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Reducing Postharvest Losses in Pulses through Improved On-Farm Storage Technologies in Punjab: A case Study from Chakwal

Burhan Ahmad[1], M. Amjed Iqbal[2]*, Mubashir Mehdi[3], Muhammad Haseeb Raza[3]
[1]Institute of Business Management Sciences (IBMS), University of Agriculture, Faisalabad 38000, Pakistan
[2]Institute of Agricultural and Resource Economics, University of Agriculture, Faisalabad 38000, Pakistan
[3]Department of Agribusiness & Entrepreneurship Development, MNS-University of Agriculture, Multan, Pakistan

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ABSTRACT

Post-harvest loss is still one of the significant constraints for the profitability and efficiency of the pulses value chain in Pakistan. Traditional storage technology is frequently used by smallholder farmers, which allows insects to infest the produce, moisture to damage it, and reduces its quality. In this study, technical and economic feasibility of the improved storage technologies such as hermetic bags and Anagi drums for chickpea and mung bean storage is evaluated in Chakwal, Punjab. The experimental approach is adopted in the storage units of the lead farmers from Lawa and Kot Sarang tehsils of Chakwal. Produce was stored for four months under three storage conditions: traditional gunny bags, hermetic bags and Anagi drums. Grain damage and quality was determined by the evaluation of local experts from the market who are the regular buyer of produce from the farmers in this area. The results showed that Anagi drums were significantly better to reduce storage losses and to preserve the grain quality than the traditional bags and hermetic bags. Hermetic bags also worked better than the traditional storage methods. The results exhibited that better storage technologies can significantly increase the value chain efficiency, lower the post-harvest losses, and increase the farmer's profitability. The study also complements the literature of postharvest management and supports to modernize the pulses value chain in Pakistan. Policy implications comprise scaling of farmer training, promoting private sector involvement and enabling access to affordable storage technologies.

Corresponding Author: M. Amjed Iqbal (Email: amjed.iqbal@uaf.edu.pk)

INTRODUCTION

In developing countries, it is estimated that post-harvest losses are 15-30% especially in cereal and pulse crops stored under traditional conditions (Kumar & Kalita, 2017). Conventional storage materials like gunny bags and open containers are commonly used by smallholder farmers in South Asia to store food and provide little protection against pest infestation, humidity, and fungal contamination (Tefera et al., 2011). Grain quality is therefore likely to decline very quickly during storage, thus leading to lower prices and higher food insecurity. New innovations in grain storage, like hermetic bags and airtight Anagi drums have proven to be successful in decreasing both the qualitative and quantitative losses during storage. Hermatic storage technologies have been found to effectively control insects' infestation, maintain grain quality and enhance farmers' economic returns in past studies (Baoua et al., 2014; Gitonga et al., 2013). However, the adoption of these technologies in Pakistan is limited because of the lack of awareness, technical knowledge, and extension assistance.

The field interaction and consultation with stakeholders under ACIAR-funded project “Developing Competitive and Inclusive Value Chains of Pulses in Pakistan” showed that the majority of grain damages are occurring during farm level storage due to the lack of adequate storage facilities and training on scientific handling of grain by the farmers. Market agents and industry stakeholders also highlighted the importance of improving farmers' storage capacity to mitigate the deterioration of the quality of the product in the market and to make it a more competitive product. This study aimed at assessing the feasibility of the improved technologies, such as hermetic bags and locally manufactured Anagi drums for keeping chickpea and mung beans under farm-level conditions in Punjab.

Theoretical Foundation

This study is based on the Value Chain Theory of Porter (1985) which states that efficiency can be improved at various stages of the value chain, thus improving competitiveness and profitability. The post-harvest stage is one of the most important in agricultural value chain due to its direct impact on the marketable surplus, product quality and farmer's income. The study is also grounded on the Postharvest Loss Reduction Framework which recommends that a combination of technological interventions, capacity development and institutional support can enhance the

efficiency of storage and food security (UNFAO, 2019). Better storage technologies also enhance the potential of the farmer for value-addition, market judgement and farmer bargaining power as well as minimizing the physical losses of the commodities.

From a sustainable agriculture point of view, better storage system contributes to:

1. Reduced food waste,
2. Enhanced food security,
3. Increased income stability,
4. Climate-smart agriculture, and
5. Development of inclusive value chain.

