Artículos

Dynamics of Information and Communication Technologies Adoption in Pakistan's Agriculture: Implications for Rural Development*

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Abstract:

The traditional agricultural economic systems, mainly in developing nations, faces various challenges including reduction in cultivated land, decreasing crop productivity, declining groundwater levels, changing pest and disease patterns, and overall climate variability. Adapting to these modifications requires considering different factors, including the information and communication technologies (ICTs). Yet, these factors and their impact remain untapped for smart farming. The representative sample of 300 farmers were chosen by using a simple random sampling technique from villages of Lahore and Multan Pakistan. The multinomial logit regression method was used to identify the determinants of ICTs adoption in agriculture. The research findings highlighted that the education level of farmers, farmers' association, compatibility of innovation, relative advantage of technology, observability of technological innovation, access to agricultural extension services, capacity building initiatives, and access to AI tools were promoting farmers' digital inclusion in agriculture significantly. Absolutely, initiating awareness campaigns and capacity building programs with the collaborative efforts of agricultural extension and advisory service departments may be highly effective for fostering understanding among small landholders regarding the significance of ICTs in agriculture. Access to agricultural extension services is crucial for enabling the farming community to make informed decisions about crop cultivation, discover new market opportunities, and adopt new information and communication technologies. Moreover, the study suggested that government officials, policy makers, farmers, and agricultural organizations should emphasize on these attributes while advocating for sustainable digital agricultural practices to promote the welfare of small landholders and rural development.

Keywords: :ICTs, Farmer's Associations, Traditional Agricultural Economic Systems, Farmers' Digital Inclusion, Sustainable Digital Agricultural Practices, Rural Development.

Dinámica de la adopción de las tecnologías de la información y de la comunicación en la agricultura pakistaní: implicaciones para el desarrollo rural

Resumen:

Los sistemas económicos agrícolas tradicionales, principalmente en los países en desarrollo, se enfrentan a diversos retos, como la reducción de las tierras cultivadas, la disminución de la productividad de los cultivos, el descenso del nivel de las aguas subterráneas, los cambios en los patrones de las plagas y de las enfermedades y la variabilidad climática general. Adaptarse a estas modificaciones exige tener en cuenta distintos factores, entre ellos las tecnologías de la información y la comunicación (TIC). Sin embargo, estos factores y sus repercusiones siguen sin aprovecharse para la agricultura inteligente. La muestra representativa de 300 agricultores se eligió mediante una técnica de muestreo aleatorio simple en pueblos de Lahore y Multan (Pakistán). Se utilizó el método de regresión *logit multinomial* para identificar los factores determinantes de la adopción de las TIC en la agricultura. Los resultados de la investigación pusieron de relieve que el nivel educativo de los agricultores, la asociación de agricultores, la compatibilidad de la innovación, la ventaja relativa de la tecnología, la observabilidad de la innovación tecnológica, el acceso a los servicios de extensión agrícola, las iniciativas de creación de capacidad y el acceso a las herramientas de IA promovían de forma significativa la inclusión digital de los agricultores en la agricultura. Por supuesto, la puesta en marcha de campañas de sensibilización y de programas de desarrollo de capacidades con la colaboración de los departamentos de extensión agraria y servicios de

asesoramiento puede ser muy eficaz para fomentar la sensibilización entre los pequeños propietarios acerca de la importancia de las TIC en la agricultura. El acceso a los servicios de extensión agraria es crucial para que la comunidad agrícola pueda tomar decisiones informadas sobre los cultivos, descubrir nuevas oportunidades de mercado y adoptar nuevas tecnologías de la información y la comunicación. Además, el estudio sugiere que los funcionarios públicos, los responsables políticos, los agricultores y las organizaciones agrarias deberían hacer hincapié en estos atributos, al tiempo que abogan por prácticas agrícolas digitales sostenibles que promuevan el bienestar de los pequeños propietarios y del desarrollo rural.
Palabras clave: tecnologías de la información y la comunicación (TIC), asociaciones de agricultores, sistemas económicos agrícolas tradicionales, inclusión digital de los agricultores, prácticas agrícolas digitales sostenibles, desarrollo rural.

Introduction

Despite the rapid industrialization and urbanization in current years, the agricultural sector remains significant in improving the social and economic well-being of rural communities and the labor indulged in farming. The fair majority of growers are small area holders having less than 5 acres of land. According to the latest Economic Survey of Pakistan 2023-24, about 90 % of farms operate on small-scale activities, and predominantly dependent on small scale agricultural practices for their livelihood (Aslam & Li, 2024). Though, these small farmers in developing countries encounter challenges in accessing knowledge, essential skills, modern agricultural technology, loan facilities, and agricultural marketing information system, hindering their ability to sustain and improve their livelihoods (Ahsan et al., 2023; Aslam & Rasool, 2013; Awan et al., 2019; Javaid et al., 2023; Hussain, 2023; Gouroubera et al., 2024, Mittal & Mehar, 2016; Okello et al., 2023).

