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Factors influencing the adoption of improved harvesting and post-harvest handling technologies on bean shelf life among smallholder farmers in Kasana sub-county Sheema district

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Abstract

Bean production plays a significant role in improving household food security, nutrition, and income among smallholder farmers in Uganda. However, post-harvest losses resulting from poor harvesting, drying, storage, and handling practices continue to reduce bean quality and shelf life. The adoption of improved harvesting and post-harvest handling technologies is therefore essential in enhancing bean preservation, reducing losses, and improving farmers' livelihoods. The study was conducted to establish the factors influencing the adoption of improved harvesting and post-harvest handling technologies on bean shelf life among smallholder farmers in Kasana sub-county Sheema district. It adopted a descriptive research design that integrated both qualitative and quantitative approaches to data collection and analysis. Data was gathered from 222 smallholder bean farmers and key informants (agricultural extension workers and local leaders) using both questionnaire and interviews. Data was managed and analyzed using SPSS version 23 to compute both descriptive and regression statistics. The study found out that adoption of improved harvesting and post-harvest technologies in Kasaana sub-county was influenced by a combination of socio-economic, institutional, and infrastructural factors. Key drivers these included education ($\beta = 0.842$, $p = 0.002$), farm size ($\beta = 0.693$, $p = 0.004$), household labor ($\beta = 0.521$, $p = 0.009$), awareness ($\beta = 1.104$, $p < 0.001$), and perceived benefits ($\beta = 0.911$, $p = 0.002$), while constraints such as poor market access ($\beta = -0.768$, $p = 0.004$) limited adoption. The study concluded that smallholder bean farmers in Kasaana Sub-county predominantly relied on basic and traditional harvesting and post-harvest technologies, despite the presence of some improved practices. Adoption of these technologies was shaped by key socio-economic and institutional factors such as education, farm size, labor availability, awareness, and perceived benefits, while poor market access remains a major constraint. Furthermore, the use of improved post-harvest practices especially proper storage, drying, and pest control played a significant role in enhancing bean shelf life. Overall, strengthening access to information, infrastructure, and markets is critical to improving adoption and post-harvest outcomes. Government and development partners should promote access to affordable improved technologies such as hermetic storage bags, solar dryers, and mechanical threshers through subsidies and credit schemes. This will enhance adoption and reduce post-harvest losses among farmers. Invest in rural infrastructure and subsidized affordable storage and post-harvest technologies is essential to improve accessibility and encourage wider adoption among smallholder farmers.

Key Words: Factors, adoption, improved harvesting and post-harvest handling technologies, bean shelf life, smallholder farmers.

Introduction

Globally, beans (Phaseolus vulgaris L.) are an important staple crop and a major source of protein, energy, and essential micronutrients, particularly in Latin America and other developing regions (Mbiu et al., 2025). Despite their nutritional and economic importance, postharvest losses continue to affect bean quality, quantity, and marketability, thereby threatening food security and farmer incomes. Effective postharvest handling practices such as timely harvesting, proper drying, careful handling, and safe storage are therefore essential in minimizing losses and improving bean shelf life and nutritional value (FAO, 2022). In countries such as Brazil and Turkey, poor storage and handling practices have been linked to significant postharvest losses, demonstrating the urgent need for improved postharvest technologies and management systems (Buyukbay et al., 2011; FAO, 2022).

Studies indicate that timely harvesting and proper postharvest management greatly reduce physical damage, pest infestation, and microbial contamination, thereby prolonging shelf life and preserving bean quality (Buyukbay et al., 2011). Developed countries such as the United States have adopted advanced storage technologies including controlled atmosphere storage, hermetic bags, and metallic silos to reduce losses and maintain grain quality. Proper storage practices such as keeping beans in well-ventilated facilities and using raised platforms help prevent moisture absorption and spoilage. The adoption of hermetic storage technologies has also proven effective in protecting beans from pests and excess moisture, significantly reducing postharvest losses and improving food safety standards (Okori et al., 2022).

