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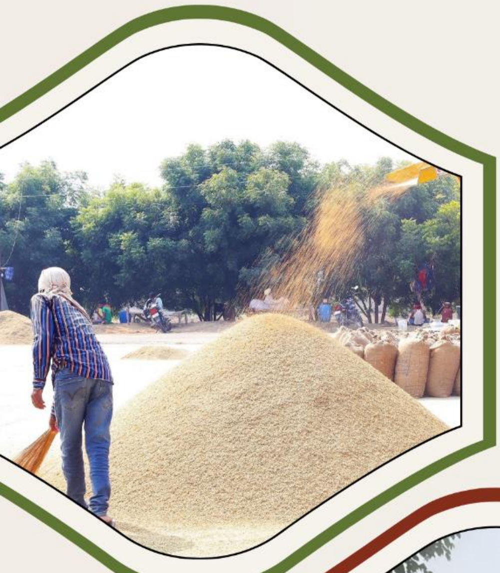
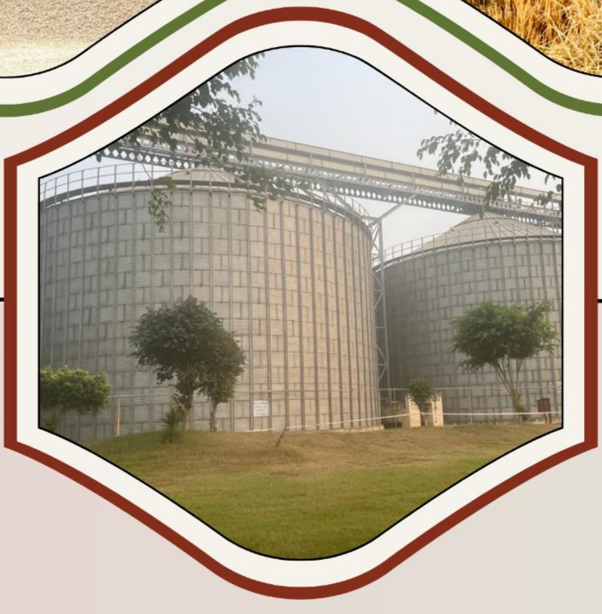
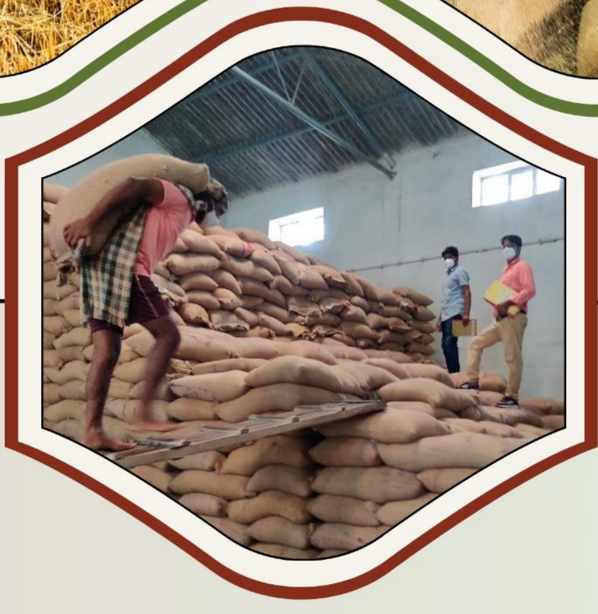
ADMI Institute for the Prevention of Postharvest Loss
University of Illinois

Reducing Post-Harvest Losses in India

Farmer-Level Interventions and Grain Management Strategies

ASHOK GULATI | RAYA DAS | ALEX WINTER-NELSON



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Foreword

The issue of harvest and post-harvest losses in the food supply chain has received significant attention globally in the last decade. This is in light of the United Nations' Sustainable Development Goals of 2030, which aim to improve food security worldwide. As climate change continues to exert its influence on agricultural ecosystem, the imperative to minimize post-harvest losses becomes more pronounced than ever before.

India, being a developing nation faces challenges of lack of technological advancement which leads to staggering post-harvest losses from harvest up to retail level. The challenge is more due to 86 percent of marginal and small farmers operating less than 2 hectares of land and lack of working capital to invest in infrastructure. The country has also regional differences in terms of agricultural development impacting the post-harvest losses across states.

In this backdrop, the present study focuses on the estimation of post-harvest losses and factors contributing to these losses at farmer level. In food loss literature, it is very crucial to estimate the losses for taking policy interventions. This study goes beyond the quantitative loss and puts forward a pioneer effort to estimate both quantitative and qualitative losses for paddy in Madhya Pradesh, Bihar, and Punjab, and for wheat, maize, and soybean in Madhya Pradesh based on primary survey of 1200 farmers. At farmer level, mechanization and use of proper storage techniques are crucial to reduce losses. However, it is also imperative for the government to reduce losses in the grain management at the centre and state levels, during the process of procurement, storage, and public distribution system. In this regard, the present study also analyses factors driving these losses in the food grain management system in India through secondary data analysis and case studies of different storage types. Additionally, the report also traces the role of private investment in storage infrastructure to reduce post-harvest losses in India.

We expect this report will engage various stakeholders, fostering strategic planning for agriculture policies and implementation of schemes aimed at effectively reducing post-harvest losses through the institutional reforms and advancements in technology.

Deepak Mishra
Director & Chief Executive
ICRIER

Preface

Globally 30 percent of the food produced never reaches to a human stomach (FAO, 2021). Tackling food loss and waste benefits the climate, food security, and sustainability of agri-food systems. According to FAO 2021, 13.2 percent of the world's food is lost from harvest to the retail stage. United Nations Environment Programme (UNEP) 2021 estimates 17 percent of food waste at the retail and consumer levels. Developing countries face substantial food loss, while developed nations have significant food waste at the consumer end. Given the grave of the situation United Nations Sustainable Development Goal 12.3 aims to halve per capita global food waste and reduce food losses substantially by 2030.

India indeed achieved tremendous growth in food grain production from 74.23 MMT in 1966-67 to 330.5 MMT in 2022-23 (DES, 2023) and is a key exporter comprising 40 percent share of global rice trade (DGFT, 2023). However, the country faces challenges of mechanization at the harvest, threshing and drying levels, and dearth of technological change in storage and grain management.

In this context, our report provides a focused analysis aimed at identifying effective policy interventions to reduce these losses, both at the farmer level and throughout the agricultural value chain. Part-1 of the report examines both the quantity and quality losses for paddy, wheat, maize, and soybean in selected states. Drawing upon extensive data gathered through 1200 farmers surveys, this section sheds light on the underlying determinants of post-harvest losses at farmers' level. By pointing areas of inefficiency, Part-1 lays the groundwork for targeted interventions aimed at improving post-harvest management practices at farmers' level. Part-2 extends into a comprehensive analysis of grain management practices by the government, particularly focusing on rice and wheat, which are central to public procurement and public distribution system in India. Through an in-depth examination of the operations of the Food Corporation of India (FCI) and the engagement of other major private sector stakeholders, this part of the report offers insights into existing grain storage infrastructure in India. By identifying best practices and areas for improvement, Part-2 serves as a roadmap for enhancing the efficiency of the grain management systems in India.

By synthesizing empirical evidence, stakeholder perspectives, and policy insights, this report aims to contribute to the policy makers, government officials, farmers, private stakeholders to move towards efficient agricultural policies to reduce post-harvest losses in India.

Acknowledgement

We take this opportunity to acknowledge and thank a number of individuals for their support, feedback, and patience. We are grateful to ADMI Institute for the Prevention of Postharvest Loss, University of Illinois Urbana Champaign (UIUC) for their financial support in this study of reducing post-harvest losses in India.

In doing the report we have received support and guidance from numerous individuals and organizations. Firstly, we express our profound gratitude to the farmers surveyed in Punjab, Madhya Pradesh, Bihar for their valuable time for participation and cooperation. We gratefully acknowledge the support from Ms. Preeti Maithili Nayak (IAS), Director of Agriculture, Madhya Pradesh in facilitating our survey work in the selected districts of Madhya Pradesh. We also express our gratitude to Shri Saurabh Kumar Suman (IAS), District Magistrate of Chhindwara, and Shri Harsh Dixit (IAS), District Magistrate of Rajgarh, for their invaluable facilitation for survey in Chhindwara and Rajgarh districts, respectively. We acknowledge the invaluable assistance provided by NABARD District Development Managers (DDMs) in selecting the blocks and villages for our survey work in their respective districts. We are indebted to the district agriculture officers and their teams at block and village levels, who provided essential support and logistics for our survey works. We also express our gratitude to various individuals, including Food Corporation of India (FCI) managers, quality check and technical staffs, mandi secretaries, private processing unit owners and managers, transporters, wholesalers, retailers, and agriculture scientists at district Krishi Vigyan Kendras (KVKs). Special mention goes to Shri Sumer Singh Meena, Manager, and B S Meena, Technical Officer (Quality), FCI, Gwalior, for their unwavering support in accessing private storage and processing units.

We extend our appreciation to our survey team for their dedication, hard work, and commitment to conducting field surveys, sample collection, and transportation, which were instrumental in the success of our endeavour.

We would like to express our profound gratitude to Dr. J.M. Singh, Professor at Punjab Agriculture University and Mr. Surinder Singh, Former Executive Director, FCI for their invaluable insights provided at the inception of our research. We extend our sincere appreciation to Mr. Aseem Chhabra, Deputy General Manager FCI, New Delhi for his invaluable contribution to our research report. We are also deeply grateful for the inputs provided by officials from FCI, the Central Warehousing Corporation (CWC) in Moga, and the officials at Adani Silos in Moga, Punjab. We would also like to extend our appreciation to Mr. Shiraj and his team from the private warehouse in Moga, Punjab. Their expertise and cooperation have greatly enriched our understanding of grain management practices. Additionally, we express our sincere gratitude to the farmer members of Farmer Producer Organizations (FPOs) in Moga, who shared their insights, which have been instrumental in shaping the findings of this report. We also extend our heartfelt appreciation to Dr. Malwinder Malhi for his support during the fieldwork conducted at FCI and private warehouses in Punjab.

We are grateful to Mr. Rahul Arora for meticulously formatting and designing the report.

Needless to mention, the responsibility for the data, analysis, and views expressed in the report, as well as any errors, rests solely with the authors.

Abbreviations

AAY	Antodaya Anna Yojana
ACZ	Agro-Climatic Zones
AIF	Agriculture Infrastructure Fund
APHLIS	African Post-Harvest Losses Information System
CACP	Commission for Agricultural Costs and Prices
CAP	Cover and Plinth
CHC	Custom Hiring Centres
CIP	Centre Issue Price
CIPHET	Central Institute of Post-harvest Engineering and Technology
CWC	Central Warehouse Corporation
DAFW	Department of Agriculture and Farmer Welfare
DCP	Decentralised Procurement System
DES	Department of Economics and Statistics
DFPD	Department of Food and Public Distribution
DMI	Directorate and Marketing and Inspection
FAO	Food and Agriculture Organisation
FCI	Food Corporation of India
FGD	Focused Group Discussion
FLI	Food Loss Index
FPC	Farmer Producer Company
FPO	Farmer Producer Organisation
FWI	Food Waste Index
GCA	Gross Cropped Area
GHGs	Green House Gas Emissions
ICAR	Indian Council of Agricultural Research
IFPRI	International Food Policy Research Institute
MSP	Minimum Support Price
NWR	Negotiable Warehouse Receipt

OMSS	Open Market Sale Scheme
PACs	Primary Agricultural Credit Societies
PDS	Public Distribution System
PEG	Private Entrepreneurs Guarantee
PFL	Prevention of Food Losses
PMGKY	Pradhan Mantri Garib Kalyan Yojana
PUNGRAIN	Punjab Grains Procurement Corporation Ltd.
SDG	Sustainable Development Goals
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
WDRA	Warehousing Development and Regulatory Authority
WRI	World Resources Institute




Part-1

Estimating Harvest and Post-harvest Losses of Wheat, Paddy, Maize, and Soybean in India

A study based on survey in Madhya Pradesh, Punjab, and Bihar

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Executive Summary

The United Nations call the attention to the concern of harvest and post-harvest losses in the food supply chain in Sustainable Development Goals 2015 for the improvement of food security. Research has highlighted that there is a significant quantity of loss of grains in developing countries. In this context, the objective of the present study is to estimate the harvest and postharvest losses of wheat, paddy, maize, and soybean in India and to trace the determinants of losses to provide policy suggestions. To the best of our knowledge, the present study stands as a pioneering effort in the context of India, as it addresses a significant research gap by comprehensively estimating both quantity and quality losses of selected crops within the supply chain. By focusing on the less explored aspect of quality losses, this research aims to provide valuable insights into the broader understanding of post-harvest challenges and potential improvements in the agricultural sector of India.

The research employs a robust data collection methodology, combining inquiry and observation approaches, along with two sample testing techniques - visual scale and laboratory testing. The comprehensive dataset was derived from a survey of 1200 farmers and 116 market-level stakeholders, distributed across 12 crop districts using a stratified random sampling method. The sample includes 600 paddy farmers, 200 each of wheat, maize, and soybean farmers, as well as 60 paddy, 20 each of maize and soybean, and 16 wheat market-level stakeholders. This rigorous approach ensures the reliability and representativeness of the data, enabling a thorough analysis of quantity and quality losses within the supply chain of the selected crops.

Through a comprehensive assessment employing both observation and inquiry methods, the aggregated loss across the supply chain is determined to be 5.96 percent for wheat, 5.75 percent for paddy, 5.20 percent for maize, and 12.02 percent for soybean. Additionally, considering the impact of quality deterioration, the overall loss, inclusive of lost quantities, stands at 7.87 percent for wheat, 6.52 percent for paddy, 5.95 percent for maize, and 15.34 percent for soybean. These findings underscore the critical need for targeted interventions to mitigate losses and enhance efficiency throughout the supply chain. The study further shows distinct share of harvesting and storage loss of crops. These evidence-based findings shed light on the critical areas where losses occur in the supply chain of these crops to implement targeted strategies to reduce post-harvest losses.

At farmer level, the linear regression results indicate that the adoption of combine harvesters in paddy and soybean cultivation is associated with lower losses compared to conventional harvesting methods, suggesting that mechanization can be an effective strategy to reduce harvest losses. The expansion of custom hiring institutes and the integration of farm machinery through an uberisation approach can be used in achieving this objective. Furthermore, the study establishes a positive association between the education level of farmers and reduction of post-harvest losses, as higher education leads to better adoption of crop management practices. This association holds true across all the selected crops, indicating that promoting education among farmers can yield significant benefits in mitigating losses during harvest and post-harvest phases. The paper also addresses the impact of land marginalization on grain losses per hectare in the

country. It highlights the need for appropriate machines for small farmers to minimizing harvest and post-harvest losses. In addition to this uberisation of farm-machineries and expansion of custom-hiring centres can increase mechanisation in India. The study also emphasizes the importance of improving storage equipment, as it reveals a concerning lack of hermetic storage facilities among farmers. By adopting a comprehensive approach that includes mechanization, promoting education among farmers, appropriate machinery for small holdings or implementation of land-consolidation strategies, and enhancing storage infrastructure, policymakers and stakeholders can effectively tackle the challenge of harvest and post-harvest losses in the agricultural sector, contributing to increased food security and sustainable agricultural practices in India.

1 Introduction

1.1 The context and importance of food grain losses

'Food loss and waste' is a complex issue responsible for people's food and nutrition insecurity, more greenhouse gas emissions and pressure on natural resources. United Nations (UN) documents mentioned 'food loss and food waste' several times in the last decades of the 20^{th} century—and the numbers have increased since then across the countries. The theme for International Day of Awareness of Food Loss and Waste 2022 was 'Stop Food Loss and waste, for the people, for the planet', which shows the issue's seriousness. Given the concern on food loss, in 2015, the 2030 Sustainable Development Goals (SDGs) was also taken into ensure sustainable consumption and production patterns. Its third target (i.e., 12.3) is—to reduce food losses along the production and supply chain and to reduce the food loss at consumers' end by 50 percent by 2030.

According to the UN's Food and Agriculture Organization (FAO), around 30 percent of the total food we produce does not reach our stomachs—that means we lose and waste around 33 percent each year along the food value chain globally. FAO estimates of 13.2 percent for food loss (between the farm and the retail distribution level-FAO, 2021) and 17 percent for food waste (from households, food service, and retail levels-United Nations Environment Programme 2021). In other words, we have enough food for our people and lose a substantial portion along the food value chain, undermining our food system's sustainability—leading to 690 million people across countries living in hunger and malnutrition.

UN Population Prospect Report 2022 says the global population will reach 8 billion marks by mid-November 2022. That means the situation may deteriorate further, given the need for more food to feed them. The amount of food we need to provide them is approximately 4.1 billion metric tonnes, assuming an average of 1.4 kilograms of food without water per day per person. For this to happen, we must produce around 5.37 billion metric tonnes of food annually, considering that we lose about 30 percent of production along the value chain.

If we see a longer horizon, the world population will reach 9.7 billion by 2050 (UN Projection, 2022), further adding 1.7 billion people globally. As a result, we will have 21.25 percent more human mouths to feed, and the food we require will be 6.5 billion metric tonnes annually in 2050. Therefore, to meet the growing food demand in 2050, we need to increase food production by approximately 62 percent or even more. So, to increase food production, we need to increase the area under production, productivity, or both. However, the scope for the required production level is limited as we have limited resources/inputs in hand. For example, the land we inhabit is limited, and the water and energy, agricultural chemicals, and other production factors we use for agricultural production are also limited. Thus, reducing postharvest food losses and improving food distribution channels are critical to ensuring future global food security (Majendie, 2020). FAO's revised estimate shows we are losing 1.24 billion tonnes of food globally each year (FAO, 2019). This figure will hit 2.1 billion tonnes by 2030, worth USD 1.5 trillion (Hegnsholt et al.,2018). So, there is a clear interlink between economic and non-economic factors and food loss issues.

Considering the relationship between food loss, food price increase and food expenditure in resource-poor countries, we must take food loss reduction strategies seriously and increase the budget allocation from around 3-4 percent to at least 10 levels of total budget allocation for the agriculture sector. Why should we spend more on loss-reduction strategies? For example, for every 1 percent increase in food prices, food expenditure in developing countries decreases by 0.75 percent (FAO, 2006)—leading to severe malnutrition in a crisis year. Moreover, if we reduce food loss and waste—say 1kg, we do not need to produce 1.45 kg more food (we lose around 31 percent). As a result, we can save resources used in growing uneaten food (land, water, agricultural chemicals, energy, and other scarce inputs) and extra budget and human efforts. That means an additional source of food supply without changing production patterns. In addition, we can also reduce the negative externalities associated with food loss (e.g., pollution created during food production) and the growing pressures on the natural resources for global food supply.

According to FAO reports, we use 28 percent of the total global arable land for the food we do not eat. In other words, if we measure in terms of the country's arable land, it would be equivalent to the cultivable land of China, Mongolia, and Kazakhstan. Nevertheless, during the process, we also lose 250 Km^3--six percent of total water withdrawals annually that can cover all households' water needs.

Reduction in these losses would have multiple positive impacts on society by increasing the amount of food available for human consumption, enhancing global food security, reducing food inflation, and increasing availability for other uses such as biofuel and industrial uses (Mundial, 2008; Trostle, 2010). Additionally, reducing food loss is promoted as a USD 700 billion business opportunity for stakeholders (Hegnsholt et al.,2018). In addition, reducing food loss also increases the real income of all producers and consumers (World Bank, 2011).

A deeper look into the other aspects of food loss and waste shows several other impacts of food loss. We have negative externalities to society through the cost of waste management, greenhouse gas production and loss of scarce resources, including its adverse impact on the economy. Green House Gasses (GHGs) are by-products of food loss and waste. Moreover, 6 to 10 percent of human-generated greenhouse gas emissions are caused due to food loss only (Gustavsson et al., 2011; Vermeulen et al., 2012). FAO (2013) estimated the carbon footprint at 3.3 $GtCO_2$ eq for 2007 (excluding land use change). However, using the Food Balance Sheets (2011), the updated estimation figure is 3.6 $GtCO_2$ eq which does not include the 0.8$GtCO_2$ eq of deforestation and managed organic soils associated with food wastage, thus a total of 4.4 $GtCO_2$ eq per year (FAO 2014). If this could be a country, it would be the world's third-largest emitting country after China and the USA (FAO, 2014).

Food loss and waste are also connected with nutrition and calorie loss. A world bank study shows that seven calories of inputs are required to produce a unit of food calories lost due to improper value chain management. Many studies state that high cost is associated with food waste decomposing anaerobically, landfills, utility bills, and taxes (US EPA, 2011; Schwab, 2010; Buzby and Hyman, 2012).

The gravity of this issue is significant, as many people across countries suffer from hunger and malnutrition, and the number has been slowly rising since 2014 (UN documents). Therefore, we must think of better policy options to achieve the objectives, including improving food and nutrition security, reducing greenhouse gas emissions and lowering pressure on water and land resources, contributing to increased productivity and economic growth. However, for better outcomes, first, we need to gain a deeper understanding of the situations in which losses occur. Second, the contextual factors guide our decision regarding the solutions and strategies that fit our objectives. Third, once we find the loss-making hotspots and why losses happen, we must estimate the amount and value of the food we lose, including food waste (we exclude the food waste part from our study). Finally, it will act as a quantitative baseline for policymakers and the food industry to set targets and develop initiatives, legislation, or policies to minimize food loss (Buzby and Hyman, 2012).

1.2 Harvest and postharvest losses of food grain

Food loss and waste, defined by Food and Agriculture Organisation (FAO), is the 'decrease in quantity or quality of food along the food value chain.' Specifically, food loss refers to losses along the food supply chain from harvesting/slaughtering/catching up to excluding the retail stage. Food waste, in contrast, happens at the retail, food services, and consumer level. Post-harvest losses are measurable reductions in foodstuffs and may affect either quantity or quality (Tyler and Gilman, 1979). Food loss is defined as measurable qualitative and quantitative food loss along the supply chain, starting at the time of harvest till its retail or other end uses (De Lucia and Assennato,1994; Hodges et al., 2011). Food waste is the loss of edible food due to human action or inaction. It usually happens at the consumption end, such as throwing away wilted produce, not consuming available food before its expiry date, or taking serving sizes beyond one's ability to swallow.

On the other hand, food loss is the unintentional loss in quantity or quality because of infrastructure and management limitations of a given food value chain. Food losses can either result from a direct quantitative loss or indirectly due to qualitative loss. Food loss and food waste add to contribute to postharvest food losses.

Food losses can be quantitative as measured by decreased weight or volume or qualitative, such as reduced nutrient value and unwanted changes to taste, colour, texture, or cosmetic features of food (Buzby and Hyman, 2012). However, quality losses are more difficult to estimate than quantity/weight losses as the former are usually expressed by several measures, such as the many factors included in an official grading standard.

1.3 The estimation of harvest and postharvest food grain losses

Till 1970, most figures for postharvest weight loss of cereals were subjective. For the first time in 1977, FAO presented a survey-based approach to postharvest crop losses, concluding that there needed to be more well-supported postharvest loss figures for cereals. These gaps in the literature inspired the development of improved loss assessment techniques in the subsequent years. The first detailed survey-based approach for assessment was undertaken by Harris and

Lindblad (1978), together with documentation on the losses themselves (National Academy of Sciences, 1978 a&b). The development of new techniques went hand in hand with FAO's Prevention of Food Losses (PFL) programmes of the late 1970s to 1990s (APHLIS, 2014). Most of the studies so far have used two principal estimation methodologies to estimate food loss across the supply chain: a macro approach, using aggregated data from national or local authorities and large companies, and a micro approach, using data regarding specific actors in the different value chain stages (FAO, 2018; Delgado et al., 2021).

An analysis of the two approaches shows that: the macro approach relies on mass or energy balances, in which raw material inputs, in terms of weight or calories, are compared to agricultural production and food products. However, the micro approach used value chain actors' declaration through structured questionnaires and interviews, direct measurements through field experiments by the researcher, food-scanning methods, etc.

The macro approach for measuring the post-harvest losses is less time and cost-consuming; the micro measurement method is substantially more complex, costly, and time-consuming. In addition, getting a large enough proportion of responses to represent an entire supply chain or region is complex (IFPRI 2017).

1.4 Relative versus absolute food grain losses

Relative is dependent, while absolute is independent. There are two ways we can present the weight losses; an absolute loss which is the actual weight of grain lost (expressed in terms of tonnes/quintals or kilograms), or a relative loss, where the weight of grain lost can be described as a percentage or proportion of the initial weight. It is imperative to remember that while relative losses may remain constant, the absolute losses may change. For example, if grain production is increased to pay off a 10 percent harvest and postharvest loss, and the relative losses will remain the same, then the absolute losses would increase at each point in the crop supply chain. This is one of the arguments why reducing postharvest losses may be a better way of increasing grain availability than increasing production alone. Similarly, if relative losses are reduced at one point in the supply chain but remain constant at other links, the absolute losses at the other points will be greater since there is now more grain to be lost at those points (APHLIS, 2014).

1.5 The dynamics of food grain quality losses and economic loss

Depending upon the damage to grains, markets (formal or informal) where the grain is traded decide the value. Formal markets have their standard, and the grains are paid for according to the grades at the trading time. On the contrary, in an informal grain market, grades are not enforced or do not matter to the trader. Thus, there is no pre-determined relationship between quality and price. There is very little data on the relative value of either weight or quality loss in either type of market (APHLIS 2014). A few studies have been done to decide the value of the quality loss of cereals in Africa, where weight and quality losses are taken into account (Zambia - Adams and Harman, 1977; Ghana -Compton et al., 1998; Compton 2002). For example, In India, as per FCI standards, if the quality losses due to damage, shrivelled, coloured and foreign matter present are more than 10-12 percent, then the consignment will be refused straightforwardly or would fetch a relatively lower price at the market place. Our study found around 10 to 30 percent average wholesale price reduction depending upon the crops and varieties.

Food loss and waste result in an opportunity cost forgone or economic loss for all actors along food supply chains, including consumers. Financial losses that arise due to food loss are multi-facet. First, food grain production requires several scarce inputs such as land, water, energy, and agricultural chemicals. After producing them, we let them lost or wasted due to inefficiencies or mismanagements at the production, mid-ways, and consumption points. Second, the inefficient use of scarce resources resulting from food loss and waste blocks the paths such as overcoming hunger and poverty, ensuring adequate nutrition, and increasing income and economic growth. Third, when we have around 86 percent of small and marginal farmers in India and their production level is for subsistence, food losses lead to a decrease in food availability and thus increase food insecurity. Finally, food losses in terms of quality loss also leads to poor nutrition - low-quality foods can be dangerous because of their adverse effects on consumers' health, well-being, and productivity.

SAVE FOOD-2015 estimated that the value of food loss and waste at the global level is one trillion US dollars. In India, CIPHET 2015 estimated an overall monetary loss of Rs 92,651 crore (USD 17,142 million) for the production year 2012-13.[2] This substantial food loss may be one of the several reasons for India's food security and nutritional issues. There were 191 million undernourished people during 2014-16 in India (FAO); that represented 24 percent of the total of malnourished people worldwide. The forward and backward linkages of food loss are also a cause of concern in today's globalized food industry chains. Food is produced in one part of the globe and processed and consumed in different regions. Therefore, foods sold in international markets and lost in one part of the world can affect food availability and prices in another location (Kotykova and Babych, 2019).

1.6 Research Objectives

The objective of the study is to develop a comprehensive framework to estimate the losses in food grains in India as follows:

- To estimate quantitative and qualitative losses for paddy, wheat, maize, and soybean.
- To trace the conditions and factors of post-harvest losses for the selected crops.
- To identify the gaps in the infrastructure development, technology infusion, and skills requirements in the sector, along with highlighting investment needs to fill the gaps.
- To assess the effectiveness of post-harvest management schemes and highlight specific and product-specific gaps for target support from the state to develop appropriate policy and implementation directives.

1.7 Expected outcomes

- Effective assessment of post-harvest losses in quantity and quality across the paddy, maize, and soybean supply chains.

[2] We used the exchange rate of 2012-13 to convert INR at 1 USD=54.05 INR)

- It is projected to provide a comprehensive and evidence-based understanding of the post-harvest losses and sectoral dynamics along the paddy, maize, and soybean supply chain.
- Identify and understand critical and prioritized infrastructure gaps in technology infusion and skills requirements that may be needed to minimize post-harvest losses in the sector.
- Mapping of domestic and international policies, and best practices, both existing and proposed, concerning post-harvest losses management.

1.8 Scope of the Study

The plan for the present study is divided into two phases; Phase I, the post-harvest loss assessment study, covered one crop, i.e., wheat (a Rabi crop harvested during April/May) in Madhya Pradesh. In Phase 2, other crops such as paddy, maize, and soybean are covered in Bihar (paddy), Madhya Pradesh (paddy, maize, and soybean) and Punjab (paddy). This study has covered the farms of the household sector, essentially the small- to medium-scale holdings producing both for their consumption and the market.

Two approaches of data collection, such as subjective and objective, and two approaches of sample testing, such as visual scale (a hybrid of the former two) and laboratory testing methods, have been used to collect and examine the data at the farm as well as market-level stakeholders. A subjective (stakeholder's declaration) approach has been employed to gather the information from the farmers/producers and other supply chain, actors. The same steps have been followed in the objective measurements except drying, on-farm transport and storage at retail channels. However, the objective measurement followed a visual scale method to replace the direct experiments in these post-harvest operations where objective measurement is not possible or convenient. On-farm transport has also not been considered because of the time and resources required to carry out these measurements. At the retail stage, storage time is too short for experimenting; however, the operational losses were estimated. All the above stages where direct experiments could not be undertaken show fewer losses experienced from the literature review so far.

1.9 Methodology, selection of states and crops

We used two sampling methods—first, to decide on the states and districts, we used a purposive sampling method. Second, we used a stratified multistage random sampling method to select the blocks, villages, farming households and market-level stakeholders. We decided the states based on the performance of agricultural activities, the level of economic development, the availability of crops and the level of farm mechanisation. We picked three states—Madya Pradesh, Punjab and Bihar. Bihar is a relatively poor state with rather lacklustre performance in agriculture, Madhya Pradesh is in the middle, and Punjab is somewhat a more prosperous state so far as agriculture is concerned. And some or most selected crops are widely available in these states. In Madhya Pradesh, we picked four food crops (wheat, paddy, maize, and soybean). In Punjab and Bihar, we picked Paddy, a Kharif crop.

To deal with the project timeline after Covid-19-related travel restrictions in January-February 2022, we picked one Rabi crop (wheat) and three Kharif crops (paddy, maize, and soybean) whose harvesting windows opened in Spring 2022 (March) and Autumn 2022 (October), respectively. Then, we chose the crop districts based on the level of crop-specific production share during the period in the state. Finally, we decided on one significant producing crop district and one relatively less-producing crop district to understand the PHL dynamics. Other factors include the allocation of production in the state-specific Agro Climatic Zones (SACZs) and the availability of different supply chain actors, such as grain mandi and storage units in the district. Chapter 3 of this report will guide us regarding the sampling and data collection methods.

The study is primarily based on field survey data collected through extensive field visits across the three states. Statistical simulations of the collected data may lead to ineffective results if collected data do not follow a scientific method. At the same time, assessing losses in numerous unit operations and market channels involves adopting a robust methodology for getting consistent results. In addition, their uniformity may help compare the results from different studies.

Several studies across countries and regions have estimated the harvest and postharvest food losses. Most studies used two principal estimation methods to assess food loss across the supply chain: a macro approach, using aggregated data from national or local authorities and large companies, and a micro approach (through a primary survey), using data regarding specific actors in the different value chain stages (CIPHET 2015; FAO 2018; Delgado et al., 2021). These studies estimate mainly quantity losses undermining the quality loss aspects in grains except for APHLIS, which has used a visual scale approach to assess the quality loss. Amongst the loss estimation methods, the micro approach, which uses direct interviews and field experiments, is more effective.

In this study, we used the micro-approach—for quantitative loss estimation; we followed the FAO and CIPHET methods. In addition, we developed our methodology for qualitative loss estimation for this research. We are on the food loss estimation part, not the food waste part. That means we estimated the loss in the grain production and supply chain parts. We excluded the losses at the consumer end (households, food services and retail buying). The unique feature of this study is that we attempt to quantify the quality loss in food grains, including quantity loss, unlike the existing research available in India. There are ways to estimate the quality losses. However, we have taken only the grain's external appearance (such as shrivelled/wilted, broken, damaged, coloured, and weevilled—that fetches a lower market price). We collected quality loss information from a multi-stakeholder survey, followed by field experiments (visual scale) and laboratory testing of grains. We used the formula: percent X (Quantity due to quality deterioration) = {percent X (Quality loss) * percent average wholesale price reduction of the crop X due to quality loss} *100. For example, if the quality loss of crop X (i.e., wheat) is 12 percent and there is a 20 percent average wholesale price reduction in grain due to lower quality, then the equivalent quantity loss is (12/100x20/100)100= 2.4 percent. The laboratory testing of grains is vital to estimate the quantity loss due to quality deterioration. Therefore, we mainly depended on this technique to calculate the quality loss. Several laboratories, including an in-house grain laboratory, facilitated our loss estimation process for all selected food crops.

1.10 The organisation of this study

We organized the Part-I study report into six chapters; each connects the concluding chapters that present a policy roadmap to minimize the post-harvest losses. After the introductory chapter, chapter 2 illustrates a review of the existing literature. We reviewed the existing literature and found gaps for further research. Chapter 3 discusses the study approach and methods we used for data collection. The chapter explains how our study differs from others, where we discussed two sampling methods for selecting states, districts, blocks, villages, farmers, and market-level stakeholders. We also explained the field survey techniques, data collection methods, data quality check procedures, data analysis, and loss estimation methods.

Next chapter provides the research result—estimation of harvest and postharvest losses along the selected crops' production and supply chain in terms of quantity, quality, and economic loss. We also showed the amount of post-harvest losses through inquiry and observation methods and then pooled them for aggregate loss estimation. This chapter further investigates a comparative analysis of our results on harvest and post-harvest estimation—vis-a-vis other contemporary literature. Chapter 5 analyses the farming practices and traces the determinants of losses at farmers' level. Finally, in chapter 6, we outline major conclusions of the study. The final chapter focuses on policies, programmes, and schemes the central government implements to support post-harvest loss management with appropriate policy recommendations. Finally, we closed the discussion by presenting a way forward and the best practices by drawing lessons that would enable us to reduce postharvest losses.

2 Overview of Measurement Approaches-A Review of Literature

2.1 Overview

Considering the criticality of the post-harvest losses assessment issues at the national, regional and international levels, we have gone through several studies, irrespective of the location, for paddy, wheat, maize, and soybean to review the methods of estimation and the types of data. We observed that the existing literature classifies it into three main categories; quantitative loss, qualitative loss, and economic or commercial loss. Quantitative loss indicates a reduction in physical weight and is easier to quantify. On the other hand, a qualitative loss is the contamination of grain by pests or moulds that leads to a loss in nutritional value, consumer acceptability of the products and caloric value (Zorya, 2011). Finally, economic loss is the reduction in the monetary value of the product due to a reduction in the quality and quantity of food (Tefera, 2012).

Most of the studies so far have used two methodologies to estimate food loss across the supply chain: a macro approach, using aggregated data from national or local authorities and large companies, and a micro approach, using data regarding specific actors in the different value chain stages (FAO 2018; Delgado et al., 2021).

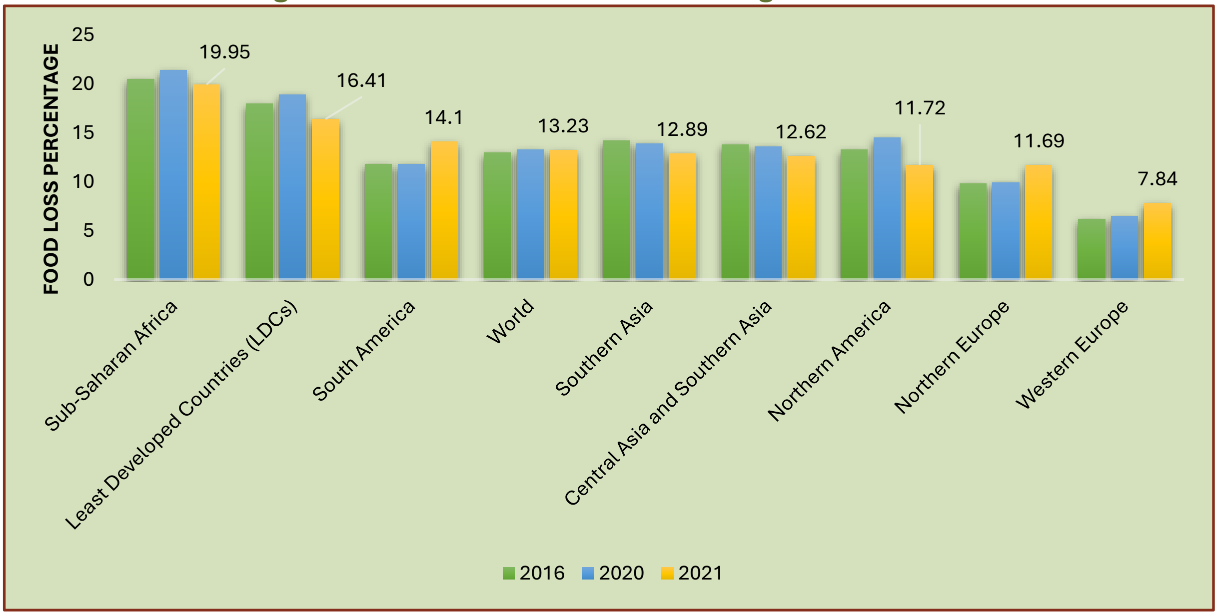
An analysis of the two approaches shows that: the macro approach relies on mass or energy balances, in which raw material inputs, in terms of weight or calories, are compared to agricultural production and food products. However, the micro approach uses value chain actors' declaration through structured questionnaires and interviews, direct measurements through field experiments by the researcher, food-scanning methods, etc. While the macro approach of measuring the post-harvest losses is less time-consuming and economical, the micro measurement method is substantially more complex, costly and time-consuming. In addition, getting a large enough proportion of responses to represent an entire supply chain or region takes a lot of work. (IFPRI 2017).