Thus, ensuring that small-scale farmers in developing economies are well-informed about new market opportunities and equipped with the state of art knowledge, skills, and technologies is often seen as a critical path for improving the livelihoods of small landholders and sustaining the overall growth and profitability of the agricultural sector in the developing nations (Ayim et al., 2022; Balyan et al., 2024; Bilali & Allahyari, 2018; Dhehibi et al., 2023; Li et al., 2018; Mansour, 2022; Nyoni et al., 2024; Ryan et al., 2023; Yang et al., 2024; Slimi et al., 2024; Bull et al., 2024).

Information and communication technologies (ICTs) encompass a range of technological innovations including the smart phones, laptop, desktop computers, internet connectivity, and smart LED TV sets etc. These technologies enable people to access, process, transmit, and disseminate information in different formats as images, messages, and voice notes (Bhatti et al., 2023; Chandio et al., 2022; Dissanayake et al., 2022; Shang et al., 2021; Wu, 2022; Hrustek, 2020; Liu et al., 2023; Zhu et al., 2021). ICTs present numerous potentials and market avenues for growers to establish valuable networks with fellow growers, access important agricultural commodity prices and related market information, and attain information about input utilization, crop productivity, and marketer preferences. Integrating ICTs into agricultural marketing can significantly reduce the reliance on intermediaries as well as market inefficiencies, lowering transaction costs, and identify potential marketers (Aslam & Rasool, 2013; Chikuni & Kilima, 2019; Chowhan & Ghosh, 2020; Emeana et al., 2020; Matthew et al., 2023; Rahman & Huq, 2023). To facilitate the adoption of ICTs for agricultural marketing, they should be user-friendly, their benefits should be demonstrated, and access to these technologies should be made available to their potential customers (Awuor & Rambim, 2022; Bahn et al., 2021; Cafer & Rikoon, 2018; Méndez-Zambrano et al., 2023; Ribeiro et al., 2023; McCampbell et al., 2023; Adamsone-Fiskovica & Grivins, 2022).

Essentially, ICTs empower small landholders by providing them with timely and authentic market knowledge, enabling them to make informed decisions for their enterprises. Various factors affect growers' adoption of ICTs

for marketing of their agricultural produce, including demographic facets like age of the farmer, sex, and education level of the farmer; socio-personal aspects as income, access to loan facilities, and land acreage; situational dynamics as proximity to markets; and institutional determinants like participation of the farming communities in training programs, access to agricultural extension and advisory service providers. These determinants are perceived to have either positive or negative associations with farmers' use of ICTs, ultimately enhancing their ability to market their produce rationally (Javaid et al., 2023; Kante et al., 2019; Khan et al., 2022; Klerkx et al., 2019; Suroso et al., 2022; Zegeye et al., 2022). Furthermore, by diminishing the role of intermediaries, a new viable marketing channel may emerge, allowing farming community to directly engage with marketers (Hoang, 2020; Untari & Vellema, 2022). Therefore, the present study aims to investigate the impact of determinants affecting the ICTs adoption in agriculture.

The innovative aspect of this study lies in its pragmatic approach to understand farmers' decision-making for the adoption of information and communication technologies within a defined time-frame. We have classified the farming community into three defined categories: early adopters, who have integrated ICTs in agriculture for five years or above; later adopters, who have utilized these ICTs practices in agriculture for a year or above; and late adopters, who have implemented these technological solutions for agriculture for less than a year. This categorization addresses a significant gap in the current literature by providing a structured framework to analyze how different levels of ICTs adoption influence farming practices and decision-making. While previous studies, such as those by Aslam and Li (2024), Shah et al. (2023), and Yang et al. (2024), have explored ICTs adoption in agriculture, they have not thoroughly differentiated between various stages of adoption and their impact on agricultural outcomes. Our study fills this gap by offering a nuanced understanding of how the duration and level of ICTs adoption affect farmers' practices and decision-making processes, thus providing valuable insights for policymakers and extension services to tailor their support strategies effectively.

The subsequent sections of the manuscript follow a structured approach as the second section outlines the methods of the study while the third section explains the results of the study, forth section exhibits the discussion, and the fifth section delves into conclusions and policy implications of the research work.

Methodology

Theoretical Framework

The diffusion of innovations theory (DOI) works as a foundational framework for comprehending the adoption of novel agricultural activities, mainly in relation to changing agribusiness scenarios. It was originally developed by the Rogers in 2003, it evaluates how new practices or innovative technologies diffuse among individuals or societies with the passage of time, with a pertinent emphasis on agricultural systems. In agriculture, the DOI theory figures out the determinants affecting growers' adoption of innovative farming and agricultural marketing methods by the utilization of ICTs. According to Rogers (2003), the diffusion mechanism refers to the transmission of novel agricultural practices gradually among the farming community who are interested to manufacture and purchase agricultural commodities, typically represented by the S-shaped curve.