In sub-Saharan Africa, smallholder farmers continue to face challenges related to low agricultural productivity, climate change, and limited access to improved technologies, all of which contribute to high postharvest losses. Poor postharvest handling practices have resulted in serious food insecurity and economic losses across the region. For example, studies in Nigeria revealed that poor postharvest management practices caused substantial financial losses among farmers, a situation that is also common in bean production systems (Shiru, 2023). In Uganda, postharvest losses account for approximately US$ 4 billion worth of food annually, highlighting the urgent need for interventions aimed at improving postharvest handling, reducing losses, and strengthening food and nutrition security (Ariong et al., 2023).

Uganda is among the leading producers of dry beans in Africa, with more than 70% of households involved in bean cultivation. However, inadequate harvesting and postharvest handling practices continue to cause significant losses estimated at up to 22% of total production (Ariong et al., 2023). Common challenges include delayed harvesting, poor drying methods, and inadequate storage facilities, all of which increase moisture content and expose beans to pests, mold, and diseases. In Sheema District, farmers largely rely on traditional postharvest handling and storage methods that compromise bean quality and shorten shelf life. Studies further show that drying beans on bare ground and failure to attain the recommended moisture content of below 13% increase contamination risks and reduce market quality, emphasizing the need for improved harvesting, drying, and storage technologies among smallholder farmers (Ocen & Kafuko, 2021; Ariong et al., 2023).

Problem statement

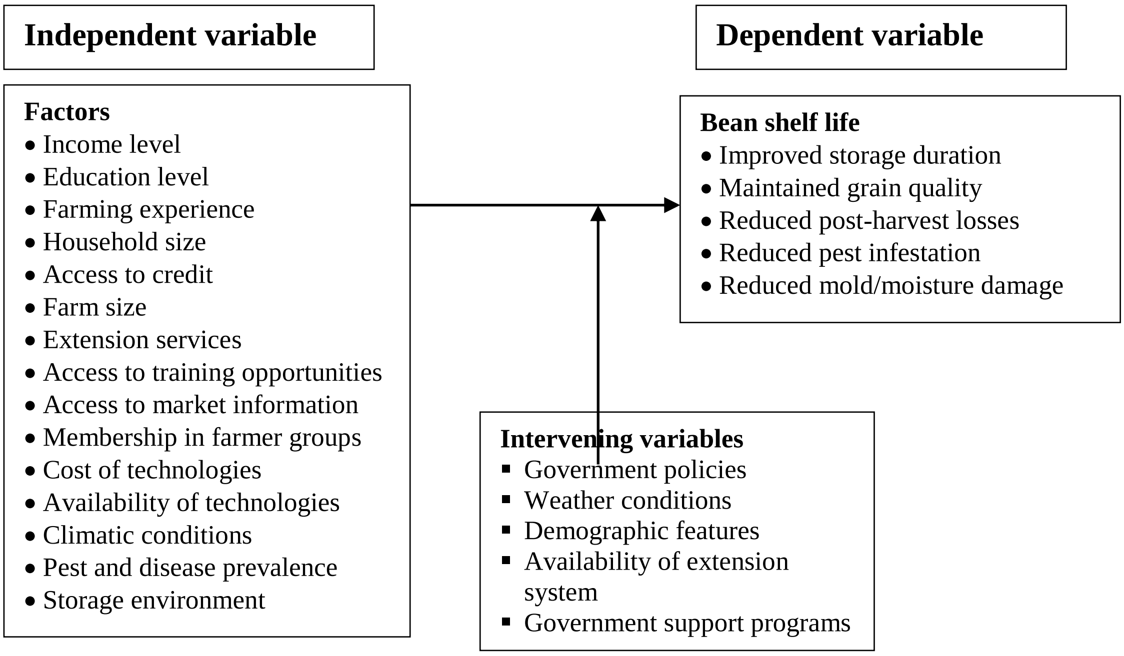
Ensuring the longevity and quality of harvested beans is essential for improving food security, nutrition, and economic stability, particularly in agricultural communities that heavily depend on bean production (FAO, 2021). Effective harvesting, proper drying, and safe storage are critical determinants of bean shelf life and market quality. Ideally, smallholder farmers are expected to harvest beans at the correct physiological maturity, dry them to the recommended moisture content of not more than 13%, and store them under conditions that protect against pests, mould, and quality deterioration (Tumwesigye et al., 2023). Proper integration of harvesting and post-harvest handling practices helps reduce both quantitative and qualitative losses while improving market value and shelf life (Nakafeero & Tumwebaze, 2023).

