seed quality to ensure that they meet the required standards. According to a study by the CGIAR, the subsidy on rice seeds has led to a significant increase in adoption among smallholder farmers (Choudhary, 2022). This program offered up to a 50% discount on improved seeds, enabling farmers to afford them more easily. This resulted in an overall increase in yields and income for the individuals involved in the process. For example, Gautam (2024) found that subsidizing improved seeds increased yield by about 20-30%, indicating a need to increase access to these seeds. Additionally, efforts are being made to enhance the level of education among farmers and other agricultural extension services, which aim to educate farmers on the application and use of new seeds in agriculture, as explained by Kumar et al. (2020).

Hybrid seeds yield unpredictable results, which are highly vulnerable to both environmental and biological factors, leaving farmers in a financially risky situation. On the other hand, the use of improved seeds eliminates such variability and the associated risks (Joshi et al., 2017). It also enhances farmers' ability to develop long-term plans and invest heavily in farming processes. The adoption of improved seeds has a tangible effect on agricultural yields, as analyzed in several studies on technology adoption in Nepal.

Several studies on the adoption of improved rice seeds in Nepal have highlighted a positive impact (Budhathoki & Bhatta, 2016), finding that adopting improved rice varieties has had a significant and positive effect on household agricultural earnings in Nepal. Households adopting these varieties have seen increased annual agricultural earnings from US\$ 153 to US\$ 185. These households also report higher annual consumption expenditures, which are US\$643–US\$907 higher compared to those that have not adopted improved varieties. This indicates not only an increase in productivity but also an enhanced quality of life for the adopters. Improved seeds help farmers save time and labor (Ghimire et al., 2015) and increase yields, enhancing food security and reducing poverty (Gautam et al., 2024). Farmers from the Terai region of Nepal have adopted improved rice seed varieties and seeds acquired through various sources, including fellow farmers and agricultural veterinarians (Khanal & Maharjan, 2014).

2.2. Factors determining improved seed adoption in Nepal

Many financial, cultural, and environmental factors influence Nepal's adoption of improved rice cultivars. Technical understanding influences seed adoption. Farmers are more likely to adopt new seed varieties that enhance yields, improve pest resistance, and increase climate resilience (Pandey, 2018). A lack of technical knowledge is the most significant factor hindering the adoption of technology by smallholder farmers (Floyd et al., 1999). Agricultural extension services provide this expertise; however, many rural Nepalese districts lack access to financing or are challenging to reach, which prevents farmers from utilizing improved seed varieties (Joshi et al., 2019).

Economic access, including loans and financial resources, is essential for improving crops. Smallholder farmers may lack funds for modern equipment. Credit helps invest in better inputs, which influences seed variety selection (Cafer & Rikoon, 2018). Cooperatives and microfinance organizations have helped Terai farmers adopt improved seeds, providing them with financial

resources; however, adoption rates vary according to the entrance barriers. Seed adoption is also affected by market accessibility. With reliable outlets to sell extra inventory at competitive prices, farmers invest in improved seedlings. In remote places like Bardiya, limited infrastructure, high transportation costs, and uncertain markets decrease farmers' financial incentives to employ improved seed (Kansiime et al., 2021). They face logistical obstacles, poor road infrastructure, and limited seed delivery. As a result, many farmers are forced to purchase unauthorized seeds or use local seed varieties, which may be of low quality and unsuitable for the area (Kuhlmann et al., 2021). Farmers fear losing their investment if they try new types of varieties without the security of production and market access, as there is no proper crop insurance facility in the country.

Risk is increasing due to factors such as globalization, which jeopardizes agricultural enterprises, and climate change (Duong et al., 2019). Climate change threatens the sustainability of agriculture through both biotic and abiotic factors (Aryal et al., 2020), revealing that increasing temperatures have a negative impact on rice production, which is a primary factor, including the spread of diseases and pests. High temperatures impact yield loss and grain weight, as a 1°C temperature rise decreases rice production by 8% (Xu et al., 2020), and flooding causes significant yield loss and damage to rice planting (Hendrawan and Komori, 2021). Nepal is one of the most vulnerable countries due to climate change, which has led to low crop production (ADB, 2023).