Though, despite concerted efforts for expediting the diffusion mechanism, challenges prevail, primarily regarding the delayed adoption practices among the farmers' family heads. This delayed adoption practices may exist due to various reasons like lack of agricultural knowledge regarding the gains of technological innovation and

the significance of technological innovation in an economy, as well as restricted information regarding the ICTs infrastructure and low participation rate of farming communities in the relevant capacity building programs.

Hence, the studies highlighted the significance of information and communication technologies in farming, not only for bolstering adoption but also for improving its diffusion effects on the rural communities. While the examination of DOI in context to farmers' acceptance of innovative technologies is an emerging arena in Pakistan's agriculture, it draws upon from present literature from Pakistan as well as from the developed world, enlightening the complex factors of technology and adoption in agriculture (Aslam & Li, 2024; Kante el al., 2019; Bahn et al., 2021; Dhehibi et al., 2024; Hrustek, 2020; Javaid et al., 2023; Shah et al., 2023).

Moreover, the research work in this discipline holds promise for providing fruitful insights for the decision makers and practitioners exploring to foster the sustainable agricultural development in the developing nations.

Empirical Framework

The study mainly emphasized on carrying out face to face interactions and focused group discussions with the farmers to comprehend their decisions for the adoption of information and communication technologies in agriculture of Pakistan. Both qualitative and quantitative research approaches were utilized to evaluate the ICTs adoption in the research areas. The collection of information involved structured, semi-structured, and non-structured interviews, aimed at figuring out information regarding the use and adoption of main technological innovations in the agriculture sector.

The purposive random sampling technique was ensured the equal participation of farmers (Aslam & Li, 2024), with the advice was sought from the Directorate General Agriculture Extension, Punjab, Pakistan. A representative sample of 300 growers was drawn by utilizing simple random sampling technique from two leading agricultural districts of Pakistan, Lahore and Multan (150 farmers from each district). Each interview was taken time from thirty to forty-five minutes whereas the focus groups lasted sixty to ninety minutes. The discussions were performed in a fair manner and conducive environment to encourage equal participation, and focus groups were assisted in a group-based activity with appropriate questions to promote dialogue. All discussions had been recorded with respondents' consent and transcribed for research outcomes.

To make sure the validity of the data, a pilot testing was performed with a small group of respondents prior to the main research work. The feedback from these discussions assisted in adjustments to the questions for precision and compatibility. Moreover, the questions were examined by field experts to verify the relevancy of data collection instruments.

Whereas the methodology portrays valuable insights, few limitations of the research work should also be acknowledged. The sampling biases arise due to the purposive selection of the respondents that influenced the generalizability of the research outcomes. In addition, the geographic emphasis of the study limited the applicability of the findings to other contexts.

The sample size calculations followed by Yamane (1967) calculations, a commonly utilized technique in various research studies (Aslam & Li, 2024; Li et al., 2018; Shah et al., 2023; Javaid et al., 2023). The confidence interval of 10 percent was adjusted for this study.

In this study, multinomial logit regression analysis was employed to categorize growers into three distinct groups based on their timing of adopting information and communication technologies (ICTs) in agriculture. The groups are defined as follows.

Early Adopters: Growers who have integrated ICTs into their agricultural practices for five years or more. This group represents those who were among the first to embrace technological innovations, reflecting a high level of experience and familiarity with ICTs.

Later Adopters: Growers who have adopted ICTs in their agricultural practices for one year or more, but less than five years. This category includes individuals who adopted the technology after its initial introduction, indicating a moderate level of engagement with the innovations.

Late Adopters: Growers who have implemented ICTs in their agricultural practices for less than one year. This group consists of those who are recent adopters, reflecting a more recent or ongoing transition to using ICTs.

This classification was made based on the duration of ICT adoption, which serves as a proxy for the timing and level of integration of technological innovations in agricultural practices. The multinomial logit model is particularly suitable for this analysis because it allows us to assess the probability of a grower being in one of these three adoption categories relative to a baseline category. By using this approach, we can evaluate the impact of key variables on the timing of ICT adoption within Pakistan's agricultural sector and gain insights into the factors influencing different stages of technological adoption. The model is defined by the following equation (1):

$$P(Y = j \mid X) = e^{(\beta_j * X)} / \Sigma (e^{(\beta_k * X)}) \text{ for } j = 1, 2, ..., J\text{-}1 \ldots\ldots\ldots\ldots \quad (1)$$

Where:

$P(Y = j \mid X)$ is the likelihood that the result is in category j.

β_j is a slope of coefficients for category j.

X is a vector of explanatory variables.

j is the total number of categorizes.

In this model, j = 3 corresponds to growers who have adopted technological innovations for five years or more, j = 2 corresponds to growers who have adopted these innovations for one year or more, and j = 1 corresponds to growers who have adopted these innovations for less than one year. This categorization is consistent with the classifications used in previous studies by Aslam and Li (2024), Li et al. (2018), and Shah et al. (2023).