However, the situation among many smallholder farmers in Uganda and East Africa remains far from ideal due to persistent deficiencies in harvesting and post-harvest management practices. Farmers often delay harvesting or harvest over-mature pods, resulting in shattering, discoloration, and seed damage, while manual harvesting methods further increase labour demands and postharvest losses (Smithson & Hall, 2023). In addition, inadequate post-harvest handling practices such as poor drying, improper sorting, high moisture content during storage, and weak storage facilities expose beans to pests, mould, and rapid quality deterioration. Studies in Uganda revealed that post-harvest losses among bean farmers account for approximately 22% of total production, with 74% of farmers failing to attain the recommended storage moisture content of 13%, thereby reducing bean shelf life and market quality (Ariong et al., 2023).

Consequently, poor harvesting and post-harvest handling practices continue to reduce the storage life, quality, and profitability of beans among smallholder farmers. Although previous studies have highlighted the importance of improved harvesting and post-harvest technologies, limited evidence exists in Kasaana sub-county regarding how the adoption of these technologies influences measurable outcomes such as bean shelf life. Furthermore, most existing studies have concentrated on single stages such as storage rather than examining the integrated chain of harvesting and post-harvest handling practices. Therefore, this study sought to establish the factors that are influencing the adoption of improved harvesting and post-harvest technologies among smallholder bean farmers in Kasaana sub-county.

Conceptual framework

The independent variable in the study were the factors influencing the adoption of improved harvesting and post-harvest handling technologies, and the dependent variable was bean shelf life. The outcome of the independent variables (IVs) was measured by the dependent variable (DV). Variations in the dependent variable (DV) were caused by the influence of the independent variables (IVs) on the dependent. However, the two sets of variables interact via intervening variables, as shown below.



The conceptual framework demonstrated how different factors influences smallholder farmers' adoption of improved harvesting and post-harvest handling technologies, which in turn affects bean shelf life. The independent variables include socio-economic, institutional, technological, and environmental factors. Socio-economic factors such as income, education level, access to credit, and farming experience determine the farmer's capacity to acquire and utilize improved technologies. Institutional factors including extension services, farmer trainings, market information, and membership in farmer associations enhance awareness and knowledge about proper harvesting and storage practices. Technological factors such as affordability, accessibility, compatibility, and perceived usefulness of improved technologies influenced farmers' willingness to adopt them. The adoption of improved harvesting and post-harvest handling technologies such as proper drying, timely harvesting, sorting, grading, hermetic storage, and pest management practices is expected to improve bean shelf life through reducing spoilage, moisture damage, pest infestation, and post-harvest losses while maintaining grain quality and market value. The framework further recognized the role of intervening variables which either strengthened or weakened the relationship between adoption and bean shelf life. These include government policies, extension support, weather conditions, infrastructure, cultural beliefs, and market accessibility.

Materials and methods

The study was conducted in Sheema District, located in the Western Region of Uganda, specifically in Kasaana Sub-county. The area is characterized by fertile soils, rolling hills, and a favorable climate that supports agriculture, particularly bean production. Agriculture is the main economic activity, with most households engaged in smallholder farming of beans, bananas, and coffee. Despite this potential, the area experiences post-harvest challenges such as poor storage and handling practices, making it a suitable setting for examining factors influencing adoption of improved post-harvest technologies.

