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Post-harvest losses and challenges faced by farmers - Focus on Sustainable Production and Minimisation of Wastage

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Abstract

Agricultural production forms the backbone of food security and economic stability, yet a significant portion of harvested produce fails to reach markets due to post-harvest losses. These losses, often arising from inadequate storage, transportation inefficiencies, poor handling practices and limited access to technology, not only reduce farmer incomes but also undermine national efforts toward sustainability and food availability. In developing economies like India, such challenges remain widespread, making it essential to examine the issue at the farmer level. This study aims to analyse post-harvest losses by assessing how much produce is cultivated, how much is lost and the underlying reasons for wastage in selected regions. The research will focus on identifying farmer-level challenges across critical stages such as harvesting, storage, transportation and market access. Data will be collected through farmer surveys, structured interviews and secondary databases from government and international agencies. Quantitative techniques will be used to estimate the extent of losses, while qualitative insights will help understand systemic barriers that aggravate wastage. The objective is to develop a comprehensive framework for evaluating post-harvest losses, integrating physical, economic and operational dimensions. By situating local realities within the broader global context, the research intends to provide actionable recommendations that can guide policymakers, farmer groups and supply chain stakeholders toward effective mitigation strategies. Ultimately, this work seeks to contribute to enhancing farmer livelihoods, reducing food waste and supporting the larger goal of sustainable agricultural development.

Keywords: *Post-harvest losses, agricultural waste, farmer-level challenges, food security, supply chain inefficiencies, sustainability*

Introduction

Agriculture remains the backbone of India's economy, supporting nearly half of the population's livelihood and contributing significantly to national food security. However, the sector continues to

grapple with a persistent yet under-addressed issue like post-harvest losses (PHL). A substantial portion of agricultural produce fails to reach markets or consumers due to inefficiencies in harvesting, handling, storage and transportation. These losses not only lead to food insecurity but also erode farmer incomes, distort market efficiency and increase environmental stress through wasted resources such as water, energy and labour.

The problem is particularly pronounced in developing economies like India, where small and marginal farmers form the majority of producers. Despite advancements in agricultural production, the post-harvest management ecosystem remains fragmented and poorly supported. Studies have indicated that inefficiencies in post-harvest systems account for a considerable percentage of total production loss, especially for perishable commodities such as grains, fruits and vegetables. While national-level analyses have provided broad estimates, localized studies capturing farmer-level realities are limited, especially in ecologically sensitive zones.

The Kuttanad region of Kerala, known as the *"Rice Bowl of Kerala,"* presents a unique case for such an investigation. It is one of the few regions in the world where farming occurs below sea level, with rice cultivation as the dominant agricultural activity. Despite fertile soil and abundant water resources, Kuttanad's farmers face recurring challenges such as bund collapses, waterlogging, erratic rainfall, inadequate mechanization and delayed government interventions. Furthermore, institutional bottlenecks such as delays in subsidy disbursement, insufficient access to storage facilities and inefficiencies in procurement through civil supplies have deepened financial stress among cultivators.

Interviews with local farmers reveal that a combination of environmental, infrastructural and policy-related factors contributes to substantial post-harvest losses. High moisture content due to unseasonal rain, limited availability of harvesting machinery, inefficient drying and storage systems and dependency on mills for procurement often result in 25–50% of the harvested produce losing its marketable value. Moreover, systemic delays in payment and insurance settlement lead to debt accumulation and long-term livelihood insecurity.

Given these complex realities, this study aims to analyse the extent, causes and economic implications of post-harvest losses in Kuttanad, focusing on rice cultivation. By integrating field-based quantitative data with qualitative insights from farmers, the research seeks to develop a comprehensive understanding of the multi-dimensional challenges in post-harvest management. The findings are expected to inform policy interventions and sustainable practices that can enhance food availability, improve farmer income stability and contribute to the larger goals of sustainable agricultural development.

Literature Review

Post-harvest losses (PHL) remain a persistent challenge across global agricultural systems, particularly in developing regions. Numerous studies have examined the magnitude, causes and mitigation measures for such losses, yet regional variations especially in wetland paddy ecosystems like Kuttanad remain underexplored.