LITERATURE REVIEW

Postharvest management has now developed as viable component of sustainable agricultural value chains, especially in the developing economies where postharvest losses have a significant impact on food availability and farmer income. The Food and Agriculture Organization (UNFAO, 2019) estimates that 1/3 of the world's food is lost or wasted, with significant amounts lost in the postharvest handling and storage processes. Rembold et al. (2011) emphasized the need of the systematic assessment and monitoring of postharvest losses for better planning of the agriculture sector and food security strategies in developing countries. Food losses during agricultural supply chains in the developing countries are largely due to inconsistent post-harvest systems of handling, transportation and storage, which decrease food availability and efficiency of the markets (Aulakh & Regmi, 2013).

Pulses are a very susceptible crop for losses during storage due to insect infestation, fungal contamination, moisture uptake and physical damage. The common post-harvest practices adopted by smallholder farmers are not providing them sufficient protection against these risks (Kumar & Kalita, 2017). In rural areas of South Asia and Sub-Saharan Africa, grains are kept in bags or traditional containers that allow oxygen, humidity and pests into the grain.

As the airtight environments developed by hermetic storage technologies result in decreased availability of oxygen and inhibit insect development, these technologies have become increasingly significant. Tefera et al. (2011) reported that hermetic storage technologies had a significant effect in reducing the losses of maize during storage and enhancing food security of the smallholder farmers. Likewise, Baoua et al. (2014) reported that the Purdue Improved Crop Storage (PICS) bags minimized losses of cowpea grain and maintained viability of grains under farmer conditions in West Africa.

There have been several studies that have identified the economic advantage of improved storage systems. According to Gitonga et al. (2013), the farmers who employed hermetic storage methods reported reduced post-harvest losses, improved grain quality and delayed market sales, which led to increased profits. In a meta-analysis of postharvest losses in Sub-Saharan Africa (SSA), Affognon et al. (2015) confirmed that better storage structures have a significant positive effect on food security and market efficiency.

Value Chain Theory (Porter, 1985) states from a theoretical point of view, that efficiency improvements at any point in the value chain can boost competitiveness and value creation in the whole value chain. Losses during storage are a key post-harvest operation that have a direct impact on marketable surplus and farmer bargaining power. Better storage technologies result into a reduction in physical losses, value addition at farm level, quality assurance and market integration.

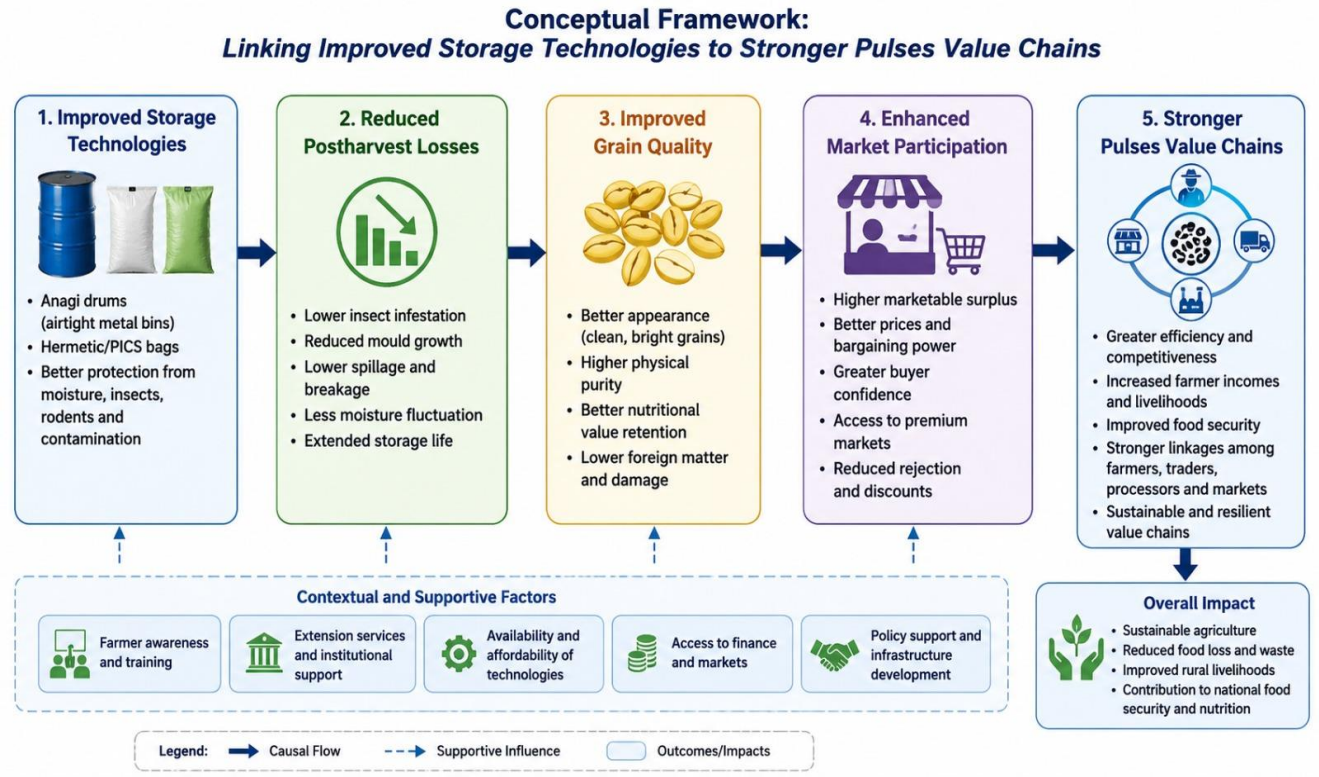
The Postharvest Loss Reduction Framework also emphasizes the use of technologies and the training of farmers and other stakeholders, alongside institutional support, to enhance agricultural sustainability and rural livelihoods (UNFAO, 2019). But the available empirical evidence in the case of pulses sector in Pakistan for the improvement in storage technologies is limited, especially at the farm level. Hence the study in hand contributes to the literature by examining practical storage interventions within smallholder pulses value chains in Punjab, Pakistan.