The study adopted a descriptive research design incorporating both qualitative and quantitative approaches to data collection and analysis. The design was appropriate because it enabled the researcher to gather detailed information on bean harvesting, drying, and storage practices without manipulating any variables. Quantitative methods involved the use of structured questionnaires to obtain measurable responses on post-harvest handling practices and bean shelf life, while qualitative methods involved interviews to capture farmers' experiences, perceptions, and challenges related to harvesting and post-harvest technologies. The study targeted smallholder bean farmers, agricultural extension workers, and local leaders in Sheema District. Data was collected from a representative sample of 222 respondents.

A combination of sampling procedures was used in selecting respondents for the study. Stratified random sampling was employed to select smallholder bean farmers based on shared characteristics such as farm size, experience, and access to post-harvest technologies. The target population was divided into strata and respondents randomly selected from each group to ensure representativeness and minimize bias. Purposive sampling was used to select key informants including agricultural extension workers and local leaders.

Data was collected using structured questionnaires and key informant interview guides. The questionnaires included both closed-ended and open-ended questions to capture quantitative data on harvesting timing, drying methods, storage facilities, and bean shelf life, while interviews provided deeper qualitative insights. Instruments were pre-tested and refined to ensure validity, while reliability was assessed using internal consistency and test-retest methods. Ethical procedures such as informed consent, confidentiality, and respect for participants were strictly followed throughout the study.

Data was analyzed using both quantitative and qualitative techniques to establish relationships between post-harvest practices and bean shelf life. Quantitative data was analyzed using SPSS version 23.0, where descriptive statistics such as frequencies, means, and percentages were generated, and inferential statistics including correlation and regression analysis were used. Qualitative data was analyzed thematically through coding and categorization of responses to identify key patterns and themes. These procedures ensured accurate, reliable, and ethically sound research findings.

Results

Table 1: Socio-economic characteristics of farmers

Sex	**Frequency (n=222)**	**Percentage (%)**
Female	134	60.4
Male	88	39.6
Age group		
19 years or less	18	8.1
20–29 years	52	23.4
30–39 years	64	28.8
40–49 years	48	21.6
50 years or more	40	18.0
Marital status		
Single	40	18.0
Married	142	64.0
Widowed	26	11.7
Divorced	14	6.3
Education level (Years)		

No formal education	36	16.2
1–7 years	94	42.3
8–13 years	70	31.5
Above 13 years	22	9.9
Farm size (acres)		
Less than 1 acre	68	30.6
1–2 acres	92	41.4
3–5 acres	46	20.7
More than 5 acres	16	7.2
Farming experience (Years)		
5 years or less	40	18.0
5–10 years	76	34.2
15–20 years	58	26.1
20 years or more	48	21.6

As shown in Table 1, majority of respondents were female (60.4%), while males constituted 39.6% of the sample. Women played a dominant role in bean production and post-harvest handling activities. Their high involvement implied that they are likely key decision-makers or implementers in matters related to harvesting and storage practices affecting bean shelf life. Most respondents were in the economically active age brackets, particularly 30–39 years (28.8%) and 20–29 years (23.4%). Farmers aged 40–49 years also constituted a significant proportion (21.6%) while older farmers (50 years and above) comprised 18.0% of the total sample. Moreover, majority of respondents were married (64.0%), followed by single (18.0%), while the widowed and divorced made 11.7% and 6.3%) individuals respectively.