Globally, Péra et al. (2023) and Paulsen et al. (2015) identified harvesting and storage inefficiencies as major contributors to crop losses, often amplified by inadequate data tracking and lack of mechanization. Shahbazi et al. (2025) and Sawicka (2020) emphasized that addressing post-harvest inefficiencies can yield more sustainable outcomes than focusing solely on increasing production, linking these losses to food insecurity and resource wastage. Similarly, Mutungi et al. (2022) and Nath et al. (2024) highlighted the potential of modern technologies such as hermetic storage and moisture

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sensors in minimising loss, while stressing barriers like high cost and limited adoption at the farmer level.

Indian studies provide critical insights into systemic inefficiencies. Gulati et al. (2024) and Basavaraja et al. (2007) estimated national post-harvest losses amounting to billions of rupees annually, identifying storage, transportation, drying as high-risk stages. Vishwakarma et al. (2019) and Verma and Deo (2024) demonstrated similar issues in pulses, where improper threshing, delayed harvesting, poor infrastructure increase both quantitative and qualitative losses. Kitinoja et al. (2018) and Bisht & Singh (2024) reinforced the need for standardized assessment frameworks and improved packaging to reduce deterioration in perishables.

Regionally, Kerala's unique agro-ecological landscape introduces distinct vulnerabilities. Lakshmi (2019) and K. T. (2020) described Kuttanad's socio-economic fragility, small landholdings, dependence on institutional support, while Ray (2018) and Jacob (2020) discussed the dual role of floods both destructive and rejuvenating in shaping paddy productivity. Despite being designated as a *Globally Important Agricultural Heritage System (GIAHS)*, Kuttanad's farming remains threatened by waterlogging, bund collapse, erratic weather. Prior studies primarily focus on production trends, socio-economic aspects, or broad environmental challenges rather than quantifying stage wise post-harvest losses and their direct economic implications for farmers.

International parallels reinforce these gaps. Arends-Kuenning et al. (2022) found operator training and contract incentives crucial in reducing losses in Brazil's soybean sector, while Nitikaroon and Petrat (2024) observed that financial constraints and inadequate storage drive inefficiencies in developing regions. Yet, little comparable field-level analysis exists for India's low-lying paddy ecosystems, where mechanisation is partial and climatic risks are high.

Research Gap

While substantial literature exists on post-harvest losses at national and global levels, there is limited empirical evidence focusing on micro-level, stage-wise loss quantification in flood-prone wetland systems like Kuttanad. Moreover, few studies integrate both quantitative loss estimation (in kg/acre) and economic valuation (₹/acre) alongside farmers' qualitative insights on causes and potential solutions. This study aims to bridge this gap by assessing the magnitude, causes, economic impact of post-harvest losses in Kuttanad's paddy farming system and identifying farmer-driven strategies for mitigation.

Study Objectives

The study aims to examine post-harvest losses and related challenges faced by rice farmers in the Kuttanad region of Kerala, an area known for its below-sea-level cultivation and vulnerability to environmental and infrastructural constraints. The research seeks to provide practical insights into reducing wastage and promoting sustainable agricultural practices.

The specific objectives of the study are as follows:

To identify the major factors contributing to post-harvest losses among rice farmers in the study area.

To assess the extent of losses occurring during key stages such as harvesting, storage and transportation.

To examine farmers awareness and access to government schemes and post-harvest management practices.

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To suggest practical and sustainable measures to minimise post-harvest losses and enhance the overall efficiency of rice production.

Methodology

Research Design

The present study adopts a descriptive and exploratory research design to examine the extent and causes of post-harvest losses among rice farmers in the Kuttanad region of Kerala. The design allows for both quantitative estimation of losses and qualitative understanding of the operational and institutional challenges faced by farmers. The research integrates field-level data collection, personal interviews and literature based contextual analysis to develop a comprehensive view of post-harvest inefficiencies within a sustainable agriculture framework.