MATERIALS AND METHODS

This study was executed to assess the effectiveness of improved storage technologies for declining postharvest losses in chickpea and mung bean under real farm-level conditions in District Chakwal, Punjab. Experimental approach and Comparative analytical framework was adopted to evaluate the technical feasibility and practical suitability of various storage materials employed or available to the smallholder farmers. The main purpose of the study is to identify those storage solutions that are low cost and locally applicable, and can help in enhancing grain quality preservation, minimizing losses during storage and strengthening pulse value chains.

This experimental activity was performed as part of a project entitled “Developing Competitive and Inclusive Pulses Value Chains in Pakistan” funded by ACIAR, whose objective was to increase the participation of smallholder farmers in competitive agricultural markets through improved value chain practices. The purpose of the study was to provide

empirical knowledge on the contribution of scientific storage systems to improve the post-harvest management and profitability of the farmers. The conceptual framework of the study is as



The methodological framework of the study was guided by the principles of Value Chain Theory and postharvest loss reduction approaches. Since storage is one of the most critical stages in agricultural value chains, improving storage efficiency can significantly reduce losses, maintain quality standards, and enhance market competitiveness. So the experiment compared traditional and improved storage technologies with similar environment and operation condition to check the effectiveness of the technologies.

Study Area

The study was carried out at two different places of District Chakwal i.e.

1. Lawa (District Chakwal) for chickpea storage experiments
2. Kot Sarang (District Chakwal) for mung bean storage experiments

These Lawa and Kot-Sarang are significant pulses producing area of the district (Chakwa) in Punjab province. These areas are semi-arid and have large smallholder farming systems where postharvest losses remain a substantial challenge.

Research Design

The study used an experimental field based comparative research design to assess the effectiveness of various storage technologies under real farm level conditions. Three methods of storage were tested:

1. Traditional gunny bags (control treatment)
2. Hermetic bags
3. Anagi drums

The experiment was performed at the storage place of the selected lead farmers involved in the ACIAR-funded pulses value chain project.

The **sampling and experimental** procedures include the following:

Lead farmers actively engaged in pulses production and storage activities were selected using purposive sampling technique. For storage experiments, one farmer warehouse in Lawa for Chickpea and another farmer warehouse in Kot Sarang for Mung bean was selected.

For each crop, the stored produce was divided into three storage treatments of:

1. Traditional gunny bags,
2. Hermetic bags,
3. Anagi drums.

Comparability was tested with all storage materials in similar environmental conditions and in the same warehouse. The storage time was about 4 months.