Most respondents had attained primary education (1–7 years) at 42.3%, followed by secondary education (31.5%). A notable proportion (16.2%) had no formal education, while only 9.9% had post-secondary education. Majority of farmers operated on small land holdings, with 41.4% owning 1–2 acres and 30.6% cultivating less than 1 acre. Only a small proportion (7.2%) had more than 5 acres confirming that bean production in Kasana Sub-county is predominantly undertaken by smallholder farmers. Small farm sizes influenced the adoption of improved harvesting and post-harvest technologies in two ways. On one hand, limited land size constrained farmers' financial capacity to invest in improved technologies. On the other hand, smallholders might have been more motivated to adopt technologies that minimize losses and improve shelf life to maximize returns from limited production. Thus, farm size played a critical role in shaping both the capacity and incentives for adoption.

Most farmers had considerable experience in bean farming and post-harvest handling, with 34.2% having 5–10 years of experience and 26.1% having 15–20 years. Additionally, 21.6% had more than 20 years of experience. This revealed that the majority of farmers possessed substantial practical knowledge of bean production and handling practices.

Table 2: regression results for factors influencing adoption of improved harvesting and post-harvest technologies among smallholder bean farmers

Variable	Coefficient (β)	Std. Error	Wald χ^2	p-value	Odds Ratio (Exp β)
Level of education	0.842	0.276	9.29	0.002**	2.32
Household income/wealth status	0.215	0.198	1.18	0.278	1.24
Farm size (landholding)	0.693	0.241	8.26	0.004**	2.00
Access to credit/financial services	0.184	0.207	0.79	0.373	1.20
Household size (labour availability)	0.521	0.198	6.92	0.009**	1.68
Awareness/knowledge of technology	1.104	0.312	12.52	<0.001***	3.02
Farming experience	0.133	0.175	0.58	0.447	1.14
Cost and perceived benefits of technology	0.911	0.289	9.94	0.002**	2.49
Access to extension services/training	0.247	0.221	1.25	0.263	1.28
Market access and distance to markets	-0.768	0.267	8.27	0.004**	0.46
Membership in farmer groups/cooperatives	0.198	0.213	0.86	0.354	1.22
Farmer attitudes and perceptions	0.856	0.274	9.77	0.002**	2.35
Peer influence and social networks	0.144	0.192	0.56	0.454	1.15
Transport and road infrastructure	0.732	0.258	8.05	0.005**	2.08
Storage facilities and space availability	0.689	0.249	7.65	0.006**	1.99
Constant	-2.134	0.641	11.09	0.001	—

Dependent Variable: Adoption of improved technologies (1 = Adopted, 0 = Not adopted)
Model Summary Statistics: -2 Log likelihood = 198.34; Cox & Snell $R^2 = 0.42$; Nagelkerke $R^2 = 0.56$; Model Chi-square (χ^2) = 86.27 ($p < 0.001$); $p \leq 0.05$ = statistically significant

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The binary logistic regression results revealed that the model was statistically significant ($\chi^2 = 86.27$, $p < 0.001$), indicating that the selected independent variables jointly explained variations in the adoption of improved harvesting and post-harvest technologies among smallholder bean farmers. The Nagelkerke R^2 value of 0.56 suggested that approximately 56% of the variation in adoption was explained by the model, implying a good model fit.

The results showed that level of education had a positive and statistically significant effect on adoption ($\beta = 0.842$, $p = 0.002$). This implied that farmers with higher levels of education were more likely to adopt improved technologies. The odds ratio (2.32) indicated that an increase in education level increased the likelihood of adoption by more than two times. This was submission that education enhanced farmers' ability to understand and utilize improved technologies.

Farm size was found to be positively significant ($\beta = 0.693$, $p = 0.004$). This indicates that farmers with larger landholdings were more likely to adopt improved technologies. The odds ratio (2.00) suggested that larger farms increased the likelihood of adoption twofold, possibly due to better resource capacity and economies of scale.

Household size had a significant positive influence ($\beta = 0.521$, $p = 0.009$). This implies that households with more members were more likely to adopt improved technologies due to increased labor availability.

Awareness and knowledge emerged as the most influential factor ($\beta = 1.104$, $p < 0.001$). The odds ratio (3.02) indicated that farmers who were more knowledgeable were three times more likely to adopt improved technologies. This demonstrated that access to information and awareness played a critical role in technology uptake.