Rahut et al. (2015) emphasized that improving market connections leads to better household output as educated households and easy access to information on credit and the market have a significant impact. A lack of finance is a major factor affecting Nepalese farmers (Upadhyay et al., 2020). Assurance of quality seeds, inefficiency in seed production, limited access to information, and a lack of effective seed policy are significant factors in Nepal (Shrestha and Gauchan, 2020). Various research shows that risk attitudes affect farmers' improved seed adoption in Nepal (Begho, 2021). Ghimire et al. (2016) suggested that the government of Nepal should prioritize the agricultural insurance program to reduce the risk of losing production and make it accessible and affordable to farmers.

Numerous factors influence the adoption of these seeds. Accessibility and farmer awareness are vital, as evidenced by the Ministry of Agriculture and Livestock Development data, which highlights ongoing efforts to distribute these seeds more effectively across various ecological zones (Karki et al., 2020). Economic factors also play a critical role; the cost of improved seeds can be prohibitive for smallholder farmers despite the potential for higher yields and increased profitability over time. In the Terai region, economic obstacles significantly hinder the adoption of improved seeds. While improved seeds resistant to pests and diseases are available, their higher relative cost poses a serious barrier, particularly for resource-poor smallholder farmers (Krupnik et al., 2021). Additionally, several other factors influence the adoption of improved seeds in Nepal, including limited access to quality seeds and fertilizers, as well as an inadequate marketing and pricing system (MoALD, 2015). These challenges highlight the need for targeted interventions to address economic and systemic barriers, ensuring that improved seeds are accessible and affordable for all farmers, particularly those with limited resources.

2.3. Challenges to the adoption of improved seeds in Nepal

The adoption of improved rice seeds in Nepal faces several challenges that necessitate dedicated financial support programs to promote the adoption of improved seeds. Since Nepalese agriculture is smallholder farming, these technologies are critical in rice-growing regions like the Terai. Smallholder farmers lack the resources to invest in improved seeds. The agricultural sector in Nepal is undergoing a transformative phase, marked by the integration of improved seeds into Nepal's agricultural production systems. However, these systems are complex and face numerous challenges (Krupnik et al., 2021). Access to improved seeds remains limited, especially in rural areas (Wyss et al., 2018; Bernard et al., 2023). The distribution networks for these seeds often do not extend efficiently into less accessible regions, which hampers the ability of smallholder farmers to benefit from agricultural innovations. This issue is compounded by Nepal's varied topography, which makes transportation and logistics particularly challenging. Inadequate information on management and the benefits that farmers can gain from new seed varieties removes any incentive for farmers to adopt new farming methods, as noted by Kumar et al. (2020).

Most often, farmers adhere to tradition out of ignorance about how new technologies can improve their yields and farming efficiency. Farmers are risk-averse, and a lack of proper understanding or training often slows the adoption process of new, improved rice seeds. There is a cultural preference for adhering to traditional varieties and farming methods. These are the cultural factors that are often left out in the promotion of new agricultural technologies. The higher costs associated with new seeds can deter adoption among farmers who are uncertain about the economic

benefits. Financial constraints and the risk of failure with new methods can lead to a preference for traditional, less risky agricultural practices, as stated by Krupnik et al. (2021).

The adoption of improved seed technology is challenging in Nepal, especially in Rajapur Municipality, Bardiya, where a lack of awareness, limited infrastructure, inadequate market access, and insufficient information sources hinder progress. Despite the potential advantages of enhanced yields, disease resistance, and climate resilience, institutional, environmental, and economic restrictions prevent the broad adoption of improved seed varieties. Understanding these challenges helps develop solutions to improve crop acceptability and yield (Tharu, 2021). A significant barrier to seed adoption is the lack of access to quality seeds and inadequate awareness (Gauchan et al., 2014). Farmers are interested in adopting new technologies, but the key challenge is access to quality seeds at affordable prices (Sah, 2014); however, they continue to adopt new technologies. The slow seed certification process in Nepal hinders the delivery of new varieties to farmers. Cost and budgetary limits are another issue.

Poor agricultural extension services hinder the adoption of improved seeds. Farmers require technical skills to adopt new seed varieties effectively. Nepal has several underdeveloped and underfunded agricultural extension programs. Thus, growers cannot get vital information on seed availability, advantages, and management. Researchers have found that extension agent training increases the likelihood of farmers adopting new agricultural technologies (Ayalew & Abebe, 2018). Market constraints might cause problems. When growers can sell extra output profitably, seed adoption grows. Poor infrastructure, costly transportation, and tiny market networks limit Terai's market access. Without market access, farmers may not be able to sell or make a profit (Kimbi et al., 2020). Thus, improved seed purchases are less appealing. Due to market instability and price fluctuations, producers are unable to make informed decisions when purchasing improved seeds.