We divide the literature review for this study into four parts. Part one of the review discusses the global status, and parts two and three discuss the review for methodology, crop-specific reviews, and economic and environmental losses reviews. Finally, in part four, we discuss the gaps in the existing literature.

2.2 Status and Trends of Global Estimates of Food Losses

FAO prepared one of the first reports on food waste and loss in 2011, which estimated that globally, we lost or wasted around one-third (by weight) of all food we produced. This substantial disappearance of food from the entire food value chain equates to approximately 1.3 billion tonnes per year. If we convert them into calories, it would be around 24 percent of all food we produce, equivalent to 614 kcal/cap/day (Kummu et al., 2012; Food and Agriculture Organization, 2013). More than half the losses and waste occurred at the consumption stages, 'close to the fork', in the developed countries, including North America, Europe, and Oceania. While in South and Southeast Asia and Sub-Saharan Africa, the estimated figure shows that two-thirds to three-quarters of the food is lost and wasted at 'close to the farm' — the initial stages of production and storage (WRI, 2011).

Figure 2.1: Share of food loss across regions 2016-2021



Source: The State of Food and Agriculture, (FAO)

Figure 2.1 shows that food loss is lower in developed countries compared to developing nations. The lower losses in the developed countries may be due to more efficient farming systems, modern transport, storage, and processing facilities, which help a significant proportion of harvested output reach markets (Hodges et al., 2011). In addition, the dry chain (for cereals and pulses) and cold chain system (for fruits, vegetables, and animal products) are more robust in these countries, prolonging the product's shelf-life. In contrast, most developing countries grapple with issues such as early harvest, inadequate and low storage facilities, and lack of processing and market infrastructure (Aulakh and Regmi, 2013).

2.3 Reviews for Methodology

We reviewed four significant studies to draft our study methodology as follows.

2.3.1 Food and Agriculture Organisation (FAO)

Food and Agriculture Organisation (FAO) contributed significantly to address the global food loss and waste issues—we have given a snapshot of the study in the prior sections of this chapter above. Through macro approaches, FAO has undertaken extensive research to measure food loss or waste (FAO 2011: Global food loss and waste – Extent, causes and prevention). The study estimates around 1/3rd of global food production across all production sectors are lost along the entire food value chain (Gustavsson et al., 2011). Later, it used the micro approach to estimate food loss in quantity (FAO, 2017: Field test report on the estimation of crop yields and postharvest losses). These studies have used several assessment methods like rapid assessment tools, probability sample surveys, modelling, and field trials.

It covers all the essential activities of the production and supply chain, spanning all critical loss-making points. However, though the studies have done a compressive estimation of the quantitative losses across the crop supply chains, it does not assess the qualitative losses of crops or commodities (that fetches lower selling price at the marketplace) and impacts on the environment due to food loss or waste.

The FAO (2018) protocol is comprehensive and provides loss measurement methods along the production and supply chain. It also gives in-depth information on sampling and analysis techniques like probability sampling, field trials and regression modelling. As a result, many assessment-based studies apply the methods to arrive at grain loss figures. However, it misses capturing quality losses in a way a few other studies do (like Delgado et al., 2017).

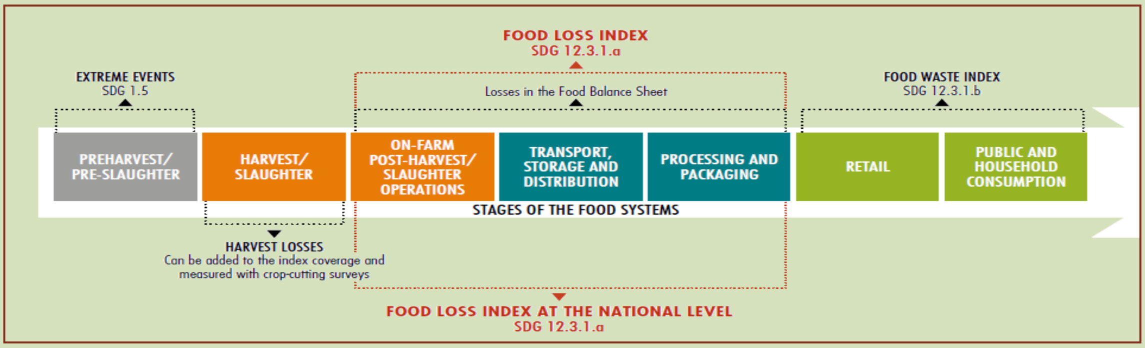
FAO's meta-analysis on food loss contains almost 20,000 data points from more than 460 publications and reports from numerous sources (including governments, universities, and international governmental/non-governmental organizations).[3] These points refer to the percentage loss of each commodity across a particular value chain for a specific country. More than 65 percent of the observations denote Central and Southern Asia; 17 percent of observations refer to sub-Saharan Africa, and 9 percent to Eastern and South-eastern Asia. India accounts for 85 percent of Central and Southern Asia observations. Fruits and vegetables account for 33 percent of all the observations, and Cereals and pulses constitute 28 percent.

Box 2.1: Food Loss Index

FAO developed a Food Loss Index (FLI) for monitoring food losses on a global level based on a traditional Laysperes fixed-base formula index. The index covered a basket of commodities (covering crops, fishery, and livestock products) over the food supply chains from harvest stage to retail. It measured the Food Loss Percentage (FLP) to estimate the change in the percentage losses over time. FLP is interpreted as the percentage of production not reaching the retail stage. Figure 2.4 illustrates FLI, which comprises three phases of the food system: On-farm, postharvest, transport, storage and distribution, and processing and packaging.

[3] The analysis excludes 5500 data points from studies measuring food loss and wastage along the entire value chain and 9107 data figures from the African Post Harvest Losses Information System (APHLIS) database. APHLIS followed a single loss observation system for different periods and crops across diverse regions.

Food Loss Index along the Supply Chain



Source: The State of Food and Agriculture (2019), FAO

Step 1. Losses of each commodity l_{ijt}

The loss percentages l_{ijt} by country (i) for a basket of commodities (j) and year (t) are the first variables to be obtained for the indicator. Losses can be measured directly through representative sample surveys along the supply chain or modelled through FAO's methodology. Loss percentages are the final output of the whole data collection effort and the central piece of the methodology.

Step 2: Compile the Food Loss Percentage of a country (FLP)

The Food Loss Percentage is the aggregation of the loss percentage of each commodity l_{ijt} weighted by the commodity's share of the total value of production and imports across all food commodities in the country. The FLP represents an estimate of the percentage of the value of food production and imports that we lost between harvest and the retail market. The final index came by multiplying the loss percentage of commodity' j' in country' i' in the period, 't' with its price and quantity, and the value, thus obtained, is divided by the total value of all the commodities in the basket.

The Food Loss Percentage (FLP) for a country (i) in a year (t) is defined as follows:

$$FLP_{it} = \frac{\sum_j l_{ijt} * (q_{ijt_0} * p_{jt_0})}{\sum_j (q_{ijt_0} * p_{jt_0})}$$

Where:

l_{ijt} is the loss percentage (estimated or observed)

i = country, j = commodity, t = year

t_0 is the base year (set as 2015 in the current study)

q_{ijt0} is the production plus imported quantities by country' i, commodity' j' in the base period

p_{jt0} is the international dollar price by commodity' j for the base period

The FLP is a relative measure of a country's food system efficiency that we can use for cross-country comparisons. Further, it can be disaggregated into a loss percentage by commodity and food supply chain stage (where stage-level information exists).

Step 3: Compile the FLI as the ratio between two Food Loss Percentages

The country-level indices (FLI) are equal to the ratio of the Food Loss Percentage in the current period and the FLP in the base period multiplied by 100:

$$FLI_{it} = \frac{FLP_{it}}{FLP_{it_0}} * 100$$

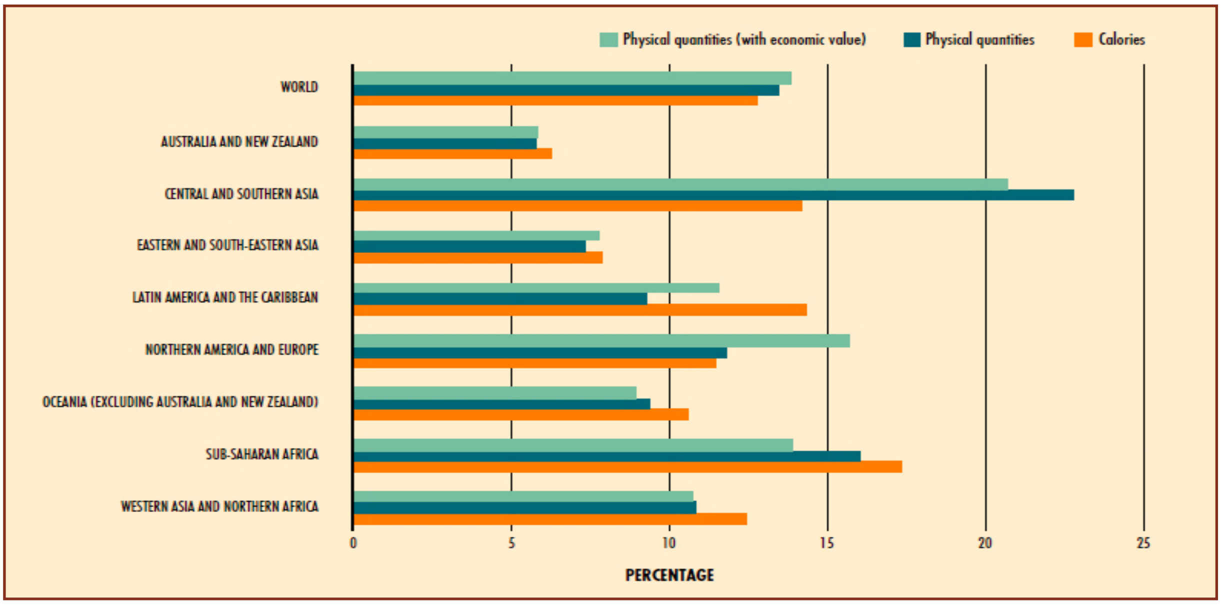
The FLI is expressed in a base of 100 and allows for analyzing the positive and negative trends in FLP compared to the base period of 2015 and for assessing countries' progress in reducing losses.

According to the study, the estimated economic loss globally – in terms of monetary value in 2016 – is 13.8 percent of food produced. At the regional level, the estimates on FLP showed a variation between 5–6 percent in Australia and New Zealand and 20–21 percent in Central and Southern Asia. However, regarding the physical quantity, the loss percentage stood at around 14 percent in 2016.

Using the calorie content of diverse foods, losses in calorific units enable the calculation of energy-dense food items (**Figure 2.2**). Results obtained for this indicator showed that loss percentages were highest for sub-Saharan Africa (around 17 percent). Some of the crucial commodities in the basket of this region include maize and rice. In addition, oil-bearing crops such as groundnut, which are high in calorie content, have increased losses in the area.

In terms of food groups, roots, tubers, and oil-bearing crops reported the highest level of loss (around 25 percent) of production, followed by fruits and vegetables (about 22 percent) (Figure 2.3). During the postharvest and storage stages, the perishable nature of tuber crops, especially in many developing countries with warm and humid climates, has resulted in significant losses (FAO, 2019).

Figure 2.2: Food loss in different metrics



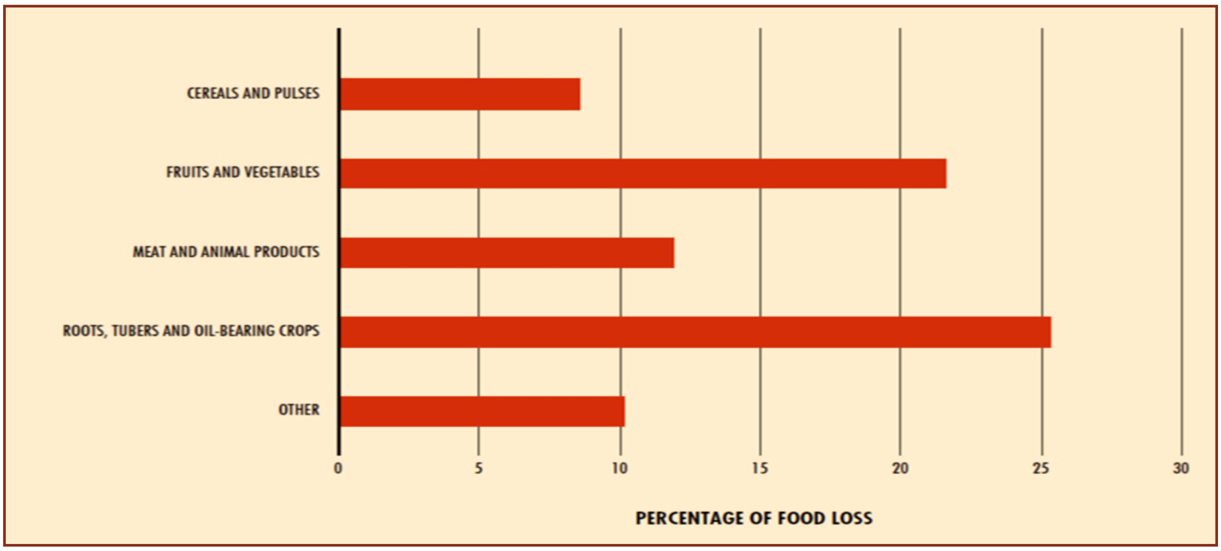
Source: The State of Food and Agriculture (2019), FAO

According to FAO (2019), the overall loss from cereals and pulses accounted for about 9 percent of the production in 2016. **Figure 2.3** shows the losses across the supply chain of cereals and pulses. On-farm losses of cereal grains and pulses are the highest in sub-Saharan Africa and Eastern and South-eastern Asia. Most of these observations are for maize and rice, and on-farm losses range from 0.1 to 18 percent. Meanwhile, more than 90 percent of observations in Central and Southern Asia are from India and report losses of less than 4 percent in on-farm postharvest activities. However, it is to note that a single report of CIPHET has highlighted most of the observations for cereals and pulses based on a nationwide survey conducted in 2005–2007.

Losses arising from storage are significant in the sub-Saharan African region-ranging, between 7 percent and 22.5 percent. In Eastern and South-eastern Asia, losses during storage range from 0.3 to 15 percent. The region comprising Central and Southern Asia reported minimum storage losses of less than 2 percent.

In the transportation stage, the review found less than 4 percent losses for sub-Saharan Africa and Central and Southern Asia, while in South-eastern Asia, the losses reported were less than 15 percent. However, if we see the reliability, we cannot emphasise these estimated figures much due to the small number of observations (40 data points); therefore, they may not be reliable (FAO, 2019).

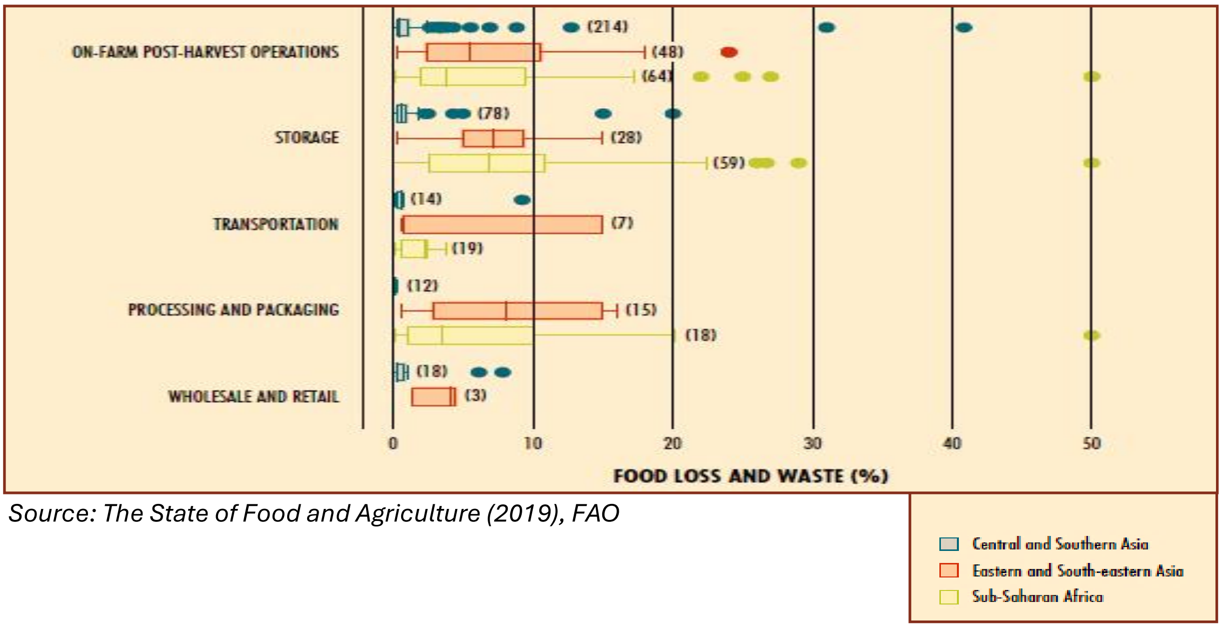
Figure 2.3: Food loss by commodity groups (percent)



Source: The State of Food and Agriculture (2019), FAO

The losses from processing and packaging cereals and pulses range between 2.5 percent and 15 percent in Eastern and South-eastern Asia, while this is up to 20 percent in sub-Saharan Africa. We have shown these estimated figures of observations undertaken for cereals that have undergone significant processing and are susceptible to considerable losses. On the other hand, in Central and Southern Asia, the losses are negligible. There may be a selection bias as a third of the crops include pulses, mostly consumed whole or split and underwent minimal processing. In Central and Southern Asia, losses in wholesale and retail accounted for less than 2 percent, while in Eastern and South-eastern Asia, it was between 1 to 4.5 percent. However, we must interpret these results cautiously, mainly due to the low number of observations for loss estimation.

Figure 2.4: Range of reported loss of cereals and pulses by supply chain stage (2000-17)



Source: The State of Food and Agriculture (2019), FAO

2.3.2 ICAR-CIPHET (Indian Council of Agricultural Research- Central Institute of Postharvest Engineering and Technology)

CIPHET has done two pan-India studies Nanda et al. (2012) and Jha et al. (2015) to measure the harvest and postharvest losses in agriculture and allied crops and commodities. Both studies use the micro approach (farmers' declaration and direct measurements) to estimate the quantitative food loss across India's agri and allied crops/commodities' supply chains. Using the approach, they assessed the post-harvest losses in the range of 4.65-9.96 percent of the selected food grains and oilseeds (Paddy, Wheat, Maize, Soyabean) produced in India (**Table 2.1**). However, elements such as the extent of damage and moisture content were assessed in the laboratory but not appropriately analyzed to infer results. In addition, their studies have not covered the aspects of qualitative loss measurement and the impact of food loss on the environment.

These studies have used a multistage stratified random sampling method with agro-climatic zones as the primary strata followed by districts, blocks, villages, and farmers as the consequent four stages, in the same order. First, they randomly selected the samples for their studies from completely enumerated data of households and market-level stakeholders. Then, the study separately estimated the overall losses for Observation and inquiry by extrapolating the village-level results to block and then to a district level and pooling them together using a weighted estimator.

ICAR-CIPHET published two comprehensive pan-India studies to estimate the harvest and postharvest losses in 2012 and 2015, covering 46 crops/commodities in 14 agro-climatic zones in the country. Jha et al. (2015) used a stratified multistage random sampling, where districts, blocks, villages, and farmers as first, second, third, and fourth stage units in each stratum. They collected data through enquiry as well as actual observations. They found that paddy's total postharvest loss is around 5.53 percent nationally. At the regional level, losses varied from 7.26 percent in the lower Gangetic plain region (West Bengal) to 3.11 percent in Punjab and Haryana. Losses at the farmers' level accounted for more than 70 percent of the total postharvest losses in paddy.

Table 2.1: Commodity-wise percent loss in different stages of the value chain

Commodity	On-farm postharvest*	Packaging	Transport	Storage#	All-India level loss	Share of farm-level loss to overall loss
Paddy	4.49	0.08	0.09	0.85	5.51	81.5
Wheat	3.89	0.1	0.08	0.85	4.92	79.1
Maize	3.62	0.16	0.13	0.75	4.66	77.7
Soybean	8.66	0.16	0.14	1	9.96	86.9

**Harvesting, collection, threshing, winnowing, drying*
#At all channels- farm, godowns, wholesaler, retailer, processing unit
Source: CIPHET (2015)

Losses for wheat were estimated at 4.92 percent at the national level, predominantly during harvesting and threshing. At the regional level, losses ranged from 7.04 percent in Gujarat to 3.36 percent in the western plateau and hills region (Madhya Pradesh and Maharashtra). In the case of maize, post-harvest loss stood at 4.65 percent at the national level. The highest loss, 6.89 percent, was observed in the central plateaus and hills region (Rajasthan). In contrast, the study found a minimum loss of 2 percent in the eastern plateau and hills region (Madhya Pradesh). Coarse cereal crops such as bajra and sorghum reported losses of 5.23 percent and 5.99 percent, respectively. The study has also estimated the monetary loss of Rs. 92.651 crores resulting from harvest and postharvest losses of the 46 agri-allied crops and commodities.

2.3.3 NABCONS (NABARD Consultancy Services) Study to Determine Post-harvest losses in India 2022

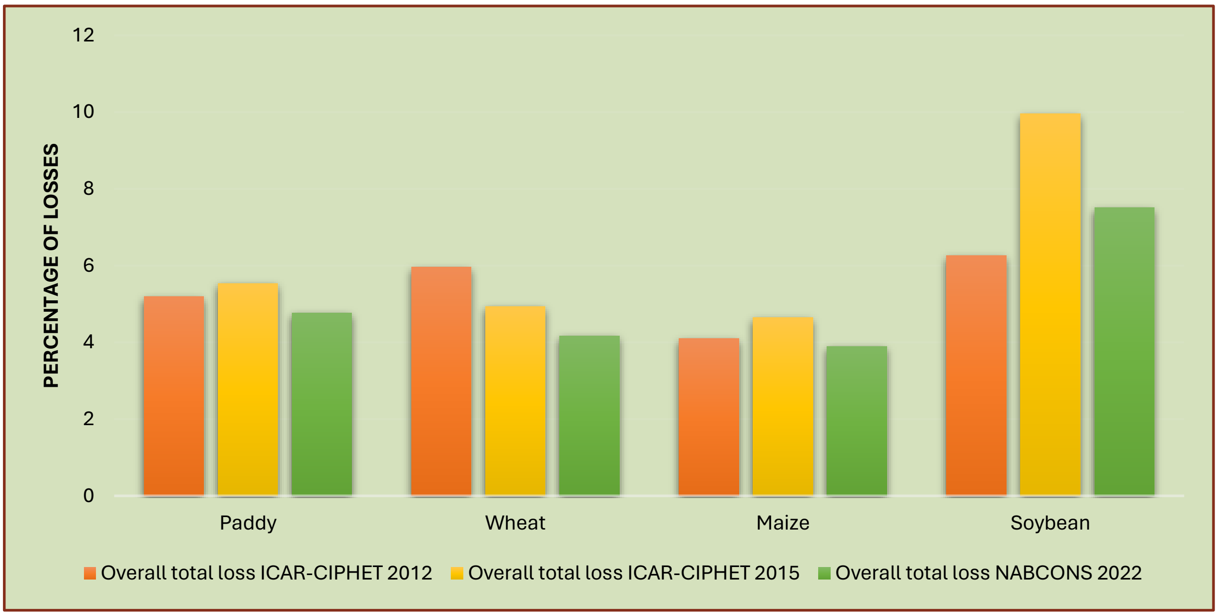
Building on the previous two ICAR-CIPHET study, NABCONS (2022) is the third and the latest large-scale survey under Ministry of Food Processing Industries (MoFPI), GOI on pan India study of post-harvest losses. The study encompasses 54 crops/commodities across 202 districts selected from all 15 agro-ecological regions of India by stratified multistage random sampling method. The purpose of the report is to develop a comprehensive national policy framework to reduce post-harvest losses in agriculture and allied sectors. Major producing districts of the selected 54 crops are covered in the survey, conducted across supply chain of the commodities by both inquiry and observation method. At farmer level, the sample size comprises 63072, in addition to that, at market level there are 1173 wholesalers, 1199 retailers, 1225 transporters, 877 storage units, and 907 processing units.

The research finding of the study indicates that the total quantity of cereal loss in the country is estimated to be 12.49 MMT with an economic value of 26,000.79 crores. The share of cereal loss comprises 17.02 percent of total agriculture and allied loss, followed by contribution of fruits at 19.34 percent and vegetables at 17.97 percent. In terms of individual commodities, the assessment reveals that guava faces the highest loss at 15.05 percent followed by tomato at 11.61 percent, and apple at 9.51 percent.

Estimates of ICAR-CIPHET reports (2012,2015) and NABCONS (2022) are summarized here for comparative study (**Figure 2.5**). Examining cereal crops, a noteworthy decline in post-harvest losses is evident for paddy, wheat, and maize. At national level the overall loss rate decreased from 5.53 percent to 4.77 percent. However, paddy experiences a significant proportion of loss, approximately 87.2 percent at the farm level, of which harvesting, collection, and threshing contribute to 67 percent. Similarly, wheat shows a decline from 4.93 percent to 4.17 percent in post-harvest losses, with 86 percent occurring at the farm level. Maize, in particular, shows a distinct reduction in loss, plummeting from 4.65 percent to 3.89 percent. For maize, threshing loss is a significant contributor constituting around 40 percent of farm-level losses.

Across all the oilseed crops, losses declined between 2015 and 2022, and the drop is the highest for soybean crops, the post-harvest losses reduced from 9.96 percent to 7.51 percent. However, soybean crop faces the highest loss among the oilseed crops and 87.6 percent of total loss happen at farm level operations. The harvesting loss for soybean is very high at 2.68 percent and the factors of harvest and post-harvest losses of soybean at farm-level is discussed in subsequent analytical chapters in our study. The NABCONS (2022) report highlighted the need of improving technology and strategic interventions to reduce post-harvest losses in the country.

Figure 2.5: Harvest and post-harvest losses across major studies at all India level 2012-22



Source: ICAR-CIPHET, NABCONS

2.3.4 The African Postharvest Loss Information System (APHLIS)

APHLIS estimation methodology combines secondary data generated through its extensive network of experts with modelling to generate food loss estimation in their region. Hodges et al. (2014) present the framework of APHLIS' food loss assessment and an insight into the causes and methods to assess the quantitative and qualitative food losses for major cereal grains grown in Sub-Saharan Africa. They use secondary data to estimate percentage loss at each crop-specific supply chain node. Using the micro approach of post-harvest losses estimation, APHLIS found between 14.3 and 15.8 percent of total grain loss from the production and post-production of cereals in their region. In addition, they used visual scale and sampling strategies for assessing damage at the different postharvest stages.[4]

2.3.5 The International Food Policy Research Institute (IFPRI)

IFPRI proposes a methodology best fit developing countries' loss estimation. They have used a micro approach to estimate losses at different value chain stages, irrespective of crops and regions. The methodology captures both quantitative and qualitative losses and discretionary losses among the processing, extensive distribution, and retail sectors. Besides the traditional self-reported method, Delgado et al. (2017) developed and tested three C, P, and A methods, i.e.,

[4] Developing visual scale involves collecting the grains with varying degrees of damage and segregating them into different categories as per the extent of damage (undamaged, infested, or damaged), usually depending on the end-use such as formal market, informal market, household consumption or livestock feed, after deliberations with market stakeholders like traders. The damaged grain could be broken, pest/ rodent/ insect eaten, discoloured, or attacked by mould, determining the acceptability in a particular market.

category, price, and attribute, respectively, for assessing food losses in four crops in five African and American countries.

The analysis done by IFPRI, 2017 is limited to losses between the harvesting/production and primary processing or processing stages; evidence shows where inefficiencies are most significant in developing countries. Furthermore, while all the segments of the value chain - the producer, intermediaries, and processor – are analyzed for potato, maize and beans, the study considered only the producer segment of the teff value chain. The study is the second in line with Hodges et al., (2014) to evaluate cereals' quantitative and qualitative losses and used both inquiry and direct measurement methods.

2.4 Reviews for food grains

2.4.1 Review of Literature on India

We found many studies assessing postharvest losses and identifying farm operations and channels contributing to losses for various crops in India.[5] However, the literature on food waste is scarce, which makes the amount of waste we generate unclear—Furthermore, there are few perception studies on food waste at the retail, service, and household level. In contrast, we found little research at the household level, leaving the question open to further research (Agarwal, Agarwal, Ahmad, Singh, & Jayahari, 2021). UNEP estimates for India in the Food Waste Index report 2021 indicate 68 million tonnes of food waste at the household level and 29 million tonnes at the food service level.

We further filtered the existing literature to understand food loss and waste better. And, then we reviewed some authentic ones on India's harvest and postharvest losses of food grains and oilseeds. Most of the literature on PHL studies included findings on measurements of quantitative data. However, very few have included information on standard deviations (for example, Nanda et al., 2012). Among the studies we reviewed on assessing postharvest losses in India, the earliest study was by the Panse Committee in 1968 evaluated the losses arising from threshing, transportation, processing and storage of wheat and rice. The committee found that the overall losses for wheat and rice (paddy) are 8 percent and 12 percent, respectively.

Mookherjee et al. (1968) conducted a comprehensive study on insect-induced losses in food grains during storage, encompassing various regions of the country and crops like paddy, wheat, maize, barley, sorghum, and bajra. Krishnamurthy (1968) further explored the total storage loss in different organizations including Cooperatives, FCI godowns, and Warehousing corporations, revealing estimated losses of approximately 1-3 percent, 0.2 percent, and 1 percent, respectively, during storage.

Girish et al. (1974, 1975) investigated wheat storage losses across regions, finding farm storage loss ranging from 0.6 to 9.7 percent in Uttar Pradesh. An interdisciplinary Seminar on Postharvest Technology of Food Grains held in 1972 (Pingle et al., 1972), organized jointly by esteemed Indian

5 We have covered the CIPHET studies in the methodology section's review. In this section we excluded them.

scientific institutions, addressed losses across harvesting and post-harvest stages. They highlighted the importance of random sampling techniques for assessing losses in farm storage, markets, and large-scale storage.

Krishnamurthy's review (1975) highlighted losses during transit and storage, revealing rail transit losses of 1 percent during 1970-71. Longer storage durations correlated with higher commercial storage losses (3-5 percent for eight months vs. 1 percent for four months). Underground storage losses ranged from 6 to 10 percent. Krishnamurthy also highlighted specific causes of loss, including hook usage (3 percent), spillage (0.1-0.2 percent), and moisture (0.5 percent) during storage.

Directorate and Marketing and Inspection (DMI 2004) conducted a study to estimate cereals and pulses' marketable surplus and postharvest losses. They conducted a nationwide survey covering 25 states in 100 districts with 15,000 cultivator households across the country, adopting a stratified multistage random sampling design. They estimated that losses ranged from 1.8 percent in wheat to 7.14 percent in lentils. The World Bank report (1999) estimated postharvest losses of food grains in India at 7-10 percent of the total production from farm to market level and 4-5 percent at market and distribution level.

A study was conducted in Karnataka during 2003-04 to estimate postharvest losses of maize in different stages at farm operations (Basappa et al., 2007). They found that the losses during harvest, threshing, cleaning, drying, packaging, transportation and storage were 0.46, 0.18, 0.05, 0.21, 0.08, 0.21 and 0.33 percent, respectively. Likewise, Basavaraja et al. (2007) estimated postharvest losses at different stages of rice and wheat in India based on the data collected from one district for each crop in Karnataka.

Basappa (2004) conducted a study on postharvest losses of maize crops in Karnataka- an economic analysis. The study was conducted from 2003 to 2004 in the Davanagere and Belgaum districts of Karnataka to estimate the postharvest loss in maize at different farm-levels. He argued that Improper postharvest handling has led to a considerable loss in maize. The postharvest loss at the farm level was estimated to be 3.02 kg per quintal. The share of harvesting loss was maximum. The study found a loss of about 0.68 kg per quintal during storage. The study also found a loss of about 0.49 kg. per quintal at the drayage level, Whereas at transportation, threshing, packaging, and cleaning levels, a loss of about 0.44 kg, 0.34 kg per quintal, 0.15 kg per quintal, and 0.10 kg. Per quintal, respectively.

A study estimated the post-harvest losses on cereals in Karnataka for the Rice and Wheat crops (Basavaraja, Mahajanashetti, and Udagatti, 2007). The main focus of the study was to identify at which stage of postharvest operations is responsible for the most significant loss. Survey data was collected using a multistage sampling design from 100 farmers, 20 wholesalers, 20 processors and 20 retailers from 2003-04 and used linear regression to examine factors affecting postharvest losses in the rice supply chain from the field to processors and sellers. The total postharvest losses were estimated to be 5.19 percent in rice and 4.32 percent in wheat. The farm-level losses accounted for more than 70 percent of the total losses, while losses at the retail level contributed to another 20 percent. They also found the highest weight loss percentage in the supply chain at the storage stage and losses at the farm level at 3.82 percent for rice and 3.28 percent for wheat. Results from the regression analysis showed that inadequate availability of labour and inappropriate storage method impacted the postharvest losses positively and significantly in rice and wheat, respectively. In addition, the education level of farmers and weather conditions also greatly influenced postharvest losses.

Grover et al. (2012) studied the postharvest loss for wheat and paddy crops in Punjab, constituting a total sample of 120 farmers for each crop of various farm size categories from the Ludhiana and Ferozepur districts. The total postharvest loss for paddy and wheat was 4.43 percent and 1.84 percent, respectively, and the losses for wheat were directly proportional to landholding size. However, in the case of paddy, it ranged from 6.02 percent for marginal farmers to 4.5 percent for large farmers. Moreover, the maximum loss was reported at the harvest stage for wheat (around 82 percent), while storage loss accounted for about 56 percent in the case of paddy.

Grover (2013), in another study, attempted to assess the post-harvest losses in wheat crops to get a new estimate of the net availability of wheat in Punjab. Losses at harvest and postharvest stages have been estimated based on the sample of 300 wheat growers in the state. Total losses at the harvesting stage have been assessed as 2.62, 1.94, 2.37 and 2.26 percent of the net production in stratum I, II, III & IV, respectively, with an overall loss of 2.30 percent at the harvesting stage in the sample area. He also estimated wheat losses to be 0.03 percent, 0.10 percent and 0.03 percent at the transportation stage, during human consumption and animal feed of net wheat production, respectively. He found the grain losses in the storage stage were negligible in the sample area, reflecting the adequate awareness, due care taken and proper grain protection material used by the farmers in the storage process

The total wheat losses at harvest and various postharvest stages accounted for 2.86 percent of net wheat production in stratum I, 2.16 percent in stratum II, 2.48 percent in stratum III & 2.42 percent in stratum IV). These losses were highest for small categories, i.e., 3.75 percent, followed by 2.73 percent in the medium category. Minimum losses occurred on large holdings, which accounted for 2.15 percent of the net wheat production. The percent wheat lost at postharvest stages was 0.30, 0.20 and 0.09 on small, medium, and large farms, respectively.

In West Bengal, Sarkar, Datta and Chattopadhyay (2013) found a higher loss for wheat (7.22 percent) due to inefficient harvesting and inadequate storage facilities. On the other hand, they estimated a postharvest loss of 3.51 percent for rice, mainly during harvesting, transportation, and storage in the state.

Kannan (2014) conducted a study showing state-wise losses for wheat and paddy crops using a sample study of 120 farmers in each crop across six states in the country. Total postharvest loss varied between 3.51 percent in West Bengal and 7.33 percent in Assam. Maximum losses occurred at threshing, transportation and storage levels in Assam, Uttar Pradesh, Tamil Nadu, West Bengal and Punjab. In the case of wheat, a significant loss at 11.71 percent was estimated for Assam, followed by Madhya Pradesh at 8.61 percent, West Bengal at 7.22 percent, Uttar Pradesh at 2.74 percent, and Punjab at 1.84 percent. He observed that losses were higher for large farmers than the small farmers in all the states, barring Uttar Pradesh. The study also conducted a soybean postharvest loss estimation Maharashtra and Madhya Pradesh. He estimated the total postharvest loss for soybean, ranging from a high of 12.56 percent in Madhya Pradesh to a low of 3.66 in Maharashtra, with over 56 percent of soybean postharvest loss in the study observed during harvesting in Madhya Pradesh. He also observed that untimely harvest of soybean pods, threshing and improper storage contributed to high losses across states.

Deepak Kumar et al. (2017) observed that grain loss of 50-60 percent during storage is due to the lack of technical inefficiency in developing countries. However, scientific storage methods can reduce these losses to as low as 1 - 2 percent. Kumar et al. (2020) studied grain storage methods adopted by farmers of the Bihta block in Bihar during 2013-2014. For this study, 120 sample farmers participated in the survey, equally divided between those who adopted improved and traditional methods of the grain storage facility. They used the personal interview method and a pre-tested schedule for data collection. *Pucca Kothi* was the most preferred method by farmers adopting improved and traditional methods with the first rank. Respondents of cereals and pulses used machines for threshing, whereas, for oilseeds, they threshed manually.

They found grain loss was more when transported manually than with the bullock cart and tractor. They also found that around 47 percent of maize and mustard growers used gunny bags for storage. A higher percent (46.00 percent) of paddy growers used *Pucca Kothi* to store grains. The highest loss (20.90 percent) was observed in the case of fertilizer bags of paddy crops, while in the case of gunny bags and earthen pots, the loss was about 7.38 percent and 7.71 percent. The study observed a minimum loss of grains in a metal bin (5.98 percent). Farmers reported that pre-storage loss during drying and cleaning was higher than during storage. The average storage cost per quintal per year was more (Rs. 21) in gunny bags and the lowest (Rs. 11) in the case of the metal bin.

Datta, Makwana and Parmar (2013) studied the postharvest loss in soybean in Rajasthan and found that the total postharvest loss in soybean stood at 3.41 percent. However, most farming households in the state reported that the overall physical condition of the storage structure was in good condition, as around 70 percent of the selected households reported well-maintained storage space.