The study focuses on farmers cultivating rice under the unique below-sea-level conditions of Kuttanad, where factors such as waterlogging, bund collapse, delayed procurement and moisture related deterioration play a crucial role in post-harvest performance.

Study Area

The research was conducted in selected panchayats of Kuttanad, located in the Alappuzha district of Kerala, India. The region is characterized by a complex network of paddy fields (locally known as *padasekharams*), canals and bunds that protect farmlands from floods. Kuttanad represents one of India's most significant rice-producing zones but is increasingly vulnerable to climatic instability, infrastructural decay and policy-related bottlenecks.

Sampling and Respondents

A purposive sampling technique was employed to select respondents who are actively engaged in rice farming. The sample consisted of small and medium-scale farmers owning or leasing agricultural land in different parts of Kuttanad. Each respondent provided information based on their most recent cultivation cycle.

For preliminary analysis, detailed interviews were conducted with a set of farmers to identify common post-harvest issues, operational challenges and potential interventions. The sample size may be expanded in later stages for the master's thesis, but for the conference paper, individual farmer-level case data form the foundation of the study.

Data Sources

The study relies on both primary and secondary data sources:

Primary Data:

Collected through structured interviews and survey questionnaires administered to farmers. The questionnaire captured demographic details, landholding size, ownership type, production data, losses at each stage (harvesting, drying, storage, transportation), causes of loss, access to storage facilities, awareness of government schemes and willingness to adopt improved practices.

Secondary Data:

Drawn from published reports of the Food Corporation of India (FCI), Department of Agriculture Development and Farmers' Welfare (Kerala), Kerala State Civil Supplies Corporation and research articles from journals such as *Agriculture (MDPI)* and *Bhartiya Krishi Anusandhan Patrika*.

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Data Analysis

The collected data was analysed using both quantitative and qualitative techniques to ensure a balanced understanding of measurable loss patterns and farmer perspectives.

Quantitative Data Analysis

Quantitative data from the survey were compiled and analysed using descriptive statistical tools. Key variables included:

Area under cultivation (acres)

Quantity harvested (quintals)

Losses at each stage (in kilograms)

Realized price per kilogram

Costs

Descriptive statistics such as mean, percentage and ratio analysis were used to estimate the magnitude and pattern of post-harvest losses. Comparative analysis was also employed to evaluate the extent of loss across different stages of the supply chain.

If sample size permits, correlation analysis may be used in the next phase to explore relationships between loss levels and factors such as land size, harvesting method, or storage type.

Qualitative Data Analysis

Qualitative responses from farmer interviews were subjected to thematic analysis to identify recurring issues such as infrastructural inadequacies, delayed government payments or lack of machinery. Farmer narratives were noted under “institutional delay,” “moisture-related spoilage,” “transport constraints,” and “insurance inefficiency.” These insights were integrated with quantitative findings to form a holistic understanding of the problem.

Ethical Considerations

All interviews were conducted with the informed consent of participants. Farmers were briefed on the purpose of the study and confidentiality was ensured. Data were collected strictly for academic purposes, maintaining transparency and ethical integrity throughout the process.

Scope and Limitations

The study provides a micro-level view of post-harvest losses within a specific regional and crop context. While the findings offer valuable insights into ground-level realities, they may not be fully generalizable to other regions or crops. However, the study serves as a basis for scaling future research and policy-level interventions in similar agro-ecological zones.

ANALYSIS AND DISCUSSION

Overview

The analysis presented in this section integrates both quantitative and qualitative findings from the field study conducted among rice farmers in the Kuttanad region of Alappuzha, Kerala. The objective was to understand the magnitude and patterns of post-harvest losses, their underlying causes, the operational, infrastructural, policy factors influencing such losses.

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Data were collected from farmers through structured questionnaires and semi-structured interviews. Quantitative data capture yield, loss, economic variables, while qualitative insights were obtained through open-ended questions on challenges and possible interventions. Statistical summaries, correlation analysis, frequency distributions were performed using Microsoft Excel, while narrative data were thematically analyzed.