Future challenges may become more severe due to the adverse effects of climate change. Resilience in rice production in Nepal can be enhanced by adopting improved seeds, and farmers should be encouraged to implement more of these in the future (Timsina et al., 2023). Priority should be given to developing heat-resistant rice seeds in future research (Karn, 2014).

2.4. Research gaps in the adoption of improved seeds in Nepal

Despite the introduction and development of 94 high-yielding varieties by the Nepal government in collaboration with the International Rice Research Institute (IRRI), which are suited to various ecological zones, mountains, hills, and Terai, only about half of these varieties have been adopted by farmers (MoALD, 2015; IRRI, 2019; Choudhary et al., 2020). This indicates a significant gap between the availability of varietal technologies and their practical application in the fields.

However, significant gaps remain in the adoption rates across different regions of Nepal. These differences can be attributed to factors such as resource availability, differences in the education levels of farmers, and regional economics (Vaiknoras and Larochelle, 2023; Karki et al., 2020). Floyd et al. (1999) revealed the adoption and associated impact of technologies in the western hills of Nepal, finding that the most significant gap in households that did not adopt the technologies ranged from 25 to 70 percent. Newly released high-yielding varieties and climate-resilient rice varieties are crucial for reducing adoption lag phases, and effective production will be ensured by minimizing yield gaps at the farm level (Timsina et al., 2023). The annual reports of the Nepal Agricultural Research Council (NARC, 2022) also identified these disparities and stressed the importance of tailored approaches in recognizing the particularities of agriculture throughout Nepal.

Furthermore, environmental factors such as soil fertility, water availability, and climatic conditions also play critical roles in these regional differences. For instance, according to Aryal (2020), areas with more fertile soil or better irrigation facilities are likely to achieve higher adoption rates and benefit more from improved seed than regions with extreme climates or poorer soil quality. This environmental variability necessitates the development of region-specific seeds that can thrive under local conditions. Basukala and Rasche (2022) suggested that there should be accessible and affordable fertilizers with a priority on closing yield gaps in Nepal.

In some regions, traditional farming practices are deeply ingrained, and farmers have reservations about adopting new technologies (Holmelin, 2021). Overcoming this skepticism requires demonstrating the benefits of new seeds through field trials and success stories, as well as engaging community leaders and influencers in promoting these technologies. Addressing these yield and knowledge gaps effectively requires a concerted effort from multiple stakeholders, including government agencies, agricultural experts, local communities, and international partners. Programs designed to educate farmers about the benefits of improved seeds and efforts to improve local infrastructure and market access will be crucial for closing these gaps. Tailoring approaches to the diverse needs of Nepal's various agricultural zones will help ensure that the benefits of agricultural advancements are realized more uniformly across the country.

Moreover, Infrastructure deficiencies, particularly in transportation and storage facilities, represent a significant gap affecting the adoption of improved rice seeds in rural Nepal. According to Joshi et al. (2019), the poor condition of roads restricts access to markets and agricultural inputs, making it challenging for farmers to obtain and utilize improved seeds.

This limitation increases transportation costs and delays seed delivery, directly impacting planting seasons and agricultural productivity. Additionally, the lack of proper storage facilities increases seed spoilage and loss, further discouraging farmers from investing in high-quality seeds (Shreya, 2023). Addressing this gap requires targeted investments in enhancing rural infrastructure, including the construction of better roads and the development of secure, climate-controlled storage solutions. Improving these facilities would facilitate more effective distribution and maintenance of seed quality, thereby promoting wider adoption of improved seed among farmers in Nepal.