2.4.2 Review of Literature of other countries

Nahemiah et al. (2021), in their report on the postharvest losses situation in Africa, highlighted that rice harvesting operations, including harvesting, threshing, winnowing and drying, resulted in an average of 11.2 percent loss due to grain spillage and poor threshing where grains are left on panicles. In addition, transportation resulted in 2.3 percent (to farm and market) and storage 3.4 percent losses indicating an approximately 15.91 percent average postharvest loss across the continent.

Arun and Ghimire (2019) studied estimating postharvest loss at the farm level to enhance food security: a case of Nepal. The study picked 300 households from ten sample districts across

Nepal. They calculated harvest loss at the farm level for each crop grown as per - the season, plot and priority and found that the postharvest loss of rice at the farm level was 3.24±0.44 percent.

Verniquet (2018), in her study, quoted that based on information from the Food and Agriculture Organisation of the United Nations (FAO), Vietnam's post-harvesting losses of rice accounted for 10 percent of the total production. She also stated that the postharvest losses in rice value chains are vastly more than in some of its neighbouring countries, such as Thailand. A study on mechanization and postharvest technologies in the rice sector of Vietnam estimated that the total postharvest losses in the Mekong Delta in 2014 were around 8-9 percent (Hieu-Hien 2018). FAO (2017), in a study conducted by the Pyongyang Agricultural Campus and Kim Il Sung University, in collaboration with the FAO and the UNDP on the postharvest losses of rice, estimated that the loss in North Korea was 15.56 percent for rice and barley across the supply chain.

Lisa et al. (2018) studied maize postharvest losses by identifying causes and sources in Nigeria. The study gathered data using Commodity Systems Assessment Methodology, which includes 26 components, structured interviews, and protocols for measuring quantity, quality, and economic losses. The study showed that cultural practices for maize vary from region to region, affecting the quality and quantity loss of maize. Poor quality seeds and fertilization affect the quality of the harvested crop. Maize is sundried on the farm before the sale. Quality and cob size affect farm gate prices. Factors that affect maize losses at the farm are; production constraints, improper drying, and lack of grades and storage. The study found farm postharvest losses of 13 percent. Mechanical damages during handling and transportation account for 2 to 3.5 percent. The study recorded an overall loss of 15 percent across the maize value chain.

Sallah (2017) in his report on postharvest losses of rice and its implication on livelihood and food security in Africa: the case of Cameroon and the Gambia, indicated that losses at threshing operations were 19 and 17 percent, drying 9.3 and 7.0 percent, storage 4.2 and 6.0 percent, milling 1.3 and 1.0 percent and transportation 1.33 and 0.8 percent, respectively for Cameroon and Gambia. A study measuring food losses and waste in Latin America and the Caribbean estimated that around 46.87 percent of rice gets lost along the whole supply chain in Mexico (FAO 2015).

Oguntade et al. (2014), in their report on postharvest losses of rice in Nigeria and their ecological footprint, found that postharvest losses in rice may be as high as 20 to 40 percent, implying conservatively between 10 and 40 percent of rice that was grown in the country never reaches the market or consumers' table. At a disaggregated level, they found that vast losses of about 11.39 percent were recorded during rice postharvest activities in Nigeria, with harvesting accounting for 4.43 percent, threshing and cleaning (4.97 percent), transporting paddy from field to homes (0.34 percent), paddy drying and storage (1.53 percent) and transporting of paddy to local markets (0.12 percent).

Abedin et al. (2012) conducted a study on in-store losses of rice and ways of reducing such losses at the farmers' level: an assessment in selected regions of Bangladesh. They found that in-store loss of rice was about 4 percent at the aggregate level, with the highest being for Boro and the lowest for *Aus* rice. Chitarra and Chitarra (2005) estimated postharvest losses of more durable products, such as grains and cereals, from 5 percent to 30 percent in Brazil. In another study by Parfitt et al. (2010) on food waste within food supply chains: quantification and potential for change to 2050, they found that postharvest rice losses range from 1 percent to 30 percent.

Arun and Ghimire (2019) studied 300 households from ten sample districts across Nepal to estimate the postharvest loss at the farm level to enhance food security. The study assessed the harvest loss of wheat at the farm level and found a loss of around 4.88 percent. The Pyongyang Agricultural Campus and Kim Il Sung University, in collaboration with the FAO and the UNDP on the postharvest losses of wheat and barley, estimated that the loss in North Korea was 16.35 percent for wheat and barley across the supply chain (FAO 2017).

According to FAO (2019), the overall loss from cereals and pulses accounted for about 9 percent of the production in 2016. On-farm losses of grains and pulses are the highest in sub-Saharan Africa and Eastern and South-eastern Asia. Most of these observations are for maize and rice, and on-farm losses range from 0.1 to 18 percent. Meanwhile, more than 90 percent of observations in Central and Southern Asia are from India and report losses of less than 4 percent in on-farm postharvest activities. However, the study highlighted that most of the observations for cereals and pulses were from a single report by CIPHET consisting of a nationwide survey conducted from 2005–2007.

Bacchi et al. (2017) conducted a case study for Brazil on postharvest losses in the wheat logistics chain. The study showed losses of 11.8 percent during the logistic stages. Of the total loss, they found that on the farms, the losses were about 6 percent, and during the storage in cooperatives were approximately 5 percent. Losses during transportation could be as high as 0.8 percent. They also highlighted the losses occurring along the wheat supply chains were substantial during harvest and storage in cooperatives, which accounted for 93.2 percent of total losses, which stand out in this context.

Fine et al. (2015) studied food losses and wastes in the French oil crops sector; they found that for soybean, mean seed losses at the farmer level were 6 percent of their total potential production. They examined several steps in the oleaginous supply chain to identify the key sources of loss, from harvesting to distribution, including storage, transport, crushing, refining and packaging.

Ghanashyam Bhandari et al. (2015) studied Maize postharvest losses and their management practices in the western hills of Nepal. The study reported that insects were the main problem in the maize field, followed by weeds and disease, as these have been playing a significant role in reducing the production and productivity of maize. Furthermore, the study found that the infection level is higher in cobs stored in the local storage structures such as open storage, semi-open storage, or closed storage by insect pests in Nepal's mid and high hills. As a result, the reported maize grain, or seed loss in storage ranges from 10-20 percent.

Dessalegn et al. (2014) study on 'Postharvest wheat losses in Africa: an Ethiopian case study', found that the overall loss in the wheat supply chain was 17.1 percent. In the study, they believed insects and rodents in storage were found to be the major causes of postharvest loss. Of the total loss, humid conditions (moisture) (11.75 percent), insects (11.57 percent) or rodents (11.12 percent) in storage were found to be the significant causes of postharvest loss.

We also found several studies on postharvest losses of cereal grains such as rice in Bangladesh (Bala, 1978, Bala et al., 1993 &1994). Bala (1978) reported the estimates of quantitative losses of paddy in Bangladesh at each stage, starting from harvesting to retailing. The over loss was about 8 percent to as high as 22 percent counting all the processes between the harvest and retail. The crucial stages of losses are threshing, drying, distribution and storage. The highest loss was reported to occur during storage. Bala et al. (1993, 1994 & 1997) evaluated the storage performances of different traditional storage systems and designed improved conventional storage systems for Bangladesh conditions. Bala et al. (2010) reported about 10.74 percent postharvest loss in Bangladesh. They said the share of farm-level loss is 85 to 87 percent of the total postharvest losses.

2.4.3 Qualitative loss and Economic loss

Most studies have so far done globally reported on the quantitative loss estimation. However, only a few studies were reviewed, including reports on qualitative data measurements. Of the studies, even lesser numbers have provided primary data on qualitative losses, and others included anecdotes or descriptions of qualitative problems observed by researchers or recalled by survey respondents. Among the studies on qualitative loss estimation, the share of studies on food grains is negligible (Kitinoja et al., 2018).

Economic loss from post-harvest losses happens due to both quantitative and qualitative crop and commodity losses. Financial loss measurement due to post-harvest losses less often attracts the researcher globally and results in unreliable reports on estimates of economic loss data. Despite this being a relatively simple calculation based on farm gate prices or local market value per kg, few post-harvest loss studies provided financial loss data (for example, Jha et al., 2015; Sharma and Rathi, 2013; FAO, 2015; and Kamrul Hassan et al., 2010; WFLO, 2010). It is also seen that a few post-harvest losses studies provided primary data on economic losses. While most of the reviewed studies have provided financial losses data for perishable goods (for example, FAO, 2015; Kamrul Hassan et al., 2010; Rwubatse and Kitinoja, 2017), a few have provided for cereal crops (for example, Jha et al., 2015; Sharma and Rathi, 2013). Most post-harvest loss studies reported economic losses in Africa and Asia (South). In contrast, we found a few studies in other parts of the world (for example, the Caribbean and Guyana).

2.4.4 Other impacts of food loss (GHG emissions and calorie losses)

Estimates suggest that 8-10 percent of global greenhouse gas emissions are associated with food produced using scarce resources and not consumed (UNEP, 2021). Although widespread hunger and malnutrition affect several people globally, we throw a third of all food we produce yearly. Not only does food waste exacerbate food insecurity, but it also causes severe damage to our environment (Lewis, 2022). Estimates suggest that growing food that goes to waste ends up using up to 21 percent of freshwater, 19 percent of our fertilizers, 18 percent of our cropland, and 21 percent of our landfill volume. Pouring a glass of milk down the sink is wasted nearly 1,000 litres of water (Lewis, 2022).

Several studies have assessed the total environmental impacts of food production, including losses (for example, FAO, Andersson et al., 1998; Bystricky et al., 2014; Jungbluth et al., 2000; Manfredi and Vignali, 2014). However, it is unclear to what extent the food losses explicitly cause these environmental impacts because most of these studies do not distinguish between the sold products for human consumption and their associated losses (Willersinn et al., 2016).

Kitinoja et al. (2016) reported calorie losses due to post-harvest losses in perishable goods (Tomatoes in Egypt). They concluded that the total calorie loss due to post-harvest losses in tomatoes is 230.4 billion kilocalories annually for Egypt only.

2.5 Gap analysis-Critical review

We referred to several research reports on the post-harvest losses to understand the gaps in this topic. Firstly, we found a lack of uniformity of post-harvest losses data in the literature. In addition to this, we also found other data-related gaps, such as inferior data quality and data gaps in information on qualitative economic losses. Furthermore, several studies on the topic did not provide any quantitative loss data (for example, Appiah 2013a, Appiah 2013b, Rwubatse and Kitinoja 2017, Emana et al. 2017). Some studies even mentioned how partially damaged crops showed no quantity losses at the market level, however faces distinct quality losses when they reached the marketplace. (Rwubatse and Kitinoja, 2017). Most existing literature has worked on the weight loss percentage, overlooking other relevant indicators along the value chain. Secondly, there are gaps in the value chain analysis. A few studies, for example, Nanda et al., Jha et al. (2012 & 2015, respectively) and FAO, 2018 (for the rice value chain in Ghana), have tried to do a complete value chain analysis.

As discussed above, there are data gaps in postharvest loss estimation across the countries. The use of microdata to estimate harvest and postharvest losses (HPHL) is a very recent phenomenon. Until 2010, most authentic studies used macro data to estimate the HPHL, whereas survey-based micro-data has recently gained momentum. Several studies have used them to estimate food loss (for example, CIPHET, 2012&2015; APHLIS, 2013, FAO, 2017 IFPRI, 2018). Their estimations rely on survey data across different actors along the food value chain; however, these studies have not covered all the issues across the value chain.

Additionally, these studies use different definitions of food loss, which hampers comparisons across other areas and crops. The methodology is also not identical; available micro-based food loss estimates are widely variable and yield inconclusive evidence regarding the extent of food loss (IFPRI 2018).

Despite many studies assessing postharvest quantity losses, quality loss estimation remained untouched. Other than the two pan-India studies conducted by ICAR-CIPHET, the research concentration is around a few states, such as Karnataka, Andhra Pradesh, Maharashtra, and Punjab and that to their main crops. In addition, these studies do not follow a standard method or a set of methods for the estimation process, leading to widening gaps in identifying the situations where the stakeholders lose the most value. Given these gaps in the literature, the present paper estimate both quantity loss and qualitative losses and traces the determinants of total losses in supply-chain addressing the harvesting, storing, and marketing practices of agricultural households.

3 Our Approach, Sampling and Data Collection Methods

3.1 Overview-How is it different from other studies?

In the previous chapter, we discussed the existing global literature and highlighted their research gaps. Studies such as CIPHET only estimated the quantitative losses in agriculture-allied crops and commodities in India. They studied around 46 crops and commodities across 14 Agro Climatic Zones (ACZs) of India's 15 ACZs. They also did not cover the loss of crops and commodities due to quality deterioration, which fetches relatively lower prices at marketplaces, eventually leading to economic loss. As discussed in chapter 1, harvest and postharvest losses can be estimated in terms of physical (quantitative, qualitative or both), opportunity cost (monetary) or external (environmental).

In this study, we are focusing only on the food loss estimation part, not the food waste part. We estimated the loss in the food grain production and supply chain. We excluded the losses at the consumers' end. We have taken only the grain's external appearance (such as shrivelled/wilted, broken, damaged, coloured & weevilled—that fetches a lower price) to estimate the quality loss. We collected information from a multi-stakeholder survey, followed by field experiments and using visual scale and laboratory testing of grains. We used the formula: percent X(Quantity)= {percent X (Quality loss) * percent average price reduction of the crop X due to quality loss} *100. For example, if the quality loss of crop X (i.e., wheat) is 12 percent and there is a 20 percent average price reduction in grain due to lower quality, then the equivalent quantity loss is (12/100x20/100)100= 2.4 percent.

Data on qualitative and quantitative assessments and the economic and demographic characteristics of the population, such as age, gender, education, etc., are important variables for post-harvest loss assessment. While the former helps to determine the status and extent of food losses, the latter supports identifying the critical areas for policy intervention. Therefore, data collection through various methods of enquiry and field experiments plays a vital role in any report, primarily based on surveys and numerous field visits. However, statistical simulations of the collected data may lead to ineffective results if the collected data do not follow a scientific methodology. The detailed data collection methods are elaborated in **Annex 3** of this report.

For this study, we conducted baseline surveys in the 12 selected districts before starting the survey to understand the major grain loss-making operations, including a collection of other relevant information. This pilot survey helped us to understand the postharvest system better, identify the causes of losses, and to get list of farmers households in the village, etc. After that, farmers are selected by random sampling for personal interview or for observing method.

The project team conducted 23 focused group discussions spanning over 12 crop districts during the baseline survey and the sample farmer survey covered at least two FGDs in a district, mostly with farmers who had not participated in the baseline survey. The FGDs accommodated female and male participants to understand their perspectives on post-harvest losses, recorded their inputs, and used them for data validation and further analysis.

3.2 Our Selection Approach-State, District, Block and Village, crop

We used two sampling methods – first, to decide on the states and districts, we used a purposive sampling method. Second, we used a stratified multistage random sampling method to select the blocks, villages, farming households and market-level stakeholders. The selection of states has been made based on the performance of agricultural activities, the level of economic development and the availability of crops. This study looks at three Indian states, Madhya Pradesh, Punjab, and Bihar (
Figure 3.1).

Bihar is a relatively poor state, Madhya Pradesh is in the middle, and Punjab is somewhat a more prosperous state so far as agriculture is concerned. And some or most selected crops are widely available in these states. In Madhya Pradesh, we picked four food crops (wheat, paddy, maize, and soybean). In Punjab and Bihar, we picked Paddy, a Kharif crop. These crops are responsible for maintaining food and nutritional security across the globe and are widely cultivated in these states.

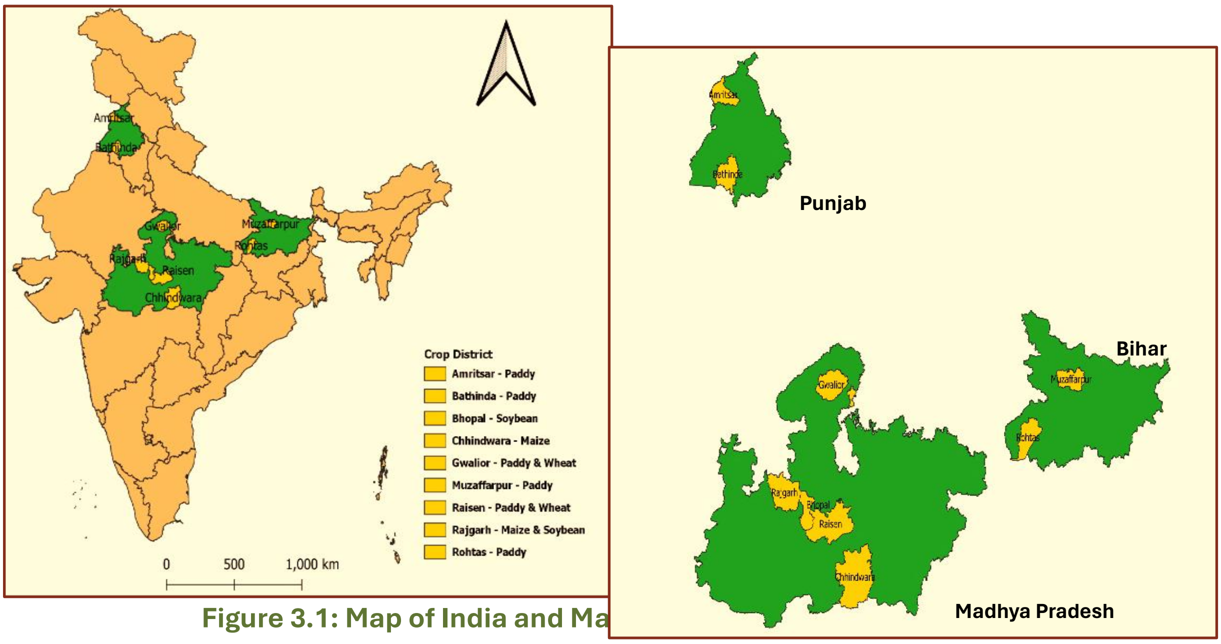


Figure 3.1: Map of India and Ma

Source: Census of India

To understand the PHL dynamics for each crop in a state, we picked one major crop-producing district and the other one that is somehow a relatively less-producing district. Other factors include the allocation of production in the State-Specific Agro Climatic Zones (SACZs-see **Table 3.1** below) and the availability of different supply chain actors, such as mandis and storage units. Mainly, we considered the crop districts based on production share (TE 2019-20) and the level of crop-specific activities in 2021-22. We chose the same districts for paddy and wheat (Gwalior & Raisen) for comparative analysis. In addition, we also consider a district with two crops in the same seasons (Rajgarh for Kharif Maize & Soybean) for the final selection of crop districts. A few exceptions exist in the district selection due to the current cropping pattern deviation from the published data.

Table 3.1: State-wise agro climatic zones

Sl. No.	State	Agro Climatic Zone
1	Bihar	Zone-1: North Alluvial Plain Zone-2: north East Alluvial Plain Zone-3: (Zone 3A South East Alluvial Plain and Zone 3B- South West Alluvial Plain).
2	Madhya Pradesh	Zone 1: Malwa Plateau Zone 2: Vindhya Plateau Zone 3: Central Narmada Valley Zone 4: Satpura Plateau Zone 5: Jhabua Hills Zone 6: Gird Region Zone 7: Kymore Plateau & Satpura Hills Zone 8: Bundelkhand Region Zone 9: Nimar Plains Zone 10: Northern Hill Region of Chhattisgarh Zone 11. Chhattisgarh plains
3	Punjab	Zone 1: Sub-Mountain Undulating Region Zone 2: Undulating Plain Region Zone 3: Central Plain Region Zone 4: Western Plain Region Zone 5: Western Region Zone 6: Flood Plain Region

Source: ICAR

3.2.1 Selection of Crop-Districts in Madhya Pradesh

We selected eight crop districts and four crops--three kharif crops--soybean, paddy, and maize, and one Rabi crop -wheat in Madhya Pradesh. Figure 3.2 illustrates the state map, showing the districts selected for the survey.

➢ **Paddy and wheat**

The sample crop districts cover two agro-climatic zones, i.e., Central Narmada Valley and Gird region, for paddy and wheat crops grown during the Kharif and Rabi seasons, respectively. For the study, we picked two districts, i.e., Raisen and Gwalior, falling into different agro-climatic zones, i.e. Central Narmada Valley and Gird region. Raisen is a significant wheat and paddy-producing district, while Gwalior is a relatively less producing based on production share (TE 2019-20).

➢ **Soybean**

The sample crop districts cover two agro-climatic zones, i.e., Malwa plateau and Vindhya plateau. Soybean crops grows during the Kharif season. For the study, we (selected three districts, i.e., Ujjain, Bhopal, and Rajgarh, falling in different agro-climatic zones.

- **Maize**

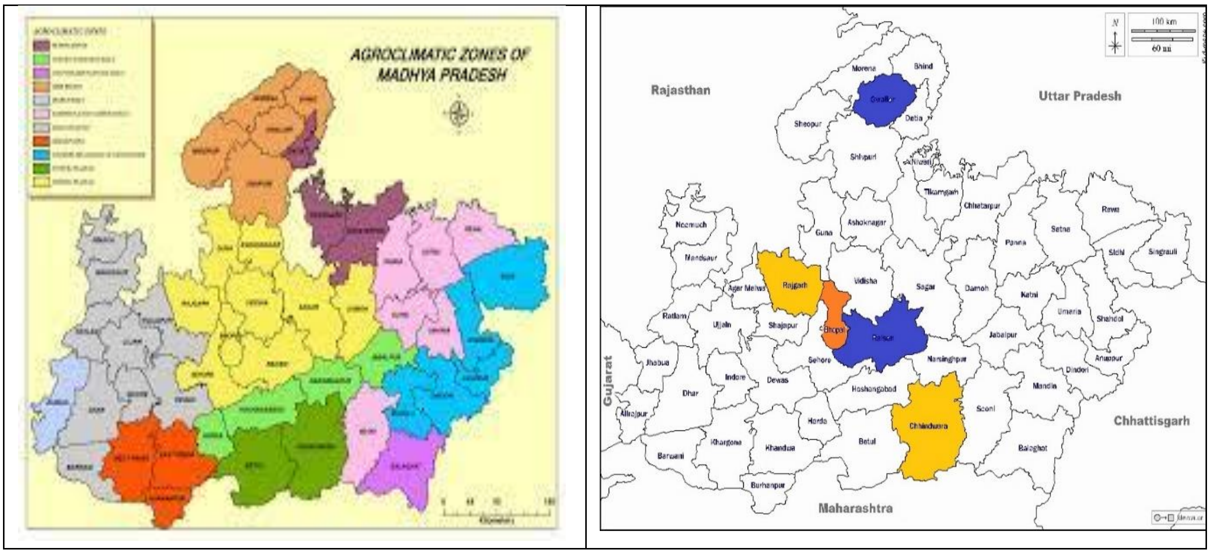
The sample crop districts cover two agro-climatic zones, i.e., Malwa plateau and Satpura plateau for Maize crops grown during the Kharif season. For the study, we picked two districts, i.e., one major producing (Chhindwara) and one relatively less producing district (Rajgarh) falling in different agro-climatic zones.

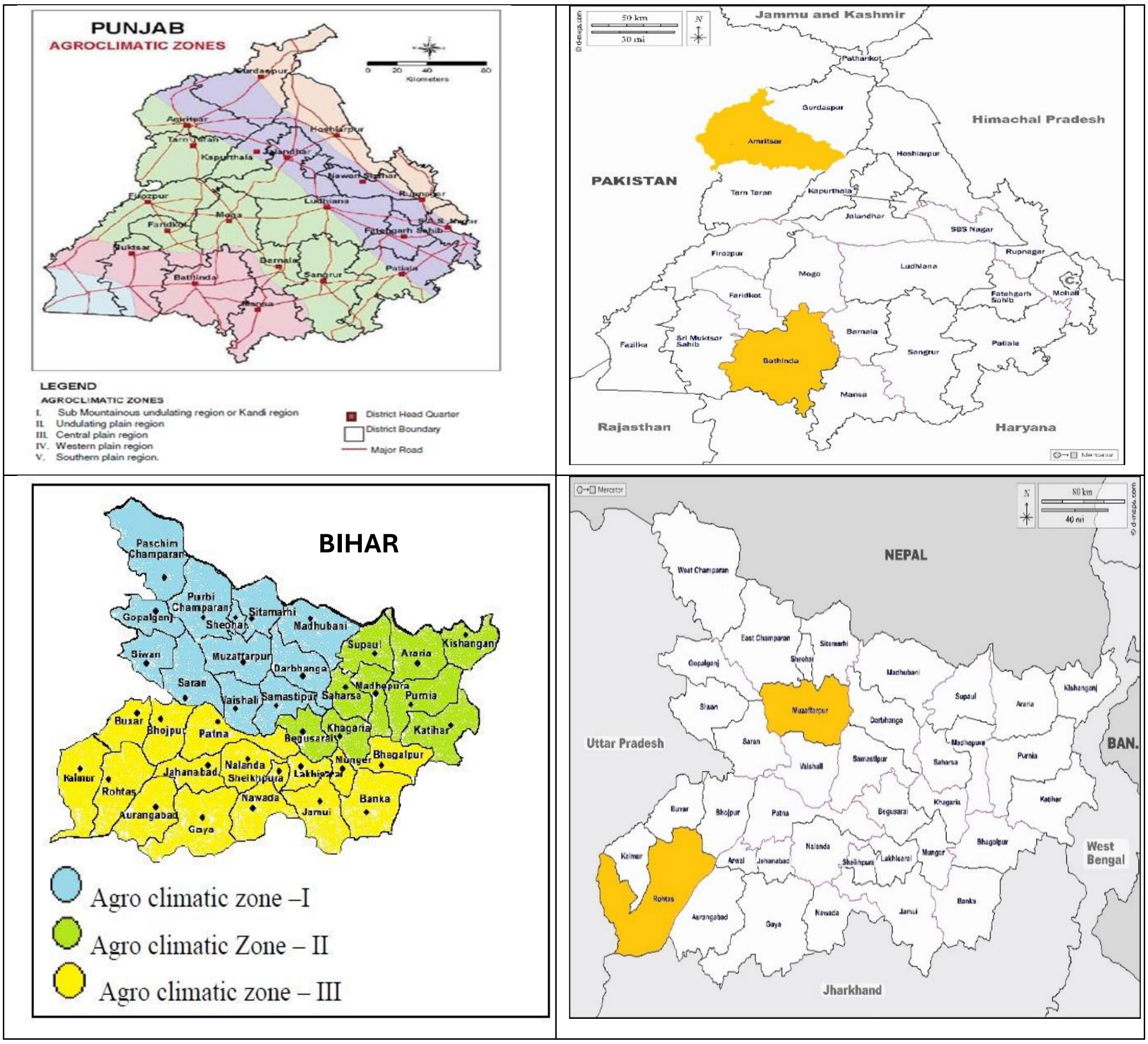
3.2.2 Selection of Crop-Districts in Punjab and Bihar

- **Paddy**

Based on the area and level of production, in Punjab and Bihar, we picked two crop districts, each from different agro-climatic zones (**Figure 3.2**). We surveyed Amritsar and Bhatinda from Punjab, falling into different agro-climatic zones, i.e., the central plane (SACZ 3) and Western zone (SACZ 5), respectively. Bathinda is a significant paddy-producing district, while Amritsar is a relatively less producing one based on production share (TE 2019-20). From Bihar, we picked the following districts—Rohtas, and Muzaffarpur; they fall in South Bihar Alluvial Plain Zone (ACZ 3) and North West Alluvial Plain Zone (ACZ 1), respectively. Rohtas is a major paddy-producing district compared to Muzaffarpur.

Figure 3.2: District Map of Madhya Pradesh, Punjab, and Bihar





Source: Created using GIS mapping based on Census of India, 2011 district boundary.

3.3 Selection of farmers and other stakeholders

The share of farming households in each zone/district has been allocated for the sample survey based on the proportionate share of production of the respective zones in the state. We use a multi-stage stratified random sampling method to select the blocks, villages, and farmers/stakeholders[6]. In the first stage, we chose the districts based on the agro-climatic zones, recent crop-specific activities (2021-22), production level, and area under production of the selected crop in the district. After that, we randomly picked two blocks and surveyed five villages in each block from the list villages. Finally, we randomly selected 100 farming households (10 farming HHs from a village) in each district chosen from the list of farmers prepared during the baseline survey (**Table 3.2**).[7]

[6]First Stage Units: Districts; Second Stage Units: Blocks; Third Stage Units: villages/warehouse/cold storage/processing units/wholesaler/retailer (trader); and the Fourth Stage Units: household/farmers/respondents.

[7]While data for all the 10 farmers selected at the HH level shall be collected based on enquiry mode, two farmers (at least 20 percent) from 10 selected farmers shall be randomly selected for the objective measurements of losses.

In our baseline survey, we prepared lists of farmers' households in each village, records of their operated land area, and other essential information. First, we listed all the HHs growing the selected crops in a specific village; after that, we categorized the HHs based on the landholding size as follows[8&9].

Table 3.2: District-wise sample size for the selected crops

Crop	Wheat	Paddy	Maize	Soybean	Total
Gwalior	128	130	0	0	258
Raisen	128	130	0	0	258
Chhindwara	0	0	130	0	130
Rajgarh	0	0	130	130	260
Bhopal	0	0	0	130	130
Bhatinda	0	130	0	0	130
Amritsar	0	130	0	0	130
Muzaffarpur	0	130	0	0	130
Rohtas	0	130	0	0	130
Total	256	780	260	260	**1556**

Source: Authors field survey, ICRIER-ADMI 2022

Apart from farmers, we also selected market-level stakeholders such as transporters, storage units, processors, wholesalers, and retailers (**Table *3.3***). For each crop, we chose ten market-level stakeholders (eight for wheat) and one laboratory in each district for data collection and experiment purposes. At each point of the selected market-level stakeholders, we randomly took two from the list of stakeholders in a district.

Table 3.3: Stakeholder-wise sample size

Stakeholders	Wheat	Paddy	Maize	Soybean	Total
Farmers-Inquiry	200	600	200	200	1200
Farmers-Observation	40	120	40	40	240
Transporters	4	12	4	4	24
Storage units	4	12	4	4	24
Processing	0	12	4	4	20
Wholesalers	4	12	4	4	24
Retailers	4	12	4	4	24
Total	256	780	260	260	1556

Source: Authors field survey, ICRIER-ADMI 2022

[8] The selection of HH involved two stages. In the first stage, we chose all those farmers growing the selected crop in a particular village. In the second stage, we categorized all farmers proportionately based on landholding size with a few exceptions.

[9] marginal farmers with operational holdings up to 2.50 acres, small farmers from 2.51 - 5.0 acres, semi- medium farmers from 5.1 - 10.0 acres, medium farmers from 10.1 - 25.0 acres, large farmers above 25 acres.

3.4 Our field survey approach

3.4.1 Survey tools for data collection

We prepared a set of five separate questionnaires to collect data from stakeholders[10] along the crop production and supply chain. In addition, we used the following instruments; a moisture meter and two portable weighing machines (can weigh from 0.1 grams up to 5 kg or more). Furthermore, we used other necessary items, including measuring tapes, ropes to bind the harvested crops, sealable plastic bags to collect samples, magnifying glasses, sampling spears, and sample testing machines. Finally, the enumerators carried out several operations in the field (identifying the fields, selecting the plot area, crop cutting, weighing, picking, and sorting samples for the laboratory, etc.), which in some cases are impractical to record on the questionnaire directly.

Through the questionnaire, we collected information (qualitative, quantitative) through enquiry and observation. We collected data regarding stakeholders' profiles, land profiles, crop production and loss at various stages--harvesting, threshing, winnowing, sorting, and grading, drying, packaging, transportation, and storage levels from the selected supply chain actors.

Our survey instruments quantify food loss (quantitative and qualitative) along the value chain before retail distribution (excluding consumer buying patterns). We first calculate aggregate self-reported data of loss: we ask farmers, transporters, storage unit managers, wholesalers, and retailers about the quantities (and the corresponding monetary values) of crops discarded during the processes that they perform (e.g., harvesting, threshing, winnowing, cleaning, transporting, packaging, etc.). This methodology is generally consistent with the essential elements in the available literature on measuring food loss.

The farmer level questionnaire for inquiry and observation has four schedules. In Schedule 1, we ask the stakeholders for basic information on the survey locations, crop survey details, and brief details of farmers and the selected crops. Schedule 2 enquires on the crop production, storage details and environmental impact parameters. In addition, schedule 2 asks questions on Harvest and postharvest quantity and quality loss at each operation (harvesting, threshing, cleaning, drying, storage, and transportation to mandi). Schedule 3, ask questions about the farmers' responses on how to minimize the loss. Finally, schedule 4 asks questions on observation method data collection for the grains' quantity, quality, and other attributes.

The market-level stakeholders' survey questionnaires also have four schedules. The transport-level questionnaire for inquiry and observation has four schedules. Schedule 1 asks for basic information on the survey locations, crop survey details, and brief details of transporters and the selected crops, including types of the fleet used for the transportation, etc. Schedule 2, ask questions on the destination to travel, date of loading and unloading, quantity loaded and

[10] Producers/farmers, Transporters, Storage units (warehouses, storage facilities, etc.).

unloaded, road quality, etc. Schedule 3, ask questions about the transporters' responses on how to minimize the loss. Finally, in schedule 4, ask questions on observation method data collection.

For storage level surveys, schedule 1 asks for basic information on the survey locations, crop survey details, and brief details of storage units, processing units, wholesalers and retailers and the selected crops. It also asks questions about the installed capacity they handle for a month or year and the storage materials they use in the store. Schedule 2, ask questions on the awareness about modern storage facilities, the nature of pesticides and chemicals used to protect the grains, including the price information of the damaged grains and causes of storage losses etc. Schedule 3, ask questions about the storage managers' responses on how to minimize the loss. Finally, schedule 4 asks questions on observation method data collection for the grains' quantity, quality, and other attributes.

4 Estimation of Harvest and Post-Harvest Loss for Reference Crops

4.1 Introduction

As we discussed in the last chapter post-harvest losses is a major concern to increase food availability, eliminate hunger and augment farmers' income. However, determining the loss in the supply chain is challenging due to differences in cropping practices across farmers and states. In order to answer this, this chapter strives to estimate harvest and post-harvest loss in quantitative and qualitative terms by both inquiry and observatory methods of major food grains (paddy and wheat), maize and soyabean and the factors driving these losses to strategize policy interventions to reduce them. We surveyed farmers and other stakeholders in Madhya Pradesh for wheat, paddy, maize, and soybean, and for paddy, we surveyed Madhya Pradesh, Punjab, and Bihar. We interviewed 1200 farming households and conducted direct measurements (observation method) for data collection for 20 percent of the farming households (240 farmers out of 1200 farmers). In the market channels, we interviewed 116 market-level stakeholders and conducted direct experiments in 24 storage units (FCI and Private warehouses) equally distributed across 12 crop districts. However, we used a visual scale approach instead of a direct measurement method for data collection for other market-level stakeholders, such as processors, wholesalers, transporters, and retailers. Using the above methodology, we estimated loss figures at each level and added them to obtain aggregate post-harvest losses across the supply chain. However, due to some data inconsistencies, missing values, and outliers, we discarded some samples. Most of the stakeholders who participated in this survey were male. However, in our focussed group discussions (FGDs), our survey also covers female stakeholders to know their views on food loss across the supply chain.

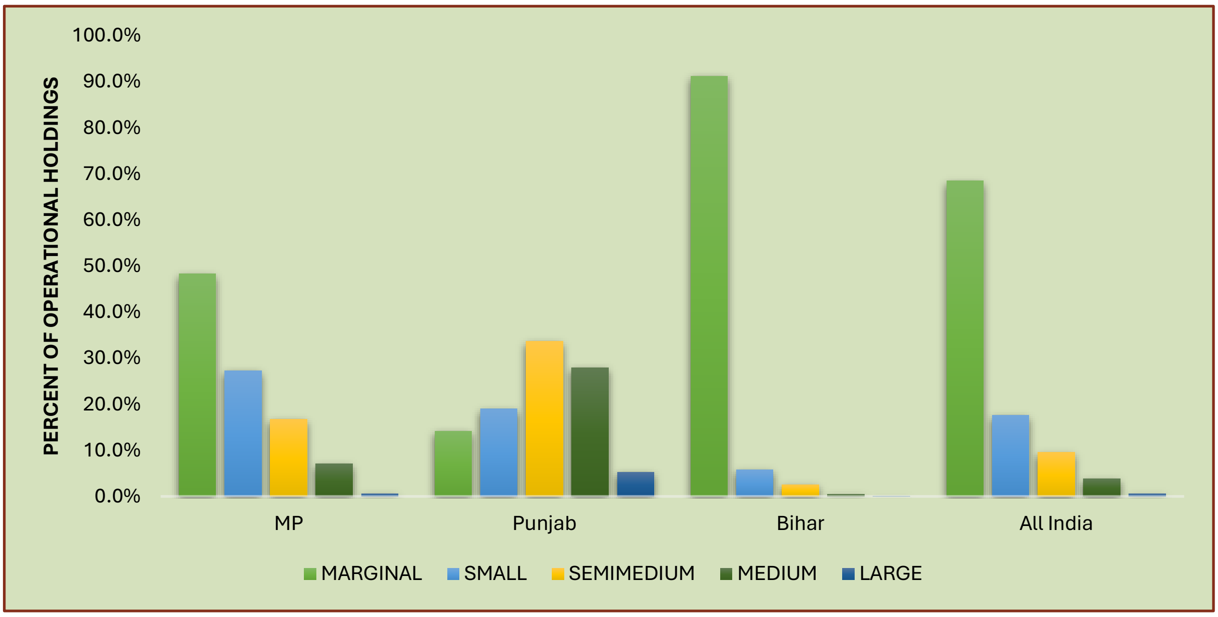
This chapter is organized as follows: first, we outline the agriculture development of states focusing on the crops discussed in the study and describes socio-economic and demographic profiles of our sample agriculture households. Second, we provide estimates of quantitative, qualitative, and economic losses of paddy, wheat, soyabean and maize for selected states. Third, we are comparing the losses across operations by inquiry and observation methods to trace the statistical differences between these two techniques. In the last section, we investigate the results of our harvest and post-harvest loss estimation with cotemporary literature.

4.2 Agriculture development of selected states and sample household characteristics

Before delving into the estimation of farm operation-wise losses, it is imperative to gain insights into the status of agricultural development in selected states. The expansion of mechanization within Indian agriculture has been characterized by uneven distribution across states and agro-ecological regions. Notably, the growth of tractor usage has been linked to an increase in cropping intensity, as observed in studies by Johl (1970) and Chopra (1972).