The multinomial logit regression is appropriate for this research because it handles the situation where the dependent variable is categorical with more than two levels. It enables us to model the probability of a grower being in each adoption category relative to a baseline, based on the influence of explanatory factors. This approach provides insights into the dynamics affecting the timing of ICT adoption and helps in understanding how different variables impact the likelihood of timely adoption of technological innovations in agriculture (Table 1).

TABLE 1.
Questions and Measurement Scale of Variables

Acronym	Variable Description	Questions	Measurement Scale
Adoption	Adoption of innovative technologies in agriculture	Have you adopted the innovative technologies in agriculture? What are the information and communication technological solutions available in agriculture? From how many years you are utilizing innovative information and communication technologies in farming?	Categorical
Qualification Level	Qualification of the grower	What is the qualification of the grower?	Continuous
Farmer's Association	Membership of the farmer in farmer's association	Are you part of any farmer level association or cooperative?	Dummy
Compatibility of Innovation	Compatibility of technological innovation in agrarian sector	Is the innovative technology compatible with your own circumstances? Is the innovative technology compatible with your own needs?	Dummy
Relative Advantage of Innovation	Relative advantage of technological	Is the innovative technology relatively more beneficial with the previous technology?	Dummy

	innovation in agrarian sector	Is the innovative technology relatively cheaper with the previous technology? Is the innovative technology relatively more useful with the previous technology?	
Observability of Innovation	Observability of technological innovation in agrarian sector	Is the innovative technology observed by your fellow farmers, peer groups and social circle? Does your fellow farmers, peer groups and social circle show interest to adopt the technology utilized by you?	Dummy
Access to Agricultural Extension Services	Accessibility of farmers to agricultural extension services	Do you have accessibility to agricultural extension services? If yes, then how frequently the agricultural extension service providers visit your farms?	Dummy Categorical
Access to AI Tools	Accessibility to AI tools by farmers	Do you have accessibility to AI tools for farming practices?	Dummy
Capacity Building Programs	Farmer's participation in capacity building programs relevant to information and communication technologies	Do you participate in capacity building programs relevant to information and communication technologies?	Dummy

Source: Author's own elaboration.

Analysis of Results

Table 2 represents the descriptive statistics concerning to the regressor factors used in the multinomial regression technique. Within the study area, the average qualification level was 10.33 years. Among the populace, 49 % reported that they were the part of farmer's associations or cooperatives in the study area. While 58 % illustrated

that their adoption decision towards innovative technology for agriculture was influenced by compatibility of technological innovation in their own circumstances or the need of the innovation in the study area.

The adoption decisions of nearly 65 % of growers were affected by the relative advantage of the technological innovation as compared to previous technology. Likewise, approximately 60 % of the growers illustrated that the observability of technological innovation affected their technology adoption decision. As majority of the farming community observe their fellow landholders' who had already adopted the technology, and they were satisfied with functionality and working mechanism of the innovation, this would surely assist for improving the diffusion process of technological innovation.

Almost 66 % of farmers quoted that their adoption decision for innovative technology was shaped by the accessibility of agricultural extension and advisory service providers on farm, 64 % informed that their adoption decision was influenced by the availability of AI tools (ChatGPT tools) for the farming practices. Absolutely, the peasants may leverage these tools for accessing a wide range of agricultural information relevant from weather forecasts, insect-pest diseases, to prevailing market trends in the agricultural industry.

Moreover, farmers may improve their learning by employing these cost-effective techniques, specifically in today's digital era where internet connectivity is widespread and information is merely a click away from the user. These AI tools are serving as a virtual mentors or instructors so these AI tools are empowering the farming community to make rational decisions regarding crop plantation and finding new market avenues and adopting new practices in agriculture.

Whereas 57 % indicated that peasants' participation in capacity building programs plays an imperative role for affecting their technology adoption decision in agriculture. Basically, these capacity building programs enrich farmer's knowledge, and enhance their skills by providing the hands-on experience through interactions with the industry representative or invited resource person. The small landholders receive valuable insights, advice, and practical understanding, enabling them to alter their agricultural practices and effectively adapt to evolving farming practices.

TABLE 2.
Description, Measurement and Summary Statistics of Variables

Factors	Description of Factors and Scale of Measurement	Mean (Std. Deviation)
Qualification Level	Qualification level of growers (number of years in schooling).	10.33 (8.37)
Farmer's Association	= 1 if a grower participates in farmers' associations, 0 otherwise.	0.49 (0.22)
Compatibility of Innovation	= 1 if a grower's technological innovation adoption decision has been impacted by the compatibility of technological innovation, 0 otherwise.	0.58 (0.47)
Relative Advantage of Innovation	= 1 if a grower's technological innovation adoption decision has been influenced by the relative advantage of technological innovation, 0 otherwise.	0.65 (0.54)
Observability of Innovation	= 1 if a grower's technological innovation adoption decision has been influenced by the observability of technological innovation, 0 otherwise.	0.61 (0.51)
Access to Agricultural Extension Services	= 1 if a grower's technological innovation adoption decision has been affected by the access to agricultural extension services, 0 otherwise.	0.66 (0.57)
Access to AI Tools	= 1 if a grower's technological innovation adoption decision has been affected by the access to AI (ChatGPT tools), 0 otherwise.	0.64 (0.52)
Capacity Building Programs	= 1 if a grower's technological innovation adoption decision has been impacted by the participation of growers' in capacity building programs.	0.57 (0.48)

Source: Author's own elaboration.