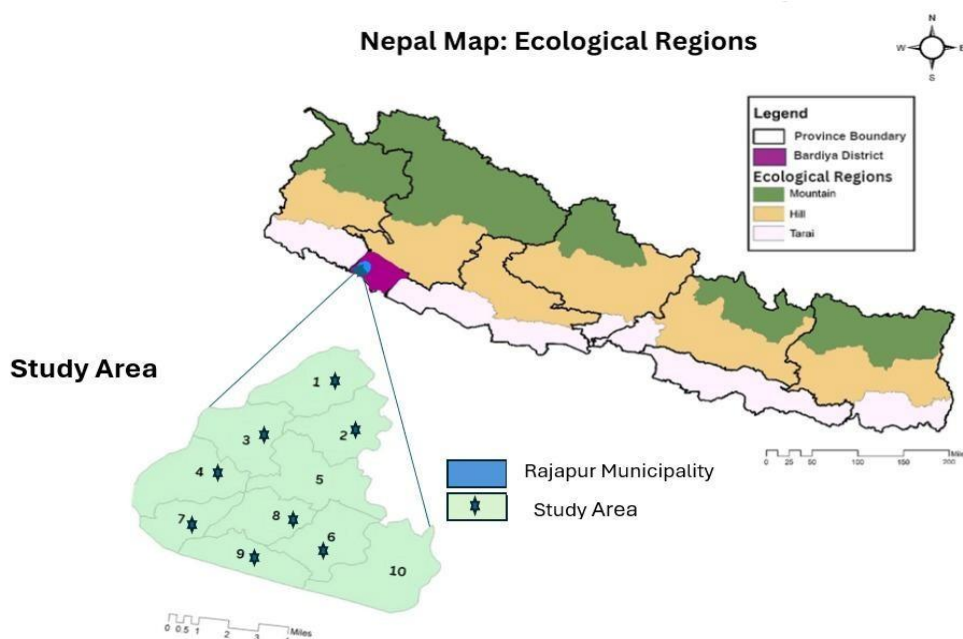
The above literature highlights that a combination of socio-economic, institutional, environmental, and technological factors influences the adoption of improved rice seeds in Nepal. Key determinants include farm size, education, financial resources, market access, and extension services, while climate resilience, pest resistance, and yield benefits play a crucial role in farmers' decision-making (Chete, 2021; Tharu, 2021). Government interventions, such as seed subsidies, research programs, and public-private partnerships, have had a positive impact on adoption; however, challenges persist. These include high input costs, limited access to credit, weak seed distribution systems, and climate-related risks (Ghimire et al., 2022; Chandio et al., 2021). Informal seed exchanges and traditional farming practices remain integral to rural adoption patterns, influencing the dissemination of improved varieties (Akpo et al., 2020; Wahab, 2020).

3. Data and methodology

3.1. Study area selection

The study was conducted in the Bardiya district of Nepal. Bardiya District is one of 77 districts in Nepal, located under the Lumbini Province. Bardiya is known as the food basket of the Terai region of the midwestern part of Nepal. It has suitable climatic conditions for Rice farming. Farmers from the Bardiya districts are generally positive and motivated to adopt new technologies. Agriculture is the primary source of livelihood for more than 71 percent of the district population (DAOBARDIYA, 2018). Rice is the predominant and most productive crop in the area, significantly impacting the livelihoods of local farmers despite some research showing that hybrid rice varieties can significantly enhance production (Salam & Sarkar, 2023). Rajapur Municipality initiated an investigation into the factors influencing the adoption of rice varieties, leading to the purposive selection of Bardiya district for this study. Rajapur Municipality, situated in the Bardiya district of Nepal, has been selected due to its strategic importance in agricultural research, particularly in the adoption of improved rice varieties. The Terai region, renowned for its suitability for agricultural research and the dissemination of technology, provides an ideal setting for this study. The research aims to enhance food security, improve the livelihoods of smallholder farmers, increase climate resilience, and inform policy decisions, making the Bardiya district a strategically important location for this study.

Data for the study was collected from both primary and secondary sources. In terms of rice production data, we have collected detailed information over three years (2019-2021) to understand the changes, trends, impacts, and factors that determine production over time. Both monsoon and spring rice production data were collected; however, not all monsoon rice growers cultivated spring rice due to uncertainty and a lack of sufficient years of experience in cultivating spring rice. The secondary data were collected from the respective offices, including the Central Bureau of Statistics, the Agricultural Research Organization, and the District Agricultural Office. Moreover, published journals and research papers were also used. The other secondary data sources included Rajapur Municipality, Bardiya District of Nepal, and Various Ministries of the Government of Nepal (2024).