India's agricultural transformation has been driven by a productivity-centred approach, particularly evident since the advent of the green revolution in the 1960s. This paradigm shift has led to remarkable growth in output, exemplified by a significant rise in total food grain production from 50.8 MMT in 1950-51 to an impressive 308.65 MMT in 2020-21. The surge in rice grain production escalated from 20.58 MMT to an astonishing 122.27 MMT, while wheat grain production witnessed a commendable increase from 6.46 MMT to 109.52 MMT over the same period. Despite these overall positive trends, the pace of technological change and the level of mechanization exhibit regional disparities, thereby influencing the extent of losses experienced at the farmers' level. The availability of agriculture market infrastructure and road density also vary across states, which further contributes to regional differences in agricultural performance and susceptibility to losses in farming operations. Understanding these intricacies is crucial to comprehending the intricacies of agricultural dynamics and the complexities faced by farmers in different regions.

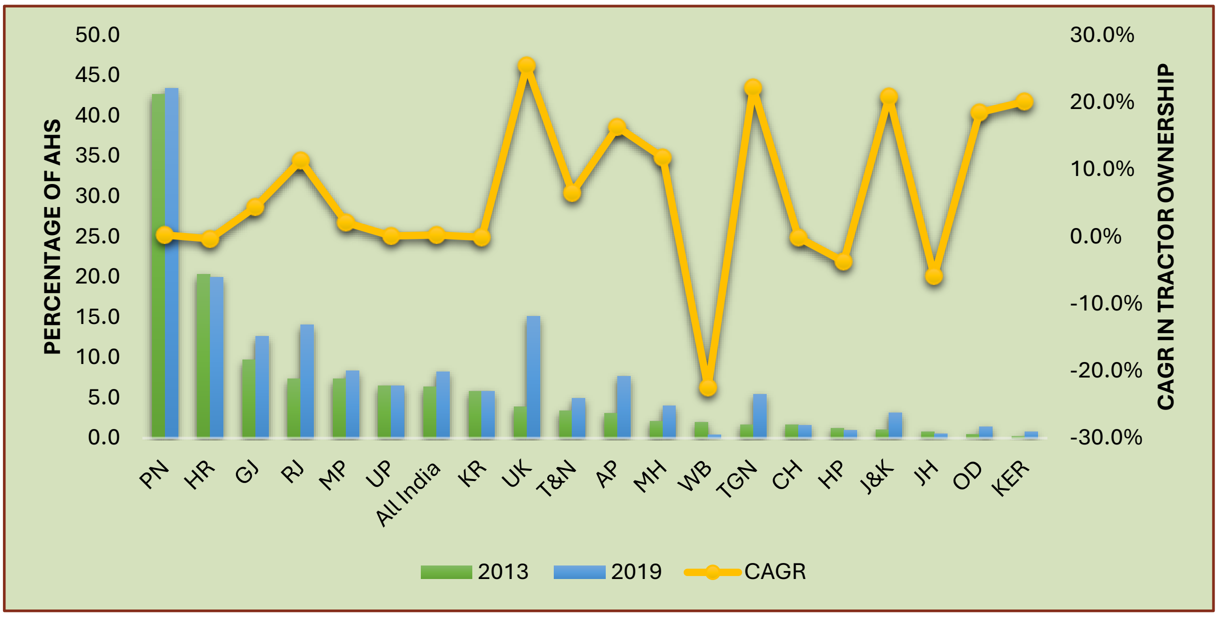
Figure 4.1: Farm-size distribution in selected states



Source: Agriculture census 2015-16

The marginalization of operational holdings in Bihar surpasses the all-India average, with marginal farmers constituting an overwhelming 68 percent share (**Figure 4.1**). The prevalence of smaller plot sizes and insufficient investment in farming act as barriers to adopting mechanization, as evident from the statistics on tractor ownership among agricultural households in India (**Figure 4.2**). The level of mechanization significantly influences harvest losses experienced at the farmers' level, making it a critical factor in shaping agricultural outcomes in the region.

Figure 4.2: Tractor ownership among agricultural households across states in India AIDIS 2013 and 2019



Source: All India Debt Investment Survey, NSS, MOSPI

4.2.1 Madhya Pradesh

The total geographical area of Madhya Pradesh is 30.8 million hectares, with net sown area accounting for 49.56 percent in TE 2016-17. It has increased marginally from 14.9 million in TE 2006-07 to 15.2 million hectares in TE 2016-17 (Figure 4.2). The area under forest, which is not available for cultivation, has remained unchanged between TE 2006-07 and TE 2016-17, at 28.26 percent and 11.43 percent, respectively. The area under the category of 'other cultivated land excluding fallow land', consisting of permanent pastures, grazing land, miscellaneous tree crops and groves, and culturable waste land declined marginally from 8.3 percent to 7.7 percent during this period. The percentage of fallow land has declined slightly, comprising 3.16 percent in TE 2016-17 as opposed to 4.07 percent in TE 2006-07.

The average land holding size in Madhya Pradesh declined marginally from 1.78 per hectare in 2010-11 to 1.57 per hectare in 2015-16. Even though small & marginal farmers comprise the largest share of farming households (75 percent) in the state, and 40 percent of the operated area, the share of farming households is lower than the national average of 85 percent.

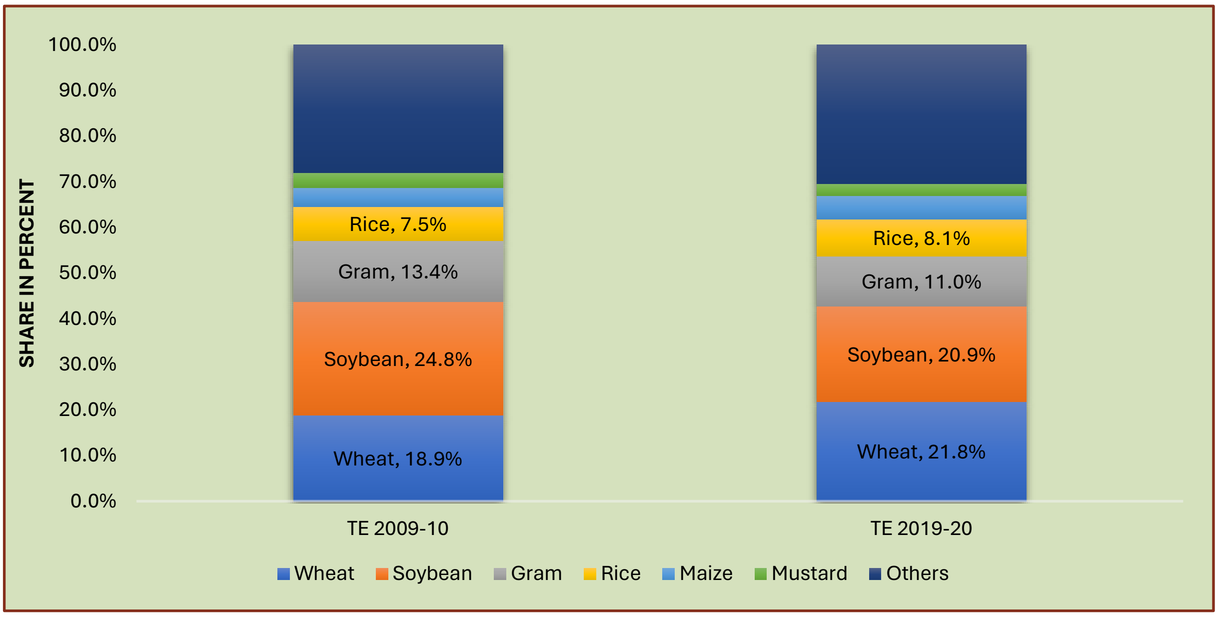
Several crops are grown in the state owing to its wide range of soil[11] and agro-climatic zones[12]. Some significant crops grown in the state include wheat, soybean, rice, gram and urad. Cereals occupied 36.6 percent of the GCA in TE 2019-20, mainly comprising wheat (22.8 percent), rice (8.46 percent) and maize (5.28 percent). In the oilseeds category, soybean is the main crop grown in the state, occupying 21.8 percent of the GCA in TE 2019-20. However, the area under soybean has declined in the state from 24.8 percent to 21.8 percent in the last decade (**Figure 4.3**). The

11 Shallow & Medium Black Soil, Deep Medium Black Soil, Alluvial Soil, and Mixed Red & Black Soil.

12 Agro-climatic zones - Chhattisgarh plains, Kymore Plateau & Satpura Hills, Chhattisgarh plains, Central Narmada Valley, Vindhya Plateau, Gird Region, Bundelkhand, Satpura Plateau, Malwa Plateau, Nimar Plains and Jhabua Hills.

area under wheat doubled from 3.3 million hectares in 2000-01 to 6.6 million hectares in 2019-20, along with a significant increase in its production from 4.8 million tonnes to 19.6 million tonnes during this period—the state is the second largest producer in of wheat in India in terms of both area and production followed by Uttar Pradesh.[13] The area under soybean increased from 4.5 million hectares to 6.2 million hectares, and the production increased from 3.4 million tonnes to 4.9 million tonnes during the same period. The area under other pulses and oilseed crops has also risen marginally in the state. Pulses occupied another 22.1 percent share, mainly comprising gram (11.3 percent), urad (8 percent) and tur (2.8 percent) in the same period.

Figure 4.3: Share of different crops in GCA (percent) in Madhya Pradesh TE 2009-10 and TE 2019-20



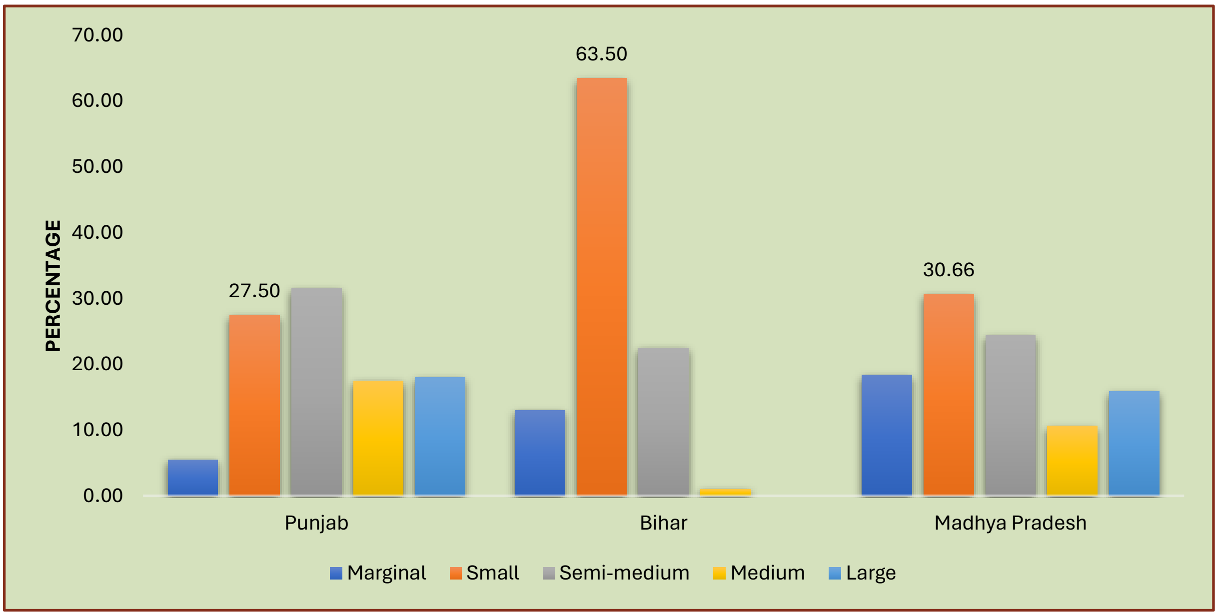
Source: Directorate of Economics and Statistics

We interviewed 800 farming households (inquiry method) and conducted direct measurements (observation method) for data collection for 20 percent of the farming households (160 farmers out of 800 farmers). In the market channels, we interviewed 76 market-level stakeholders and conducted direct experiments in 16 storage units (FCI and private warehouses) equally distributed across eight crop districts (Annex 3). We have applied the same approach for all the commodities across all the selected states.[14] Here we present the socio-economic profile of farmer households based on the sample survey of eight districts of the state. Farmers' socio-economic profile shows the average age of the farmers and years of experience doing farming activities are 46.5 and 24.5 years, respectively. In addition, the average family size above 16 years of members per farming HHs is 4.45. Of the 800 FHHs, 95 percent of farmers own the land they cultivate; the family jointly owns 5 percent, and the remaining is leased, more than half of the farmers have a soil health card and 60 percent to 80 percent have their crop insured. The average

13 In 2021-22, the total wheat and soybean production was 22.4 and 4.3 million tonnes respectively.
14 We use a "winsorizing" technique, replacing extreme outliers (5 percent from the upper and lower extremes) with missing values assuming all extreme values are due to measurement error. "Winsorized mean is an averaging method that involves replacing the smallest and largest values of a data set with the observations closest to them. It mitigates the effects of outliers by replacing them with less extreme values."

operational landholding size is 3.81 hectares, and the crop-wise average landholdings are relatively more for paddy, followed by wheat, soybean, and maize. **Figure 4.4** shows surveyed farmers' landholding size and crop-wise average cultivated area.

Figure 4.4: Farm-size distribution based on operated land



Source: Authors field survey, ICRIER-ADMI 2022

The average production of wheat, paddy, maize, and soybean farming HH is 114.8 quintals, 250 quintals, 72.3 quintals and 35.6 quintals, respectively. The average retention for self-consumption; therefore, storage in their house is 21.5 quintals, 3.5 quintals and 1.99 quintals for wheat, paddy, and maize, respectively. Of the 800 FHHs, over half of the farmers use plastic bags (including fertilizer bags) to store at their homes, and the others use jute bags. In the case of wheat, more than half of the farmers (78 percent) use metal silos to keep at their homes. Economic conditions and crop types are the main drivers of using jute and plastic bags. Most wheat and paddy farmers use dry neem leaves to protect their grains from mites during home storage. The main storage pests responsible for the losses in maize grain are weevils (Sitophilus granarius) and the lesser grain borer (Rhyzopertha dominica). However, a few maize and soybean farmers (30 percent) use insecticides to protect their grains during home storage.

Most farmers sell the crop after harvesting due to financial pressure and a lack of adequate storage facilities at home. In the surveyed districts, around 70 to 80 percent of farmers sell their crops just after harvesting to meet household expenses and school fees and buy seeds and fertilizers for the subsequent crop field treatment. The lack of storage facilities at farmers' houses also motivates them to sell crops to reduce crop storage loss. However, the early sale implies that the farmers miss the opportunity to increase the revenue from selling the crops during the peak demand seasons.

In all surveyed districts, we observed gender division of agriculture work; more men (60 to 70 percent) do the crop harvesting, collecting and threshing activities than women. On the other hand, more women (80 percent) engage in manual cleaning, drying, and minor processing activities.

4.2.2 Punjab

The agrarian economy of Punjab has gone through exceptional growth since the green revolution period of 1960s. The state has made tremendous growth in paddy production by adopting the dwarf variety of rice varieties and technological change and considered as 'rice bowl of India' contributing to around 22 percent of rice procurement and 10 percent of total production. With a geographical area of 5.04 million hectares in Punjab, the net planted area accounts for 83 percent in TE 2017-18 (DES, 2020-21).

Over the years, Punjab has concentrated on food grain production, with the area under food grains as a share of gross cropped area increasing from 76.5 percent in TE 1986–87 to 82.9 percent in TE 2015–16, while the share of cotton, sugarcane and oilseeds has declined significantly. The state specializes in rice and wheat production within the food grain sector. The total gross cropped area in the state is 7.9 million hectares and with excellent irrigation infrastructure, 98.5 percent of the gross area sown is irrigated. Cropping intensity-- the ratio of gross cropped area to net sown area, is 190 percent in TE 2018–19 in Punjab in comparison to all India figure of 141.8 percent (DES, 2020-21).

Within cereals, wheat has traditionally been the dominant crop, but the higher profitability of rice, ensured by free water and an assured market, prompted farmers to shift to rice cultivation (Gulati et al. 2021). Punjab (the bread basket of India) contributed 25 percent to the central pool of rice and 31 percent to wheat during 2021-22. As a result, the area under rice kept increasing and stood at 40.1 percent of the total cropped area, while the area under wheat remained stagnant at 44 percent (Economic Survey of Punjab 2022-23). In Punjab, the two cereal crops, wheat and rice, are grown in rotation annually. These are the two main crops grown in Punjab. Rice is the principal crop grown in the kharif season, and wheat is the main crop of rabi season. Punjab's average land holding size was 3.62 hectares (Agri-census 2015-16). Medium and semi-medium farmers comprise 61.6 percent of the landholdings and operate in around 68.6 percent of the total area. In terms of farm mechanisation, the state has the highest farm power availability at 2.6 Kw/ha. compared to all India figure of 1.5 Kw/ha.

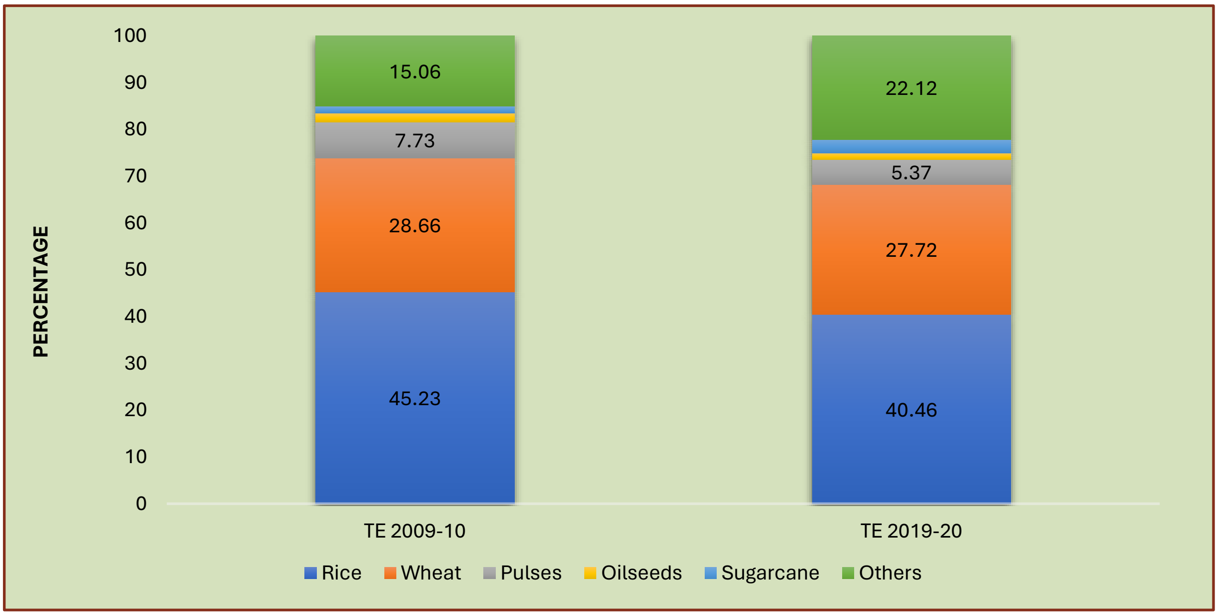
The farmers' socio-economic profile (Annex 3) shows the average age and years of experience doing farming activities are 49.8 and 31.4 years, respectively. In addition, the average family size above 16 years of members per farming HHs is 4.49. All surveyed farming households own the land they cultivate; around 52 percent of the farmers have a soil health card, and 91 percent have their crops insured. The average operational landholding size is 4.42 hectares in the survey districts.

4.2.3 Bihar

Bihar is in eastern India, and West Bengal surrounds it in the East and Uttar Pradesh in the west. It lies on the river plains of the river Ganga basin, endowed with fertile alluvial soil making the land rich and diverse in agricultural produce. Bihar, with a geographical area of 9.4 million hectares, the net sown area accounts for 56.2 percent in TE 2016-17. It has declined marginally from 5.7 million hectares in TE 2006-07 to 5.3 million hectares in TE 2016-17. The area under forest, and the area not available for cultivation, have remained unchanged between TE 2006-07 and TE 2016-17, at 6.6 percent and 22.9 percent, respectively. The area under the category of 'other cultivated land excluding fallow land', consisting of permanent pastures, grazing land, miscellaneous tree crops and groves, and cultivatable wasteland, remained unchanged at 3.3 percent. On the other hand, the fallow land has increased from 8 percent in TE 2006-07 to 11 percent in TE 2016-17. Bihar's average land holding size was 0.4 hectares in 2015-16. Small and marginal farmers comprise 96 percent of the landholdings and operate in around 76 percent of the total area.

Bihar is mainly a food grain growing state, with around 74 percent of its gross cropped area devoted to rice, wheat, and pulses in TE 2019-20. Within food grains, rice is the essential crop growing in the state. However, its share has marginally declined from 45 percent in TE 2009-10 to 40 percent in TE 2019-20 (**Figure 4.5**). Wheat is the second most important crop grown in the state, occupying 28 percent of the GCA in TE 2019-20. Pulses, oilseeds, and sugarcane accounted for around 10 percent of the GCA in the same period.

Figure 4.5: Share of different crops in gross cropped area (percent) in TE 2009-10 and TE 2019-20



Source: Directorate of Economics and Statistics

Agriculture occupies a crucial space in Bihar's economy employing 53.6 percent of the total workforce, higher than the national average of 46.9 percent (Labour Bureau 2015–16). Most of the population (88.5 percent) lives in rural areas, and agriculture is an essential source of livelihood for them, with more than 80 percent of the people of Bihar depending on agriculture. The share of agriculture and allied activities in gross state domestic product has declined from 34.9 percent in the triennium ending (TE) 2003–04 to 19.8 percent in TE 2019–20 (at constant prices 2011– 12).

4.3 Estimation of harvest and post-harvest losses across states

In the following section we discuss the survey results so obtained across selected crops and states followed by assessment of loss by inquiry and observation methods. **Table 4.1** gives the aggregate results for the harvest and post-harvest losses across states and for the selected crops.

Our result shows that the total loss of paddy grain during harvest and post-harvest is the highest in Bihar (8.50 percent) followed by Madhya Pradesh (6.52 percent), and Punjab (5 percent). Punjab has high coverage of mechanical harvesting (almost 100 percent), resulting in lower level of farm-loss compared to Bihar. Harvesting and threshing loss comprise 3.48 percent for paddy in Bihar, whereas the value is 3.03 percent in Madhya Pradesh followed by 2.88 percent in Punjab. At farmer level, the loss for paddy is also distinctly lower in Punjab because of their direct selling to state procurement centres directly from the field after the mechanized harvest. Contrary to that, in Bihar rice is produce at household level by drying and parboiling and also stored for longer time for availing better price resulting in 0.96 percent and 0.34 percent of storage loss and drying loss, respectively. The difference in loss is wider between Punjab and Bihar, combining post-harvest operations, the estimated quantity losses for paddy crops are 6.95 percent in Bihar and 4.34 percent in Punjab, respectively. The quality deterioration losses of paddy are 0.66 percent in Punjab and 1.55 percent in Bihar.

Table 4.1: Aggregate post-harvest losses of the selected crops—ICRIER-ADMI study (in percent)

Stakeholders	Operations	Madhya Pradesh				Punjab	Bihar
		Wheat	**Paddy**	**Maize**	**Soybean**	**Paddy**	**Paddy**
Farmer level	Harvesting	3.93	2.61	1.73	5.97	2.81	1.88
	Threshing#	0.01	0.42	1.16	3.48	0.07	1.60
	Cleaning	0.30	0.25	0.46	0.59	0.21	0.36
	Drying	0.00	0.04	0.21	0.19	0.00	0.34
	Storage	0.39	0.43	0.50	0.66	0.00	0.96
	Transportation to mandi*	0.54	0.56	0.14	0.33	0.23	0.64
	Total loss (FL)	5.17	4.31	4.20	11.22	3.32	5.78
Market level	Storage	0.09	0.11	0.12	0.20	0.15	0.33
	Transportation	0.02	0.13	0.10	0.15	0.08	0.13
	Processing	0.00	0.46	0.12	0.19	0.51	0.40
	Wholesaler	0.24	0.27	0.22	0.24	0.20	0.22
	Retailer	0.21	0.13	0.18	0.19	0.08	0.09
	Total loss (ML)	0.43	1.10	0.74	0.97	1.02	1.17
Total quantity loss		**5.60**	**5.41**	**4.94**	**12.19**	**4.34**	**6.95**
Quality loss (in percent quantity)		**2.27**	**1.11**	**1.01**	**3.15**	**0.66**	**1.55**
Overall loss		**7.87**	**6.52**	**5.95**	**15.34**	**5**	**8.50**

Source: Authors' estimation based on field survey data, ICRIER-ADMI 2022

*#: including stalling and transportation; *: including mandi handling*

We separately estimated grain loss (quantitative and qualitative) at the farmers' end (harvesting, threshing, cleaning & winnowing and storage, including transportation from farmers' houses to the mandi) and at market levels (transporters, storage units, processing units, wholesalers, and retailers). Loss figures include the quantitative loss, i.e., the quantity of product lost in the supply chain. We have given the detailed composition of all the losses in **Table 4.1**. We found the largest loss share at the farmers'/producers' level (on-farm operations), which is substantially more prominent than the market-level (off-farm) operations. Among the on-farm processes, grain loss at the harvesting level represents around 60 to 70 percent of the total supply chain loss. The substantial share of on-farm losses viz-a-viz off-farm operation may be due to the unfavourable weather during harvest time and less holding time in the market channels. Here, we explain the operation wise losses by different methods across surveyed states and crops.

4.3.1 Madhya Pradesh

Madhya Pradesh is surveyed for wheat, paddy, soybean and maize crop. At state level total loss is the highest for soybean crop (12.19 percent), followed by wheat (5.6 percent), paddy (5.41 percent), and maize (4.94 percent). If we compare crop-wise total loss combining all the sample farmers of the, the loss is the highest for soyabean followed by paddy, maize, and wheat. Quality related crop loss is more in soyabean (3.15 percent) and wheat compared to other crops (2.27 percent). **Tables 4.2 to 4.5** give the results of our survey by inquiry and observation methods.

Through the inquiry method of data collection, we estimated that the mean quantity grain loss in wheat, paddy, maize and soybean at harvesting end were at 3.93 percent, 2.43 percent, 1.73 percent and 5.97 percent and the total loss at farmers' end are 5.17 percent, 4.47 percent, 4.20 percent and 11.22 percent respectively. And the overall quantity loss across the supply chain is 5.60 percent, 5.57 percent, 4.94 percent, and 12.19 percent. In addition, the unexpected rain during the survey (in September-October 2022) delayed the harvesting activities and led the farmers to hold the harvesting activity longer. Then, through laboratory testing of the collected samples from farmers' field and market channels, we estimated the qualitative losses of 11.35 percent, 11.1 percent, 10.1 percent and 15.75 percent for wheat, paddy, maize, and soybean respectively in terms of damaged grains (broken, pest infected, etc.), shrivelled grains and the presence of foreign matters. We have seen two types of incidents during the direct measurement activities. First, when we inspected the field before harvest, we caught up to half percent (wheat, paddy, and maize) and 2.5 percent (soybean) of the total harvested quantity of grain attached with stem scattered in the selected harvested plot. Therefore, it indicates the left-out product in the field is lower quality than the harvested product. Second, when we inspected the plot after harvest (one each after manually and combine harvester use for paddy and soybean), we found that in the case of manual harvesting, fallen grains were less than that in the harvested mechanically. Overall, the quantity affected by the loss at pre-harvest and harvest is considerably more significant than the quantities lost or affected by a loss during postharvest activities. Therefore, it indicates that the most significant losses occur in the field or during harvest activities. The mean moisture content during harvesting is approximately 8.5 percent (wheat), 18 percent (paddy), 19 percent (maize) and 21 percent (soybean). Therefore, on average, we found more grain damage for soybean during harvesting and threshing than for wheat, paddy, and maize.

Table 4.2: Losses in Wheat in Madhya Pradesh: agro-climatic zone wise and method wise

Stakeholders	Farm Operations	Central Narmada Valley			Gird Region			Aggregate		
		Inquiry	Observation	Difference	Inquiry	Observation	Difference	Inquiry	Observation	Difference
	No. of observations	100	20		100	20		200	40	
Farmer	Harvesting	3.98	5.45	-1.46***	3.81	5.39	-1.60***	3.93	5.43	-1.50***
	Threshing	0.03	0.27	-0.26***	0.11	0.27	-0.25***	0.01	0.27	-0.26***
	Cleaning	0.31	0.56	-0.25***	0.26	0.56	-0.30***	0.30	0.56	-0.26***
	Drying	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Storage	0.41	0.50	-0.09***	0.34	0.51	-0.17***	0.39	0.50	-0.12***
	Transportation	0.56	0.45	0.12***	0.50	0.41	0.08***	0.54	0.44	0.11***
	Farmer level losses	5.29	7.23	-1.94***	5.02	7.15	-2.24***	5.17	7.20	-2.03***
Market	Storage	0.04	0.09	-0.05	0.04	0.09	-0.05	0.04	0.09	-0.05
	Transportation	0.06	0.02	0.04	0.06	0.02	0.04	0.06	0.02	0.04
	Processing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Wholesaler	0.12	0.24	-0.12	0.12	0.24	-0.12	0.12	0.24	-0.12
	Retailer	0.21	0.21	0.00	0.21	0.21	0.00	0.21	0.21	0.00
	Market level losses	0.43	0.56	-0.13	0.43	0.56	-0.13	0.43	0.56	-0.13
	Total Quantity loss	5.72	7.79	-2.06	5.45	7.71	-2.26	5.60	7.76	-2.16

Threshing includes threshing, stalling and transportation within field

**** Statistical significance at 1 percent level for t-test (mean comparison)*

Source: Field survey by authors, ICRIER-ADMI 2022

Table 4.3: Losses in Paddy in Madhya Pradesh: agro-climatic zone wise and method wise

Stakeholders	Farm Operations	Central Narmada Valley			Gird Region			Aggregate		
		Inquiry	Observation	Difference	Inquiry	Observation	Difference	Inquiry	Observation	Difference
	No. of observations	100	20		99	20		199	40	
Farmer	Harvesting	2.50	3.41	-0.91***	2.72	3.56	-0.83***	2.61	3.45	-0.84***
	Threshing	0.72	1.01	-0.29**	0.14	0.69	-0.55***	0.42	0.92	-0.50***
	Cleaning	0.28	0.36	-0.08***	0.23	0.39	-0.16***	0.25	0.36	-0.11***
	Drying	0.07	0.15	-0.08***	0.01	0.12	-0.11***	0.04	0.14	-0.10***
	Storage	0.43	0.64	-0.21***	0.43	0.64	-0.21***	0.43	0.64	-0.21***
	Transportation	0.56	0.60	-0.04***	0.57	0.60	-0.03***	0.56	0.60	-0.04***
	Farmer level losses	4.56	6.16	-1.60***	4.10	6.00	-1.90***	4.31	6.12	-1.81***
Market	Storage	0.11	0.31	-0.20	0.11	0.31	-0.20	0.11	0.31	-0.20
	Transportation	0.13	0.13	0.00	0.13	0.13	0.00	0.13	0.13	0.00
	Processing	0.46	0.46	0.00	0.46	0.46	0.00	0.46	0.46	0.00
	Wholesaler	0.27	0.27	0.00	0.27	0.27	0.00	0.27	0.27	0.00
	Retailer	0.13	0.13	0.00	0.13	0.13	0.00	0.13	0.13	0.00
	Market level losses	1.10	1.30	-0.20	1.10	1.30	-0.20	1.10	1.30	-0.20
	Total Quantity loss	5.66	7.46	-1.80	5.20	7.30	-2.10	5.41	7.42	-2.01
Threshing includes threshing, stalling and transportation within field										

*Notes:*** Statistical significance at 1 percent level; ** Statistical significance at 5 percent level for t-test (mean comparison)*

Source: Field survey by authors, ICRIER-ADMI 2022

Table 4.4: Losses in Maize in Madhya Pradesh: agro-climatic zone wise and method wise

Stakeholders	Farm Operations	Malwa Plateau			Satpura Plateau			Aggregate		
		Inquiry	Observation	Difference	Inquiry	Observation	Difference	Inquiry	Observation	Difference
	No. of observations	100	20		100	20		200	40	
Farmer	Harvesting	1.77	2.03	-0.26***	1.69	2.21	-0.52***	1.73	2.19	-0.46***
	Threshing	1.18	1.08	0.10***	1.12	1.15	-0.024*	1.16	1.14	0.02
	Cleaning	0.49	0.47	0.02	0.43	0.44	-0.01	0.46	0.45	0.01
	Drying	0.21	0.48	-0.27***	0.21	0.49	-0.28***	0.21	0.49	-0.28***
	Storage	0.53	0.90	-0.37***	0.47	0.70	-0.23***	0.50	0.72	-0.22***
	Transportation	0.14	0.66	-0.52***	0.14	0.67	-0.53***	0.14	0.66	-0.52***
	Farmer level losses	4.32	5.61	-1.03***	4.06	5.66	-1.07***	4.20	5.65	-0.99***
Market	Storage	0.12	0.26	-0.14	0.12	0.26	-0.14	0.12	0.26	-0.14
	Transportation	0.10	0.10	0.00	0.10	0.10	0.00	0.10	0.10	0.00
	Processing	0.12	0.12	0.00	0.12	0.12	0.00	0.12	0.12	0.00
	Wholesaler	0.22	0.22	0.00	0.22	0.22	0.00	0.22	0.22	0.00
	Retailer	0.18	0.18	0.00	0.18	0.18	0.00	0.18	0.18	0.00
	Market level losses	0.74	0.88	-0.14	0.74	0.88	-0.14	0.74	0.88	-0.14
	Total Quantity loss	5.06	6.49	-1.43	4.80	6.54	-1.74	4.94	6.53	-1.59
Threshing includes threshing, stalling and transportation within field										

*Notes:*** Statistical significance at 1 percent level; ** Statistical significance at 5 percent level; * at 10 percent level for t-test (mean comparison)*

Source: Field survey by authors, ICRIER-ADMI 2022

Table 4.5: Losses in Soybean in Madhya Pradesh: agro-climatic zone wise and method wise

Madhya Pradesh Stakeholders	Farm Operations	Central Narmada Valley			Malwa Plateau			Aggregate		
		Inquiry	Observation	Difference	Inquiry	Observation	Difference	Inquiry	Observation	Difference
	No. of observations	100	20		100	20		200	40	
Farmer	Harvesting	6.02	7.64	-1.62***	5.92	7.14	-1.22***	5.97	7.30	-1.33***
	Threshing	3.31	1.24	2.07***	3.63	1.18	2.45***	3.48	1.20	2.28***
	Cleaning	0.61	0.51	0.01***	0.57	0.64	-0.07***	0.59	0.60	-0.01
	Drying	0.20	0.13	0.07***	0.20	0.11	0.09***	0.19	0.12	0.07***
	Storage	0.66	0.27	0.39***	0.67	0.26	0.41***	0.66	0.26	0.40***
	Transportation	0.32	0.56	-0.24***	0.33	0.57	-0.24***	0.33	0.57	-0.24***
	Farmer level losses	11.12	10.34	0.78***	11.32	9.91	1.41***	11.22	10.05	1.17***
Market	Storage	0.20	0.33	-0.13	0.20	0.33	-0.13	0.20	0.33	-0.13
	Transportation	0.15	0.15	0.00	0.15	0.15	0.00	0.15	0.15	0.00
	Processing	0.19	0.19	0.00	0.19	0.19	0.00	0.19	0.19	0.00
	Wholesaler	0.24	0.24	0.00	0.24	0.24	0.00	0.24	0.24	0.00
	Retailer	0.19	0.19	0.00	0.19	0.19	0.00	0.19	0.19	0.00
	Market level losses	0.97	1.10	-0.13	0.97	1.10	-0.13	0.97	1.10	-0.13
	Total Quantity loss	12.09	11.44	0.65	12.29	11.01	1.28	12.19	11.15	1.04
Threshing includes threshing, stalling and transportation within field										

*Notes:*** Statistical significance at 1 percent level for t-test (mean comparison)*

Source: Field survey by authors, ICRIER-ADMI 2022

Storage losses are directly proportionate to the storage duration. To substantiate this, we have taken samples to test the storage losses occurring over time, indicating an increase in the percentage losses with an increase in the storage time, also verified from our second visit (approximately one month after the first visit, (May 2022 for wheat; November 2022 for paddy, maize, and soybean).

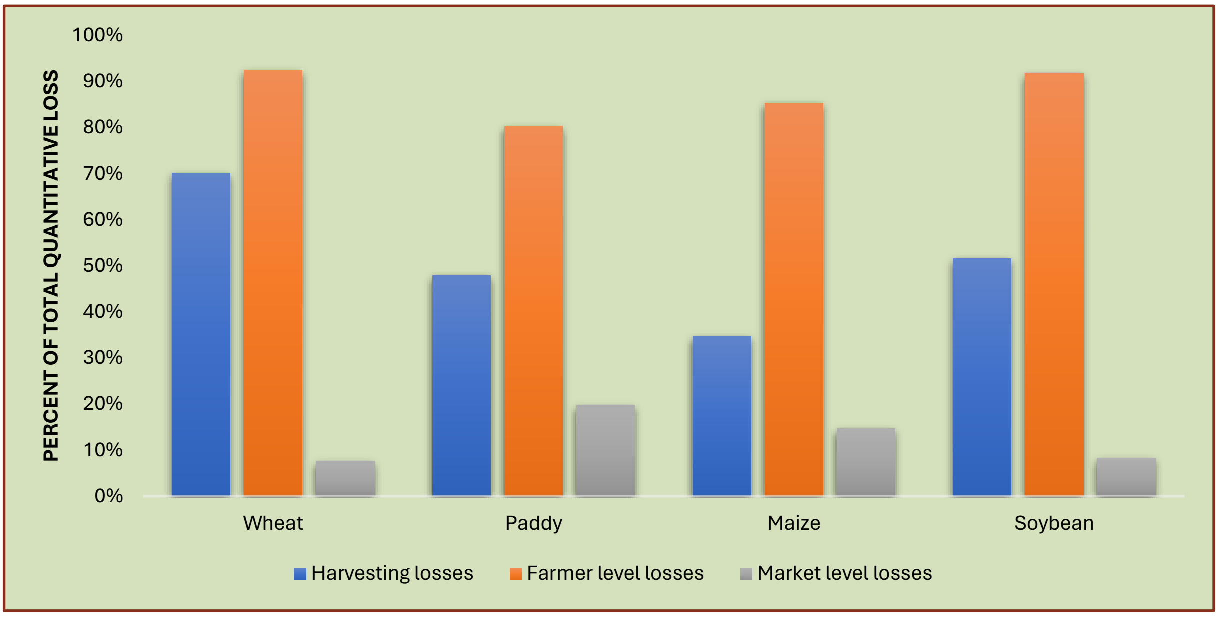
In our third and final visit for wheat in July 2022 and paddy, maize, and soybean in January 2023, we found a negligible increase in storage losses, which is not statistically significant except for maize (relatively more quality loss). Generally, storage losses kick in after the third month when moulds and insect infections start. Therefore, it may explain that the storage losses estimated here are insignificant. A comparative discussion of loss estimated by inquiry and observation method shows that average losses reported by farmers are lower than that of field measurements.