Cost and perceived benefits of technology was positively significant ($\beta = 0.911$, $p = 0.002$). This suggests that farmers who perceived technologies as beneficial relative to their cost were more likely to adopt them. The odds ratio (2.49) indicated a strong influence of cost-benefit considerations on adoption decisions.

Market access had a negative and significant effect ($\beta = -0.768$, $p = 0.004$). This implied that greater distance to markets reduced the likelihood of adoption. The odds ratio (0.46) indicated that farmers located farther from markets were less likely to adopt improved technologies due to reduced market incentives and higher transaction costs.

Farmer attitudes were positively significant ($\beta = 0.856$, $p = 0.002$). This suggests that farmers with positive perceptions toward improved technologies were more likely to adopt them. The odds ratio (2.35) indicated that favorable attitudes substantially increased adoption likelihood.

Transport infrastructure was found to be significant ($\beta = 0.732$, $p = 0.005$) an indication that better road access facilitated adoption. The odds ratio (2.08) suggested that improved infrastructure doubled the likelihood of adoption by easing access to inputs and markets.

Storage availability was positively significant ($\beta = 0.689$, $p = 0.006$). This implied that farmers with adequate storage facilities were more likely to adopt improved technologies. The odds ratio (1.99) showed that improved storage nearly doubled adoption probability.

Discussion

The findings provided a comprehensive understanding of the multifaceted factors influencing the adoption of improved harvesting and post-harvest technologies among smallholder bean farmers. These factors operate at household, institutional, economic, and infrastructural levels, shaping farmers' decisions in complex and interrelated ways. The results further demonstrate that adoption of improved technologies is not determined by a single factor, but rather by the interaction between farmers' socio-economic characteristics, access to information, perceptions, and the enabling environment within which farming activities are conducted.

Level of education emerged as a significant determinant of adoption ($\beta = 0.842$, $p = 0.002$), implying that better-educated farmers were more likely to embrace improved technologies. In the context of Kasaana, farmers with at least primary or secondary education were more capable of interpreting extension messages, understanding instructions on the use of hermetic storage bags, improved threshing methods, or proper drying techniques. Educated farmers are also more likely to attend trainings, keep farm records, compare alternative technologies, and make informed production and marketing decisions. For instance, a farmer in villages such as Kyeihara or Rweibare who has attended school is more likely to follow recommended moisture content levels during bean drying compared to a less educated counterpart. Education also increases farmers' ability to access agricultural information through radios, mobile phones, and farmer groups, thereby enhancing awareness and confidence in the use of modern technologies. This finding aligns with studies in Ethiopia and Kenya, where education significantly enhanced adoption of agricultural innovations due to improved cognitive and decision-making abilities (Bizimana & Nshimiyimana, 2022). Education therefore reduces uncertainty, improves managerial capacity, and increases confidence in trying new technologies.

Farm size was also positively significant ($\beta = 0.693$, $p = 0.004$), indicating that farmers with larger landholdings were more likely to adopt improved technologies. In Kasaana, farmers cultivating larger plots often located in relatively fertile areas tend to produce surplus beans, which necessitates efficient harvesting and storage solutions to minimize losses and maintain quality. Such farmers are more likely to invest in tarpaulins for drying, improved threshers, moisture management practices, or even small storage structures because they handle larger volumes of produce and expect higher returns. Larger farms also provide an opportunity for experimentation with new technologies without exposing the entire production system to risk. This is consistent with findings from Tanzania and Nigeria, where larger farm sizes were associated with increased adoption due to better access to capital, economies of scale, and the need to manage higher output volumes (Bizimana & Nshimiyimana, 2022). Smaller-scale farmers in Kasaana, by contrast, often rely on traditional methods due to limited output, fear of risk, and constrained financial resources.