The discussion unfolds in four parts:

Descriptive statistics of key variables

Stage-wise loss analysis and economic implications

Correlation and pattern exploration

Qualitative insights from farmer interviews

Descriptive Statistical Analysis

Descriptive statistics provide an initial overview of the study area's production environment and post-harvest performance. Table 1 presents the means, ranges, standard deviations of the primary quantitative variables.

Table 1: Descriptive Statistics of Key Variables

Variables	*Mean*	*Median*	*SD*	*Min*	*Max*
Loss_pct	*18%*	*18%*	*0.021203885*	*14%*	*22%*
Yield_qt_per_acre	*22.80*	*22.50*	*1.87*	*20.00*	*27.25*
Revenue_loss_per acre_₹/acre	*11294.80*	*11349.33*	*1427.87*	*8400.00*	*13757.33*

The data reveal that, on average, farmers achieve a yield of 22.8 quintals per acre, which is within the expected productivity range for paddy in the Kuttanad ecosystem. However, an average post-harvest loss of 18% represents a significant reduction in marketable produce. The mean revenue loss per acre is approximately ₹11,295, which, extrapolated across larger holdings, translates to substantial financial strain for small and medium farmers.

The low standard deviation in loss percentage (2.12) suggests that losses are consistently high across respondents rather than being concentrated in outliers, indicating systemic inefficiencies rather than individual negligence.

The average farm size in the dataset is small to medium (5–6 acres), consistent with the regional agricultural structure of fragmented landholdings.

Stage-wise Loss Distribution

Losses were further disaggregated into different stages of post-harvest operations — harvesting, drying/handling, storage — to identify the most critical points of wastage. Table 2 summarizes the mean losses at each stage.

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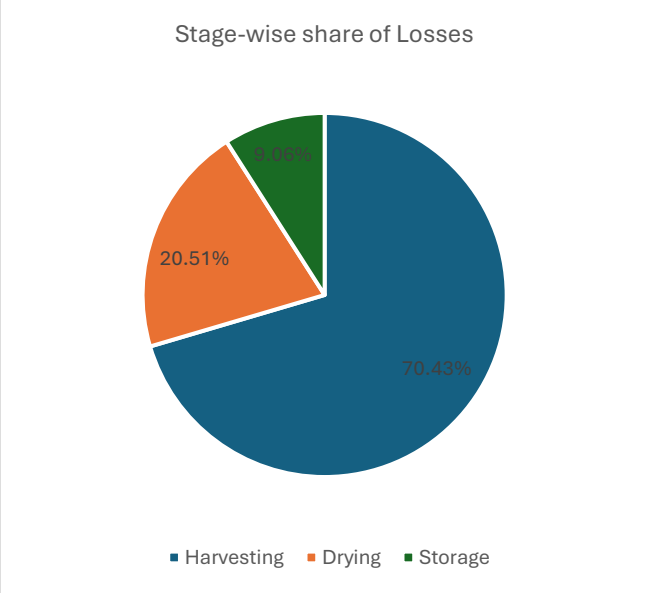
Stages	*Harvesting*	*Drying*	*Storage*	*Mean total loss*
Mean Loss	*2036*	*593*	*262*	*2891*
Mean loss % (wrt to total loss quantity)	*70.43%*	*20.51%*	*9.06%*	*Mean harvested qty*
Loss % (wrt harvested quantity)	*12%*	*4%*	*2%*	*16535*



The analysis clearly shows that the harvesting stage accounts for more than 70% of total post-harvest loss, primarily due to weather fluctuations, bund collapse, delayed collection by mills. Farmers noted that during monsoon months, millers often refuse to take freshly harvested paddy if moisture content exceeds permissible limits (17%), forcing farmers to store produce temporarily in open fields where sprouting and fungal damage occur.

Losses during drying and storage are relatively smaller but still significant. On-field drying is often interrupted by sudden rainfall, most farmers rely on basic farm sheds or open-ground drying, which leads to moisture retention and qualitative degradation. Only a few farmers (less than 10%) reported using any form of improved or hermetic storage.

The loss percentages relative to total harvest (12% at harvest, 4% during drying, 2% in storage) indicate that physical inefficiencies dominate early in the value chain, while post-storage management is less critical but still relevant.