Figure 1: Map of Nepal showing the ecological regions and study area

Source: CBS, 2024 and edited

3.2. Data collection and sampling methods

A total of 347 households were surveyed using a multi-stage sampling technique, with 23 villages purposively selected from Rajapur Municipality. In the first stage, districts have been selected based on their importance in rice production and the availability of agricultural extension services. In the second stage, villages were randomly selected within the specified districts. Finally, households in those villages were randomly selected to sample the village in a representative manner. A sample size was determined that would provide sufficient statistical power to analyze the factors influencing seed adoption while also considering resource constraints and logistical feasibility.

3.3. Analytical techniques

A cross-sectional survey design was employed to collect data from a large sample of farmers residing in various villages in Nepal. Using quantitative research design, this study aims to provide strong and data-driven insights into the adoption of improved rice varieties in Nepal ((Duckett, 2021; Fischer et al., 2023). STATA was used to conduct descriptive statistics on the characteristics of adopters and non-adopters, as well as their adoption rates (Dong, 2023). Additionally, a probit regression model was employed to identify significant factors influencing the adoption of improved rice seed varieties (Skiera et al., 2021). The probit model is used for the dependent variables (i.e., "1" for improved seed adoption, "0" for non-adoption) (Greene, 2012, Güneri & Durmuş, 2020) and the model was used for identifying the factors, such as age, education, farm size, training received, etc., which affect the probability of adoption (Cameron and Trivedi, 2005).

The primary dependent variable of the study is the adoption of improved rice seed varieties, defined as the farmers who adopted these varieties in the 2019, 2020, and 2021 planting seasons. The independent variables include both household characteristics and institutional factors:

–*Age of the household head*: The time frame is measured in years to capture the impact of experience and age-related risk elasticity on adoption.

–*Gender of the household head*: Estimating the effect of a binary variable indicating whether male- or female-headed households are more likely to adopt.

–*Years of education*: Formal education levels of the household head are recorded as a continuous variable.

–*Household size*: Labour availability is reflected by the total number of individuals in the household.

– *Non-farm activities*: Household engagement in non-agricultural income-generating activities as indicated by using binary variables.

– *Tropical Livestock Assets*: Livestock assets are a measure of household wealth in terms of livestock assets.

– *Total landholding*: The land size in hectares represents an individual's economic status and resource availability.

– *Household expenditure*: Monetary indicator of economic well-being, which is measured as a household's monthly expenditure.

– *Access to training*: Participation in agricultural training programs; binary variable.

– *Distance to facilities*: The influence of accessibility on adoption is indicated by the average time in minutes to access agricultural facilities.

Probit model representation for improved rice seed variety adoption 1

$$P(Y_i = x_i) = \Phi(X_i\beta_i) \quad (1)$$

Where,

$P(Y_i = x_i)$ is the probability that a farmer adopts an improved seed.

$Y_i = 1$ if farmer i adopts improved seeds, and 0 if farmer i does not adopt improved seeds.

X_i is the explanatory variable that influences seed adoption (like age, education, farm size, training received, extension service access, etc.)

β_i is the coefficients that show how every factor influences the probability of adoption.

Φ is the cumulative normal distribution function.

4. Descriptive statistics

4.1. Descriptive statistics of factors determining the adoption of improved rice seed varieties in Nepal

Table 1: Descriptive statistics of improved rice seed adoption

	Not adopted		Improved seed	
	Mean	Std. dev.	Mean	Std. dev.
Age of head (years)	48.40	11.00	46.31	10.62
Gender of head	89%		89%	
Nos of years of education	5.04	4.93	5.85	5.13
Household size	6.46	3.31	6.21	3.02
Non-farm employment	65%		74%	
Tropical Livestock Assets	2.00	1.46	1.92	1.69
Total landholding (hectare)	1.55	1.22	1.29	1.15
Total household expenditure	27,948	30,003	34,566	73,094
Average distance to facilities (min)	43.97	18.35	44.07	20.33
Received training	41%		28%	

Source: Author's survey

Table 1 shows the determinants and characteristics of improved rice seed adoption in Nepal. On average, the age of household head adopters is slightly younger (46.31 years) than that of non-adopters (48.40 years). Younger farmers have a greater propensity to adopt improved seed varieties. Younger farmers may be more prone to innovation and are more likely to adopt new agricultural technologies. Interestingly, there is no gender difference in the uptake of improved seeds, with 89% of male-headed households in both groups. This uniformity suggests that gender may play a role in access to resources, but it does not directly influence the decision to adopt improved seed varieties in this sample.