Household size had a positive and significant influence ($\beta = 0.521$, $p = 0.009$), suggesting that larger households were more likely to adopt improved technologies. In Kasaana, bean farming is largely labor-intensive, particularly during harvesting, drying, sorting, packaging, and storage management. Households with more members can mobilize family labor to implement labor-demanding practices such as timely harvesting, proper sorting, frequent turning during drying, and monitoring stored beans against pests and moisture damage. For example, a household with several active members can manage staggered harvesting more effectively than a smaller household, thereby reducing delays that may expose beans to spoilage or pest infestation. In addition, larger households may have a wider range of experiences and ideas, which can influence decision-making and increase openness to innovation. Similar findings have been reported in Malawi and Uganda, where family labor availability significantly influenced the adoption of agricultural technologies (Agaba et al., 2022).

Awareness and knowledge emerged as the most influential factor ($\beta = 1.104$, $p < 0.001$), indicating that informed farmers were three times more likely to adopt improved technologies. In Kasaana, awareness is often shaped by extension services, farmer groups, radio programs, demonstration plots, and NGOs operating in the area. Farmers who have participated in training sessions or demonstrations such as those organized by district agricultural officers are more likely to adopt improved post-harvest practices like hermetic storage, proper drying on raised platforms, or timely harvesting techniques. Knowledge helps farmers to understand the benefits, proper application, and expected outcomes of improved technologies, thereby reducing fear and uncertainty associated with innovation. Farmers who are aware of the economic losses caused by poor post-harvest handling are more motivated to adopt technologies that preserve bean quality and increase profitability. This finding is strongly supported by studies in Ghana and India, where access to information significantly enhanced adoption rates (Gebreselassie & Abebe, 2022). Lack of awareness remains a major barrier, especially in remote villages where extension services and information dissemination are limited.

Cost and perceived benefits of technology were also positively significant ($\beta = 0.911$, $p = 0.002$), indicating that farmers' decisions were strongly influenced by economic considerations. In Kasaana, farmers are more likely to adopt technologies such as improved storage bags, tarpaulins, or solar drying methods if they perceive clear benefits, including reduced post-harvest losses, improved grain quality, longer shelf life, and better market prices. Farmers often compare the costs of purchasing technologies with the expected returns before deciding whether to adopt them. Technologies that demonstrate quick and visible economic benefits are more readily accepted. However, high upfront costs can deter adoption, especially among resource-constrained farmers who lack savings or access to agricultural credit. For instance, while hermetic bags are effective in preserving bean quality, some farmers may still rely on traditional granaries due to affordability challenges. This finding is consistent with studies in Bangladesh and Nepal, where cost-benefit analysis played a crucial role in technology adoption (Mottaleb et al., 2016).

Market access had a negative and significant effect ($\beta = -0.768$, $p = 0.004$), suggesting that farmers located farther from markets were less likely to adopt improved technologies. In Kasaana, poor access to markets such as those in Kabwohe or Mbarara reduces farmers' incentives to invest in improved post-harvest practices because of limited opportunities to obtain premium prices for quality produce. Farmers in remote areas often sell their produce at low farm-gate prices to middlemen, which discourages investment in technologies aimed at improving bean quality and shelf life. Poor market access also limits farmers' interaction with traders, extension agents, and fellow farmers who may influence technology adoption. Additionally, transportation challenges increase transaction costs and reduce profitability, making adoption less attractive. This finding aligns with research in Uganda, where distance to markets reduced adoption due to higher transportation costs and lower returns (Nakafeero & Tumwebaze, 2023).