Through the inquiry method, we estimated that the losses at the farmers' end were 5.17 percent (wheat), 4.31 percent (paddy), 4.20 percent (maize) and 11.22 percent(soybean) across the two crop districts each. However, the average loss estimated by field measurement (observation method) was 7.20 percent, 6.12 percent, 5.65 percent and 10.05 percent for wheat, paddy, maize, and soybean respectively. Whereas for soybean, total loss at farmers' level by inquiry method is significantly higher than observation method, with a difference of 1.17. For other three crops, loss at farmers' level is significantly higher in observation method than the inquiry method. FAO 2018 came across a similar observation that there is an under-reporting of losses through the inquiry method than the observation method data collection. The difference in loss estimation figures between the two sets of operations may be due to the lack of knowledge of harvest and postharvest losses in quality (mostly) and quantity (partially). The other factor of lower knowledge of grain losses may be that farmers in the countryside are generally less aware and don't keep records of the grain they produce, store and sell in the market.

The aggregate quantity (weighted mean of observation and inquiry method) loss across the supply chain (weighted mean of inquiry and observation means) is 5.96 percent (wheat), 5.75 percent (paddy), 5.20 percent (maize) and 12.02 percent (soybean). And the overall loss is 7.87 percent (wheat), 6.52 percent (paddy), 5.95 percent (maize), and 15.34 percent (soybean), including the quantities, affected, or lost by quality deterioration.

The pan-India studies by the ICAR-CIPHET (2015) found that the quantitative paddy, maize, and soybean losses across the supply chain were 4.93 percent, 5.53 percent, 4.65 percent, and 9.96 percent, respectively, at the national level. Hence, our study estimated losses in quantity and quality terms, and it is higher compared to the ICAR-CIPHET (estimated only quantity loss). For example, we calculated the quantity loss by taking the production share of the two districts and quality loss through laboratory testing. The overall share of grain loss is at the farmers' end comprising 92 percent, 80 percent, 85 percent, and 92 percent of the total quantitative losses across the supply chain for wheat, paddy, maize, and soybean, respectively. The amounts affected by quality deterioration at harvest and quantities lost or affected by quality deterioration during postharvest activities contributed 29 percent (wheat), 17 percent (paddy), 17 percent (maize) and 21 percent (soybean) of the total production and supply chain loss.

Figure 4.6: Share of harvesting, farmers' level loss and market level loss of the total post-harvest quantity loss in Madhya Pradesh



Notes: Farmer level loss includes harvesting-loss. Source: Field survey data, ICRIER-ADMI 2022

Coming to the economic loss of the state due to harvest and post-harvest loss, the total economic loss caused by the crop loss for wheat, paddy, maize and soybeans in the eight crop districts is Rs. 980 crores.[15] And the crop-wise monetary losses are Rs 292 crores (wheat), Rs 231 crores (paddy), Rs. 161 crores (maize) and 296 crores (soybean). Therefore, the study estimated a quantity loss of around 1.45 Lakh tonnes (wheat), 1.1 Lakh tonnes (Paddy), 0.8 Lakh tonnes (Maize) and 0.7 Lakh tonnes (Soybean) in the surveyed crop districts.[16]

4.3.2 Punjab

In Punjab, the survey has been done to estimate harvest and post-harvest losses of paddy. We separately estimated grain loss (quantitative and qualitative) at the farmers' and market levels (transporters, storage units, processing units, wholesalers, and retailers). In addition, at farmers' levels, we estimated the loss at the harvesting, cleaning & transportation from farmers' houses to the mandi. As the farmers use combine harvesters, there are no other operations like threshing, drying, stalling, transport within the field is reported separately. For comparison with other states, the operations have been combined for harvest and associated operations.

We have given the detailed composition of all the losses in **Table 4.6**. We found the largest loss share at the farmers'/producers' level for paddy in the state (on-farm operations), which is substantially more than the market-level (off-farm) operations. Among the on-farm processes, grain loss at the harvesting level represents around 60 to 70 percent of the total supply chain loss. The substantial share of on-farm losses viz-a-viz off-farm operation may be due to the unfavourable weather during harvest time and less holding time in the market channels.

15 Using the minimum support price (MSP) of the 2022-23, the MSP for wheat, paddy, Maize and Soybean is INR 20150, 20600, 19620 and 43000 per tonnes respectively.
16 Based on Directorate of economics and statistics paddy, maize and soybean production estimates figure for 2021-22.

Through the farmers' declaration method of data collection, we estimated that the mean quantitative paddy loss during harvesting is 2.81 percent and total at the farmers' end it is 3.32 percent. And the overall quantity loss across the production and supply chain is 4.34 percent (**Table 4.6**). In addition, the unexpected rain during the survey (in October-November 2022) delayed the harvesting activities and led the farmers to hold the harvesting activity longer.

Table 4.6: Losses in Paddy in Punjab: agro-climatic zone wise and method wise

Punjab	Farm Operations	Central Plain Zone			Western Plain Zone			Aggregate		
Stakeholders		Inquiry	Observation	Difference	Inquiry	Observation	Difference	Inquiry	Observation	Difference
	No. of observations	100	20		100	20		200	40	
Farmer	Harvesting	2.90	3.75	-0.85***	2.73	3.27	-0.54***	2.81	3.45	-0.64***
	Threshing	0.16	0.00	0.156**	0.00	0.00	0.00	0.07	0.00	0.07**
	Cleaning	0.21	0.38	-0.17***	0.22	0.35	-0.13***	0.21	0.36	-0.15***
	Drying	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Storage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Transportation	0.22	0.22	0.00	0.23	0.23	0.00	0.23	0.23	0.00
	Farmer level losses	3.47	4.35	-0.88***	3.16	3.84	-0.68***	3.32	4.04	-0.71***
Market	Storage	0.15	0.20	-0.05	0.15	0.21	-0.06	0.15	0.21	-0.06
	Transportation	0.09	0.07	0.02	0.07	0.16	-0.08	0.08	0.12	-0.04
	Processing	0.50	0.50	0.00	0.52	0.52	0.00	0.51	0.51	0.00
	Wholesaler	0.21	0.21	0.00	0.19	0.19	0.00	0.20	0.20	0.00
	Retailer	0.07	0.07	0.00	0.09	0.09	0.00	0.08	0.08	0.00
	Market level losses	1.02	1.05	-0.03	1.02	1.16	-0.14	1.02	1.12	-0.10
	Total Quantity loss	4.49	5.40	-0.91	4.18	5.01	-0.83	4.34	5.16	-0.81
Threshing includes threshing, stalling and transportation within field										

**** Statistical significance at 1 percent level; ** Statistical significance at 5 percent level for t-test (mean comparison) | Source: Field survey by author, ICRIER-ADMI 2022*

Table 4.6 also shows the quantity loss of paddy based on objective measurements, is 5.16 percent, and the quantity affected by quality deterioration is 0.66 percent. In **Annex 4**, we have given the details of the objective measurement techniques. First, we estimated the average harvest loss for paddy at 3.45 percent, followed by cleaning (0.36 percent) and transportation to mandi loss (0.23 percent). Then, through laboratory testing of the collected samples from farmers' field and market channels, we estimated the qualitative losses of 6.6 percent in terms of damaged grains (broken, pest infected, etc.), shrivelled grains and the presence of foreign matters.

A comparison of loss estimated by inquiry and observation method shows that average losses reported by farmers are lower than that of field measurements. Through the inquiry method, we estimated that the losses at the farmers' end were 3.32 percent across the two crop districts each. However, at the farmers' end, the average loss estimated by field measurement (observation method) was 4.04 percent; we observed similar losses for the other post-production stages where we conducted field experiments. The estimation of loss by observation method is significantly higher than the inquiry method at farmers' level, whereas there are no significant differences between two methods of estimation at market level.

Coming to the economic loss estimation of paddy harvest and post-harvest loss, we find that the total economic loss in the two surveyed districts is Rs. 234.4 crores. [17] The estimated loss for Bhatinda and Amritsar is Rs. 141 crores and Rs. 93.3 crores, respectively. The study assessed the total quantity loss in the two survey districts is around 1.16 Lakh tonnes (grain).[18]

4.3.3 Bihar

Bihar is also surveyed for assessing harvest and post-harvest losses of paddy cultivation. Through the farmers' declaration method of data collection, we estimated that the mean quantitative paddy loss during harvesting is 1.88 percent and total loss at the farmers' end is 5.78 percent in the state. As most farmers in Muzaffarpur harvested manually (backward district in the state), the study found relatively more loss (7.52 percent) in Muzaffarpur than in Rohtas (6.57 percent). And the overall quantity loss across the production and supply chain is 6.95 percent. In addition, the unexpected rain during the survey (in October-November 2022) delayed the harvesting activities and led the farmers to hold the harvesting activity longer. **Table 4.7** shows the quantity loss of paddy based on observations and inquiry for both the agroclimatic zones. The quantity affected by quality deterioration is 1.55 percent. First, we estimated the average harvest loss for paddy at 2.13 percent, followed by threshing (including field stalling and transport to the threshing floor) for manually harvested crops at 1.94 percent, transport to mandi (0.65 percent) (including mandi handling), storage (0.62 percent), drying (0.34 percent) and cleaning (0.52 percent). Then, through laboratory testing of the collected samples from farmers' field and market channels, we estimated the qualitative losses of 15.5 percent in terms of damaged grains (broken, pest infected, etc.), shrivelled grains and the presence of foreign matters.

We have seen two types of incidents during the direct measurement activities in the state similar to Madhya Pradesh and Punjab. First, when we inspected the field before harvest, we caught up to half percent of the total harvested quantity of grain or grain attached with stem scattered in the selected harvested plot. Therefore, it indicates the left-out product in the field is of lower quality than the harvested product. Second, when we inspected the plot after harvest (separately after manual and combine harvester use), we found that in the case of manual harvesting, fallen grains were less than that in the harvested mechanically. Overall, the quantity affected by the loss at farm level is considerably more significant than the quantities lost or affected by a loss during

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17 Using the minimum support price (MSP) of the 2022-23, the MSP for paddy is INR 20600 per ton.

18 Based on Directorate of economics and statistics paddy, maize and soybean production estimates figure for 2021-22.

postharvest activities. The mean moisture content during harvesting is approximately 18.7 percent.

A comparative discussion of loss estimated by inquiry and observation method shows that average losses reported by farmers are lower than that of field measurements. Through the inquiry method, we estimated that the losses at the farmers' end were 5.78 percent across the two crop districts each. However, the average loss estimated by field measurement (observation method) was 6.21 percent. We observed similar losses for the other post-production stages where we conducted field experiments. We used the inquiry method loss data for other nodes where we did not conduct field experiments.

Table 4.7: Losses in Paddy in Bihar: agro-climatic zone wise and method wise

Bihar	Farm Operations	Northwest Alluvial Plain Zone			South Bihar Alluvial Zone			Aggregate		
Stakeholders		Inquiry	Observation	Difference	Inquiry	Observation	Difference	Inquiry	Observation	Difference
	No. of observations	100	20		100	20		200	40	
Farmer	Harvesting	1.97	2.44	-0.47***	1.80	1.99	-0.19***	1.88	2.13	-0.25***
	Threshing	1.82	1.93	-0.11**	1.41	1.95	-0.54***	1.60	1.94	-0.34***
	Cleaning	0.39	0.48	-0.09***	0.34	0.53	-0.19***	0.36	0.52	-0.16***
	Drying	0.33	0.33	0.00	0.35	0.35	0.00	0.34	0.34	0.00
	Storage	0.97	0.65	0.32***	0.94	0.61	0.33***	0.96	0.62	0.34***
	Transportation	0.61	0.61	0.00	0.68	0.68	0.00	0.64	0.65	-0.01
	Farmer level losses	6.09	6.43	-0.34***	5.52	6.10	-0.58***	5.78	6.21	-0.43***
Market	Storage	0.42	0.30	0.12	0.29	0.35	-0.06	0.33	0.33	0.00
	Transportation	0.26	0.26	0.00	0.08	0.08	0.00	0.13	0.13	0.00
	Processing	0.32	0.32	0.00	0.44	0.44	0.00	0.40	0.40	0.00
	Wholesaler	0.39	0.39	0.00	0.13	0.13	0.00	0.22	0.22	0.00
	Retailer	0.05	0.05	0.00	0.11	0.11	0.00	0.09	0.09	0.00
	Market level losses	1.43	1.31	0.12	1.05	1.11	-0.06	1.17	1.17	0.00
	Total Quantity loss	7.52	7.74	-0.22	6.57	7.21	-0.64	6.95	7.38	-0.43
Threshing includes threshing, stalling and transportation within field										

**** Statistical significance at 1 percent level for t-test (mean comparison)*

Source: Field survey by authors

The aggregate quantity loss of paddy in Bihar across the supply chain is 6.95 percent, and the overall loss is 8.5, including the quantities affected or lost by quality deterioration based on our survey. The pan-India studies by the ICAR-CIPHET (2015) found that the quantitative paddy loss in eastern India is around 7 percent. Our result comes out around 7 percent as well; however, we are slightly different on the overall losses figure due to the addition of quality loss numbers.

Our study estimated losses in quantity and quality compared to the ICAR-CIPHET (estimated only quantity loss). For example, we estimated the quantity loss by taking the production weight of the two districts and quality loss through laboratory testing. The overall share of grain loss at the farmers' end is 83 percent of the total quantitative losses across the supply chain. Among the on-farm processes, grain loss at the harvesting level represents around 27 percent of the total on farm quantity loss. The amounts affected by quality deterioration at harvest and quantities lost or affected by quality deterioration during postharvest activities contributed 17 percent of the total production and supply chain loss.

Coming to the estimation of economic loss due to harvest and post-harvest losses, the total estimation in the two surveyed districts is Rs. 239 crores. [19] The estimated loss for Rohtas and Muzaffarpur is Rs. 160.3 crores and Rs. 78.7 crores, respectively. The study estimated that around 1.19 Lakh tonnes (grain) were lost from the two surveyed crop-districts production and supply chain in terms of quantity and quantities lost or affected by quality deterioration during harvest and postharvest activities.[20]

4.4 Estimated loss comparison with contemporary literature

The pan-India study by the ICAR-CIPHET (2015) found that the quantitative wheat, paddy, maize and soybean losses across the supply chain were of 4.93 percent, 5.53 percent, 4.65 percent, and 9.96 percent, respectively, at the national level. show other food loss studies conducted on a state-specific, region-specific, or limited crop coverage scale. Here we will discuss how the present study contribute to the overall picture. The literature review found several studies (including the two ICAR-CIPHET studies) that contained micro data on postharvest losses. Most of these studies conducted by experts and scientists working at government-affiliated institutions (ICAR, Punjab Agriculture University, etc.).

We provide a comparative analysis of statistical differences in loss estimation between our analysis and contemporary literature (**Table 4.8**). In addition, these studies used different methods; therefore, we cannot compare them straight forward. However, they help assess the quantity of loss, and we can compare that with our results. The range of overall percentage of loss is 1.76-11.76 percent for wheat, 3-7 percent for rice, 1-4.6 percent for maize, and for soyabean it hovers around 6.26-9.96 percent.

In this section, we compare our results with some pioneer studies in this field as ICAR-CIPHET (2012&2015), Kannan (2014), FAO (2018c). For example, the estimated loss for rice (paddy) by

[19] Using the minimum support price (MSP) of the 2022-23, the MSP for paddy is INR 20000 per ton.

[20] Based on Directorate of economics and statistics paddy, maize and soybean production estimates figure for 2021-22.

Kannan (2014) was around 6 percent and 11 percent in the Government of India study in 1971 (cited in Jha et al. 2015). While FAO (2018c) estimates a 7.4 percent loss in two selected districts of Andhra Pradesh (East Godavari and Nellore), and the losses at harvesting &threshing, drying, transportation, storage at mills and storage at (CWC & FCI) warehouse were 6 percent, 0.2 percent, 0.5 percent, 0.3 percent, and 0.4 percent respectively. In other studies, the total loss estimates in rice are too varied and are not comparable because of the diverse definitions and measurement methods used (WRI 2021). Furthermore, the studies mainly focus on farm-level losses— there is no information on grain losses in the supply chain beyond the farm.

Table 4.8: T-test results of comparison of mean harvest and post-harvest loss in major literature in India and results of the present study ICRIER-ADMI 2022

S. No.	Study	Author	Year	Crop	Losses (percent)	Remarks
1	Assessment of Quantitative Harvest and Postharvest Losses of Major Crops/Commodities in India (CIPHET)	S. N. Jha R. K. Vishwakarma Tauqueer Ahmad Anil Rai Anil K. Dixit	2015	Paddy	5.53***(H)	Enquiry and Observation at the farm level
				Wheat	4.93***(L)	
				Maize	4.65***(H)	
				Soybean	9.96***(L)	
2	Assessment of Quantitative Harvest and Postharvest Losses of Major Crops/Commodities in India (CIPHET)	S.K.Nanda R.K.Vishwakarma H.K.V Bathla Anil Rai P.Chandra	2012	Paddy	5.19***(H)	
				Wheat	5.96***(H)	
				Maize	4.10***(L)	
				Soybean	6.26***(L)	
3	Assessment of Pre and Postharvest Losses in Wheat and Paddy Crops in Punjab	D.K.Grover J.M.Singh Parminder Singh	2012	Wheat	1.84	Farm Level data
		D K Grover	2012	Paddy	4.43***(H)	
			2013	Wheat	2.3	
4	Assessing postharvest losses in India	Panse Committee, GoI	1971	Rice	11***(H)	Cited in Jha et al.
				Wheat	8***(H)	
				Maize	7.5***(H)	
(H) indicates reported loss is higher than recorded loss in our study						
(L) indicates reported loss is lower than recorded loss in our study						

In this section, we further draw a comparison between our current study and the latest extensive pan India survey conducted by NABCONS in 2022, focusing on food losses across various agricultural operations and aggregations for the same state (**Table 4.9**). Our analysis reveals that, at an aggregate level, our estimation of paddy crop losses exceeds those reported in the NABCONS survey for the three studied states, with the most significant disparity observed in Bihar for paddy crop. When examining the data operation-wise, it becomes evident that the disparities in losses at the farmer level are more evident than the variations in quantity losses at the market level between these two studies.

Specifically, our research reveals that farmer-level losses for paddy are 1.73 percent higher in Bihar, 0.62 percent greater in Punjab, and 1.5 percent higher in Madhya Pradesh. It is important to note that while our study and the NABCONS study are comparable in terms of inquiry method of survey, they differ in terms of their geographic and agro-ecological region coverage. For instance, the NABCONS study for Bihar, which encompasses an average of 5 districts, including one of our survey districts, Rohtas, reported a farm-level harvest loss of 1.32 percent, which closely aligns with our estimation for Rohtas at 1.80 percent. However, in the case of our other survey district in Bihar, Muzaffarnagar, situated in the North alluvial zone of Bihar, we observe notably higher harvest losses due to lack of agricultural development and mechanization in that region. It is important to note that the NABCONS study did not include Muzaffarnagar, making state-level food loss figures non-comparable.

Table 4.9: Comparison of three studies on harvest and post-harvest losses (in percent) for Paddy across selected states by inquiry method (Farm level + Market level)

States	Study	Overall loss in percent
Paddy		
Bihar	NABCONS 2022	4.67
	ICRIER-ADMI 2022	6.95
Punjab	NABCONS 2022	3.25
	ICRIER-ADMI 2022	4.34
Madhya Pradesh	NABCONS 2022	3.45
	ICRIER-ADMI 2022	5.41
Wheat		
Madhya Pradesh	NABCONS 2022	4.20
	ICRIER-ADMI 2022	5.60
Maize		
Madhya Pradesh	NABCONS 2022	4.01
	ICRIER-ADMI 2022	4.94
Soybean		
Madhya Pradesh	NABCONS 2022	7.72
	ICRIER-ADMI 2022	12.19

Source: Authors' estimation based on field survey data, ICRIER-ADMI 2022, NABCONS 2022

The observed variations in Madhya Pradesh could also be attributed to the aggregation of data from different districts spanning various agro-ecological regions in the state to arrive at the state-level figures. For instance, when examining the data at the agro-ecological level, we note a substantial decrease in the overall loss of soybean crops from 13.16 percent in 2015, as reported by NABCONS, to 6.54 percent. Our survey did not cover the central plateau agro-ecological region and did not reveal a substantial decline compared to the previous ICAR-CIPHET study of 2015 for other surveyed agro-ecological regions of the state. Nonetheless, our study included one of the districts- Rajgarh in the Western plateau region of the state, which was also covered by the NABCONS study along with ten other districts for soybean crops. Here, we observed that our loss estimation is higher than that reported by NABCONS for that agro-ecological region, primarily due to differences at the harvest level. Given the disparities in regional coverage, making direct comparisons between both studies may lead to misleading conclusions. Where NABCONS study offers vast regional coverage and average of multiple districts, this study is more localized for assessing the losses. It is widely acknowledged in the literature that losses at the farmer level are highly localized and dependent on the specific cropping practices adopted by farmers.

4.5 Conclusion

Reducing harvest and post-harvest loss increase farmers' profitability and increase grain supplies for food security. Changing crop management practices through technological change and increase in awareness among stakeholders are two critical points for prevent loss in supply-chain. To control losses, it is important to accurately measure the losses across operations. Therefore, this chapter aims to estimate quantitative, qualitative, and economic losses of paddy, wheat, maize, and soybean from the survey of selected states in India.

Operation-wise disaggregation shows that, harvest loss at farmers' level comprises the largest share of total losses across all crops. However, within crops, soybean suffers the largest loss at 13.28 percent followed by wheat (8.53 percent), paddy (6.86 percent), and maize (6.54 percent). An important departure from the previous study is the assessment of quality loss of crops. In case of wheat shrivelling of grains, yellow rust etc. result in quality loss of crops. Untimely rainfall, heatwaves aggravate the loss quantity and quality.

The aggregate quantity loss at the farmers' end is 4.57 percent for paddy, 4.73 percent for maize, and 9.11 percent for soybean, of which loss during harvesting is 2.92 percent for paddy, 1.90 percent for maize, and 6.50 percent for soybean. The estimated loss in the market channels (transport, storage, wholesalers, and retailers) is 1.18 percent for paddy, 0.80 percent for maize, and 1.02 percent for soybean.

In addition to that, this chapter finds out that for paddy, wheat, and maize loss at farmers' level is significantly higher in observation method than the inquiry method, which indicates the actual losses is higher than perceived quantity loss. Finally, this chapter compares our harvest and post-harvest loss figures with contemporary literature, while for wheat, the estimation is not statistically different from some of the recent studies (Grover and Singh, 2012, 2013), other crops seem to face higher losses from our estimation. To reduce harvest and post-harvest losses, it is imperative to understand the associating factors of cropping practices, hence the next chapter traces the determinants of losses based on our farmers' survey.

5 Harvest and Post-harvest Crop Management Practices and Determinants of Loss

5.1 Introduction

The previous chapter describes the estimation of quantity and quality losses by inquiry and observation method from farm to market. As the findings indicate that loss at farmers' level is significantly higher than the market and retail level. In this context, in this chapter, we shall discuss the cropping practices in selected states for paddy, wheat, soybean, maize and trace the determinants of harvest and post-harvest losses at farmers' level based on our sample survey of 1200 agricultural households. Agriculture sector in India has wide variation in terms of technological change, use of different combinations of techniques, accessibility to inputs, scale of operations across states and regions (Agarwal, 1983). Green revolution brought a package of tools to augment the production level since the 1960s, but the pace of implementation is not the same across states and farm-size groups (Rosenzweig and Binswanger,1992; Mishra, 2008). However, green revolution has crop-wise, region-wide differences in impact.

During grain supply-chain at farmers' level, the crop goes through multiple stages from harvesting, threshing, winnowing, drying, storage, transportation, and marketing. During each stage the loss depends on the equipment used, the environment of the operation, the process of handling. Hence, a deeper understanding of these operations and associated losses provides a causal understanding of harvest and post-harvest losses. Here, we analyse these operations across crops and states based on our sample survey.

5.2 Harvest and post-harvest cropping practices at farmers' level for selected crops

5.2.1 Paddy

Paddy is the prominent food grain produced in India and plays a vital contribution in the agriculture economy. India is the second largest producer of rice in the world after China, producing 129.5 MMT of rice grains. With expansion of irrigation intensity and the green revolution package of HYV seed and fertilizer, the production in the country increased six times, from 20.58 MMT to 122.27 MMT in 2020-21. As the latest national level study on harvest and post-harvest loss by CIPHET exhibits that 5.53 percent loss of paddy, indicating loss of 9.12 MMT (1 kg of paddy=0.67 kg of rice). Traditionally paddy cultivation is labour intensive in India. Since the green revolution period of 1960s, expansion of mechanisation along with HYV variety of cultivation, increased irrigation intensity boosted the production of grain in the country. Punjab, the pioneer state of the green revolution in India, has the highest yield and comprises 10 percent of production. Owing to large subsidies in inputs, investment in machinery, rice production and yield have drastically increased in Punjab. There has been continuous increase in area under HYV rice in Punjab, the yield of rice in the state is 4366 kg per hectare, above the national average of 2566 kg per hectare. **Table 5.1** shows that the level of mechanisation is the lowest in Bihar compared to other two states.

Table 5.1: Rice profile of selected states 2021-22

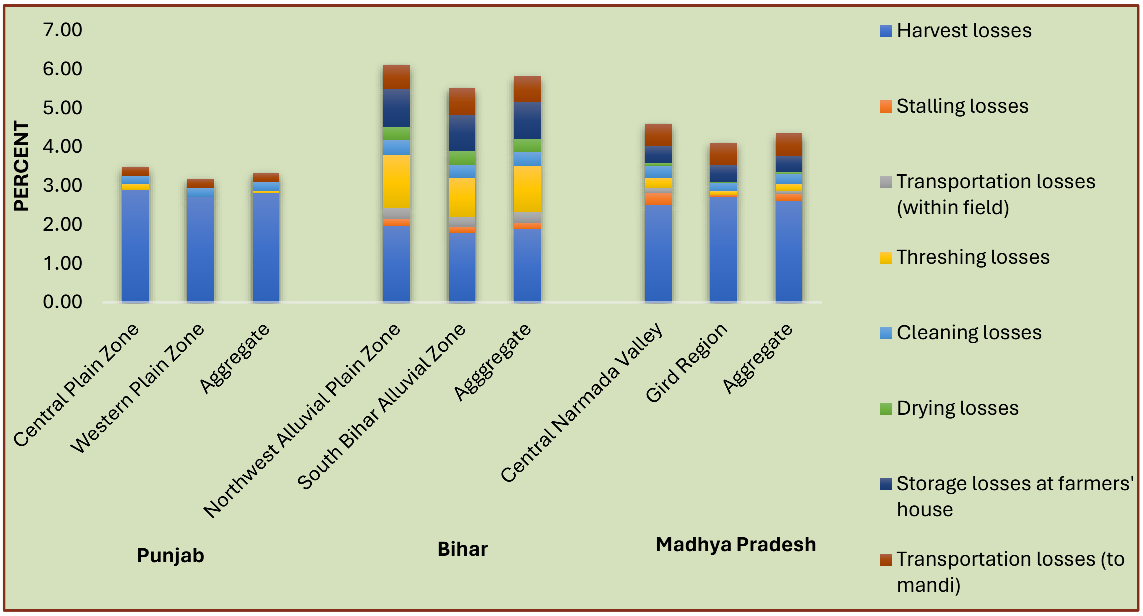
Selected states	Area in Mha.	Production in MMT	Yield (kg. /hectare)	Cost per ha#.	Cost of machinery per ha.	Procurement in MMT*
Punjab	2.93	12.78	4366	46203	10541	12.54
Bihar	3.02	6.75	2276	27774	4923	3.09
Madhya Pradesh	2.12	4.41	2061	34835	10073	3.07
All India	45.77	124.37	2713	43756	10500	57.58

Source: DES, FCI

*Notes: * 2021-22 KMS #for Paid-out cost for paddy per hectare*

Mechanisation has increased the technical efficiency and total factor productivity of farmers. Harvesting operation comprises cutting the stalks, and bundling up the lots from field. The operation-wise losses of paddy grain vary across states. For paddy, 97 percent households use combine harvesters in Punjab, whereas in Bihar only 10 percent paddy producing households use combine harvesters. Bihar has numerical preponderance of marginal and small farmers. Even though, farm-size distribution of the sample households is moderately skewed towards larger farmers of the state (76 percent of the sample are marginal and small farmers), the share of marginal and small farmers in the state is at 93 percent (Agriculture census, 2015-16). Lack of 'scale appropriate' machinery leads to persistence of labour-intensive cropping practices in the state. Disaggregated losses during harvest exhibits that threshing loss is very high in Muzaffarpur district in north-west alluvial agro-climatic zone in Bihar (**Figure 5.1**).

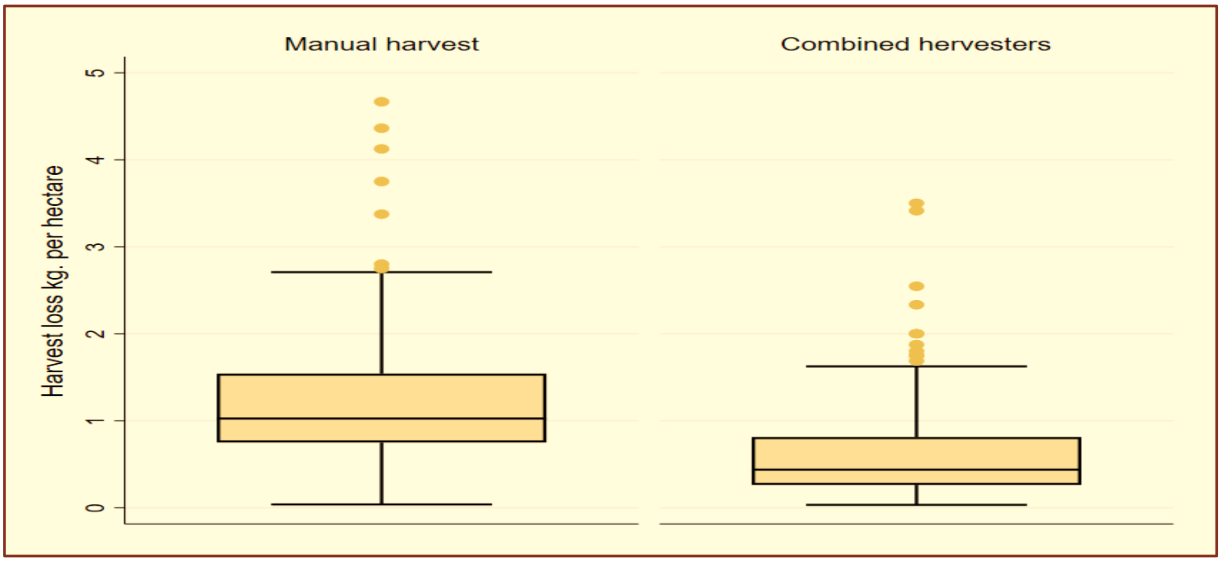
Figure 5.1: Operation-wise quantity losses for paddy across studied agro-ecological regions and states at farmers' level



Source: Authors' field survey, ICRIER-ADMI 2022

The activity profile of the farmers shows most crop grower use hired labour for farming activities. Moreover, 87 percent of the farmers in Madhya Pradesh and 79 percent in Punjab were aware about the right moisture content for harvesting but are traditional, like pressing the grains between teeth and looking at the grain colour. In Bihar, most farmers use threshers to thresh the crop-- because the land holding size is smaller and there is the unavailability of harvesters in the locality. However, residue burning is not a regular practice in Bihar, with 6 percent of paddy farmers doing it in the survey areas. In all surveyed districts, more men (70 to 80 percent) do the crop harvesting, collecting and threshing activities than women. On the other hand, more women (more than 80 percent) engage in manual cleaning, drying, and minor processing activities than men.

Figure 5.2: Percent of total loss among farmers using manual vis-à-vis combine harvester for Paddy



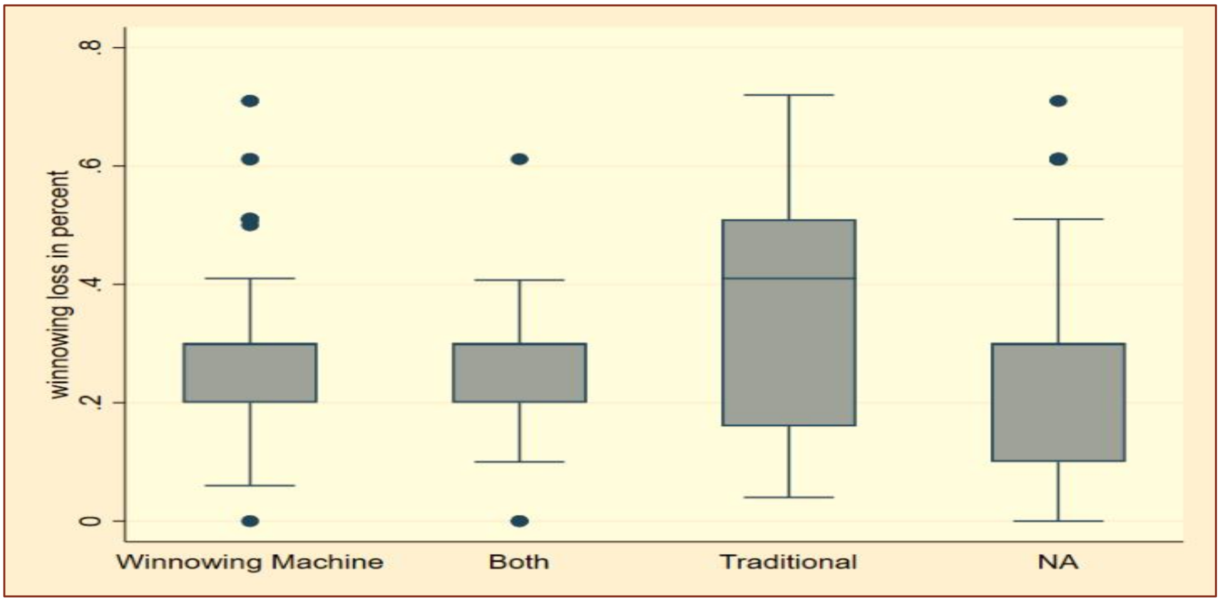
Source: Field survey data, ICRIER-ADMI 2022

The ANOVA analysis of variance shows that mean and variance of harvesting loss is significantly higher in manual harvesting compared to combine harvesters (**Figure 5.2**). Paddy harvest loss is also related to the harvest duration, mostly hired combine harvesters need to minimize harvest time as wheat is immediately sown after the paddy harvest. The losses of grain in developing countries are quite common due to lack of infrastructural facilities. The harvested crop before threshing is generally spread out on roads. Drying is performed by sun drying or mechanical drying. Sun drying takes longer time and also susceptible to get damaged in case of untimely rainfall and stronger wind flow. Drying process does not take place in Punjab's paddy field as combine harvesters cut the crop and thresh it followed by delivering the clean grain into the grain tank of the machine. After that the grain is directly sold in the mandi, where the grain gets kept for drying for a day or so before the storage. Whereas, in Bihar 100 percent of farmers faced drying loss with a range of .02 percent to .82 percent with mean of .34 percent and coefficient variation of 38 percent.

Threshing is the process of removing paddy kernels or grains from panicles. Manual threshing after drying paddy by paddles result in significant losses. As we discussed use of combine harvester is the least in Bihar, the average threshing loss in the state is 1.18 percent whereas in Punjab, the average of harvest loss by combine harvesters which include the threshing process is 2.89 percent. Across farm-size groups, threshing loss is higher among marginal farmers in Bihar due to usage of traditional threshing machine, usage of older machine damage the grains during the process. Around 24 percent of farmers in Madhya Pradesh faces threshing losses with a range between 0 to 1.01 percent. Whereas the range of threshing loss in Bihar is as high as 4.04 percent at upper boundary. The available data also shows that threshing loss appears to be higher in 1.37 percent in Muzaffarpur district of Bihar compared 1 percent in Rohtas.

After threshing by traditional machinery or combine harvester, threshed paddy is separated from straws, husk and chaffy material by the process of winnowing or cleaning. In Punjab 100 percent of agriculture households use winnowing machinery, whereas in Bihar only around 30 percent agriculture households manage to do so. Winnowing loss is significantly lower if winnowing machine is used, the mean winnowing loss is 0.21 percent in Punjab, whereas the value is 0.36 percent in Bihar. However, in Madhya Pradesh also, usage of winnowing machine is lower compared to Punjab resulting in 0.39 percent of loss during this operation on an average for paddy crop (**Figure 5.3**).