The average level of education of persons who have adopted improved rice seeds is 5.85 years, and 5.04 years among those who have not. This difference suggests that education matters for adoption, with more educated farmers being better equipped to understand the benefits of improved seeds or having greater access to information and resources. The average household size of non-adopters is slightly larger than adopters. The difference is quite slight, but it suggests that perhaps smaller households will find it easier to reallocate resources to adopt improved seeds. Non-adopters run non-farm activities in a smaller proportion than adopters. This shows that households with several sources of income are more likely to adopt improved seeds. Although agricultural income may provide some financial stability for farmers, non-farm income, for example, could serve as an additional source of funds that farmers can use to invest in agricultural inputs, such as improved seeds.

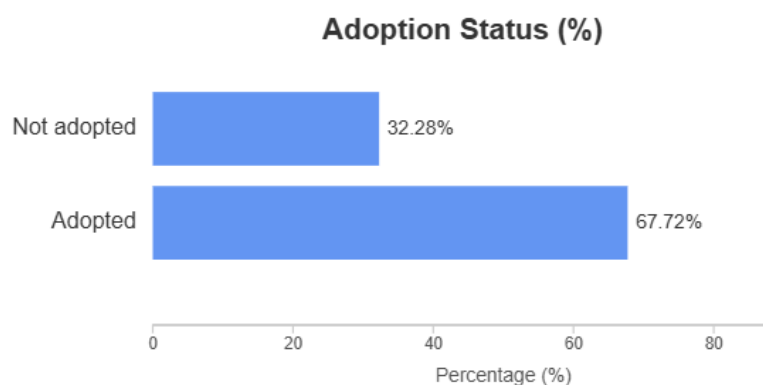
However, the livestock assets of adopters are slightly lower than those of non-adopters. Perhaps households that depend more on livestock can earn a living and are less likely to purchase improved seeds. Average landholdings are larger for non-adopters than for adopters. Adopters spend more money on average than non-adopters. Hence, the implication is that adopters are relatively wealthier or enjoy higher purchasing power, which allows them to afford improved seeds. However, market expenditure by adopters has a wide range of expenditure, suggesting significant variation among adopters, which may indicate income inequality even among adopters. The average distance to facilities is used as a measure of supply inaccessibility. If we examine the type of training participants received, we can observe that adopters received less training than non-adopters, specifically 28% compared to 41% respectively. The finding suggests that the content or manner in which training programs are delivered may not significantly affect adoption or other factors that influence adoption, except for formal training.

Descriptive statistics in Table 1 reveal that farmers with diversified income sources (non-farm activities) are younger, more educated, and more likely to adopt improved seeds. Both smaller landholdings and higher expenditures are correlated with adoption, indicating a managerial allocation of resources and financial capability. Nevertheless, more surprising findings – higher training participation among non-adopters – warrant a closer examination of the quality and relevance of training programs. These results can help inform policies that support the adoption of improved rice seed varieties, taking into account farmers' specific needs and barriers.

5. Empirical results

5.1. Improved rice seed adoption status

Figure 2: Percent of households adopting Improved seed adoption



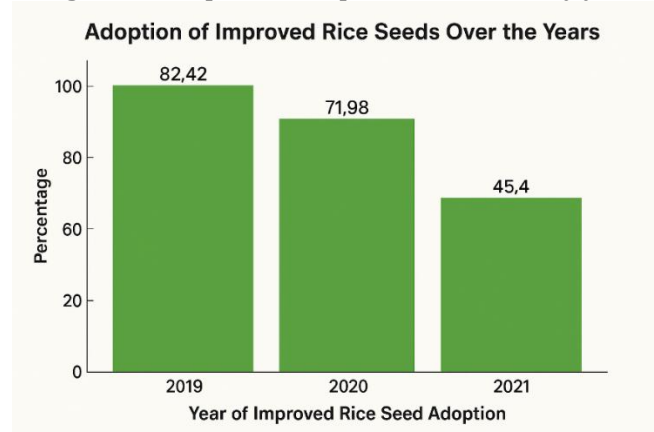
Source: Auther's survey

The Figure 2 shows that 67.72 percent of households have adopted improved seed varieties while 32.28 percent have not. This implies that most households are already aware of the benefits of adopting improved seeds and have incorporated this idea into their farming practices. This indicates a greater awareness of and acceptance of more agriculture technologies being adopted by farmers. In other words, the remaining 32.28% of non-adopters indicate the potential existence of further impediments, such as financial obstacles, the absence of adequate training, or simply conventional resistance that must be addressed to increase the adoption rates even further.