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Interpretation

The pattern reveals that field-level and infrastructural bottlenecks, rather than market or retail inefficiencies, drive wastage. The harvesting losses are strongly correlated with environmental exposure and timing delays, underscoring the vulnerability of Kuttanad's low-lying topography to flooding and bund collapse.

These findings align with national studies (e.g., Sidhu et al., 2024; Kitinoja et al., 2018), which identify harvesting and on-field handling as the stages contributing 60–70% of total post-harvest losses in cereals.

Correlation Analysis

To explore the relationships among key operational variables, Pearson's correlation coefficients were computed and the results are summarized in Table 3.

Table 3: Correlation Matrix

Variable Pair	*r-Value*	*Interpretation*
Area and Loss %	*–0.177*	*Weak negative correlation : larger farms show slightly lower loss percentage.*
Experience and Loss %	*0.106*	*Very weak positive correlation : experience alone doesn't ensure lower losses.*
Yield and Loss %	*–0.215*	*Weak negative correlation : higher yields tend to accompany slightly lower loss percentages.*
Area and Revenue Loss	*0.971*	*Strong positive correlation : larger farms incur higher total revenue loss in absolute value.*

Interpretation

The strong positive correlation (r = 0.97) between land area and revenue loss indicates that while larger farms may have marginally better efficiency, their absolute financial exposure is far greater, magnifying the economic impact of post-harvest inefficiencies.

The weak relationship between farming experience and loss suggests that systemic and environmental factors—not individual skill—are the dominant determinants of wastage. Even highly experienced farmers face similar challenges when infrastructure and policy mechanisms fail.

The negative correlation between yield and loss % supports the observation that better-managed farms (with efficient timing and drying) achieve slightly higher yields and lower losses, but the relationship is not statistically strong enough to infer causation.

Economic Implications

The average revenue loss per acre, estimated at ₹11,295, represents the aggregate effect of all post-harvest losses including those occurring during harvesting, drying, storage stages.

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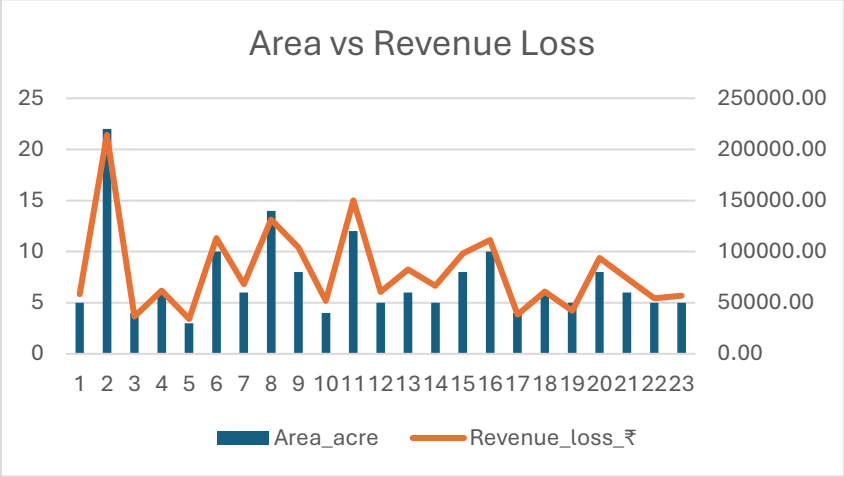

Figure *Area vs Revenue Loss* plots each farmer's landholding (bars) against the corresponding estimated revenue loss (line). The plot shows a clear positive relationship, farmers with larger landholdings tend to incur higher absolute revenue losses, which is consistent with the strong area-revenue correlation observed in the dataset ($r \approx 0.97$). At the same time, some farms with similar area show different revenue losses, reflecting variation in yield, stage-wise loss amounts and price/quality deductions.
Implication: while percentage loss is fairly uniform across farms, absolute financial exposure grows with scale, so mitigation should combine per-acre loss-reduction measures (better bunds, drying, storage) with targeted financial protections (timely payments, individual insurance) for larger holdings.