The following basic information was documented before storage:

1. Harvesting method,
2. Storage objectives,
3. Initial grain condition,
4. Existing damage percentage.

Grain quality was assessed at the end of the storage at the help of local grain experts and collectors. Observations focused on:

1. Insect infestation,
2. Grain discoloration,
3. Moisture-related damage,
4. Overall quality deterioration.

Analytical Approach

The study used a comparative analytical framework to evaluate the relative effectiveness of storage treatments. Descriptive analysis was conducted to compare storage outcomes among the three storage systems.

The analytical framework focused on:

1. Damage reduction efficiency,
2. Grain quality preservation,
3. Practical feasibility,
4. Economic implications for smallholder farmers.

The results were interpreted within the framework of agricultural value chain theory and postharvest management literature.

RESULTS AND DISCUSSION

The storage experiment was carried out to compare the storage technologies namely traditional and improved under actual farm level situation for chickpea and mung bean in Punjab, Pakistan. Three different storage methods were tested and compared: traditional gunny bags, hermetic bags and Anagi drums, over a storage period of about four months. The results are important evidence on the contribution of scientific storage technologies towards minimizing post-harvest losses, maintaining the grain quality and enhancing efficiency of pulses value chains.

The results showed that in general, improved storage technologies had significantly better grain quality and reduced deterioration as compared to traditional storage technologies. The findings are discussed in the context of Value Chain Theory (Porter, 1985) which states that efficiency and competitiveness can be enhanced throughout the value chain by improving the efficiency in the critical stages of the value chain. The findings also align with the Postharvest Loss Reduction Framework, which underscores the importance of technological interventions to enhance food security and decrease postharvest losses in developing countries (UNFAO, 2019).

Comparative Performance of Storage Technologies

The comparative evaluation of storage technologies showed that there is significant difference in the storage performance between three storage materials. While traditional gunny bags showed the highest grain deterioration and insect infestation, whereas the improved grain storage technologies proved to be significantly better in preserving grain quality.

Table 1: Comparative Performance of Storage Technologies for Chickpea and Mung Bean

Storage Material	Protection Against Insects	Moisture Protection	Grain Quality Preservation	Structural Durability	Overall Performance
Traditional Gunny Bags	Low	Low	Poor	Moderate	Weak
Hermetic Bags	High	Moderate to High	Good	Moderate	Good
Anagi Drums	Very High	High	Excellent	High	Best

Source: Field experiment conducted under the ACIAR pulses value chain project.

The results showed that the best overall performance was achieved by Anagi drums among all tested technologies. Farmers and local grain evaluators noticed that the grains kept in Anagi drum retained better quality, minimal insect infestation and better physical appearance than grains kept in the traditional bags and hermetic bags. The airtight nature of the Hermetic bags also provided significant benefits over conventional storage methods by limiting the amount of oxygen available and limiting insect growth. But they were not as structurally durable as Anagi drums in the field. Traditional Gunny bags provided some protection from insects, weather and moisture exposure. Therefore, the grains kept in traditional bags showed more deterioration in their quality and visible damages during the storage period. These results are in line with Tefera et al. (2011) who found that under smallholder farming conditions, storage losses were low and grain preserved well with the use of airtight storage technologies. In the same context, Baoua et al. (2014) noted that the hermetic storage systems helped to minimize post-harvest losses and maintain the quality of cowpeas in the storage systems in West Africa. The results also corroborate Kumar and Kalita (2017) who noted that lack of storage facilities was one of the most significant factors contributing to post harvest losses in developing countries. They found that in long term storage, use of scientific storage systems was important to ensure quality of grain and reduce deterioration.

The super performance of Anagi drums over conventional bags is also in accordance with Affognon et al (2015) who highlighted the need to improve the storage space as a way of enhancing smallholder's profitability and prevent food losses after harvest. Theoretically these results demonstrate that postharvest management is not only a technical challenge, but a strategic value chain intervention. Value Chain Theory (Porter, 1985) shows that inefficiencies at any level of the value chain will diminish the overall level of competitiveness and value creation. The use of better storage techniques in the current study, led to reduction in quantitative and qualitative losses, thereby enhancing the value addition by farmers in the chain. This indicates that investments in postharvest infrastructure contribute to increase storage efficiency and market integration as well as rural economic sustainability.