It highlights the need for targeted interventions to close the gap between adopters and non-adopters. The 32% of households that have not adopted it could be targeted by policy measures to improve their educational access to training or subsidies could be provided to tackle the socio-economic challenges.

5.2. Adoption of improved rice seed by year

Figure 3: Adoption of Improved rice seed by year



Source: Auther's survey

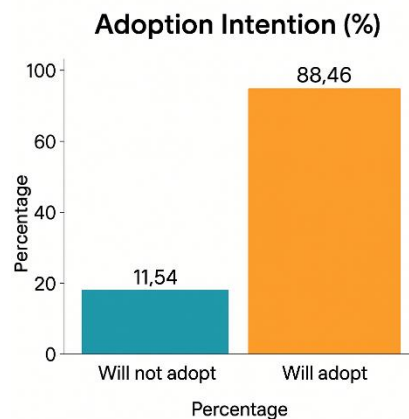
The Figure 3 illustrates the percentage of households adopting improved rice seed varieties over three agricultural years: 2019, 2020, and 2021. We observe a downtrend in the adoption rate over this period, from 82.42% in 2019 to 71.98% in 2020 and 45.4% in 2021, respectively, of households adopting improved rice seeds. The adoption rate reached its highest point in 2019, at 82.42%. Such enterprising levels of progress could be attributed to the initial success of awareness campaigns, agricultural extension services, and the availability of improved seeds that year. Despite its exorbitant cost, some farmers may have considered improved seed varieties to be of better quality, yield more, and be more resistant to environmental stress, and thus, widely adopted.

The adoption rate was down 71.98% in 2020 compared to the previous year. Perhaps due to the global COVID-19 pandemic or simply a decline in accessibility to agricultural inputs (e.g., seeds, fertilizers) resulting from logistics or economic issues, this decline is occurring. The pandemic could have disrupted supply chains and limited the reach of agricultural extension programs, hindering farmers' access to improved seeds or other training. From 2019 to 2021, the adoption rate declined and reached a low of 45.4% by 2021. The very sharp decline in recent years suggests that financial hardships, lack of access to seeds, and reduced effectiveness of support programs may persist. This may also reflect growing farmer skepticism about the benefits of improved seed due to inconsistent yields or inadequate follow-up on agricultural services.

Additionally, the data further reinforces the need to preserve farmers' trust. However, policymakers and agricultural organizations must ensure that the benefits of improved seeds are consistently realized and effectively communicated. Better support systems—such as subsidies, credit schemes, and training programs – are likely to strengthen efforts to reverse declining rates of adoption and sustained use of improved rice seed varieties.

5.3. Future adoption intention of improved rice seed varieties

Figure 4: Improved seed adoption intention in the Future



Source: Auther's survey

The results (Figure 4) reveal that a significant majority of households (88.46%) are willing to adopt improved seeds in the future, while only a small minority (11.54%) are unwilling to do so. This overwhelming willingness to adopt suggests that farmers are well aware of the potential benefits of improved seeds, such as their higher yield potential, resilience to pests and diseases, and adaptability to changing climatic conditions. The high percentage of farmers willing to adopt also reflects a positive perception of improved seed varieties and a hopeful outlook among farmers. It indicates their belief that current challenges—such as financial constraints and limited access to agricultural inputs – can be overcome if supportive measures and enabling policies are implemented. This optimism highlights the importance of addressing systemic barriers and providing the necessary resources to unlock the full potential of improved seeds.

The results also highlight that 11.54% of households have no intention of adopting improved seeds in the future. This reluctance could stem from various forms of resistance, such as skepticism about the effectiveness of improved seeds, a preference for traditional or hybrid varieties, or practical challenges like high input costs, limited access to resources, and insufficient capacity or training. Additionally, poor past experiences with improved seeds or limited exposure to their benefits may have reinforced their hesitation. Addressing these concerns requires targeted efforts to build trust, demonstrate the advantages of improved seeds, and provide accessible support systems to overcome financial and logistical barriers. By doing so, policymakers and extension services can help bridge the gap and encourage broader adoption among hesitant farmers.