Figure 5.3: Winnowing loss across conventional and modern methods



Source: Field survey data, ICRIER-ADMI 2022

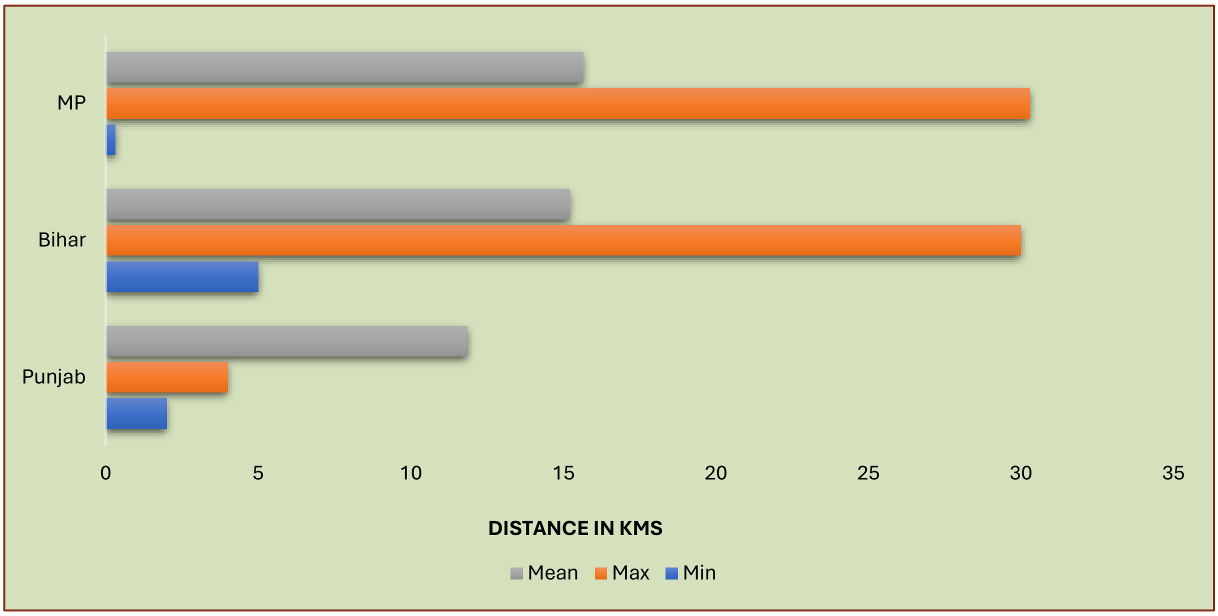
Punjab paddy farmers do not store their produce, after harvesting they directly sell it to procurement agencies or private traders. Hence, there is no storage loss at farmers' household level in the state. Around 98 percent of agriculture households reported no storing of paddy in Punjab. Whereas, in Bihar and Madhya Pradesh, all farmer households in the sample stored paddy grain. The average storage loss is the highest in Bihar, around 1 percent, covering about 18 percent of total harvest and post-harvest loss, contrary to that the loss percent is 0.43 percent in Madhya Pradesh. Difference in storage loss is due to lack of modern storage facilities available in Bihar. The average production of paddy farming HH is 68.7 quintals, and the average retention for self-consumption; therefore, storage in their house is 4.6 quintals in Madhya Pradesh. Of the 200 FHHs, over 82 percent use plastic and jute bags (including fertilizer bags) to store at their homes, while the others use drums and small metal silos., Most paddy farmers use dry neem leaves to protect their grains from mites during home storage.

In response to the question on storage facilities, farmers in Bihar said that they sell the crop after harvesting due to financial pressure and a lack of adequate storage facilities at home. In the surveyed villages, most farmers sell their crops immediately after harvest to meet household expenses and school fees and purchase seeds and fertilizers for the subsequent crop. The lack of storage and handling facilities at farmers' houses also motivates them to sell crops to reduce crop storage loss. However, price realization could be better for the crops after the peak harvest season.

Loss during transporting the grain to mandi depends on the mode of transport, handling techniques and distance from the field to mandi. Our results indicate that the correlation between transport loss and the distance from mandi is 0.28 for paddy in Bihar, interestingly, there is no correlation between these two variables in Punjab and Madhya Pradesh. Market density vary across the three states; however, our sample agriculture households of paddy show that the mean distance coverage for marketing grain output is the shortest in Punjab (11 km), followed by Bihar and Madhya Pradesh. Hence, the average transport loss is the lowest in Punjab at 0.22

percent, whereas in Bihar the loss during transport to mandi ranges between 0 to as high as 2.68 percent, with an average of 0.64 kg per quintal of paddy (**Figure 5.4**).

Figure 5.4: Mean distance from farmers' field to mandi across states



Source: Field survey data, ICRIER-ADMI 2022

5.2.2 Wheat

Wheat is one of the most produced and traded cereal in the world. India is the third largest producer of wheat in the world comprising 13 percent of 753 MMT of wheat production as of 2019-20, followed by European Union and China. Even though India has the largest share of wheat area of the world, yield gap is distinct from the top two regions of wheat production. Technological change and use of HYV variety ushered significant growth in wheat production in the country from 6.5 MMT in 1950-51 to 109.52 in 2020-21. Coming to the regional performance of wheat production Uttar Pradesh ranks first in terms of wheat production with 32 percent share of total production, followed by Madhya Pradesh (16 percent), and Punjab (15 percent). However, yield is the highest in Punjab at 4868 kg per hectare compared to other states above the India's average of 3521 kg. per hectare[21]. While augmenting yield is challenging, it is important to improve efficiency of wheat production by controlling losses during harvest and post-harvest operations. Literature indicates loss of wheat grains ranging between 1.84 percent to 8.1 percent based on large scale studies of the last decade (see Chapter 4, Table 4.9). Several studies estimated harvest and post-harvest loss in wheat crop, particularly focused on Punjab, one of the pioneer states to expand wheat production in India. One of the earlier studies in 1980s on Punjab estimated 9.06 percent of loss in wheat production, where 2.63 percent during harvesting, 1.50 percent during threshing, 4.34 percent during storage and 0.59 during marketing of grains (Gill et al., 1986). Over the years the harvest losses have declined in the state.

[21] The average yield in China is 5500 kg per hectare as of TE 2019-20.

Table 5.2: Wheat profile 2021-22

States	Area in MHa	Production In MMT	Yield (Kg/ha.)	Cost per ha. # (Rs.)	Cost of machinery per ha. (Rs.)	Procurement MMT 2021-22
Madhya Pradesh	6.08	18.18	2989	26927	9366	12.81
Punjab	3.53	17.18	4868	33690	12837	13.22
India	31.12	109.58	3521	31327	9985	43.34

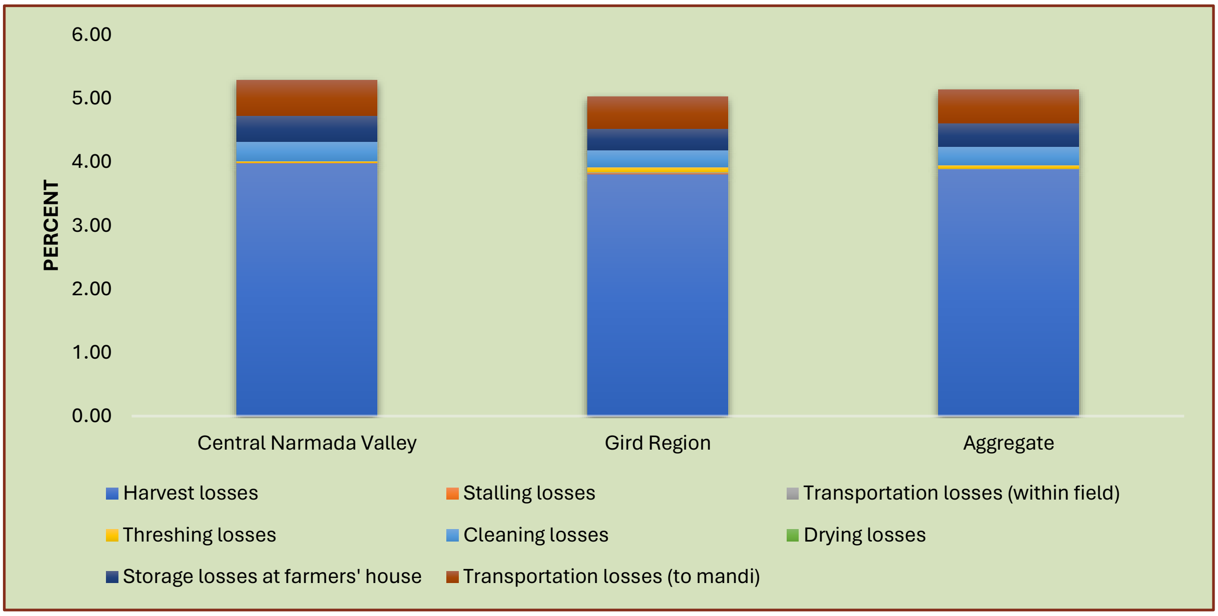
Source: DES, FCI Note: #for Paid-out cost

The present study analyses the crop management of wheat and associated losses in Madhya Pradesh based on the 200 agricultural households' survey. The analysis also takes up the case study of wheat loss in Punjab to address the impact of extreme climate events on harvest and post-harvest losses of wheat. Both the states are important in terms of wheat procurement and country's food security constituting 60 percent of procurement as RMS 2021-22.

In case of wheat cultivation, the average of total estimated loss at farmers' level in Madhya Pradesh was 14 kg per quintal, where the average wheat yield of the sample households in the state was 3285 kg per hectare. Within the state, yield vary across agro-ecological regions, Gird region has higher wheat yield, comparable to Punjab at 4247 kg per hectare, and the yield is at 3285 kg per hectare in Central Narmada valley agro-ecological region. The average percent of wheat grain loss in these regions are 4.70 and 4.54 percent, respectively.

Figure 5.5 shows that the loss during harvest operation comprises the largest share of loss in the state. Around 90 percent of farmers in Madhya Pradesh use combine harvesters for wheat crop. However, our result indicate that the percent of harvest loss is marginally higher among farmers using combine harvesters at 3.97 percent in comparison to 3.10 percent (10 percent of sample) for agricultural households using combine harvesters. The losses in wheat during harvest is high in case of late-harvesting and lack of awareness of right moisture content during the harvest.

Figure 5.5: Operation-wise quantity loss across selected agro-ecological regions in Madhya Pradesh for wheat



Source: Field survey data, ICRIER-ADMI 2022

Central Narmada valley region has higher use of combine harvesters, 96 percent of agricultural households use combine harvester for wheat, whereas the share is 85 percent in Gird region. In Central Narmada valley only 2.7 percent share of farmers do not use combine harvesters, whereas the share is 30 percent in Gird region. For wheat the rate combine harvester is around Rs. 2000 per hectare in the region, however, there is seasonal peak in demand of combine harvesters. Studies find out that combine harvesters from Punjab comes in the region and during pandemic period in 2020, there was shortage in availability of harvesting machine during wheat harvest. The activity profile of the farmers shows that around 77 percent use hired labour for farming activities—more wheat farmers hire labour to do farming activities. Moreover, 80 percent of the farmers know the right moisture content for harvesting but the method is traditional, like pressing the grains between teeth and looking at the grain colour.

At farmers' level wheat is stored for the next years' seed conservation and domestic consumption. Wheat grain suffers both quantitative and quality losses during storage, and the loss depends on the duration, and technology adopted for storage. Our case study of Punjab shows that, farmers store in steel drums or jute bags or in silos for bulk storage and there is not much of use of hermetic bag. Hermetic storage technology keeps the grain in airtight bag such as polyvinyl chloride bags (PVC), which increases the CO_2 concentration in the container and control the growth of insects in storage by maintaining optimum environmental condition of storages. Somavat et al. (2016) studied comparison among gunny bag, metallic bins and hermetic storage for wheat and rice storage in India. The study illustrates that hermetic storage had significantly lower infestation and maintained the grain quality better than traditional methods.

Use of chemical fumigants is a common method for storing grains in India, however, pests develop resistance over period against the same chemical fumigants (Nayak et al., 2003). In both the states, farmers use Celphos tablet to control infestation in storage. Our sample from Madhya Pradesh found that 79 percent of farmers use Celphos tablet dosage and 21 percent use neem leaves along with lower dosage of Celphos tablet, and storage loss is lower in the latter practice.

Madhya Pradesh has become one of leading state of wheat procurement under Decentralised Procurement Scheme (DCP) in the last decade and the state has good mandi network. The average marketed surplus is at 68 percent, whereas the shares are 75 percent and 61 percent in Central Narmada Valley and Gird agro-ecological regions, respectively. On an average the transport loss to mandi in the state for wheat grain at 0.53 percent, with range between 0.23 percent to 0.84 percent. All the farmers use trucks for transportation, however, covering the grain is not practiced which adds to the loss of grains during transport.

- ***Wheat loss in Punjab due to weather vagaries***

Climate change has increased the frequency of natural calamities and has made the agriculture operations more uncertain. In this context, the wheat production in India has suffered from unseasonal rain resulting loss in the production in Rabi season of 2023, shortly before harvesting the crop. We conducted a case study by direct interview of farmers Panglian Village, Ludhiana district, traders in Khanna grain market, scientists in Borlaug Institute of South Asia (BISA), and experts in Punjab Agriculture University to assess the intensity of wheat grain loss after the unseasonal rain of last three weeks of March, 2023. The field reports indicate qualitative loss and logistical issue of harvest rather than higher quantitative loss. Apart from yield loss, quality loss has also been a major concern due to shrivelled grain and loss of lustre due to discoloration of kernel.

Majority of the wheat harvest in Punjab is performed by combine harvesters either by owned or hired. The renting cost of combined harvester was Rs. 2,000 per hectare, and some regions where lodging was more, the rate spiked due to higher fuel energy consumption. Due to rainfall during harvest, the crop faced lodging. The stalling loss was higher due to inefficiency of combine harvesters to reap the crop at ground level. Our findings indicate that cropping practices impact the loss in grains during harvest. Farmers who practiced mulching and used Happy Seeder faced lower lodging, and even higher yield (about 24 quintal) after rain compared to farmers who did crop residue burning (CRB). The Happy Seeder directly drills the wheat seed into rice residues after the harvest, which results in early sowing and earlier maturation of grain in these fields. The mulch also helps to reduce weed biomass by 60 percent, increase organic carbon content, and controls evaporation from soil (Sidhu et al., 2007). In the milieu of more climate change events, cropping practices need to be modified to control losses during harvest and post-harvest operations. As our field observation indicates that farmers who practiced mulching, and avoided over watering in February month faced lesser lodging of kernels and shattering of grains.

As we find that at farmer level lodging was the major issue, higher moisture content is a challenge for storing the grains due to greater probability of fungal attacks. The permissible limit of moisture content determined by FCI is at 12 percent, which was relaxed to up to 14 percent for that years' procurement. Also, lack of shading infrastructure at market resulted in wetting of grain at mandi yard due to unseasonal rainfall. We visited Khanna grain market—the largest grain market of Asia, spread over 35 acres of land with more than 300 licensed commission agents. Cleaning of grain at market yard was being done manually, after unloading the sacks at mandi, resulted in loss of grains and addition of foreign matters during the process. Mostly gunny bags were getting used for carrying the grains in the mandi.

While rice is not much retained in Punjab at household level for domestic consumption, wheat is retained for self-consumption. Storage loss at farmers' level depends on the type of storage equipment, moisture contents in grains, Under the unseasonal rain circumstances, it is important to dry up the grains properly before the storage as microbial activities increase with higher moisture content. Higher grain moisture is susceptible to quick mould attacks, germination, and grain discolouration, eventually resulted in more quantity and quality losses during processing and storage. Our findings indicate that for storage, jute bags are used followed by fumigation of bags in godowns. Farmers at household level and in godowns, mostly use Celphos tablets to control infestation in storage of grains. However, overdose of chemical increases the residue level in grains and result in health hazard. Also, a higher moisture content in the wheat due to excessive rainfall might lead to more storage loss at the later period. Hence, it is important to expand mechanical drying of grains and use of hermetic

Source: Case study of wheat farmers of Punjab by authors, 2023

5.2.3 Maize

In India maize is cultivated both in kharif season (83 percent) and rabi season (17 percent). Even though maize production of India comprises 2 percent of global production, the production substantially increased in the country from 1.73 MMT in 1950-51 to 31.51 MMT in 2020-21 with an improvement of yield from 547 kg per hectare to 3195 kg per hectare during the period. Madhya Pradesh is the largest producer of maize in India comprising 13.8 percent of production TE 2020-21 (**Table 5.3**).

Table 5.3: Maize profile 2021-22

Maize	Area Mha.	Production MMT	Yield (kg/ha.)	Cost per ha.# (Rs.)	Cost of machinery per ha. (Rs.)
Madhya Pradesh	1.41	3.88	2763	38950	6773
India	9.89	31.65	3199	39599	9491

Source: DES, FCI. Note: #for Paid-out cost

Maize is largely produced in India as feed for livestock sector, hence augmenting yield and production are underlying for the growth of the sector. Kharif maize faces biotic and abiotic stresses due to rainfed agriculture (IIMR report, ICAR 2019). Here, we will discuss the operations of maize harvest and post-harvest management system in India and associated losses based on the sample survey of 200 maize producing households in Malwa agro-ecological region and Satpura agro-ecological region in the state of Madhya Pradesh. In our sample survey, farmers produce maize during kharif season and it is of 4-5 months crop, cultivated in June and harvested during October-November. The yields of maize are higher than the state average in Chindwada and Rajgarh districts of Malwa and Satpura agro-ecological regions of Madhya Pradesh at 34 quintal per hectare and 31 quintal per hectare, respectively. Chindwada is known as 'corn city' of India due to expansion of corn field and suitable climatic and soil conditions for corn cultivation. The loss at farmers' level ranges between 3.1 percent to 5 percent with a mean of 4 percent. The loss at farmers' level is marginally higher in Malwa region compared to Satpura agro-ecological region.

On an average sample households harvested 71.76 kg of maize, where the average holding size is 2.35 hectares. Harvesting loss comprises the largest share of harvest and post-harvest loss for maize as well, constituting 71 percent of total loss. Whereas for other crops, more farmers harvest mechanically, 90 percent of wheat farmers, followed by paddy (79 percent) and soybean (39 percent), for maize, all farmers in our survey regions harvest the crop manually. Farmers experience on an average 2.88 percent of total harvest loss, including stalling, threshing and transport within the field (**Figure 5.6**). Around 10 percent of households reported rainfall during harvest which increases the moisture content fosters the growth of microbial infestation during storage.

Figure 5.6: Operation-wise quantitative losses across selected agro-ecological regions of Madhya Pradesh for maize crop

Source: Field survey data

5.2.4 Soybean

Soybean known as *Golden Bean* is one of the major sources of oilseed in India. India produces 12.61 MMT of soybean oilseed with an average yield of 976 kg per hectare. Madhya Pradesh is the largest soybean oilseed producer state in India producing more than half of country's soybean production followed by Maharashtra, and Rajasthan. As discussed in the previous chapter area under soybean has declined from 24 percent share of GCA to 20 percent GCA spreading over 6.67 Mha (**Table 5.4**). The decline in area under soybean in the state is due to loss associated with weather events and marginal increase in area under paddy. Soybean is a kharif crop and associated with rainfall risks. The cost of cultivation of soybean in Madhya Pradesh has increased due to higher requirement of pesticides for more frequent pest attacks. Also, incessant rainfall many times create losses for standing crops in recent years.

Table 5.4: Soybean profile 2021-22

Soybean	Area Mha.	Production MMT	Yield (Kg. /ha.)	Cost per ha.# (Rs.)	Cost of machinery per ha. (Rs.)
Madhya Pradesh	6.67	4.27	639	23204	6950
Maharashtra	4.29	6.26	1460	40435	11019
India	12.92	12.61	976	27138	7683

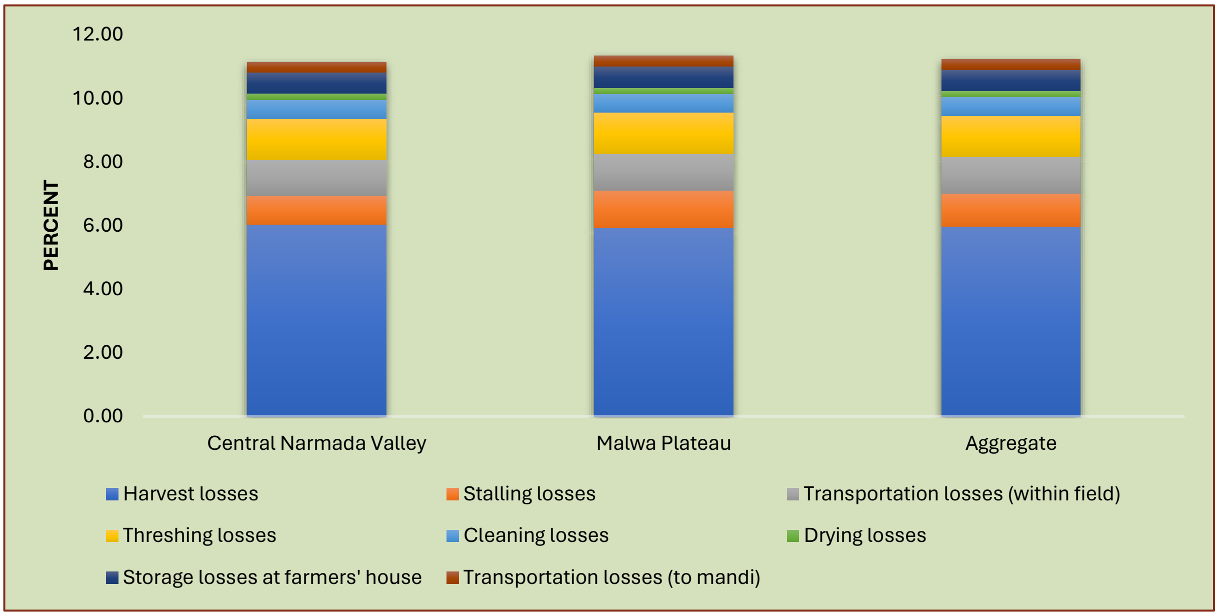
Source: DES. Note: #for Paid-out cost

Soybean crop faces losses during harvesting, storage, marketing operations. This section describes the harvesting and post-harvesting techniques and associated losses based on the 200-sample survey of soybean farmers in Madhya Pradesh.

Harvest, threshing and stalling comprise 87 percent of total loss of soybean harvest and post-harvest. Harvesting of soybean requires knowledge of right moisture content, which should not be more than 14 percent. As per our survey 78 percent soybean farmers reported that they were aware about the right moisture content. In terms of techniques used, we find that only 39 percent of the soybean farmers use combine harvesters and loss during harvest is significantly higher in manual harvesting than the farmers using combine harvesters. The range of loss during harvesting is between 6.8 percent to 13.8 percent for manual harvesters, whereas the upper limit is 10 percent for combine harvester users. In Malwa plateau-- Rajgarh district has been surveyed and the use of manual harvesting is higher than the Central Narmada region. The latter agro-ecological region is agriculturally advanced due to expansion of canal irrigation. The reason of higher manual harvesting in Malwa region is also smaller plot size. The average land holding area under soybean are 4.47 hectares and 2.27 hectares in Central Narmada and Malwa region, respectively. Harvesting of soybean is susceptible to weather condition and late harvesting result in more harvest losses. Around 33 percent of soybean farmers reported to harvest late in the state and 32 percent farmers experienced rainfall during harvest.

In most cases, harvesting by combine harvesters is common among the soybean farmers in the Bhopal districts. The study found that harvesting loss for those who used combine harvesters is lesser than for those who harvested manually—as there are a few farm operations such as field stalling, transportation to the threshing floor, and threshing do not include in mechanical harvesting. This may be due to crop variety unsuitable for harvester use (for example, JS 2034-a shorter variety soybean). As we observed most soybean farmers in Rajgarh harvested manually because it falls under a hilly area region, and the landholding size is unfavourable for mechanical harvesting mention the average holding size compared to state average of 3.38 ha. (**Figure 5.7**).

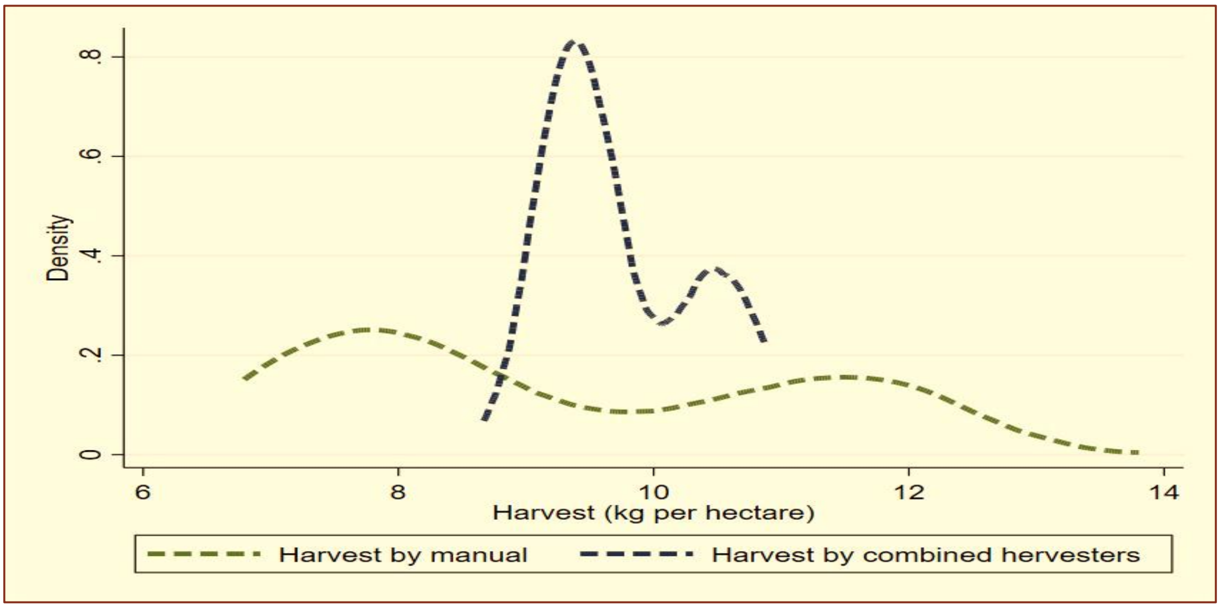
Figure 5.7: Operation-wise quantity loss at farmers' level across selected agro-ecological regions in Madhya Pradesh for soybean crop



Source: Field survey data, ICRIER-ADMI 2022

Figure 5.8 shows the density distribution of harvest losses of soybean for both the combine harvest usage and manual harvest. Farmers who practice manual harvesting have longer tail indicating the greater losses for them compared to combine harvest users.

Figure 5.8: Distribution graph (K-density) of harvest loss by manual and combine harvesters for soybean crop in Madhya Pradesh



Source: Field survey data, ICRIER-ADMI 2022

There is also principal-agent problem generating more loss during harvester operations. Studies found that who own harvesters face lower loss than hire combine harvester operators. Researches on Latin America about soybean harvest loss indicates older combine harvesters generate higher loss than new harvesters. Also, harvesters with radial mechanism have higher loss than axial mechanisms during soybean harvest. Soybean is directly sold to the market and farmers do not store the grain.

Farmers do not store soybean seeds for longer time and market the produce after harvest and most of them use tractor as mode of transport. Storage loss is around 0.66 percent at state level. The average distance to mandi from farmers' field are 17 kms and 13.7 kms in Central Narmada valley region and Malwa plateau region, respectively. While transporting the loss quantity is 0.33 percent of one lot or 0.69 kg per quintal in Malwa plateau and the same is 0.32 percent of one lot or 0.67 kg per quintal or 33 kg per sack (50 kg bag).

5.3 Determinants of harvest and post-harvest loss for selected crops

The study uses micro-approach to estimate harvest and post-harvest food losses in both quantitative and qualitative terms by observatory and inquiry method. This section focuses on the determinants of relative quantity loss (quantity loss per hectare) for four studied crops—wheat, paddy, maize, and soybean. The dependent variable is the total losses per ha. at farmers' level comprising harvesting, threshing, cleaning/winnowing, drying and storage losses.

- **Paddy**

We assess the determinants of paddy loss for the studied states and comprising all the samples at farmers' level. The coefficient estimates for the variables which provided significant results are presented for the four models in Table 5.4. The cross-sectional Model 1comprising all the samples' controls for state fixed effect to estimate the parameters. The linear regression equation is as follows:

$$Y = \alpha_0 + \sum_{i=1}^{3} \beta_i x_i + \mu \ldots\ldots (1)$$

In equation 1, Y is the loss kg per ha. for paddy at farmers' level comprising harvest loss, winnowing loss, drying loss, storage loss, and transport loss. Among input variables, x_1=total land under the crop in hectare x_2= secondary or above education, x_3= dummy of combine harvester usage. β_i is the vector of unknown parameter in linear regression model and determine how the change in independent variable impact the dependent variable, and μ is the error term, normally distributed.

We have also checked for multi-collinearity of independent variables for estimating the regression model by variance inflation factor (VIF). The value greater that 1.5 indicates multicollinearity. Variables which do not have multicollinearity are included in the model. The p value in the regression results indicates that acceptance or rejection of null hypothesis and the value lower than significance level shows enough evidence to reject the null hypothesis of no correlation.

The first hypothesis here is that marginalisation of land result in more losses of grains. The regression results exhibit that a one unit increase in area under crop is associated with 7 percent lower losses per hectare at significant level in Model1 (**Table 5.5**). Similarly, the increase in area under paddy is negatively associated with loss per hectare for Punjab and Bihar (Model 1&2). However, the extent of marginalisation of land is the highest in Bihar, where 76 percent of agricultural households are marginal and small farmers in the sample. A one unit increase in area under paddy leads to around 1 kg per hectare lesser losses of paddy grain in Bihar at statistically significant level. The mean loss per hectare for marginal farmers in the state is 3.5 kg per hectare, whereas it is 1.16 kg per hectare and 0.69 kg per hectare for semi-medium and medium farmers, respectively.

The results of the determinants of harvest and post-harvest losses indicate that the share of total loss per hectare is very high at farmers' level for grains due to adoption of different harvesting practices. The hypothesis here is that usage of combine harvester reduces total grain losses. The regression results show that the coefficient of usage of combine harvester is negatively associated with losses per hectare for paddy. Agricultural households using combine harvesters on an average faces 0.50 kg per hectare lesser losses compared to manual harvesting for paddy at statistically significant level (Model 1). For manual harvesting, losses are shatter loss, threshing loss, carrying loss whereas under mechanical harvesting cutting, threshing and winnowing are combined. Studies from other states and countries also found that loss is lower in mechanical harvesting compared to manual harvest. Even at state level, the coefficients for combine harvester usage also show negative and significant results for Punjab, Bihar, and Madhya Pradesh. In Punjab, the usage of manual harvesting leads to 1.32 kg per hectare higher losses at 1 percent significant level. Usage of combine harvester also reduces the harvesting time which has an influence on the grain losses. Labour crunch during harvest time creates pressure on farmers for timely harvesting. A study conducted by Kannan et al. (2013) found a similar result—a high quantity of grains loss per acre during late harvesting. Lack of mechanical harvesting results in increase in loss due to lengthy time required in manual harvesting and also susceptibility to natural calamity; like rainfall occurrences. The total over-all harvest and post-harvest losses is the highest in Bihar and only 10 percent paddy cultivating households use combine harvesters. The state level result shows paddy loss per hectare is 24 percent lower in mechanical harvesting using combine harvesters compared to manual harvesting in Bihar. Hence, the higher loss of grains in the state is mainly due to the harvesting practices. The cost of cultivation figures also indicate that the extent of mechanisation is very low in Bihar, machinery cost per hectare for paddy is Rs.4203 per hectare, whereas it is around three times higher in Punjab at Rs. 12,583 per hectare (DES, 2019-20). Hence, efforts should be made to expand usage of combine harvesters through custom hiring centres and 'uberisation of farm-machinery' to reduce losses.

Education profile reflects the awareness and knowledge of farmers. The regression result shows that secondary and secondary above educated farmers experienced lesser loss compared to primary educated farmers. The share of secondary or above educated farmers is also lower in Bihar (14 percent) compared to Madhya Pradesh (15 percent), and Punjab (36 percent). Higher education helps farmers for better knowledge capability for technological change and access to extension services. Awareness about harvest and post-harvest loss and dissemination of knowledge on technical know-how through training program by extension agents is pertinent to curtail harvest and post-harvest losses. Comprising all states, farmers with secondary or above education faces 13 percent lower paddy grain loss compared to farmers with only primary level of education.

Distance covered during transport of grains for the market is a key variable explaining total loss. The variable is not significant for Punjab and Madhya Pradesh due to higher market density, whereas the variable is significant for Bihar. As per the spatial spread of agriculture markets in India, market density varies from 0.32 - 0.84 per 1000 sq. km in Bihar, 0.85 – 1.43 per 1000 sq. km. in Madhya Pradesh, and 3.31 – 6.93 sq. km. in Punjab (Agmarknet). A one unit increase in distance from mandi increases paddy loss per ha. by 1.4 percent in Bihar. Our survey results also show that in Bihar, 61.50 percent used tractor as mode of transport whereas the share is almost 100 percent in other two states. Hence, expansion of market infrastructure and development of FPOs to aggregate the produce before transport may reduce losses of paddy grain in supply-chain.

Table 5.5: Regression results of determinants of harvest and post-harvest loss for paddy

Dependent variable= Quantity loss (kg per hectare)	**All states (Model1)**		**Punjab (Model 2)**		**Bihar (Model 3)**		**Madhya Pradesh (Model 4)**	
	Coefficient	**Standard error**	**Coefficient**	**Standard error**	**Coefficient**	**Standard error**	**Coefficient**	**Standard error**
Independent variables								
Area under the crop in ha.	-0.075*	0.006*	-0.062*	0.006	-0.983*	0.053	-0.069*	0.009
Secondary or above education (Yes=1, No=0)	-0.130**	0.063	-0.060	0.051	-0.096**	0.075	-0.127**	0.139
Use of combine harvester (Yes=1, No=0)	-0.509*	0.104*	-1.316*	0.165	-0.241**	0.126	-0.402**	0.171
Distance from mandi in km.					0.014***	0.004		
Constant	1.885*	0.085*	2.267	0.163	3.734*	0.102	1.732*	0.192
R squared		**0.401**		**0.508**		**0.648**		**0.209**
N		**600**		**200**		**200**		**200**

*Notes: P value representation: ***p< 0.01, **p <0.05, *p <0.10*

Inquiry at farmer level.

Source: Based on field survey data, ICRIER-ADMI 2022

- **Wheat**

To trace the determinants of wheat loss per ha., we used OLS regression model and the variables which provided significant results are tabulated in **Table 5.6** based on the sample survey in Madhya Pradesh where N is 200.

$$Y = \alpha_0 + \sum_{i=1}^{5} \beta_i x_i \text{.......} \ (2)$$

In equation 2, Y is the wheat loss kg per ha. at farmers' level combining harvest loss, winnowing loss, drying loss, storage loss, and transport loss. As explanatory variables, we used x_1=total land under the crop in hectare x_2= secondary or above education, x_3= dummy of combine harvester usage, x_4=distance from mandi, and x_5=add neem with Celphos tablet during storage. β_i are the vector of unknown parameter needs to be estimated from the model and α_0 is the error term, normally distributed.

Increase in farm-size has advantage of scale of production, as one unit increase if area under the crop reduces the wheat loss per ha. by 13 percent at significant level. This negative association of area and loss, indicates that efficiency of production is higher at larger farm-size in terms of controlling losses. Hence, losses per ha. is minimum for wheat in Madhya Pradesh, the finding is in line with Grover and Singh (2012) study on harvest losses of wheat in Punjab.

Concerning the impact of education level of farmers on wheat losses show that, farmers having secondary or above education face 1.8 percent lower loss compared to farmers having only primary education. Education of farmers indicate the awareness of farmers on the duration of harvesting, access to information like weather related events, and capacity to adopt technical skills. For wheat crop, the usage of combine harvesters indicate negative but not significant association, as 90 percent of the sample farmers use combine harvesters, however, there is distinct range of loss among combine harvester users due to differences in age of machine.

For wheat, the distance from mandi is positively and significantly associated with wheat grain loss per ha. One unit increase in distance from mandi result in 4.3 percent higher loss per ha. in the state at significant level. On an average the mandi distance needs to be covered by sample farmers for marketing wheat grains in Madhya Pradesh is 14.8 km., even though farmers use tractors for transport, the physical losses during transport increases with distance. However, the correlation between this variable is not very strong, at 0.21, indicating the other factors like packaging and transport equipment are also associated with losses of grains.

Storing practices vary across states—unscientific storage practices lead to weevils and other pest attacks in storage. The regression result indicates that addition of neem with Celphos tablet reduces the overall losses, as the neem acts as natural agent to reduce pest attack in storage.

Table 5.6: Regression results for determinants of wheat loss at farmers' level

Dependent variable= loss pe per ha.	Coefficient	Standard error
Independent variables		
Area under the crop in ha.	-0.130***	0.023
Secondary or above education (Yes=1, No=0)	-0.018*	0.012
Distance from Mandi in km.	0.043**	0.018
Add neem with Celphos	-0.964***	0.315
Constant	2.821***	0.437
R squared	0.230	
N	200	

*Notes: P value representation: ***p< 0.01, **p <0.05, *p <0.10*
Inquiry at farmer level.
Source: Based on field survey data, ICRIER-ADMI 2022

- **Maize**

This section traces the determinants of maize losses among sample farmers in Madhya Pradesh where N=200. The results of the OLS regression to determine losses of maize per ha. is summarized in Table 5.7. The independent variables explain 37 percent of variation in the model.

$$Y = \alpha_0 + \sum_{i=1}^{4} \beta_i x_i + \mu \ldots\ldots (3)$$

In equation 3, Y is the maize loss kg per ha. at farmers' level. As input variables, we used x_1=total land under the crop in hectare x_2= secondary or above education, x_3= use of family labour or hired labour, x_4= events of early harvest. β_i are the vector of unknown parameter needs to be estimated from the model and μ is the error term which is normally distributed.

The average holding size of maize crop based on the sample is 3.38 hectares, where 58 percent farmers are marginal and small farmers. The regression results exhibit that with increase in farm-size, the mean of loss kg. per ha. reduces at significant level. One unit increase in area under maize, the loss reduces by 0.36 kg per hectare. Higher loss in small-scale farming system in maize cultivation may be due to lack of adoption of handling techniques by small farmers.

Those farmers with lesser education level face more losses, on average farmers get 35 percent higher losses per ha. who do not have secondary or above education qualification levels. The finding is in line with literature on determinants of harvest and post-harvest of maize crop in African countries, which show that increased years of education and skill among farmers reduces loss generation (Kuenning et al., 2022).