In this research, the Variance Inflation Factor (VIF) was used to assess the presence of multicollinearity among the explanatory factors (Aslam & Li, 2024). For our predictor variables, the VIF values ranged between 1.895 and 3.976, all of which remain below the threshold level of 10 (Aslam & Li, 2024). Thus, we did not encounter the issue of multicollinearity among our predictor variables in the data (Table 3).

TABLE 3.
Variance inflation Factor (VIF) Approach

Variable	Tolerance	VIF
Qualification Level	.589	2.497
Farmer's Association	.354	2.322
Compatibility of Innovation	.589	2.890
Relative Advantage of Innovation	.327	2.794
Observability of Innovation	.397	1.895
Access to Agricultural Extension Services	.4779	2.392
Access to AI Tools	.1946	1.931
Capacity Building Programs	.6538	3.976

Source: Author's own elaboration.

Furthermore, in our study, early adopters of ICTs innovations in agriculture accounted for 73 farmers (24.34 %), while later adopters of ICTs innovations in agriculture numbered 127 farmers (42.33 %), and late adopters of ICTs innovations in agriculture totaled 100 farmers (33.33 %) respectively (Table 4; Figure 1).

TABLE 4.
Time-based Comparison of Small Landholders Groups for Innovation Adoption in Agriculture

Innovation Adoption Groups	Frequency (Percentage)
Early adoption of innovations by small landholders	73.0 (24.34 %)
Later adoption of innovations by small landholders	127.0 (42.33 %)
Late adoption of innovations by small landholders	100.0 (33.33 %)
Total	300 (100 %)

Source: Author's own elaboration.

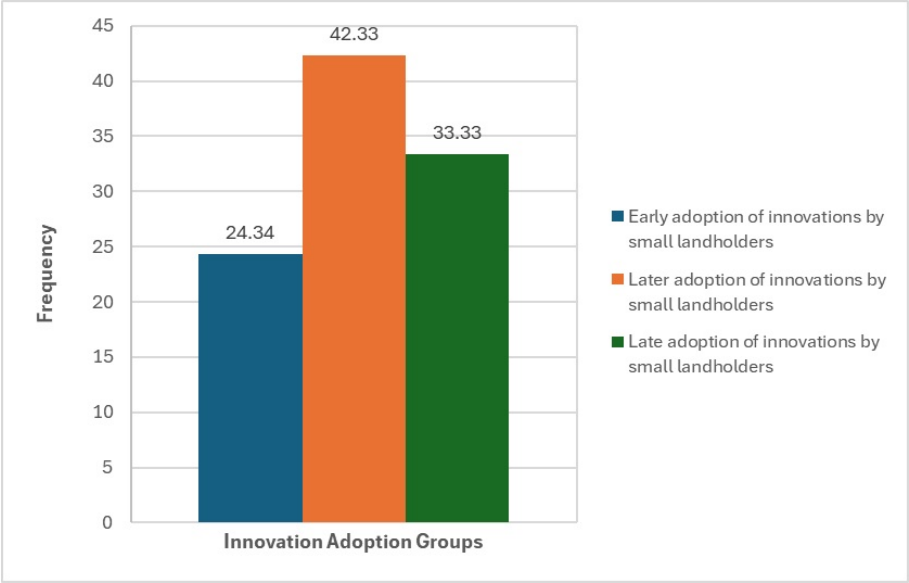

FIGURE 1.
Time-Based Comparison of Small Landholders for ICTs Adoption
Source: Author's own elaboration.

The research utilized multinomial logit regression method to identify the variables influencing farmers' timely ICTs adoption decision in agriculture. The peasants were categorized into three groups, like early adoption of innovations by small landholders, later adoption of innovations by small landholders, and late adoption of innovations by small landholders. The later and late adoption groups were taken as the reference points in the research work. The value of pseudo R. 0.592 indicated that the predicted model accounted for 59.20 % of the probability of peasant's ICTs adoption in farming, representing a strong fit with our data set. Furthermore, the value of LR Chi-Square yielded a significant finding at the 1 % level ($P < 0.05$), reflecting that specific predictor determinants in the model affected peasants' ICTs adoption decision in farming (Table 5).

The qualification level of the peasant indicated a profound and positive association with the adoption of information and communication technologies in agriculture for the initial phases of implementation on their agricultural farms. Well-educated farmers were more likely to adopt ICTs decisions timely as compared to the less educated ones who adopted these technologies later on. This finding inculcates that the peasants having higher qualification levels were more inclined to adopt information and communication technologies than those having lower qualification levels in the study area. The study also observed that there is a positive relationship between farmer's association and adoption of information and communication technologies in agricultural practices for the initial phases.