Storage Losses and Grain Quality Preservation

The experiment revealed clear differences in grain quality preservation among the storage technologies. Improved storage systems reduced both quantitative and qualitative deterioration compared with traditional storage methods.

Table 2: Observed Storage Conditions and Grain Quality Outcomes

Storage Material	Insect Infestation	Grain Discoloration	Moisture Damage	Overall Grain Condition
Traditional Gunny Bags	High	High	Moderate to High	Poor
Hermetic Bags	Low	Low	Low	Good
Anagi Drums	Very Low	Very Low	Very Low	Excellent

Source: Authors' field observations and local grain expert evaluation.

The results showed that traditional gunny bags were linked with higher level of insect attack, grain discoloration, moisture-related deterioration. Further, produced stored in conventional bags also suffered through quality decline and grain breakage which ultimately affected its market acceptability. While quality and appearance characteristics of grain did not change during the storage period in hermetic bags and Anagi drums. The higher performance of improved storage systems can be described by their airtight conditions and more durable physical protection against environmental exposure. The lower insect infestation seen in hermetic bags and Anagi drums is also confirmed by Murdock et al. (2012) who found that hermetic storage systems reduces survival of insects by providing an oxygen deficient atmosphere, which disrupts insect respiration and reproduction. This biological mechanism has contributed much to the observed decline in pest activity during the experiment.

The results also support the outcomes of Gitonga et al. (2013) who described that better storage facility led to a reduction in household grain losses and better food security among smallholder farmers. The benefits of improved grain quality preservation have significant impacts on market competitiveness, as grain appearance and quality significantly affect traders' preferences and market prices. The premium prices and access to higher value markets are more likely to be available to better quality grains.

The results also reinforce the Postharvest Loss Reduction Framework which advocates for the need to strengthen the storage technologies to increase food availability through the reduction of postharvest losses. The Food and Agriculture Organization (UNFAO) 2011 and 2019 also highlighted the importance of post-harvest loss reduction as one of the most cost-effective interventions in developing countries to enhance food security and sustainability.

Economic Implications of Improved Storage Technologies

The findings suggest that improved storage technologies can generate substantial economic benefits for smallholder farmers by reducing losses and improving grain marketability.

Table 3: Economic Implications of Storage Technologies

Storage Material	Expected Storage Losses	Market Price Potential	Storage Life	Farmer Economic Benefit
Traditional Gunny Bags	High	Low	Short	Limited
Hermetic Bags	Moderate to Low	Moderate to High	Moderate	Good
Anagi Drums	Very Low	High	Long	Very High

Source: Based on field observations and farmer feedback during the experiment.

Better storage facilities allowed farmers to safely store their produce for longer periods and to avoid immediate post-harvest sale of produce when price is not attractive. This can enhance farmers' flexibility in taking marketing decisions and enable them to sell their produce at the time of more favorable market condition.

Improved storage technologies boosted the:

1. Marketable surplus,
2. Bargaining power,
3. Price realization,
4. Income stability.

The results are in consist with Affognon et al. (2015) who found that the development of better postharvest management systems can significantly increase the profitability of smallholders and their market integration. Likewise, Gitonga et al. (2013) reported that better storage technologies have positive effects on household income and food security, due to low post harvest losses. The results also align with Birthal et al. (2015) who found that poor postharvest handling and storage was a key driver of food loss in the agricultural value chains of South Asian countries. As in the current research, they found that better storage facilities can have a strong positive impact on the strength of the value chain efficiency and ultimately the profit of the farmers. Similarly, Yigezu et al. (2018) noted that the adoption of improved storage technologies among smallholder farmers has a significant role in reducing postharvest losses, increasing the resilience of the households and improving their market participation. The present results also suggest that the scientific storage technologies facilitate farmers' participation in competitive agricultural markets. The Value Chain Theory (VCT) holds that the declining the storage related inefficiencies rises value retention within the agricultural chain. So better storage arrangements are therefore being a way to commercialize agriculture and transform rural economies.

Implications for Pulses Value Chain Development

The study demonstrates that postharvest storage management is a critical component of competitive and inclusive pulses value chains. Storage-related losses not only reduce food availability but also weaken the economic position of smallholder farmers.

Table 4: Value Chain Implications of Improved Storage Technologies

Value Chain Dimension	Traditional Storage	Improved Storage Technologies
Grain Quality	Low	High
Market Competitiveness	Weak	Strong
Farmer Bargaining Power	Limited	Improved
Value Addition Potential	Low	High
Market Participation	Restricted	Enhanced
Food Security Contribution	Moderate	Strong

Source: Authors' interpretation based on field findings and Value Chain Theory.