Field interactions revealed that several factors simultaneously contribute to the income erosion faced by farmers. The dominant sources of financial loss include:

Physical losses during harvesting caused by flooding, bund collapse, rainfall that often result in uncollected or spoiled grain.

Reduced grain quality due to high moisture content, sprouting, or fungal growth, leading to millers paying lower effective prices or deducting quantities from the total weight.

Delayed procurement and payment cycles, which force farmers to sell at distress prices or rely on private collectors for immediate liquidity.

Transportation challenges from the low-lying inland fields of Kuttanad, which increase costs and occasionally lead to spillage or spoilage during transit by boat or lorry.

Given an average yield of 22.8 quintals per acre and a market price of ₹28/kg, each 1% increase in post-harvest loss translates to an approximate income reduction of ₹640-₹650 per acre. With the mean loss estimated at 18%, the cumulative income decline per acre approaches ₹11,000-₹11,500.

Interview insights reinforce these findings. Farmers emphasized that even minor improvements such as timely availability of harvesting machines, strengthening of field bunds, construction of small connecting pathways from farmlands to the mainland could significantly reduce physical losses. Others pointed to the need for higher base prices, individual crop-failure insurance, quicker subsidy disbursal, noting that financial vulnerability amplifies the impact of physical loss.

At a regional scale, extrapolating this per-acre revenue loss across Kuttanad's ~50,000 hectares of paddy cultivation suggest a potential cumulative annual economic loss exceeding ₹500-600 crore. This

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figure underscores not only the magnitude of the problem but also the critical need for policy, infrastructural, institutional interventions to safeguard farmer incomes and ensure the sustainability of paddy cultivation in Kerala's wetland ecosystem.

Frequency Analysis: Causes of Loss

Farmers were asked to indicate 3 primary causes of harvest loss. Responses were categorised and counted to determine their relative frequency (Table 4).

Table 4: Major Causes of Post-Harvest Losses

Causes	*Count*
Bund collapse	*14*
Rain	*10*
Inadequate storage facilities	*8*
Delayed harvest (due to mill issues)	*6*
Harvesting machines issues/ non availability	*6*
Weather fluctuations	*5*
Lack of proper roadways from inland to mainland	*5*
Moisture	*5*
Lack of drying facilities	*4*
Flooding	*4*
Govt initiatives and delays	*2*

Interpretation

The most frequently cited cause- bund collapse reflects the geographic and hydrological vulnerability of Kuttanad, which lies below sea level. Weak outer bunds lead to flooding, waterlogging, sometimes total crop failure before harvest.

Rain and inadequate storage facilities follow closely, emphasizing climatic unpredictability and infrastructural gaps. The persistence of mill delays and non-availability of harvesting machines points to logistical inefficiencies, while issues like "lack of proper roadways to mainland" further complicate post-harvest transport.

These causes collectively reveal that losses are multi-factorial, combining natural (rain, flooding), structural (bund strength, road connectivity), institutional (mill and subsidy delays) dimensions.

Qualitative Insights: Farmer-Suggested Solutions

In addition to quantitative data, farmers were encouraged to propose practical measures to reduce losses. The responses were thematically coded into five dominant themes (Table 5).

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Table 5: Farmer-Suggested Solutions by Theme

Theme	*Representative Suggestions*	*Frequency*	*% of Total (n=23)*
Infrastructure Development	*Strengthen/repair bunds; construct small pathways for transportation; establish block-level storage and drying units; improve storage facilities in adverse weather*	*7*	*30.40%*
Financial & Policy Support	*Increase base/fair price; timely subsidies; ensure civil supply payments; easy loan allowances; reduce intermediaries; extend support during adverse conditions*	*7*	*30.40%*
Insurance & Risk Management	*Provide individual-level crop failure insurance instead of block-level schemes*	*3*	*13.00%*
Technology & Innovation	*Introduce improved, resistant seed varieties; ensure availability of modern harvesting machines; provide incentives and rewards for higher yield*	*3*	*13.00%*
Capacity Building & Governance	*Farmer training and exposure programs; time-bound support from Krishibhavan; better field-level engagement from officials*	*3*	*13.00%*

Interpretation

A substantial majority of farmers prioritise infrastructure (30.4%) and financial/policy measures (30.4%). Their suggestions are practical and context-specific like bund reinforcement, small transportation paths and localised drying units directly address the root causes of loss.