The research analysis depicted that peasants' decisions to adopt information and communication technologies during the initial phases were impacted by the compatibility of the technological innovation in agriculture. It implies that the peasants who perceived the information and communication technologies as more suitable for their own situations were more inclined to adopt information and communication technologies for agricultural and farm operations. Therefore, the compatibility of technological innovation was noted to have a significant and positive association with the peasants' decisions to adopt information and communication technologies on farms.

The outcome identified that peasants' decision to adopt information and communication technologies during the early phases were affected by the relative advantage of the technological innovation in agriculture. It implies that the peasants who sought that the new technology is a relatively more beneficial in terms of cost and functionality, were more inclined towards adopting information and communication technologies during the early phases of technological development in agriculture.

The findings showed that peasants' decisions to adopt information and communication technologies during the initial phases of technological innovation were affected by the observability of innovative technology by the fellow peasants, peer groups, relatives, and social groups. It implies that the peasants who observed fellow peasants who adopted the information and communication technologies in agriculture were more inclined to adopt information and communication technologies in agriculture.

Another important variable for peasants' information and communication technologies adoption is the access to agricultural extension and advisory services to the farming community for agricultural activities. In the research, this factor had a profound and positive effect on peasants' information and communication technologies adoption for farming activities. Basically, through accessing these services, small landholders are better equipped to perform their farming activities efficiently and effectively (Table 5).

TABLE 5.
Multinomial Logit Regression Outcomes for Early Technology Adoption in Agriculture

Determinant	**Early Innovation Adoption by Small Landholders**	
	Coefficients	**Standard Error**
Qualification Level	0.792*	0.189
Farmer's Association	0.258*	0.150
Compatibility of Innovation	0.771*	0.538
Relative Advantage of Innovation	0.493	0.309
Observability of Innovation	0.133	0.244
Access to Agricultural Extension Services	8.902*	4.891
Access to AI Tools	7.635*	5.149
Capacity Building Programs	2.215*	1.758
	LLog-likelihood value = 495.9, LR chi-square value = 125.76, Chi-square significant = 0.000, Pseudo R2 = 0.592	

Source: Author's own elaboration.
Notes. *Represent the significance level at 1 % significance whereas **shows the significance level at 10 % significance. Later and late adoption decision-making group is a reference category.

Furthermore, accessibility to AI tools also had a considerable and positive effect on peasants' information and communication technologies adoption in the initial phases of technology advancement in agriculture. Essentially, the AI tools may support farming community in precision agriculture, encompassing predictive analytics, smart irrigation practices, optimization of agribusiness supply chains, and crop monitoring as well.

The engagement of smart landholders in precision farming and information and communication technologies-based capacity building programs also improves their inclination towards involving in robotic farming. Our study

observed a similar trend, reflecting that improved participation of small landholders in capacity building programs correlates with enhanced adoption of information and communication technologies in agriculture.

Comparative Analysis

To strengthen the study's significance and depth, a comparative analysis with past literature on information and communication technologies adoption in agriculture in developing economies was performed. This comprehensive comparative analysis supported a clearer perception of the unique drivers affecting ICTs adoption in Pakistan, pinpointing the similarities and differences with broader rural contexts.

Recent studies have examined the adoption of information and communication technologies (ICTs) in agriculture across various regions, highlighting critical factors influencing productivity. In Zambia, research published in the Open Journal of Business and Management found that the adoption of ICTs, particularly when combined with the use of seeds, fertilizer, and financial loans, positively and significantly impacted agricultural productivity, although some combinations showed non-significant effects (Ali et al., 2016). In Nigeria, a study in the Journal of Entrepreneurship and Information Management revealed that social influences and perceptions of usefulness and ease of use critically affected the adoption and use of ICTs among small and medium agribusinesses (Aleke et al., 2011). Furthermore, Agricultural and Food Economics reported that factors such as farm income, crop yield, and access to input and output markets were significant determinants of technology adoption in Nigeria (Awotide et al., 2016).

In Ethiopia, research featured in Information Technology for Development utilized Actor Network Theory to demonstrate how citizens and technological tools collaborated to establish agricultural knowledge centers, thereby facilitating access to digital resources (Birke & Knierim, 2020). A study in Taiwan, as published in Information Research, indicated that the adoption of ICT positively influenced technological innovation practices, enhancing organizational competitiveness (Chen & Tsou, 2007). In Uganda, the African Journal of Agricultural and Resource Economics highlighted the distinct roles of gender in fertilizer adoption decisions, finding that male and female heads of households had different influencing factors (Diiro et al., 2015). Research in Zambia, detailed in Agriculture, Ecosystems and Environment, pointed out that while many farmers were interested in advanced technologies, limitations in resources hindered their adoption (Grabowski et al., 2016).