The results suggest that better storage technologies can positively impact various aspects of value chain development. Improved grain quality and loss reduction enhances market competitiveness and enables value added processing and premium market participation. It also shows that losses reduction has a significant impact on food security without the need for extra production inputs or for cultivated areas to be expanded. This is especially crucial in developing countries where resource limitations and population density persist and pose threats to agricultural sustainability.

The results are consistent with the findings of UNFAO reports, (2011; 2019), which found postharvest loss reduction as one of the most effective measures to improve food availability and reduce food loss and enhance agricultural sustainability in developing countries. The results are also aligned with the World Bank (2020), which noted that the quality of the postharvest infrastructure and food loss need to be improved to enhance the sustainability in agriculture, rural livelihood and the resilience of food systems in less developed countries. The present research was conducted under farm level conditions as compared to many studies conducted in the laboratories, thereby enhancing the applicability and practical relevance of the findings. The findings from the study show that value chains of pulses can be strengthened in Pakistan through low-cost and locally appropriate technological interventions, which could enhance the grain preservation and can minimize post-production losses.

The experiment also highlighted the need of demonstration approaches that are farmer-oriented. Farmers who witnessed the success of the good storage technologies were more interested in implementing scientific storage practices in the future. The implication is that demonstrations can help to speed up technology dissemination within rural groups. The study also confirms the Value Chain Theory by demonstrating the impact of the storage phase on the competitiveness and sustainability of the value chain. Better storage also helps to achieve quantitative and qualitative losses reductions, quality improvement, higher marketable surplus and better farmer-market linkages. Scientific storage technologies can therefore be a key player in strengthening competitive and inclusive agricultural value chains in developing countries.

Discussion of Findings and Theoretical Implications

The results presented here are consistent with earlier studies which highlighted the significance of better storage technologies to minimize post-harvest losses and enhance the agricultural value chain. As in Tefera et al. (2011), the study shows that the use of airtight storage is effective in lessening pest development and maintaining grain quality with smallholder farm conditions. Similarly, the better performance of Anagi drums over traditional gunny bags is corroborated by the study findings of Affognon et al. (2015) which emphasized the need for improving storage infrastructure to boost the profitability of smallholders and reducing food loss in developing countries.

The conclusion is also in line with Kumar and Kalita (2017), who pointed out that lack of storage facility is one of the significant factors causing postharvest losses in grain-based farming system. During present research, traditional storage systems were subjected to moisture changes, insect infestation and quality loss, while improved storage systems significantly reduced these risks. Likewise, Murdock et al. (2012) reported that hermetic storage technologies reduce insect survival by blocking insect respiration and reproduction, owing to the lack of oxygen, this is one of the possible reasons for the reduced pest infestation in the hermetic bags and Anagi drums that was observed during the experiment.

The findings also confirm the verdicts of Gitonga et al. (2013), and Yigezu et al. (2018) which reported that adoption of better storage technologies has a positive impact on food security, market involvement and farmers' resilience due to the reduction of food losses and better preserving grain quality. The same results were obtained in this study as well, where better storage systems increased the marketability and storage life of chickpea and mung bean under farm conditions.

The present research itself is done under farmer storage condition unlike many laboratories based results, so making it more practical and applicable. It was an experimental approach on the farm level that enabled farmers to capture

the positive impacts of the improvement, and this first hand impression could encourage future adoption as well as the sharing of knowledge among rural communities. The findings, therefore, indicate that low-cost and locally adaptable technological interventions are able to substantially enhance the value chains of pulses in Pakistan, through the enhancement of grain preservation, and reducing the post-harvest losses.

Theoretically, the results further support the notion that postharvest management should not be considered a technical problem, but rather a value chain intervention. Inefficiencies at any point in the Value Chain can diminish overall competitiveness and value creation, according to Value Chain Theory. This indicates that investment in post-harvest infrastructure facilities may improve storage efficiency and integration into markets, rural income security and sustainability in farming.