In terms of usage of labour, the result indicates that farmers relying on family labour face higher losses by 39 percent compared to hired labour run farms. This may be due to longer time required for family farms to harvest resulting in higher shattering loss for maize. Maize harvest and post-harvest management is labour intensive as it is entirely manual (handpicked or by machetes) in the surveyed region. Also, the loss is related to the timing of harvest. In case of early harvest, loss is substantially higher than timely harvest due to higher moisture content in maize cob and longer time to dry the shells. The overall loss per ha. is 0.43 kg higher if harvested early compared to on-time harvest of maize.

Table 5.7: Regression results for determinants of maize loss at farmers' level

Dependent variable= loss kg per ha.	Coefficients	Standard error
Independent variables		
Area under the crop in ha.	-0.291***	0.039
Secondary or above education (Yes=1, No=0)	-0.382*	0.198
Use of combine harvester (Yes=1, No=0)	-1.674***	0.207
Constant	5.514***	0.351
R squared	0.265	
N	200	

*Notes: value representation: ***p< 0.01, **p <0.05, *p <0.10 | Inquiry at farmer level.*
Source: Based on field survey data, ICRIER-ADMI 2022

- **Soybean**

This section investigates the determinants of soybean loss in Madhya Pradesh at farmers' level. Table 5.8 presents the regression results of empirical model of soybean losses per ha. based on the 200 sample farmers.

$$Y = \alpha_0 + \sum_{i=1}^{3} \beta_i x_i \ldots\ldots (4)$$

In equation 4, Y is the soybean loss per ha., whereas x_1=total land under the crop in hectare x_2= secondary or above education, x_3= dummy of combine harvester usage.

The results of regression model for soybean also indicate significant and negative relationship between farm-size and loss per ha., keeping other variables constant. The findings underline the fact that economy of scale of production reduces harvest and post-harvest losses. One unit increase in area leads to reduction of the loss per ha. by 29 percent at statistically significant level. The obtained findings are in line with literature in South Asian and Latin American countries.

Education level has a positive impact on harvest and post-harvest management. As noted for other crops as well, the regression result assesses that farmer who has secondary or above education level manages to reduce harvest and post-harvest losses by 0.38 kg per ha. on an average. The effect of education may impact the awareness of farmers about the losses and adoption of technological change which result in reducing harvest and post-harvest losses. Delgado et al. (2021) also highlighted that socio-economic background, particularly education level plays a key role to reduce harvest and post-harvest losses.

The major contributing factor with the higher magnitude of coefficient to explain losses is the usage of combine harvester for this crop in OLS regression model. Agricultural households who use combine harvesters on an average experience 1.67 kg per ha. lower losses compared to farmers who do not use combine harvesters. This result may indicate that grain loss in manual harvesting results in more due to shattering of grains. As discussed in earlier section, total loss percent is the highest among four studied crops for soybean at 10 percent. The drying pace of grain is quite high in soybean and manual harvesting takes longer duration compared to mechanical harvesting.

Table 5.8: Regression results for determinants of soybean loss (kg. per hectare) in Madhya Pradesh

Dependent variable= loss kg. per ha.	Coefficient	Standard error
Independent variables		
Area under the crop in ha.	-0.360***	0.039
Secondary or above education (Yes=1, No=0)	-0.356**	0.198
Use of Labour (Family Labour =1, Hired Labour =2)	-0.398**	0.207
Early harvest (yes=1, no=0)	0.437**	0.194
Constant	4.153***	0.354
R squared	0.370	
N	200	

*Notes value representation: ***p< 0.01, **p <0.05, *p <0.10*
Inquiry at farmer level.
Source: Based on field survey data, ICRIER-ADMI 2022

5.4 Conclusion

The chapter analyses the harvest and post-harvest management practices and factors associated with losses for paddy, wheat, soybean and maize crop in selected states India based on the sample survey farmers. We note three major findings from the analysis.

First is that the total loss per ha. reduces across farm-size, which is very pertinent to note in the context of India. The greater extent of marginalisation of land result in greater losses for all the studied crops. The association is stronger in Bihar, where the marginalisation is higher compared to other two states. Scale of operation has advantage at both harvest and post-harvest supply chain. The finding indicates the need of land consolidation for better efficiency concerning management of grain losses. Also, aggregation of output may reduce transport loss for marginal and small farmers.

We also identified that higher years of education of farmers is likely to be associated with lower losses. The education level of farmer who attended secondary and above education impact the harvest and post-harvest losses, implying that better education helps the farmer to understand the technical skills of crop management practices. The education level also plays a key role for bringing awareness among the farmers to minimize losses.

Our findings in line with contemporary literature confirms that usage of combine harvesters reduce the harvest losses. As the machine complete the task of reaping, threshing, stalling, and transport at the field at one time, the loss is much lower than individual operations in conventional method. However, the usage of combine harvesters also show a range of harvest losses indicating the lack of proper application of the machinery; like duration of harvesting, header vibration, improper adjustment of header, age of the machinery etc. Farmers also narrated that the poor road connectivity creates inconveniences for the machine owners to go inside the farms. The cross-sectional analysis postulate that poor adoption of farm mechanisation in Bihar, resulting the highest grain loss in paddy compared to Punjab and Madhya

Pradesh. Lack of usage of combine harvesters is largely due to small plot-size and lack of 'small-farm friendly' machinery.

In addition to that, we find that the timing and moisture content of grain during harvest are also crucial, at lower moisture content, wheat grain shatters, whereas higher moisture content increases the probability of fungal attacks. For maize crop also, loss is higher when the farmer harvest early. Our findings also show that extreme climate events impact the harvest and post-harvest losses, hence adaptive cropping practices is needed to achieve the sustainable development goal of efficient production pattern. At storage level, there is no usage of hermetic bags, hence promotion on farmers adaptation of hermetic storage technology is pertinent to keep the moisture of the grain intact and reduce the probability of insect infestation more than conventional storage. The policy implications of our findings are discussed in the next chapter.

6 Conclusion and Policy Recommendations

6.1 Major Findings

The paper estimated the harvest and postharvest physical losses (quantitative and qualitative), comparing farmers' declarations with those based on field observations in wheat, paddy, maize and soybean for Madhya Pradesh, Punjab and Bihar in 2022-23. In addition, this research also focuses on the monetary loss due to food grains' disappearance from their supply chains. The study presented an improved methodological design to justify the objectives for a comprehensive loss assessment across the supply chain.

A substantial part of the study methodology for quantitative loss estimations is broadly in line with those available in Jha et al. (2015), APLISH (2014), and FAO (2018). However, we have improved the methodology, assessed economic loss by wholesale price and percentage grain-quality loss data, and converted them into quantity terms. The latter approach is unique, unlike the studies available in India. The report's finding shows that the estimates based on objective measurements tend to be consistently higher than farmer's interview-based estimates, consistent with the result of the FAO 2018 field test report. However, the weak correlation between the two sets of loss estimation data (farmer interview-based viz-a-viz objective measurement) needs further research to substantiate the findings.

Direct measurement method of data collection in the farmers' field and market channels is challenging. It involves several skilled persons, experienced data collection teams, and well-defined questionnaires that best fit the local context and reflect actual farming practices. In addition, adequate training and pre-testing data collection tools are also necessary, especially when a study requires objective measurement methods for data collection. For example, we faced several real-time technical issues during the survey due to the lack of a professional data collection team and well-educated respondents. Sometimes, the malfunctioning of the instruments delayed some measurements and affected the data collection activities.

The study finds the following factors contributed to the harvest and postharvest losses. On the on-farm operations, factors like labour skill, farmers' age, education level, experience in crop cultivation, moisture content, weather conditions, state of the on-field crops (whether standing or laying of the surface), use of quality or defective machinery (or poorly customized), quality of roads among others contributed to losses. On the other hand, in the marketing channels, factors influencing grain loss are quality of transport system, types of road connectivity, en-route leakages due to open lorry transport vehicles, poor quality packaging materials, level of moisture, length of storage, use of iron hooks, improper storage practice and picking several samples from the grain bags, etc.

6.2 Policy Recommendation

To meet the growing future food demand, we need to increase food production substantially while making distribution channels more efficient and reducing losses to enhance food availability and accessibility. However, the scope for the required production level is limited as we have limited resources/inputs in hand, as discussed in section one of this report. Thus, reducing harvest and postharvest food losses and improving food distribution channels are critical to ensuring future global food security. There are several policy implications of our findings to reduce harvest and post-harvest losses.

6.2.1 Technical guidance for farmers to minimize losses

Our analysis shows that farmers with secondary and above education have association with lower harvest and post-harvest losses. More awareness programmes for the farmers and labourers during harvesting can make roads to reduce loss at the crop production points. Increase in extension services might improve the technical know-how of the farmers regarding crop management practices.

6.2.2 Expansion of use of combine harvesters

The adoption of harvesting machinery is uneven across Indian states. The present study finds out that only 10 percent farmers in Bihar uses combine harvesters. The regression results indicate that usage of combine harvesters is negatively associated with losses at farmers' level for paddy and soybean at significant level. Several studies found that losses reduced to 0.3 percent in rice, 0.4 percent in maize, 0.75 –1 percent in soybeans, and 1 percent in wheat with combine harvesters use (Paulsen, Kalita and Rausch, 2015). A study in Bangladesh shows that the benefit-cost ratio of combine harvester use for harvesting paddy is 1.55. Harvesting cost and labour savings in combine harvester were 57.61 percent and 70 percent, respectively (Hasan et al., 2019).

Due to the high costs of these machines in India, combine harvesters are mainly owned by merchants and private parties and rented out to farmers. Custom Hiring Centres (CHC) perform around 90 percent of harvest operations in the more mechanized states like Punjab and Gujarat than in other states. Although it may not be financially feasible for small and marginal farmers in the country to own these machines, the Farmer Producer Organisation (FPO) can encourage group leasing and place the liability of making lease payments on the group instead of individual farmers.

The government of India has taken several initiatives, such as the Sub-mission on Agricultural Mechanization (SMAM-2014), Agriculture Infrastructure Fund (launched in 2020), to improve the postharvest infrastructure. However, a lot needs to be done in the form of additional investments in research to understand the critical loss-making hotspots and then strengthen them. By enhancing the adoption of farm mechanization for on-farm operations such as harvesting and threshing, we can prevent postharvest losses substantially.

6.2.3 Maintenance of machinery to reduce loss

The study also exhibits a range of harvest loss among combine harvester users, from 2.15 percent to 4.03 percent for paddy and 2.80 to 5.51 for wheat. Farmers' price elasticity of demand for renting-in harvesting and post-harvesting equipment is high--the lower the rental price higher is the demand. So, the equipment owners supply older and defective equipment at relatively lower rental prices than the newer ones. However, most farmers believe older or faulty equipment causes more quantity and quality losses than newer ones. So, firstly, the government must ensure the quality from the supply side during the production of agricultural equipment. Secondly, experienced quality check experts regularly inspect machines twice to three times during harvesting time. Finally, the government must enforce a maximum number of years a particular equipment can operate and subsequently scarped to minimize grain losses.

6.2.4 Technological change in storage of grains

As we saw in our previous section, storage at farmers' houses exhibits more losses than in the market channel storage facilities. It is because most farmers use traditional storage methods, unlike the modern storage facilities available in the market channels. For example, even if farmers use steel silos for storage –they can store a small amount for their self-consumption. But, on the other hand, bigger silos are costly, and resource-poor farmers cannot afford the facility. Many small and marginal farmers often store grains in their residential units to sell them at a lucrative market price later. An appropriate grain storage solution – cost-effective, easily storable and transferable – can help such farmers. The storage method must maintain constant humidity as a vital part of the dry chain. We can achieve the result through the use of modern hermetic storage methods. Hermetic storage methods place an airtight seal around grain, creating an internal environment that controls insects and other pests and moisture.

One of the most effective ways for farmers to reduce postharvest losses is using hermetic bags. With the ability to create a hypoxic environment, this technology minimizes losses by creating unfavourable conditions for the development and reproduction of insects. Standard hermetic technologies include silos (metal and plastic), drums, cocoons, and airtight plastic bags. Many agencies promote this technology for smallholders in sub-Saharan Africa and Asian countries. For example, the two most common hermetic bags, Purdue Improved Crop Storage (PICS) bags and Super Grain Bag, have recently gained popularity among smallholder farmers in developing countries. Between 2007 and 2019, around seven million farmers used PICS bags across 35 countries worldwide, using more than 20 million bags. As a result, they saved USD 1.5 billion (Baributsa and Ignacio, 2020). These bags range from USD 3 to USD 5.3 for a 90 kg capacity with two to four years of durability (CIMMYT, 2011). PICS bags are now available for less than USD 2, and their prices have decreased. Besides, airtight bags are now manufactured in India by companies such as Save Grain Advanced Solutions Private Limited, based in Pune, Maharashtra. Shukla, Baylis and Pullabhotla (2019) conducted a cost-benefit analysis study in Bihar and its impact on the on-farm hermetic storage technology. They found that hermetic bags use improved the farmers' income by Rs 117.25 per 50 kg, assuming the entire stored produce sold out in the market. Also, on average, a farmer could cover the total cost of an airtight bag in one agricultural season.

There are several studies in other countries on the impact of hermetic storage to reduce storage losses. In Niger, cowpea was stored in conventional and hermetic bags for five months under normal conditions. The results showed that PICS bags had 40 percent more grain weight per 100 cowpea grains when compared to the conventional woven bags (Manandhar, Milindi and Shah, 2018). An experiment shows, in Bangladesh, the moisture content remained constant (14 percent) in GrainPro and PICS bags throughout five months' storage time. In addition, these bags were airtight, and the stored produce did not absorb atmospheric moisture (Hossain et al., 2019). A similar study conducted by ADMI in Haryana (2015) found silo bags to be the most effective pest control and moisture loss compared to metal bins and jute bags. Overall, hermetic technology is effective as conventional fumigants. It made the presence of pests and insects almost negligible, with merely a 0.15 percent loss in weight over 15 months (Said and Pradhan, 2019).

The Jute Packing Material Act, which makes it mandatory for the packaging of 100 percent of food grains and 20 percent of sugar in jute bags, results in food loss. These bags are susceptible to attack from pests and insects and contamination through mycotoxins which adversely affects the quantity and quality of the produce. We need to revisit and rectify these policies by removing restrictions on packaging food grains in jute bags and encouraging hermetic bag use for better loss reduction in the storage and distribution system.

Using metal silos in the grain storage and distribution chain helps ensure food security for smallholder farmers who can feed their families year-round and have the flexibility to sell the surplus harvest later. Grains can be stored in these silos for three years without damage (SDC, 2008a). These silos are available in a range of sizes, thus enabling farmers to keep as much grain as possible. An improvement in grain's qualitative and nutrient value is ensured through reduced usage of insecticides and sealing off rodents and insects. In most developing countries, the metal silo has improved the status and empower women farmers as they primarily own and manage the product in a silo (SDC, 2008a). In a few sub-Saharan African countries, we found that engaging rural youth in manufacturing this silo created an additional source of income for their family, especially during the lean season in agriculture.

However, one of the major obstacles associated with adopting silos is the requirement for higher initial investment. An economic analysis of advanced storage structures showed the benefit of using a metal silo instead of a polypropylene bag. By spending USD 171 (1.8-ton capacity) to USD 316 (0.36-ton capacity) as an initial cost of the silo, farmers could save up to USD 100 per ton of grains after 12 months of storage. (Kimenju and Hugo, 2009). Also, the technologies associated with these storage systems require higher technical skills and capital investment, which makes it infeasible for a smallholder farmer in developing countries.

Chowdhury et al. (2021) conducted a study to analyze the financial feasibility of silos with a capacity of 5000 MT and compare them with conventional warehouse storage for paddy crops in Bangladesh. It showed that storage in jute bags in warehouses or homes outperformed modern technologies regarding financial returns at observed prices. However, although silos or hermetic cocoons ensured almost no losses of grains, we can think of facilitating such modern storages through public sector co-investment. An economical alternative is community-level silos which reduce the cost per unit of grains due to a larger capacity. In addition, the maintenance cost is also relatively low, thus compensating for the higher initial investment.

6.2.5 Strengthening rural infrastructure and market channels

As the study shows distance from mandi result in higher losses, particularly for paddy in Bihar and also significant is Madhya Pradesh for wheat. In Punjab, the market channels are relatively developed compared to Bihar; therefore, we observed more losses in Bihar at the market channels. The unavailability of administrated farmers' markets also leads to higher monetary losses for farmers. FCI does not operate in Bihar, so the Primary Agriculture Credit Cooperation Society (PACCS—state government-supported society) procures grains. On the one hand, delays during selling cause quantity and quality losses; therefore, middle agents buy at a lower price. We overserved up to 15 percent of monetary loss to farmers over the government-administered price. Hermetic technologies over traditional jute bags may reduce grain loss at several storage points. For example, some studies show that airtight (sealed) bags can reduce grain losses by minimizing pest attacks. The government may endorse hermetic bags through FCI and other public-sector warehouses by providing subsidies to farmers to cover a fraction of the costs of these bags. It is part of the solution. In addition, the government should create modern storage facilities like the 'Adani Agri Logistics' storage silos to ensure long-term food grain quality preservation. We need to dry the grain to maintain the proper moisture in the grains before storage. Most farmers in India do sun drying as we do not have mechanical grain dryers. So, we must invest in this direction to reduce losses at the drying level.

6.2.6 High-Speed Air Clean Machines to reduce drying loss

We find that most farmers still rely on open-air/sun drying, which is costly due to higher labour expenses, exposes the grain to contamination and losses, and is often unreliable, especially in adverse weather conditions such as rain. Although widespread in farming circles, this cleaning method does not eliminate heavier impurities (gravel, foreign grains, earth (FAO Manual). Removing these foreign matters is critical to improve the drying and storability of grain, reduce dockage at milling, and improve milling output and quality; seed cleaning will reduce damage by disease and improve yields. Therefore, it becomes critical to the quality of the final grain, seed, feed, or food product, reducing the chances of insect infestations and mycotoxin contamination. Unfortunately, most farmers cannot buy automatic cleaning machines—that can easily remove the heavier matters from the grain. Therefore, the government must find the best way to install high-capacity and high-speed cleaning machines at Mandi levels.

We must dry the cereals to a moisture content of under 14 percent from a harvest moisture level of more than 20 percent to avoid severe deterioration in storage. Therefore, improved grain drying is the first step in creating a dry chain. However, many options exist for improved drying through small-scale dryers that farmers could use and larger-scale dryers that farmer organizations or aggregators might supply.

For example, studies in Bangladesh show that BAU-STR dryer use as a small-scale LPG or charcoal-fuelled dryer technology can reduce postharvest drying loss by 2.5-4 percent compared to traditional sun drying methods. Farmers widely use the EasyDry M500 in sub-Saharan African countries like Kenya (Walker & Davies, 2017). Solar bubble dryers also showed effective results for smallholders in some contexts. The purchase price of these dryers is approximately Rs 1,60,000, with a use-life of around ten years and a payback period of 3.47 years. A cost-benefit analysis by the International Rice Research Institute found that Southeast Asian countries can reach a breakeven point if individual farmers use the dryer with two hectares of rice fields and two crops yearly. Where aggregation is possible, large-scale mechanical dryers can reduce drying costs and are often closely linked to climate-controlled storage facilities.

6.2.7 Role of Custom Hiring Centre and Uberization of farm machinery

According to the Agriculture Census 2015-16, around 85 percent of farmers are small and marginal. They do not have costly agriculture buying capacity. Therefore, to deal with these regional variations in losses with higher losses in less mechanized states, the government must first come in and make machinery available to the resource-poor farmers at affordable rates. Second, an "Uberization" platform can provide farm machinery for small and marginal farm holders. Third, the above thought process will be helpful for the states where mechanization of operations is dependent on machinery borrowed from other states, leading to more losses due to a lack of on-time availability of farm machinery. For example, the BIMARU states rely on the combine harvesters from Punjab and Haryana during the harvesting seasons; when this does not reach on time, losses escalate due to late harvesting (CIPHET, 2015). Thus, the small and marginal farmers can neither afford to purchase new machinery nor can they receive services on time.

Data shows that Punjab's greater mechanization led to relatively lower losses among the selected states for this study. However, the poor status of CHC[22] and farm tools availability (per 1000 hectares) in Madhya Pradesh and Bihar led to more losses, reinforcing the link between farm mechanization and food loss. In addition, we found in the literature that the losses are more in the states with a low level of mechanization than in the more agriculturally advanced states.

Uberization of farm machinery can fill this service gap. Cab services like Uber and Ola have become household names that bring cabs to your doorstep at a button. We can think of this mechanism to provide farm equipment to the farmer. Uber has its circle of drivers who affiliate themselves with the company and provide doorstep cab service. In the case of Indian agriculture,

[22] However, there is an uneven penetration and presence of CHCs and implements in different states. At the same time, 12.9 percent, 10.9 percent and 20.4 percent of the total app users belong to Bihar, Rajasthan and Uttar Pradesh, respectively[3], and the per hectare availability of CHCs and implements is relatively low in these states. For example, Bihar has only 0.13 CHCs and 0.18 implements per thousand hectares. Rajasthan has 0.09 CHCs and 0.19 tools compared to the highly mechanized states of Punjab and Haryana, which have 2.69 and 2.01 CHCs, and 2.12 and 6.57 implements per thousand hectares, respectively. It further emphasizes the need for mechanization in states like Bihar and West Bengal.

farm machinery's underuse led to overcapitalization. For example, only 50-60 percent utilization of tractors (1000 hours per year) illustrates this (Gulati & Juneja, 2020).

Moreover, machinery is used in a limited time window of a particular activity, so owning different implements for multiple operations is economically unviable, especially for small farm holders (ibid). If farmers who own machines could rent their service to non-owning farmers on demand through an 'Uber-like' set-up, this would be a win-win for all (Report of the Committee on Doubling Farmers' Income - Volume VII - Input Management for Resource Use Efficiency, 2018). The above arrangement will give an extra-income to machine owners. Also, that will lead to optimal use of idle investments made for machines. In addition, those possessing the skills of operating the machines would find employment, and farmers needing the devices for different farm operations would receive the service promptly at affordable prices (ibid). In the model, custom hiring centres, high-tech hubs, and Farm Machinery Banks (FMBs) will help to set up to ease the mechanization process of farms. There were 7,326 thousand CHCs, 177 thousand Hi-tech hubs, and 7,987 thousand farm machinery banks set up in TE-2021-22 spread across different states in India.[23] In addition, a computer-based application called 'FARMS'- Farm Machinery Solutions, a Government of India initiative, has been acting as a platform for selling and purchasing old equipment and machinery and making them available for rent. Hence adaptation of suitable mechanization and technological change in supply-chain might reduce harvest and post-harvest losses in the country.

[23] Source: SMAM electronic portal maintained by Department of Agriculture & Farmers' Welfare, Ministry of Agriculture & Farmers Welfare, Govt. of India SUB-MISSION ON AGRICULTURAL MECHANIZATION (SMAM) (agrimachinery.nic.in)

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8 Annexures

Annexure 1: Fieldwork, data collection and compilation

Training of the field teams

The project needs several technical pieces of information and complex data collection techniques. Therefore, we trained the survey team to properly handle the data collection process. The project team conducted two training programmes before the actual survey. The project team initiated the first training for the survey enumerators and distributed the questionnaires and user manuals in December 2021. The training was, therefore, helpful in clarifying some of the most complex concepts and providing additional insights to conduct the interviews, field measurement and data collection by observation, including other relevant information.

We coincide the second training with our baseline survey in the survey districts to educate the survey enumerators on the on-field dynamics. During the baseline survey, we enumerated farming households or other stakeholders in the selected villages/districts for the final selection of households/stakeholders in the survey. In addition, we involved the local agriculture officials in understanding the local dynamics and facilitating the survey work properly. We conducted field trials of the questionnaire, plot placement and field measurement techniques.

Deployment of the field teams

We hired a survey agency and a state coordinator for farm and market-level data collection. The survey agency deployed three field enumerators and one supervisor to conduct the survey work. At the top, the project team coordinated the survey. A total of 7 people, including the data collection team, facilitated the survey. In addition to the core team (of 7 members), local agriculture officers and district development managers of NABARD are also included in the team. The objective of the field team was not only to collect data but also to sensitise and educate the farmers, supply chain actors and the wider community on how to minimise the post-harvest losses.

Monitoring and quality control

The Study team at ICRIER do all the monitoring visits to the districts where survey work is ongoing. The monitoring team also took DDM of the respective district for the monitoring works, such as checking completed questionnaires; randomly choosing a household to survey to visit; discussing with field enumerators the challenges they face and providing solutions, where possible.

We ensured at least one visit of the project coordinator to each selected district to ensure the quality of the data collection activity. In addition, the project team had the privilege of imposing on the data collection team to recollect if there were errors in the collected data on the first visit.

The survey team submitted the completed data collection forms to the survey supervisor for crosschecking and quality control before submitting them to the project coordinator/supervisor at ICRIER for further crosschecking. After crosschecking at different layers (survey supervisor, project coordinator), the survey agency submitted the final cleaned data for analysis.

Data entry procedures and quality control

The survey coordinator scrutinised the collected data on paper or through google forms and cleaned and validated the data. Finally, the survey agency submitted the final data sets to the project coordinator at ICRIER. In addition, several consistency rules were applied to identify issues in the information reported by the survey agency. Cleaning and validation activities were done at harvest and post-harvest activity-wise to make the data flow continuous and logically sound. For example, the total farm area reported by farmers should not be greater than the area for a particular crop, etc. In addition, the reported quantities harvested should not be larger than those handled at the different processing stages (threshing, drying, etc.).

Suppose, at some point, some inconsistencies and the rejection of some questionnaires are found. In that case, these questionnaires will be sent back to the survey supervisors for clarification, or the survey team may be asked to collect the required information from the farmers/stakeholders again. For example, the survey team had missed collecting a few relevant pieces of information. Therefore, they went to the field again to complete the data collection. This type of data validation activity is time-consuming or may delay the final delivery of the data sets; however, it will ensure a minimum level of data quality. After properly scrutinising the collected data with a certain acceptable quality level, we converted and saved it in Excel formats suitable for further analysis.

Data processing, and cleaning are vital parts of a reliable and predictable study report primarily based on survey. However, it has been seen that a certain amount of collected data remains missing and incorrect in value and units in the final cleans datasets. Therefore, we cleaned it again to minimise gaps in the final datasets. In addition, we found a few outliers for some of the critical variables. In such cases, we removed the top and bottom one percent of the observations.

Annexure 2: Data collection methods

Harvesting/Crop cutting

In consultation with the farmer, the survey team decided the date and time of harvesting activities. Finally, the survey team reached the selected farmer's plot on the date of actual harvesting with all the equipment to experiment and measure the area of the chosen field. First, the enumerators recorded the total size of the plot, and then they randomly selected a sub-plot of 5x5 metres (near-to-corner sub-plots are preferable). Proper plot area measurement is necessary to calculate the production, yields and losses obtained from the subplot.

After fixing the entire field and sub-plot area, the survey team requested the farmer/labourers to start the crop-cutting of the sub-plot following the actual practice they used. The survey team observed the crop cut-cutting from the sub-plot and collected the required data from the experimented plot for further analysis. The project team tried to ensure that the production from the sub-plot/field was close to the actual production and not the potential or maximum production. For example, if the total production of the sub-plot (5x5=25m2) is 12 kg and the total area of the plot is 2000m2, then the total output of the plot will be 12[2000/25] =960 kg.

After the crop cutting/harvesting in the sub-plot, the survey team returned to the subplot to collect necessary data and weigh the produce remaining on the ground. All efforts were made to train the field team to do the activities as required for the selected crops. Therefore, the quantity lost is equivalent to the weight of grain remaining on the ground after harvesting in the sub-plot. The survey team also collected samples for the quality assessment in the laboratory.

In the surveyed districts of Madhya Pradesh, most farmers use crop harvesters or combine harvesters for harvesting. In such cases, the enumerators recorded a few pieces of information, like the types of harvesters used, the optimal use parameters, the speed of the routers set during harvesting, etc. Then, to measure the qualitative losses, the survey team collected samples for laboratory testing to determine the number of damaged grains, moulds or insects attacked, the presence of foreign materials, etc.

Measurement of losses during postharvest operations

Threshing

In consultation with the selected farmer for the objective measurement, the survey team fixed a threshing date and remained available to experiment. First, the farmer was requested to thresh the crop according to the usual method. After this process, the grain obtained and the discarded plant material (straw, etc.) are weighted separately. Next, the survey team took a sample of 250g of the discarded straw, and the grains in this sample were collected and weighted. This amount is then divided by 250 to estimate the weight loss at threshing.

The farmers may do the threshing activity manually or mechanically. During this activity, the quality of grains may be affected/deteriorate depending upon the mode of threshing operations.

If done mechanically, the speed of the thresher needs to be optimal. The higher the thresher speed, the more the grain quality is affected. Sometimes the farmers use buffaloes or bullocks to thresh the crops (paddy/wheat); the grains are more likely to be damaged. To measure the qualitative losses, the survey team observed the threshing process and collected samples for laboratory testing to determine the number of damaged grains, presence of foreign materials, etc. After the laboratory testing, the project team analysed the finding, and the aggregate quality loss was estimated.

Cleaning or winnowing

Immediately after the threshing process, the enumerators requested the farmer/labourers to clean the grains according to the usual method. After this process, the cleaned grains and the discarded unclean grain-straw mixture were weighed separately and recorded. Next, the survey team took a sample of 250g of the discarded straw-grain mix, and the grains in this sample were collected and weighed. This amount is then divided by 250 to estimate the weight loss at cleaning.

Storage at farmer's house

The objective measurement at the farmers' storage generally takes a more extended period, up to nine months or more. However, the project team have decided to keep the storage experiment time for six months to fit into the study objective. First, the survey team requested the selected farmers to facilitate the experiment on the first visit[24] and collected samples for laboratory testing. Losses during storage are generally caused due to improper storage of materials, rodents, insects, mites, pests, moulds, fungi, etc.

The quality of the grain varies inside the storage space and containers: the grain in the uppermost and outermost layers is relatively fresh compared to the middle and lowermost layers. To deal with such situations during the survey, the project team gave preliminary information and training to the survey team. Accordingly, the survey team collected data and samples for further analysis and laboratory testing. Finally, the project team calculated the storage loss (quantitative and qualitative) with all the required information.

Measuring losses on the off-farm/market channels

Transportation

The harvested crop at the farmer's house or storage facilities needs transportation to the nearest mandis or marketplaces (wholesalers/retailers). Some of the farmers used open tractor trolleys and some used trucks. In the surveyed districts, the farmers transported the harvested crop directly from the farms to mandis or private storage for selling; the transportation loss remains low or negligible for some farmers due to less distance to reach the mandis. At the market channels, transportation is critical to distribute the grains at the end-user. To this observation, the project team appointed a state coordinator and gave the required training to undertake the

[24] There will be at least three visits for the experiment.

transport-level experiments. The actual transport experiment started in the first week of May 2022.

First, the state coordinator prepared a list of transport owners and storage units (who are about to transport the grains to the marketplace) to experiment with during the crop movement. Then, on the date of the actual experiment, the state coordinator selected the samples (at least three bags) randomly from the bags of the crop chosen at the storage facilities. Then the survey coordinator recorded the necessary readings (weight of the selected samples, moisture content, place of loading, distance to cover, type of transportation, etc.) before despatch. After reaching the destination, the enumerators repeated taking readings for further analysis and loss estimation during transportation. Transport-Losses are generally caused in terms of the difference of weights between the quantity loaded and the unloaded (weigh-in and weigh-out) for short-distance transportation. However, moisture content and qualitative damage during transit should also be recorded for long transport operations (such as to reach ports and other export points).

Storage at market channels (warehouses, wholesalers, retailers):

The supply of grains is seasonal or at the time of harvesting, but the demand for the grains is throughout the year; therefore, storage is critical to keep the grains suitable for human consumption. Unfortunately, several studies show a substantial amount of grains loss usually occurs during storage operations as the grains require longer time at storage points to meet the demand throughout the year. The potential causes of losses may be due to attacks by insects, mites, pests, moulds, fungi, etc.

For this study, we have taken storage experiments at three places (farmers' houses, FCI, Pvt. storage facilities and wholesalers). The project team followed the identical procedure for the objective measurement described in the storage experiment's description at the farmer's house.

The state coordinator collected laboratory samples for testing and analysis for qualitative loss estimation. The quality of grains varies inside storage space and containers, where the grain in the uppermost and outermost layer is relatively fresh compared to the middle and lowermost layers. Thus, we tried to ensure collecting representative grain samples from at least three bags (one at the bottom, one at the middle and one at the top) inside a storage facility at various depths. At the same time, we also used a visual scale to measure the qualitative losses and record the information to compare with the laboratory testing result.

Annexure 3: Data analysis techniques

This section discussed the techniques and equations for the post-harvest losses assessment of quantitative and qualitative food losses. In addition, we undertook other impact assessments such as the environment, nutrient and calorie losses embedded in the food lost. While the environmental damage is a function of the GHG emissions embedded in the food lost, the Loss of various macro and micronutrients is calculated using the nutrients present in the desired crop lost. In addition, the impact of nutrient and calorie loss on the population is also derived from the secondary information on the annual dietary requirements of different population groups in India.

Quantitative and qualitative assessment techniques

Quantitative assessment (Observation method)

Harvesting Loss (in percent)

$$l_H = \frac{L_H}{H+L_H} \quad \text{... (1)}$$

Where l_H: is the percentage loss during harvesting and H and L_H denotes total crop harvested and crop loss during harvesting activities.

Storage/Stalling Loss (in percent):

$$l_{stl} = \frac{L_{stl}}{(H-L_H)+L_{stl}} \quad \text{... (2)}$$

Where l_{stl}: is the percentage loss during stalling at the plot and (H-L_H) and L_{stl} denotes total crop stalled at the plot and stalling loss during stalling activities.

Threshing Loss (in percent)

$$l_T = \frac{L_T}{T} \quad \text{... (3)}$$

Where l_T is the percentage loss during threshing; T and L_T denote total crop threshed and Loss during threshing activities.

Cleaning Loss (in percent)

$$l_C = \frac{L_C}{C} \quad \text{... (4)}$$

Where l_C is the percentage loss during cleaning; C and L_C denote total crop cleaned and Loss during cleaning activities.

Drying Loss (in percent)

$$l_D = \frac{L_D}{D} \quad \text{... (5)}$$

Where l_D is the percentage loss during cleaning; D and L_D denote total crop dried and Loss during drying activities.

Transport Loss (in percent)

$$l_{Tr} = \frac{L_{Tr}}{Tr} \quad \text{... (6)}$$

Where l_{Tr} is the percentage loss during cleaning; Tr and L_{Tr} denote total crop transported and lost during transporting activities.

Storage Loss (in percent)

$$l_S = \frac{L_S}{S} \quad \text{... (7)}$$

Where l_S is the percentage loss during cleaning; S and Ls denote total crop stored and lost during storage activities.

$l_{S(t)}$ ... (8)

t=3 visits; $l_S^{(t)}$ is the percentage of storage loss at visit t calculated using the count and weight method given in equation 11 below.

Total harvest and postharvest losses are estimated by aggregating the losses at each operation.

Total harvest and postharvest Loss (in percent)

$$l_{PH} = \frac{L_{PH}}{H} \quad ...(9)$$

$$l_{HPH} = \frac{L_{PH}+L_H}{H+L_H} \quad ...(10)$$

Where l_{HPH} and l_{PH} are the percentage loss in the postharvest (threshing, cleaning, drying and storage) and harvest& postharvest operations, H, L_H, L_{PH} and LHPH denote total crop harvested and lost during harvest and postharvest operations.

Storage Loss (by Observation)

Percentage losses during storage are directly calculated, using laboratory measurements. The count and weight method are used, based on the formula proposed by Harris and Lindblad (1978):

$$l_S^{(t)} = \frac{1}{w_u}\left[\frac{N_d}{N}w_u - \frac{N_u}{N}w_d\right]..................(11)$$

Where,

$l^{(t)}{}_S$ is the percentage loss; N_u is the number of undamaged grains (W_u the corresponding Weight); N_d is the number of damaged grains (W_d the corresponding Weight), and N=N_u+N_d is the total number of grains in the sample.

For a comprehensive quantification, losses at each stratum was calculated and aggregated using the methodology developed by Jha et al. (2015). First, the losses stated by farming households and observed by the evaluators are extrapolated to block and district. Then it would be calculated for the state-specific Agro-climatic zones and the state level. Finally, the standard deviation, variance and confidence interval will be calculated for the precision of the estimates.

The formulae used to calculate the desired results are given below, and the notations are explained in the Annexure:

District-level losses: Farm level

Losses estimation by inquiry:

The total quantity handled at the block level $\hat{\bar{Y}}_i$ is given by:

$$\hat{\hat{Y}}_i = \frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}} y_{ibvf}$$

The total loss incurred $\hat{\hat{\delta}}_i$ is obtained using:

$$\hat{\hat{\delta}}_i = \frac{B_i}{b_i}\sum_{i=1}^{b_i}\frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}} \delta_{ibvf}$$

The loss (in percent) is given by:

$$\hat{L}_i = \frac{\hat{\hat{\delta}}_i}{\hat{\hat{Y}}_i} X100$$

Estimated variance for losses is obtained using the following set of equations:

$$\hat{V}\left(\hat{L}_i\right) = \left(\frac{\hat{\hat{\delta}}_i}{\hat{\hat{Y}}_i}\times 100\right)^2 \left(\frac{\hat{V}\left(\hat{\hat{\delta}}_i\right)}{\left(\hat{\hat{\delta}}_i\right)^2} + \frac{\hat{V}\left(\hat{\hat{Y}}_i\right)}{\left(\hat{\hat{Y}}_i\right)^2}\right)$$

$$\hat{V}\left(\hat{\hat{X}}_i\right) = \frac{1}{b_i(b_i - 1)}\sum_{b=1}^{b_i}\left(\hat{X}_{ib} - \hat{\hat{X}}_i\right)^2$$

$$\hat{X}_{ib} = \frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}} x_{ibvf}$$

$$\hat{\hat{X}}_i = \frac{1}{b_i}\sum_{b=1}^{b_i}\hat{X}_{ib}$$

Where, the mean quantity handled or lost (Xi in the last equation) is substituted in the earlier equations.