In another Ethiopian study, findings related to the non-adoption of green revolutionary techniques revealed that various socio-economic characteristics significantly impacted farmers' decisions (Hassen, 2015). In Sri Lanka, the Development Studies Research journal discussed the importance of technological innovation for economic development through the lens of Actor Network Theory, shedding light on the mechanisms of technological change (Heeks & Stanforth, 2015). In Ethiopia, the Journal of Agriculture and Food Research emphasized that access to agricultural finance greatly improved technology adoption rates among farmers (Girma, 2022). Research in Iran, as presented in the Journal of International Food & Agribusiness Marketing, employed the Theory of Planned Behavior to identify key determinants influencing farmers' ICT adoption, finding that education and training were paramount (Alavion et al., 2017).

The Telecommunications Policy journal explored how participatory radio campaigns in six Sub-Saharan African countries enhanced listeners' skills and facilitated early adoption of ICTs in agriculture (Hudson et al., 2017). In Vietnam, an investigation published in Agricultural Economics established a positive association between internet connectivity and agricultural productivity, particularly benefiting younger farmers who effectively utilized internet resources (Kaila & Tarp, 2019). An additional study in the Asian Journal of Agricultural Sciences underscored the significance of socio-economic factors in adopting improved seed varieties in Zambia, revealing

that farmers' expectations regarding market prices and crop yields were crucial drivers (Kalinda et al., 2014). Lastly, research in Egypt, published in Information Development, highlighted the need for improved agricultural advisory services through mobile platforms to enhance farmers' access to critical information (Kassem et al., 2019). In a study conducted in Vietnam, researchers explored the relationship between women's leadership and internet usage within agricultural cooperatives. The findings revealed that strong female leadership significantly correlated with increased internet use, which in turn had a positive impact on several key performance indicators: farmers' returns on assets, returns on equity, workforce productivity, and wages. Additionally, the study highlighted the role of farmers' associations in enhancing insurance coverage and improving the quality of agricultural commodities produced. However, the regression models indicated that while internet usage was beneficial, it also exacerbated earnings inequality among cooperatives. As a result, the study recommended initiatives aimed at bolstering women's leadership and implementing ICT-based education and skill programs to further enhance agricultural performance in the region (Nguyen et al., 2023). Collectively, these studies underscore the multifaceted challenges and opportunities in integrating ICTs into agricultural practices, emphasizing the necessity for targeted strategies that consider gender, socio-economic factors, and regional contexts.

By scanning literature from different parts of the world mainly Sub-Saharan Africa, and Southeast Asia, we observed almost common bottlenecks and successful strategies which might be helpful for practitioners and decision makers in Pakistan. Basically, this analysis not only augmented the international relevance of the research but also portrayed the valuable insights for concerned departments aiming to enhance the adoption of information and communication technologies in agriculture.

Elaborating these comparisons will enrich the findings and contextualize the research outcomes within a broader context, consequently leading to a more robust understanding the role of information and communication technologies in rural agribusiness development across diverse settings.

Discussion

The study aims to identify major drivers influencing farmers' decision to adopt information and communication technologies (ICTs) for agricultural practices. Exploring these drivers may be helpful for agricultural stakeholders, agricultural value chain actors, technology service providers, environmentalists, decision makers for improving ICTs adoption and heading towards the sustainable agriculture. Multinomial logit regression method was employed to assess the determinants affecting ICTs adoption decision for agriculture.

In our study we observed that there was a positive as well significant relationship exist between qualification of small landholder and ICTs adoption in agriculture. Additionally, the peasants who equipped with knowledge how to utilize information and communication technologies, as well as their perceptions regarding the costs and advantages were able to make early and rational decisions regarding information and communication technologies on farm. This outcome is aligned with the findings of Ayim et al. (2022), Balyan et al. (2024), Dhehibi et al. (2023), Nyoni et al. (2024), Yang et al. (2024), who also quoted that well-qualified peasants were more inclined to timely adoption of information and communication technologies for agricultural activities.

The research also identified the positive association between farmer's association and adoption of ICTs in agriculture at early stages of technology commencement. This outcome is consistent with the studies of Untari and Vellema, (2022), Ayim et al. (2022) and Aslam and Li (2024).

The compatibility of technological innovation and ICTs adoption had significant and positive association with the peasants' decisions to adopt information and communication technologies on farms. This outcome is aligned with the findings of Shang et al. (2021), McCampbell et al. (2023), Adamsone-Fiskovica and Grivins (2022), Hoang

(2020), Javaid et al. (2023), Kante et al. (2019), Khan et al. (2022), Zegeye et al. (2022), who represented that the compatibility of technological innovation positively influences peasants' early adoption decision for agricultural and farming practices.

The relative advantage of technology indicated a profound and positive relationship with the information and communication technologies adoption in agriculture. This outcome is in line with the findings of Shang et al. (2021), Chikuni and Kilima (2019), Emeana et al. (2020), Kante et al. (2019), Zhu et al. (2021), who identified that the relative advantage of technological innovation positively affects the peasants' early adoption decisions for farming activities.