CONCLUSIONS

The comparative effectiveness of traditional and improved storage technologies for chickpea and mung bean were assessed under actual farm level condition in Punjab, Pakistan. The results showed that the improvement in storage systems, especially the use of Anagi drums and hermetic bags had significant improvement on the grain quality and reduced deterioration during storage as compared to the traditional gunny bag storage system. In overall performance, Anagi drums performed best of all the tested technologies because of its stronger protection against moisture, insects and environmental exposure.

This study endorses the importance of post-harvest storage which is still overlooked in agricultural value chain in Pakistan. In addition to the loss of marketable volume, poor storage has also adverse impacts on the quality of grain and overall market competitiveness. This experiment validated that affordable, simple and easily replicable storage solutions can substantially enhance storage results under smallholder farming systems. Another significant contribution of the study is that it is practical and participatory. The results of this experiment were obtained directly from farmers' stores and hence are not the result of controlled laboratory conditions. This increases the confidence, usefulness and applicability of these results for rural farmers at their own level.

The paper also makes a valuable addition to the existing literature on the postharvest management and contributes with empirical evidence of the pulses sector in Pakistan where limited research has been conducted on scientific storage technologies under field conditions. The results offer a good basis for further research, policy development and interventions for the development of sustainable pulses value chains as well as the management of postharvest systems. The findings of the study suggest that with high potential, the adoption of improved storage technologies can boost the efficiency, sustainability, resilience, and competitiveness of pulses value chain in Pakistan and contribute to food security and farmer's livelihoods.

RECOMMENDATIONS

Based on the findings of the study, institutional, and research-oriented recommendations are proposed to strengthen postharvest management systems and improve the competitiveness of pulses value chains in Pakistan.

Expansion of Farmer Demonstration Programs

Practical field demonstrations should be expanded in pulse-growing areas to increase farmer awareness, confidence, and understanding regarding improved storage technologies. Demonstration-based learning approaches can accelerate technology adoption by enabling farmers to directly observe the effectiveness of scientific storage systems under local conditions. Such participatory approaches may also enhance peer-to-peer learning and knowledge dissemination within rural communities.

Institutional Support for Technology Dissemination

Agricultural extension departments, research institutions, universities, and development organizations should collaborate more effectively to disseminate improved storage technologies among rural farming communities. Greater institutional coordination is essential to ensure that smallholder farmers receive adequate technical guidance, training, and access to postharvest innovations as well as further improvement in such technologies particularly making them affordable to farmers. Special attention should be given to resource-constrained farmers who face greater barriers in adopting improved storage systems.

Promotion of Locally Manufactured Storage Solutions

Locally manufactured storage technologies such as Anagi drums should be promoted because they are relatively practical, durable, and potentially more affordable for rural households. Encouraging local production and commercialization of improved storage technologies may reduce costs, and improve accessibility. Promotion of indigenous and locally adaptable technologies may also improve long-term sustainability of postharvest interventions.

Integration of Postharvest Management into Agricultural Development Programs

Agricultural development projects and value chain interventions should incorporate dedicated postharvest management components alongside production-oriented activities. Historically, many agricultural programs have

focused primarily on increasing crop productivity while giving limited attention to postharvest losses. The findings of the present study indicate that improving storage systems can substantially enhance the effectiveness of agricultural value chain programs by reducing losses and improving marketable surplus.

Strengthening Multi-Stakeholder Collaboration

Closer coordination among farmers, traders, processors, researchers, extension agencies, and policymakers is necessary to improve postharvest management systems within pulses value chains. Multi-stakeholder collaboration can facilitate:

1. Knowledge sharing,
2. Innovation diffusion,
3. Quality standard development,
4. Market-oriented production,
5. Improved access to storage technologies.

Such collaborative approaches may also strengthen linkages between smallholder farmers and agribusiness actors, thereby enhancing value chain integration and market participation.

Future Research Directions

Further research is needed to strengthen the evidence base regarding scientific storage technologies and postharvest management systems in Pakistan's pulses sector. Future studies should particularly focus on:

1. Quantitative estimation of storage losses under different storage technologies,
2. Detailed economic cost-benefit analysis of storage investments,
3. Farmer adoption behavior toward improved storage systems,
4. Scalability of storage innovations across different agroecological zones,
5. Gender dimensions of postharvest management practices,
6. Integration of digital monitoring technologies in grain storage systems,
7. Long-term impacts of improved storage on food security and farmer livelihoods.

Such research would further support evidence-based policymaking and contribute to the modernization and sustainability of Pakistan's pulses value chains.

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