The demand for individual crop insurance underscores a perceived unfairness in the existing block-based insurance model, where compensation is denied to some affected farmers if the entire block isn't declared a disaster zone.

Equally noteworthy is the readiness of farmers to adopt technology, all respondents rated themselves as "very willing" to use improved methods if provided at subsidised rates. This indicates high receptivity to modernization, contradicting stereotypes of farmer resistance.

The call for farmer-focused training rather than generic seminars suggests that institutional extension systems need to be more participatory and field-driven.

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Integrating Quantitative and Qualitative Insights

Bringing together numerical and narrative evidence provides a holistic understanding of post-harvest losses in Kuttanad:

Quantitatively, harvest losses dominate (70% of total), while drying and storage add another 30%.

The 18% average total loss mirrors national averages for paddy reported by FAO and ICAR studies, confirming that local experiences fit into a broader pattern of post-harvest inefficiency in India.

Despite facing repeated losses, farmers demonstrate high adaptability and openness to technological and organizational reforms, indicating strong potential for improvement if supported adequately.

Synthesis: Discussion and Implications

The findings highlight several interlinked dimensions of post-harvest loss:

Physical and Environmental Vulnerability:

Kuttanad's below-sea-level topography, combined with aging bund structures and erratic monsoons, makes harvest operations highly risky. Physical protection through stronger outer bund reinforcement and integrated flood management is indispensable.

Economic and Institutional Barriers:

Price realization remains low (₹28/kg) and stagnant for three years, while delayed government payments and subsidy disbursal exacerbate farmer indebtedness. The strong correlation between land area and revenue loss shows that scale does not insulate farmers from systemic inefficiencies.

Technological Gaps:

Although all farmers use mechanised harvesting, machine non-availability and poor maintenance lead to timing delays that increase exposure to rainfall and sprouting losses. Introducing a decentralised, cooperative machinery sharing model could mitigate these issues.

Storage and Drying Constraints:

On-farm drying is mostly open-air, moisture and fungal contamination are recurring issues. Establishing block-level drying and storage centers with simple solar or mechanical dryers can significantly reduce loss percentages.

Policy and Governance Shortcomings:

Farmers consistently expressed frustration about delays in insurance, procurement, subsidy systems. There is also a lack of effective coordination between Krishibhavans, procurement mills, civil supply agencies.

Farmer Agency and Willingness:

Importantly, all respondents indicated strong willingness to adopt improved practices if supported through financial incentives or training. This reflects a proactive mindset and provides a strong foundation for intervention programs.

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Implications for Practice and Policy

Infrastructure Investments: Strengthening outer bunds and rural road networks should be prioritised under the state's agriculture infrastructure fund.

Policy Simplification: Transition from block based to individual crop insurance could ensure fairer compensation.

Price Support Revisions: Revisiting the base fair price and aligning it with cost of cultivation is essential to prevent disguised farmer indebtedness.

Extension Reforms: Implement farmer-led, field-based training and participatory technology demonstrations rather than top-down seminars.

Data-Driven Monitoring: Encourage local FPOs or cooperatives to maintain real-time digital records of losses, improving transparency and planning.

Conclusion

This study set out to examine the extent and causes of post-harvest losses among rice farmers in the Kuttanad region of Kerala, with a focus on understanding the physical, economic, institutional challenges that hinder sustainable agricultural productivity. The findings reveal that while technological adoption in the form of mechanized harvesting has become widespread, significant inefficiencies persist across other stages of the post-harvest value chain, particularly at the harvesting and drying stages, resulting in a substantial loss of income and resources.