The observability trait of technology indicated a profound and positive association with the peasants' decisions to adopt information and communication technologies for farming. This outcome is consistent with the findings of Shang et al. (2021), Kante et al. (2019), Cafer and Rikoon (2018), who demonstrated that the observability trait of novel technology positively affects fellow farmers' early adoption of innovative solutions on farms.

There was positive and profound relationship found between access to agricultural extension workers and ICTs adoption in agriculture. This outcome is supported by the studies of Aslam and Li (2024), Awuor and Rambim (2022), Ayim et al. (2022), Khan et al. (2022), Zegeye et al. (2022), Gouroubera et al. (2024), Mittal and Mehar (2016), Okello et al. (2023).

It was also observed that there was a positive and significant relationship exist between the access to AI tools and ICTs adoption in agriculture. This result aligns with the research work of Javaid et al. (2023), Ryan et al. (2023).

Moreover, there positive and significant relationship existed between small landholder's participation in agricultural training programs and ICTs adoption in agriculture. This outcome is consistent with the results of Aslam and Li (2024), Ayim et al. (2022), Khan et al. (2022), Liu et al. (2023), Shang et al. (2021), Zegeye et al. (2022).

In summary, the study underscores the importance of education, social networks, compatibility, perceived benefits, observability, access to support services, AI tools, and training in influencing the adoption of ICTs in agriculture. These factors collectively enhance the likelihood of timely and effective adoption of technological innovations, which is crucial for advancing sustainable agricultural practices.

Conclusions

The sustainable integration of information and communication technologies and agriculture by the rural communities play an imperative role for the success of modernized agriculture. The early information and communication technologies adoption may direct substantial benefits as securing premium prices of agricultural produce, rising income, establishing direct connections with high-end agribusiness value chains. Though, there exists a lack of understanding about the innovative technological practices and its' importance is not communicated in the required manner by the agricultural authorities. In addition, there is limited evidence regarding the determinants influencing small landholders' early adoption decisions regarding these innovative technological practices in agriculture. The study estimates outlined that qualification level of small landholders was shaping ICTs decision positively as well as significantly. According to outcomes of the research work, small landholder's active involvement in farming cooperatives or farmers' associations had a considerable and positive impact on timely adoption of information and communication technologies. It was also confirmed that the technological traits as relative advantage of innovation, compatibility of technological innovation and observability of technology emerged as significant drivers of ICTs adoption in agriculture. This research analysis also figured out that the small landholders' ICTs adoption decisions were affected by the accessibility of

agricultural extension or advisory service providers. Moreover, participation in capacity building programs also played a vital role in improving small landholders' adoption decisions regarding ICTs initiatives in agriculture.

To augment the impact of the research outcomes, the recommendations have been tailored to particular stakeholders. *Small holders Farmers*: Our outcomes hold practical implications for promoting the widespread adoption of innovative information and communication technological practices among the farmers in the developing nations. The early adoption of these technologies may enhance the overall welfare of small landholders. Therefore, it is crucial to encourage small landholders' timely adoption of these agricultural technologies. *Policy Makers*: Policies makers should devise the policies which encourage the early adoption of information and communication technologies by taking into consideration small landholder's decision-making process and characteristics.

Local Government Bodies: For instance, agricultural extension and advisory service providers may play a dominant role by engaging the rural masses in informal capacity building programs, specifically targeting the less educated small landholders. These efforts may assist farming communities to get be informed about the several advantages of information and communication technologies in agricultural production, including improvements in crop productivity, and profitability. Furthermore, the accessibility of AI tools is also affecting positively to small landholders' early ICTs adoption decisions in agriculture. Therefore, there is essential for the governments to prioritize ensuring the accessibility of both internet as well as AI tools in rural areas. This initiative may considerably promote the ICTs adoption process and further facilitate the diffusion of digital agricultural sustainability. *International Organizations*: Promote linkages between local bodies and international organizations to disseminate best agricultural practices and technologies for rural agricultural development.

In addition to the social implications, the research work also highlights the economic gains of information and communication technologies adoption in agriculture. As access to information and communication technologies lead to improved agricultural productivity through better farm management and judicious use of input resources. These ICT tools also assist in reduction of operating costs from streamlined operations to improve agribusiness supply chain management. Utilization of these digital gadgets, financial earnings of rural farming communities can be accelerated by entering into international markets.

Lastly, there is a dire need to identify the steps to be taken for the practical implementation of the recommendations at various tiers viz. Community level, regional level and national level. At community level, there is a need to initiate pilot projects to check information and communication technologies in collaboration with smallholder farmers, collecting feedback for further improvement. At regional level, the regional conferences, symposiums and knowledge-sharing platforms should be organized to foster coordination among farming community. At national level, the national policies should be developed which encourage usage of information and communication technologies in agriculture truly based on successful regional case studies.

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Notes

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