5.4. Probit model on factors determining the adoption of improved seed variety

Table 2: Probit model on factors determining the adoption of improved seed variety

Number of obs	347				
LR chi2(10)	18.13				
Prob > chi2	0.053				
Pseudo R2	0.042				
Log-likelihood	-209.17				
Improved Seed Adoption	Coeff	Std. err.	z	P>z	[95% conf. interval]
Age of head (years)	0.005	0.008	0.590	0.556	-0.011 0.020
Gender of head	-0.079	0.240	-0.330	0.742	-0.550 0.392
Nos of years of education	-0.018	0.015	-1.180	0.237	-0.049 0.012
Household size	-0.008	0.030	-0.270	0.790	-0.067 0.051
Non-farm employment	-0.157	0.172	-0.910	0.362	-0.494 0.180
Tropical Livestock Assets	-0.025	0.053	-0.460	0.645	-0.129 0.080
Total landholding (hectare)	0.262	0.113	2.320	0.020**	0.040 0.483
Total household expenditure	-0.188	0.131	-1.430	0.153	-0.445 0.070
Average distance to facilities (min)	-0.002	0.004	-0.470	0.637	-0.009 0.006
Received training	0.356	0.155	2.300	0.022**	0.052 0.661
Constant	1.537	1.354	1.140	0.256	-1.116 4.191

Source: Author's Survey, "*, **", and "*** indicate significance at the 10%, 5%, and 1% levels, respectively".

Table 2 shows the probit model on factors determining the improved rice variety. The factors determining the adoption of improved rice seed varieties are explored using probit regression analysis. The analysis performed in the logistic regression model aimed to explain the factors that influenced the better adoption of rice seeds by the 347 beneficiary households. The model yielded a likelihood ratio chi-square of 18.13 with a p-value of 0.053; thus, the model was statistically significant at the 10% level of significance ($p < 0.1$). A low pseudo-R-squared value of 0.042 indicates that the model explains only about 4.2 percent of the variability in adoption decisions.

Total landholding emerged as a statistically significant factor influencing adoption, with a regression coefficient of 0.262 ($p = .020$). The training received by the farmer was also statistically significant, with a regression coefficient of 0.356 ($p = .022$). Households with larger landholdings were more likely to adopt improved seeds, indicating that economic capacity factors influenced farmers' decisions to invest in or experiment with new, improved seeds. Likewise, the positive coefficient of training also increased adoption rates because training enables farmers to face new changes through information empowerment. Another important factor was that access to resources and training were crucial factors for technology adoption.

On the other hand, other predictors, such as age of the household head, gender of the household head, years of education, household size, non-farm employment, tropical livestock assets, total household expenditure, and distance to facilities, were not statistically significant. These results suggest that while these variables may have an impact on adoption in other contexts, they had no significant effect in this sample. However, the above results show that the economic status of the

farmers has mixed effects, as total landholding is the only significant predictor of improved seed adoption.

6. Conclusion and policy implications

The study highlights that total landholding and access to training are the most critical factors driving improved seed adoption, while demographic variables such as age, education, and gender have no significant influence. Despite the potential of improved seeds to boost agricultural productivity and food security, adoption rates are declining due to financial constraints, logistical challenges, and systemic barriers. Farmers recognize the benefits of improved seeds, but structural inefficiencies, inadequate training, and limited access to resources hinder their widespread adoption. Addressing these barriers through targeted interventions is essential to unlock the full potential of improved seed technologies and ensure sustainable agricultural growth.

To promote the adoption of improved seeds and address the barriers identified in this study, policymakers must prioritize targeted interventions that enhance accessibility, affordability, and knowledge dissemination. First, agricultural training programs should be redesigned to be more practical, localized, and responsive to farmers' specific needs, with a focus on reaching younger farmers and smallholders who are less likely to participate in current programs. Second, financial support mechanisms, such as subsidies, credit facilities, and free seed distribution, should be expanded to make improved seeds more affordable for resource-poor farmers. Third, logistical improvements in seed distribution systems are essential to ensure timely and reliable access, particularly in remote areas. Leveraging informal networks, such as cooperatives and community-based groups, can enhance the reach and effectiveness of extension services. Ultimately, long-term monitoring and research are necessary to assess the effectiveness of interventions and address emerging challenges. By implementing these measures, policymakers can create an environment that enables improved seed adoption, ultimately boosting agricultural productivity, enhancing food security, and supporting sustainable development.

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Conflicts of interest

The authors declare that they have no conflict of interest.

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