Farmer attitudes were positively significant ($\beta = 0.856$, $p = 0.002$), highlighting the importance of perceptions, beliefs, and experiences in shaping adoption behavior. In Kasaana, farmers who perceive improved technologies as reliable, beneficial, easy to use, and compatible with their farming systems are more likely to adopt them. Positive attitudes are often developed through direct observation of successful outcomes among fellow farmers, participation in demonstrations, or previous positive experiences with innovation. For example, farmers who have witnessed reduced storage losses through hermetic storage are more inclined to continue using such technologies and recommend them to others. Conversely, negative attitudes often driven by past failures, misinformation, fear of risk, or cultural attachment to traditional practices can hinder adoption. Similar observations have been made in studies conducted in Uganda, where farmer perceptions significantly influenced technology uptake (Agaba et al., 2022). This suggests that improving farmer attitudes through sensitization and practical demonstrations is essential for increasing adoption levels.

Transport infrastructure was also significant ($\beta = 0.732$, $p = 0.005$), indicating that better road access facilitated adoption. In Kasaana, areas with relatively better road networks enable farmers to access markets, extension services, training centers, and input suppliers more easily and at lower cost. Improved roads reduce transportation costs, minimize delays in moving harvested beans, and decrease post-harvest losses during transit. Farmers in areas with accessible roads are also more likely to interact with extension workers and participate in agricultural programs that promote improved technologies. Better infrastructure therefore creates an enabling environment for agricultural commercialization and innovation uptake. This finding is supported by studies in Ethiopia and Rwanda, where infrastructure development was closely linked to increased agricultural commercialization and technology adoption (Gebreselassie & Abebe, 2022). Poor road conditions in some parts of Kasaana, however, continue to constrain access to markets and agricultural services.

Finally, storage availability was positively significant ($\beta = 0.689$, $p = 0.006$), suggesting that farmers with access to adequate storage facilities were more likely to adopt improved technologies. In Kasaana, farmers with improved storage options such as granaries, improved stores, metallic silos, or hermetic bags can preserve bean quality for longer periods, reduce pest infestation, and minimize moisture-related damage. Adequate storage facilities also enable farmers to delay sales until market prices improve, thereby increasing profitability and encouraging investment in complementary practices such as proper drying, sorting, and grading. Farmers lacking proper storage facilities are more likely to experience post-harvest losses and may be forced to sell immediately after harvest at low prices. Similar findings have been reported in Uganda, where improved storage significantly enhanced adoption of post-harvest technologies and reduced grain losses (Katusiime & Twinamatsiko, 2024). Thus, improved storage facilities play a critical role in enhancing both bean shelf life and farmers' willingness to adopt modern post-harvest technologies.

Conclusion

The study confirmed that smallholder bean farmers in Kasaana Sub-county predominantly relied on traditional harvesting and post-harvest handling technologies, with limited adoption of improved and mechanized options. While some intermediate technologies have been embraced, major constraints such as cost, labor limitations, and inadequate access to information continue to hinder modernization. The study concluded that adoption of improved harvesting and post-harvest technologies in Kasaana sub-county was influenced by a combination of socio-economic, institutional, and infrastructural factors. Key drivers included education, farm size, household labor, awareness, and perceived benefits, while constraints such as poor market access limited adoption. Overall, improving access to information, infrastructure, and affordable technologies is essential to enhance adoption among smallholder farmers.

Recommendations

- Government and development partners should promote affordable improved post-harvest technologies such as hermetic storage bags, solar dryers, and mechanical threshers through subsidies and credit schemes to reduce post-harvest losses.

- Agricultural extension services and farmer training programs in Kasaana Sub-county should be strengthened through regular training, demonstrations, and farmer field schools to improve farmers' awareness and technical skills in modern harvesting and post-harvest practices.
- Rural infrastructure and access to affordable storage and post-harvest technologies should be improved to encourage wider adoption among smallholder farmers.
- Farmers should be supported to adopt improved drying and hermetic storage technologies through subsidies and capacity-building initiatives to maintain safe moisture levels and minimize storage losses.
- Extension programs should emphasize integrated post-harvest management practices, including proper harvesting, threshing, cleaning, drying, storage, and pest control, to enhance bean shelf life and quality.

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Competing interests
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