Quantitative analysis indicates that farmers lose an average of 18% of their harvested paddy, with harvesting alone accounting for over 70% of total losses. The average revenue loss per acre (₹11,295) highlights how closely physical losses are tied to financial instability, particularly when compounded by moisture-related deductions imposed by rice mills. The correlation analysis further revealed that while experience do not strongly influence the percentage of loss, there is a strong positive relationship between landholding size and absolute revenue loss, suggesting that larger-scale farmers bear higher absolute financial burdens.

Field-level interviews painted a deeper picture of systemic and contextual challenges. Farmers consistently pointed to bund collapses, erratic rainfall, moisture accumulation as the most frequent and damaging causes of post-harvest losses. The unique topography of Kuttanad, lying below sea level, exacerbates these vulnerabilities, where a weakened outer bund can destroy an entire season's produce. Despite multiple government initiatives and insurance programs, delayed disbursement of payments and lack of timely support have forced many farmers into cycles of debt and lower Cibil score. Civil supplies payments often take up to a year to reach farmers, eroding trust in institutional systems and weakening financial resilience.

Qualitative insights also suggest a structural imbalance between technological research and on-ground implementation. Farmers expressed frustration that while new crop varieties and machinery are being developed, their availability and affordability remain limited. Moreover, insurance mechanisms based on block-level claims fail to capture individual losses caused by localised bund failures or rainfall patterns, leaving many farmers uncompensated.

When viewed holistically, the data show that infrastructure development and policy reforms emerge as the most urgent areas of intervention. Over 60% of farmer suggestions emphasised the need for stronger bunds, local storage facilities, timely subsidies, fairer pricing mechanisms. These structural

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improvements, coupled with better governance and targeted training, could significantly reduce both physical and economic losses. Farmers also displayed a high willingness to adopt improved storage and drying technologies if made affordable or subsidised, indicating readiness for innovation if supported by enabling infrastructure.

The broader economic implications are substantial. Even a modest reduction in post-harvest losses could translate into savings worth crores of rupees annually across Kuttanad's vast paddy fields. This not only represents potential economic gains for individual farmers but also contributes to the larger goals of food security, environmental sustainability, efficient resource use.

In conclusion, this study underscores the multi-dimensional nature of post-harvest losses, driven by a mix of environmental fragility, infrastructural deficits, administrative bottlenecks. Addressing these issues requires an integrated strategy that bridges policy intent with on-ground execution. Strengthening bunds and local transport pathways, ensuring timely subsidy and insurance payouts, promoting improved seed and drying technologies, empowering farmers through participatory governance can collectively transform the agricultural landscape of Kuttanad. Future research could build on this study by conducting multi-seasonal assessments and comparing outcomes across different agro-ecological zones to generalize the findings and develop scalable mitigation frameworks.

Ultimately, reducing post-harvest losses is not merely an efficiency goal, it is a sustainability imperative. Protecting every grain harvested is synonymous with protecting farmer livelihoods, ensuring food security, fostering resilience in the face of climate uncertainty.

Scope for Further Study

While this study provides valuable insights into the nature and magnitude of post-harvest losses among rice farmers in the Kuttanad region, the findings also open several avenues for further exploration. Future research can expand the sample size across multiple districts and cropping seasons to capture inter-seasonal and regional variations in losses. A comparative analysis between mechanised and semi-mechanised harvesting practices could help quantify efficiency differentials and guide appropriate technology adoption strategies.

Further, the integration of remote sensing and GIS-based mapping can provide spatially accurate estimates of areas vulnerable to bund collapse, flooding, moisture retention, enhancing the precision of policy targeting. Researchers can also assess the effectiveness of government interventions such as crop insurance, storage subsidies, civil supplies payments through longitudinal tracking of beneficiaries. In-depth case studies of Farmer Producer Organizations (FPOs) and community-based storage models may reveal scalable solutions to reduce dependence on intermediaries and mills.

Finally, future studies can build on this groundwork to design a post-harvest loss mitigation framework specific to low-lying paddy ecosystems like Kuttanad integrating infrastructural resilience, institutional responsiveness, technological adaptation. Such applied research would not only strengthen the evidence base for policymaking but also contribute meaningfully to Kerala's long-term vision for sustainable agricultural development.

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