District-level losses: Storage

Loss estimation using inquiry:

Quantity withdrawn at the district level, quantity lost for ith district and loss percentage are given using the following three equations.

$$\hat{\hat{P}}_i = \frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}}\left(\sum_{t=1}^{T} p_{ibvft}\right)$$

$$\hat{\hat{\zeta}}_i = \frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}}\left(\sum_{t=1}^{T} \zeta_{ibvft}\right)$$

$$\hat{L}_i = \frac{\hat{\hat{\zeta}}_i}{\hat{\hat{P}}_i}\times 100$$

Market level (wholesaler, retailer) storage losses

Loss estimation using observation:

The loss estimate for data collected through observation is computed using the given equation. An estimate of corresponding variance is obtained using the subsequent equation where the values of di and TGi are the same as previous equations.

$$\hat{L}_i = \frac{\sum_{b=1}^{b_i}\sum_{t=1}^{T} d_{ibt}}{\left(\sum_{b=1}^{b_i}\sum_{t=1}^{T} d_{ibt} + \sum_{ib=1}^{ib}\sum_{t=1}^{T} u_{ibt}\right)} \times 100$$

Qualitative Loss Assessment

The study used primarily laboratory test data to estimate the qualitative loss in the paddy, maize, and soybean supply chain. However, the study used the following method to estimate the quality loss. For example, we used the formula: percent $X_{(Quantity)}$= {percent X $_{(Quality\ loss)}$ * percent price reduction of the crop X due to quality loss} *100. For example, if the quality loss of crop X (i.e., paddy, maize, and soybean) is 12 percent and there is 20 percent price reduction in paddy, maize and soybean due to lower quality, then the equivalent quantity loss is (12/100x20/100)100= 2.4 percent

Generally, quality loss of a product is associated with lower prices if there is an excess supply of that product in the market. But, on the other hand, during the lean period, when there is a shortage of products in the market, even low-quality products fetch a reasonable market price and vice-versa. For this study, we use survey-based price information for damaged wheat, paddy, maize, and soybean grain to estimate the quality loss during harvest and postharvest operations. We have used two sets of wholesale prices, one for when the producers sell to storage units or local aggregators and the other for when local aggregators/storage units/wholesalers sell in the market channels.

Annexure 4:Symbols and notations used in the Annexure 3

$\hat{\hat{Y}}_i$	**Estimate of quantity handled in district i for data collected by an inquiry for a specific farm operation.**
Bi	Number of blocks in district i.
bi	Number of blocks selected from district i.
V_{ib}	Number of villages in block b of district i.
v_{ib}	Number of villages selected in the selected block b of the designated district i.
F_{ibv}	Number of farmers of a crop in the selected village v of the designated block b of the selected district i.
f_{ibv}	Number of farmers of a crop selected from selected village v of the selected block b of the selected district i.
y_{ibvf}	Quantity handled by a farmer f of a particular crop during a specific farm operation in the selected village v of the selected block b of the selected district i, for data collection by inquiry.
$\hat{\hat{\delta}}_i$	Estimate of loss in quantity of a specific crop during a farm in district i for data collected by inquiry.
δ_{ibvf}	Quantity lost for the selected farmer f belonging to the selected vth village of the selected bth block in the selected district i, using data collected by inquiry.
$\hat{L}_i$	Estimate of the percentage quantity lost in the ith district using data collected by inquiry.
$\hat{\hat{V}}(\hat{L}_i)$	Estimated variance of the percentage quantity lost in the ith district for data collected using inquiry.
$\hat{V}(\hat{\hat{\delta}}_i)$	Estimated variance of the total quantity lost in the ith district for data collected using inquiry.
$\hat{V}(\hat{\hat{Y}}_i)$	Estimated variance of the total quantity handled in the ith district for data collected using inquiry.
$\hat{\hat{Y}}'_i$	Estimate of quantity handled in district i for data collected by observation for specific farm operation.
y'_{ibvf}	Quantity handled of a particular crop in the selected district i, of the selected block b of the selected village v by a farmer f, from data collection by observation.
$\hat{\hat{\delta}}'_i$	Estimate of loss in quantity in district i for data collected by observation.
δ'_{ibvf}	Quantity lost for the selected farmer f belonging to the selected village v of the selected block b of the selected district i, from data collected by observation.
$\widehat{L'}_i$	Estimate of the quantity lost in percentage in the ith district using data collected by observation.
$\hat{\hat{V}}(\hat{L}'_i)$	Estimated variance of the percentage loss in the ith district for data collected using observation.
$\hat{V}(\hat{\hat{\delta}}'_i)$	Estimated variance of the total quantity loss of a specific crop during a particular operation in the ith district for data collected using observation.
$\hat{V}(\hat{\hat{Y}}'_i)$	Estimated variance of the total quantity handled of a specific crop during a particular operation in the ith district for data collected using observation.
$\hat{L}_i^{(c)}$	Estimated combined percentage loss for a crop c in the district i.

$\hat{s}_i$	Estimate of standard error of percentage loss in a particular farm operation in the ith district for data collected by inquiry.
$\hat{s}'_i$	Estimate of standard error of percentage loss in a particular farm operation in the ith district for data collected by observation.
n_i	Number of data points taken for data collected via inquiry during a particular farm operation for the ith district for a specific crop.
n'_i	Number of data points for data collected via observation during a particular farm operation for the ith district for a specific crop.
$\hat{S}_i$	Estimated standard error of combined loss percentage for a farm operation in the district i.
$\hat{P}_{iz}$	Production estimate of the selected district i in the selected agroclimatic zone z for the year under consideration.
$\hat{L}_{iz}$	Estimated loss percentage of the considered crop for the district i present in the agroclimatic zone z, for data collected using inquiry.
$\hat{L}_z$	Estimated loss percentage of the considered crop for the agroclimatic zone z, for data collected using inquiry.
$\hat{L}'_{iz}$	Estimated loss percentage of the considered crop during a farm operation for the district i present in the agroclimatic zone z, for data collected using observation.
$\hat{L}'_z$	Estimated loss percentage of the considered crop during a farm operation for the agroclimatic zone z, for data collected using observation.
$\hat{L}_N^{(c)}$	National level crop loss percentage for the selected crop.
$\hat{L}_{iN}$	Estimated loss percentage obtained by pooling inquiry and observation data for agroclimatic zone i.
$\hat{L}'_s$	Estimated storage loss at agroclimatic zone level.
$\hat{L}_{sN}^{(c)}$	Storage loss at national level.
$\hat{P}_{iN}$	Total production of a crop at the agroclimatic zone i.
$\hat{s}_{iz}$	Standard error estimate of the percentage crop loss in district i, in the agroclimatic zone z, using data collected via actual observation/ inquiry.
$\hat{S}_z$	Standard error estimate of estimated loss percentage in a farm operation conducted in the agroclimatic zone z using the data collected from inquiry/ observation.
$\hat{L}_z$	Pooled estimated loss percentage for a farm operation on a specific crop in the agroclimatic zone z.
$\hat{S}_z$	Combined standard error estimate of estimated loss percentage in a farm operation carried out in the agroclimatic zone z.
P_z	Production of the crop under consideration in the agro-climatic zone z.
$\hat{L}_N$	Estimated loss percentage for a crop in a national level farm operation.
$\hat{S}_N$	Estimate of standard error in loss percentage for a crop during a particular farm operation at national level.
$\hat{P}_i$	Total quantity of produce withdrawn from the storage of selected farmers of the selected district i during the entire inquiry period.

p_{ibvft}	Total quantity withdrawn from storage facility between two visits – previous visit and the visit t – to a farmer f belonging to selected village v of the selected block b in the ith district.
$\hat{\in}_i$	Estimated total quantity loss of the selected farmers of the selected district i, for the entire inquiry period.
$\in_{ibvft}$	Total quantity lost between two visits – previous visit and the visit t – to a farmer f belonging to selected village v of the selected block b in the selected ith district for the data collected by inquiry.
d_{ibvft}	The number/weight of the crop damaged in a sample taken during the visit t, for a selected farmer f belonging to the selected village v from the selected block b in the selected district i, for the data collected via observation.
u_{ibvft}	The number/weight of the crop undamaged in a sample taken during the visit t, for a selected farmer f belonging to the selected village v from the selected block b in the selected district i, for the data collected via observation.
TG_{ibvft}	Total number/ weight of the crop damaged in a sample taken during the visit t, for a selected farmer f belonging to the selected village v from the selected block b in the selected district i, for the data collected via observation.
$\widehat{S_i{}'}(d_i)$	Standard error estimate of number/weight of the crop damaged in farmer storage of district i computed for data collected via observation.
$\widehat{S_i{}'}(TG_i)$	Standard error estimate of total number/weight of the crop drawn from the farmer storage of district i computed for data collected via observation.
d_{ibt}	The number/weight of the crop damaged in a sample taken during the visit t, from the wholesaler/ retailer/processor (b) from the selected district i using data collected by observation.
u_{ibt}	The number/weight of the undamaged crop in a sample taken during the visit t, from the wholesaler/ retailer/processor (b) from the selected district i using data collected by observation.
d	Number of districts in the agroclimatic zone z.
a	Number of agroclimatic zones for the crops selected for the survey.

Part-2

Assessment of Post-Harvest Grain Management System of FCI and Effectiveness of Private Warehouses to Reduce Food Loss in India

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Executive Summary

Harvest and storage losses remain crucial challenges in developing countries compared to the developed nations due to lack of technological change in transport and storage infrastructure. In many countries the most true-cost effective measure to improve food availability is to improve post-harvest grain management technology. Over the years Food Corporation of India (FCI), the country's nodal public agency of grain management, has worked to expand storage capacity in India. However, storage and transit losses remain a challenge due to lack of modernisation of infrastructure and lack of efficiency. In this context, this paper provides an analysis of the current grain management system in India and the role of private warehouses to minimise postharvest losses in rice and wheat. This study aims to bridge the research gap by pioneering a holistic analysis of various operations involved in grain procurement, storage, and distribution across different agencies. Given the pivotal role of FCI as the primary agency for procurement and storage, our data collection spans infrastructural facilities, quality standards, storage regulations, and various grain storage models across states, with additional insights from the Warehouse Development and Regulatory Authority (WDRA). We have also incorporated case studies of different storage types, techniques, and drivers of losses in storage and transit. By scrutinizing associated techniques and conducting a comparative assessment of diverse storage types, the paper offers insights for policy interventions targeting the development of storage infrastructure and the reduction of transit losses in the grain management system of India.

Findings indicate that the grain storage capacity of the country has not increased at pace with increases in grain production. Even though FCI has an objective to phase out Cover and Plinth (CAP) storage, during peak periods the management of grains has to rely on CAP. In terms of storage techniques, bulk storage is more efficient than bag storage (storage cost is also less than warehouses), but it requires capital investment and infrastructural development. At procurement, inadequate facilities including shaded yards, sacks, and covered storage areas in markets, contribute to losses from rodents and dusts. Major causes of losses at storage are moisture content, aeration, and biotic factors. Regionally skewed procurement leads to transit losses during movement of rice and wheat from surplus to deficit regions for the Public Distribution System (PDS), through which 800 million people receive free wheat/rice (5kg/person/month). Expanding procurement and storage infrastructure in consuming regions would reduce transit losses.

The rice-wheat market is regulated by government policies, and FCI has to pay heavy rent to silos and private warehouses for storage of grains. The public-private partnership through implementation of Private Entrepreneurs Guarantee (PEG) scheme has been beneficial to expand the storage capacity. However, it has not promoted substantial technological investment like use of conveyor belts to reduce handling losses. Modernisation of storage techniques through use of hermetic bags can also reduce storage and movement losses. Hence, amending Essential Commodity Act (ECA) to encourage private sector participation in expanding modern storage infrastructure would help reduce post-harvest grain losses in India.

1 Introduction

Addressing the imperative of food security with increasing population pressures amidst unpredictable weather variations induced by climate change poses a critical challenge for mankind. In this situation, there is also severe post-harvest loss which has huge economic and environmental cost. Post-harvest loss is defined as the reduction of quantity and quality of edible grains from harvest up to the retail level (Boxall, 1986). Globally 30 percent of the food produced disappears in the value-chains and is not available for consumption (FAO, 2021). Therefore, reducing post-harvest losses can contribute substantially to more sustainable use of resources in agriculture. The literature shows that storage and transit losses are higher in developing countries compared to developed nations due to poor technologies and inadequate management in storage facilities, manual handling processes, and use of outdated equipment (Kumar & Kalita, 2017; Hodges et al., 2010; FAO, 2011). Annually India losses 12.49 million metric tonnes (MMT) of cereal grains with economic value of Rs. 26,000.79 crores, which is an alarming figure, given India's 224.3 million people (16 percent of the population) who are undernourished (NABCONS, 2022; FAO, 2022).

India indeed achieved tremendous growth in food grain production from 74.23 MMT in 1966-67 to 330.5 MMT in 2022-23 (DES, 2023) and is a key exporter comprising 40 percent share of global rice trade (DGFT, 2023). However, the country faces a "paradox of plenty" due to lack of efficient grain management. This results in part from the success of production-oriented policies that have often neglected the vital aspects of food storage and distribution. With demand projections of 130.6 MMT of wheat and 147.8 MMT by 2032 (OECD/FAO, 2023) the imperative to assure increased availability of grains remains. However, cereal production, particularly rice production, comes with ecological cost, as groundwater levels are falling over time and environmental sustainability of production practices is in question. Hence, the true-cost effective strategy to increase food availability is arguably to improve post-harvest grain management technology.

Over the years, the Food Corporation of India (FCI), the country's nodal public agency of grain management, has done quite a lot to expand storage capacity in India. However, storage and transit losses remain a challenge due to lack of modernisation of infrastructure. The postharvest loss of grains depends on the time of harvest, moisture content in the produce, the shelf life, and the storage environment. Cereals are the most important produce in India based on scale of production and demand for consumption throughout the year. Since, the harvesting of rice and wheat is seasonal, efficient grain storage facilities are needed to feed the population continuously through the year. Hence, the grain storage system is crucial for food security of the country. Moreover, because grain losses during storage represent squandered environmental resources, such as the water used in production, hence, there is an environmental motive to address postharvest loss in addition to concerns for food security.

In India, storage of grain happens at farmer, trader, and government level. Notably, rice production experienced a substantial increase from 20.58 MMT in 1950-51 to 135.7 MMT in 2022-23, accompanied by a marketed surplus ratio reaching 84.35 percent as of 2015 (Agriculture Statistics at a Glance, 2022). Out of 135.7 MMT of rice production 55.8 MMT of rice was procured in 2022-23 by the government highlighting the importance of adequate storage infrastructure. Similarly for wheat the production escalated from 6.46 MMT in 1950-51 to 110 MMT in 2022-23 and 18 MMT of wheat of procured during 2022-23.

Hence, the GOI has to manage this large-scale storage through FCI and other state agencies to control rice and wheat price fluctuations and to ensure food security in the country. The infrastructure for this strategic storage has improved over the years, however expanding storage facilities remains a challenge due to increases in grain production and marketed surplus, and costliness of investment. In this context, the paper provides a comprehensive analysis of the government's current grain management system, alongside the evaluating the effectiveness of private warehouses in reducing postharvest losses in wheat and rice in India.

1.1 Research Gap

The existing body of research exhibits a noticeable gap in addressing the intricacies of food grain losses within the Indian agricultural landscape. While specific studies exist, focusing on the impact of infestation on storage losses for rice and wheat, as well as on aspects of agriculture market infrastructure, there is a clear need for an interdisciplinary approach that comprehensively examines grain management practices employed by both public and private enterprises. This study aims to bridge this research gap by pioneering a holistic analysis of various operations involved in grain procurement, storage, and distribution across different agencies. By evaluating associated techniques and conducting a comparative assessment of diverse storage types, the paper intends to offer valuable insights for policy interventions, specifically targeting the development of storage infrastructure and the reduction of losses in the Indian grain management system.

1.2 Objectives

Questions to be addressed in this report include the following:

- How does the FCI manage grain storage, including the use of storage facilities, labour use, techniques, and can technological advancements reduce post-harvest losses within FCI?
- What are the primary factors contributing to post-harvest losses in traditional warehouses and cover and plinth (CAP) storage facilities vis-à-vis modern silo facilities in India?
- What are the common causes of losses during the procurement process of major grains in mandis (agricultural markets) in India?
    - How do these losses vary across different regions and grains?
    - What strategies can be implemented to minimize losses during procurement?
    - How do storage conditions, transportation, and handling practices impact the quality and quantity of grains?
- What are the key stages in the public distribution process of grains in India?
- What is the extent of grain loss during storage, and to what extent does the use of hermetic storage methods reduce these losses when compared to traditional gunny bags?

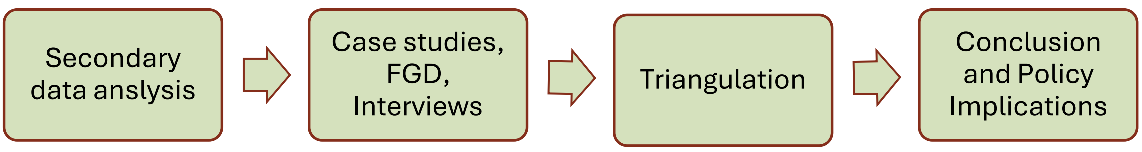
1.3 Database

The research is underpinned by a comprehensive analysis of secondary data sources and in-depth case studies on diverse storage facilities in India, as represented in **Figure 1.1**. Given the pivotal role of FCI as the primary agency for procurement and storage, our data collection spans infrastructural facilities, quality standards, storage regulations, and various grain storage models across states, with additional insights from the Warehouse Development and Regulatory Authority (WDRA). We have also incorporated secondary data on market infrastructure, road density, and state-level budget allocations for food and warehousing. Furthermore, as described in **Table *1.1***, primary case studies were conducted in key procuring states, specifically Punjab, focusing on rice and wheat during November, 2023. To assess the involvement of Farmer Producer Organizations (FPOs) in storage, a focused group discussion (FGD) was conducted in Moga district, Punjab, involving FPCs and farmers to evaluate the availability of storage facilities at the grassroots level (**Figure 1.1**).

Table 1.1: Case Studies location and specifications

Name and Type of storage	Commodity	Location
Private warehouse hired by FCI	Wheat, rice	Moga Punjab
Adani Agri logistics	Wheat	Moga, Punjab
Concrete silos	Wheat	Moga, Punjab
Farmer level storages	Rice, wheat	Moga, Punjab
Conventional storages of FCI (Control group for case study) operated by CWC	Rice, Wheat	Moga, Punjab

Figure 1.1: Research design



2 Assessment of FCI's postharvest grain management system

Wheat and rice are the major staple grains for food security in India. Being the major components of the Public Distribution System (PDS), it is essential to efficiently manage the procurement, storage and distribution of the grain. In India, the rice and wheat markets are characterized by high stocks at FCI granaries, regionally concentrated procurement, and huge demand for public distribution of the commodities. Given the strategic importance of these grains, rice and wheat market are largely controlled by the governments for price stabilization in domestic market.

FCI, the nodal agency of grain management system in India, established on 1965 under the Food Corporation Act, 1964 under the Department of Food and Public Distribution, GOI. FCI manages procurement of produce at fixed prices, procures rice and wheat at the Minimum Support Price (MSP), allocates and distributes grain under NFSA and other welfare schemes at the Central Issue Price (CIP)[26]. The operational cost of FCI is the difference between the procurement and distribution of grain (economic cost) and the CIP, which the government reimburses to FCI as food subsidy. Also, GOI pays the cost of carrying the buffer stock of food grains to FCI which is also added to food subsidy bill. Between procurement and distribution, FCI also transports grain for the Open Market Sales Scheme (OMSS) to control domestic inflation.

The following section details the operations of FCI and associated losses.

2.1 Procurement

One of the major policy tools to ensure food availability after the implementation of the Green Revolution package in 1960s was assured procurement of grain from farmers by central or state agencies at MSP. From the period of dearth of food grain of 1960s, India attained self-sufficiency and surplus of grain production over the last six decades. However, the policy lever of rice-wheat procurement and stocking, the Essential Commodity Act[27], kept the grain market under the control of the government at the cost of a mounting food subsidy bill at Rs. 2.87 trillion (USD 34.69 billion) in the Financial Year 2022-23 (FY 23).

At all India level, paddy procurement increased from 35.58 MMT to 84.77 MMT between 2013 to 2022-23 (FCI, 2023). Wheat procurement has also gone up with drop in procurement in recent years due to lower harvest (see **Annex 5**). With the escalation in procurement and a concurrent rise in MSP, FCI also hires storage facilities from private enterprises. As on 31st March, 2022, the storage of capacity of 42.67 MMT was available with FCI, 36.17 MMT with state agencies for central pool stock, for 78.84 MMT of total covered capacity. During peak market arrival periods, FCI hires CAP storage facilities, as in 2021-22 when a total of 3.49 MMT of CAP storage was

[26] The subsidy is given to the FCI and states for procuring food grains from farmers at government notified prices and selling them at lower subsidised prices (known as Central Issue Prices) under the National Food Security Act, 2013.The Act mandates coverage of 75 percent of the population in rural areas and 50 percent in urban areas, and currently covers 81 crore people.

[27] The government of India passed the Essential Commodities Act, 1955 in order to regulate the production, supply, and storage of essential commodities (including food crops, oilseeds, jute, seed, etc.) and control hoarding. One of the three proposed Farmer Laws of 2020 was to amend this act in an effort to incentivize private players to invest in food processing and storage facilities.

used,32 percent of which was hired. To increase the storage facilities FCI also engages with private entrepreneurs via Private Entrepreneurs Guarantee (PEG) scheme for covered warehouses and the capacity is also getting expanded by hiring silos.

The increasing production of wheat and rice (see **Annex *12***), over the years, is due to power subsidies in some states, free irrigation water availability, intense use of chemical fertilisers and pesticides, and marketing support in the form of assured procurement at MSP. The procurement of paddy at MSP especially in Punjab and Haryana has long influenced the farmers' cropping choices and the area under paddy has substantially increased over the years.

There is spatial heterogeneity in procurement of rice and wheat in India. Centralised procurement has been concentrated in Punjab and Haryana. In these States, farmers sell their paddy produce to procurement agencies via commission agents (*arhtiyas)* and the value is adjusted for foreign matter. The paddy is then delivered to shellers for milling and from there the rice is stored in go-downs that are owned or hired by the FCI.

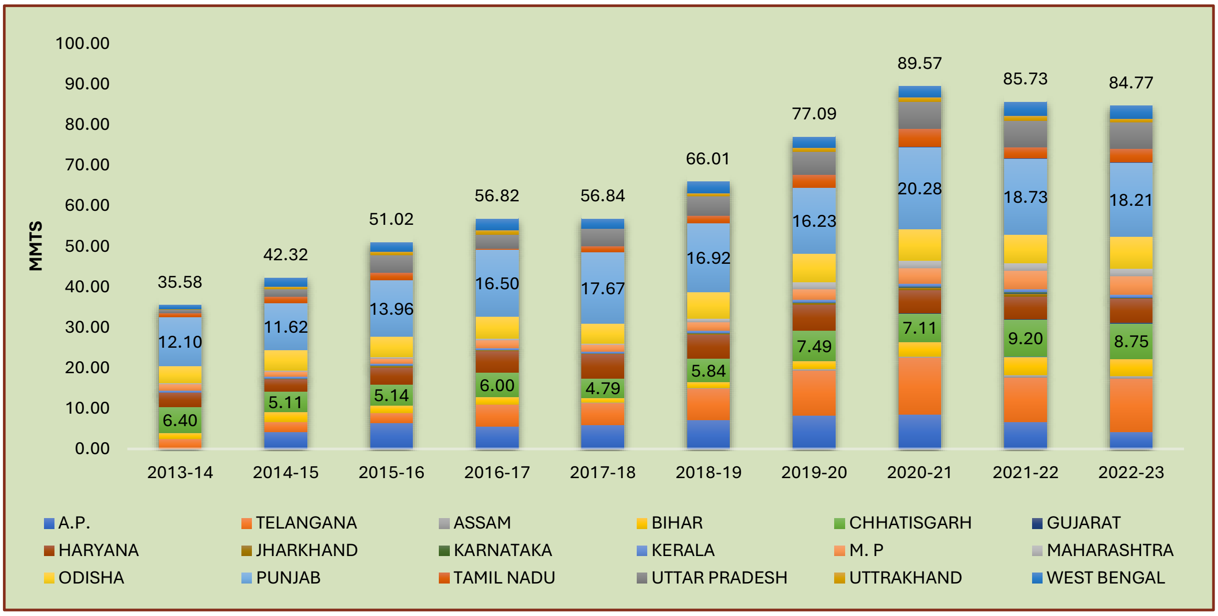
In Punjab, commission agents or *arhtiyas* led open-end procurement, free electricity power, and huge subsidies on urea increased the paddy procurement from 12.10 MMT in 2013-14 to 18.21 MMT in 2022-23 (**Figure 2.2**). There is evidence that in Punjab and Haryana that the arhtiyas system increases the transaction cost in the value-chain as they get commission from the farmers (Singh, 2011). Arhtiyas charge 2.5 percent commission fee on their transaction value from farmers for their services in market yard in facilitating the sale of agricultural produce.

In contrast to the centralised procurement system, a decentralized procurement system (DCP) has been implemented in states such as Telangana, Andhra Pradesh, Odisha, and Chhattisgarh. In centralized procurement, the FCI and state agencies handle the procurement of food grains, with states handing over the grains to central pool and receive funds. Conversely, in decentralized procurement, the state governments manage procurement and distribution, with an MOU with the DFPD, with surplus grains delivered to FCI and deficits supplied by FCI. In decentralised procurement system state level bonuses over MSP often increases procurement leading to surpluses. In 2017, GoI announced that they would not accept stocks in the Central pool acquired by DCP states exceeding their requirements, if purchased through bonuses (GOI, 2017). However, electoral politics in India has witnessed announcement of state level bonuses for rice and wheat in some DCP states in the latest state-level elections in India in 2023 (Das and Gulati, 2024).

For instance, the increases in assured procurement coverage along with state-level bonus over MSP has increased paddy arrival in Chhattisgarh. Procurement of paddy doubled in the state between 2018 to 2023 (**Figure 2.1**). Since 2016, the public procurement in Telangana also escalated after the state enacted the Food Security Act in 2015 to help meet high demand of the PDS. Odisha has also expanded market infrastructure and increased public procurement in the state through PACs. However, procurement facilities are limited in Bihar and West Bengal due to poor market infrastructure and a large section of farmers sell to local traders.

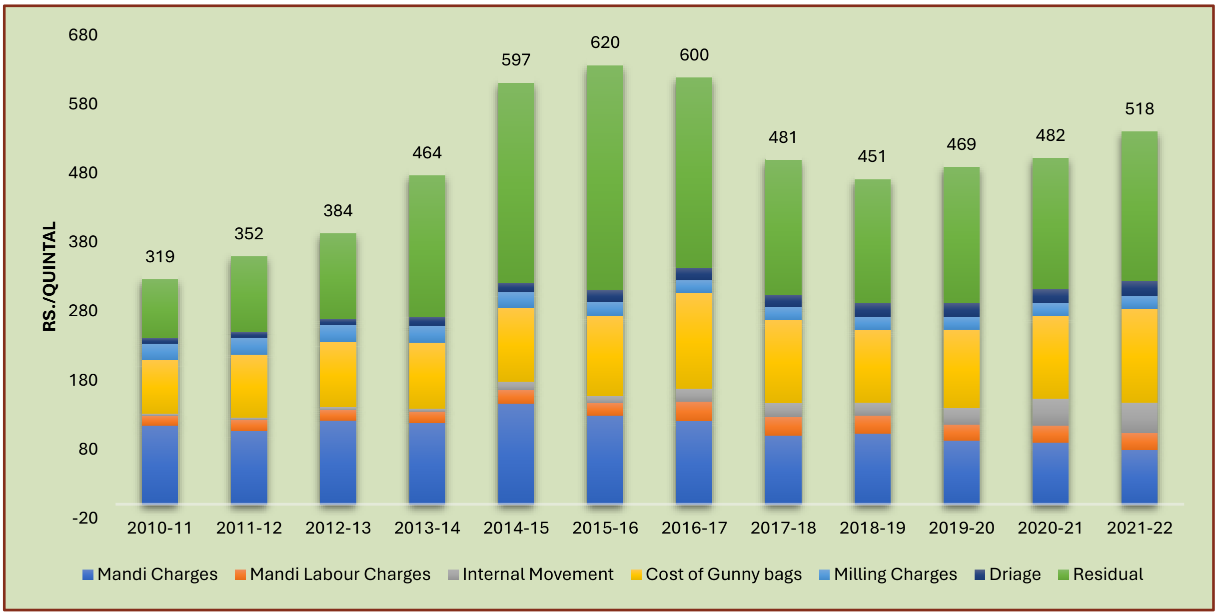
Aggregation of output require institutional framework to reduce transport loss from farmers to mandi. PACs in eastern states have reduced the challenge of aggregation of output. However, in West Bengal, Bihar the functioning of PACs is yet limited.

Figure 2.1: State-wise trend in paddy procurement (2013-14 to 2022-23)



Source: Food grain Bulletin, DFPD, Ministry of Consumer Affairs, Food and Public Distribution

Figure 2.2: Procurement cost of Rice for FCI (2010-11 to 2021-22)



Source: FCI Annual reports (various issues)

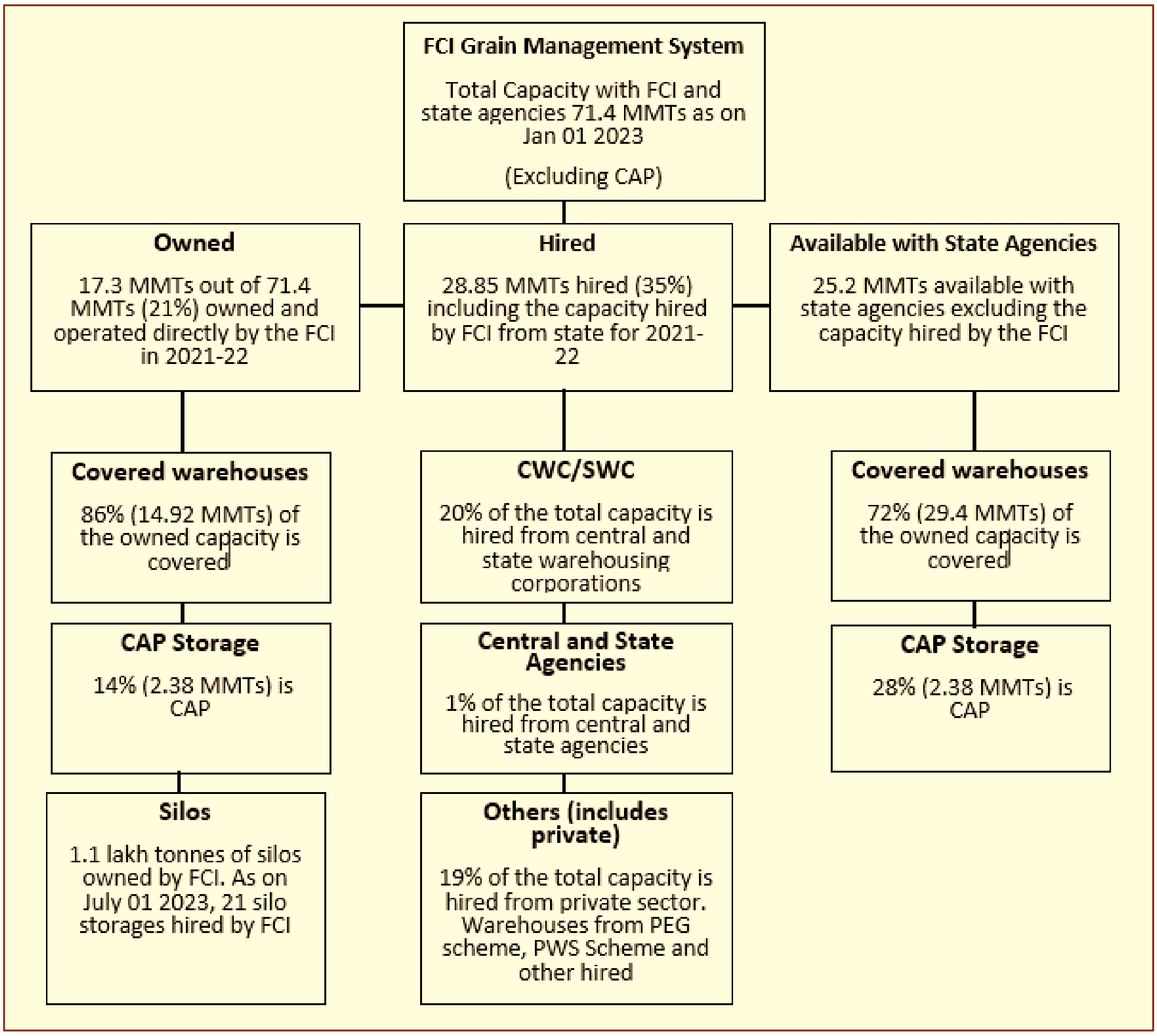
Open ended procurement has increased paddy production in some states have incentivised farmers to increase area under paddy production leading to stockpiling of surplus grain by the FCI. Whereas the MSP policy and other developments have increased cereal production in the country, the ability to store the grain efficiently remains a challenge. Hence, there have been reported instances of huge losses at storage due to difficulties in managing large quantity of stored grain (Anand, A, 2022, July).

Losses and costs during procurement depend on marketing infrastructure, aggregation processes, and, handling methods. **Figure 2.2** shows the composition of costs incurred in the procurement of rice; the data show that mandi charges and cost of gunny bags constitute significant shares in total cost. The Jute Package Material Act (JPM Act, 1987) makes it compulsory for the FCI and state agencies to use jute bags for storage, the cost of gunny sacks is unavoidable under the existing policy context. The use of gunny sacks also contributes to highly labour-intensive operations at FCI the costs of which has been addressed somewhat over the last decade through casualisation and piece-rate work that have increased efficiency of handling (**Annex 6**). Still, technological improvements in internal movement can reduce loss of grains and the cost of procurement. Inadequate infrastructural facilities including lack of shaded yards, unreliable supply of sacks, and contribute to losses from rodents during procurement. Moreover, rainfall immediately after the harvest time damages crops at the market which further escalates the storage losses. Overall, management of grain flows becomes especially difficult during peak periods, particularly in years of bumper production.

2.2 Grain management system by FCI

The storage system under consideration encompasses FCI's own warehouses, those rented from the Central Warehousing Corporation (CWC), State Warehousing Corporations (SWC), and privately owned warehouses (**Figure 2.3**). FCI uses the Cover and Plinth (CAP) storage system, which is a short-term storage technique and the usage varies across years. CAP storage facilities are still continuing as the food grain production in India increased at higher pace compared to expansion in storage infrastructure. The advantage of using CAP as storage is lower cost of construction, however, storage loss is higher compared to other systems. **Figure 2.4** demonstrates the structure of storage infrastructure with Centre and State. The total capacity of storage with FCI as on January, 2023 has been 71.4 MMT without hired CAP storage.

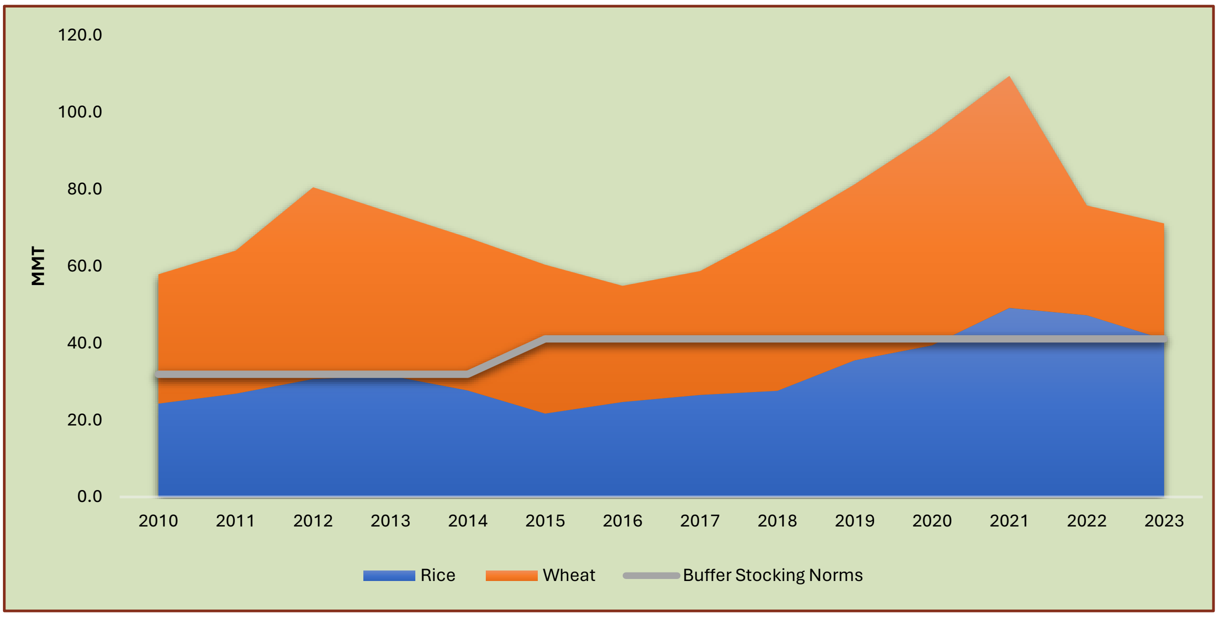
Figure 2.3: Structure of storage infrastructure with Government (Central and State), January 2023



Note: The total storage capacity increases or decreases each year (through hiring) depending upon the requirement and it excludes hired CAP storage; CWC: Central Warehousing Corporation; SWC: State Warehousing Corporations; CAP: Cover and Plinth. Source: FCI

At state level storage capacities, a distinct 28 percent are CAP storage, whereas 72 percent are covered warehouses. Usage of CAP storage is more when production exceeds capacity; for example, on January 1, 2021, approximately 15 MMT of CAP storage capacities were availed by FCI and state agencies in India. The CAP storage type resulted in significant loss of grains in India.

Figure 2.4: Opening stock of food grains with central pool against the buffer stocking norms as on July 01 each year (2010 to 2023)

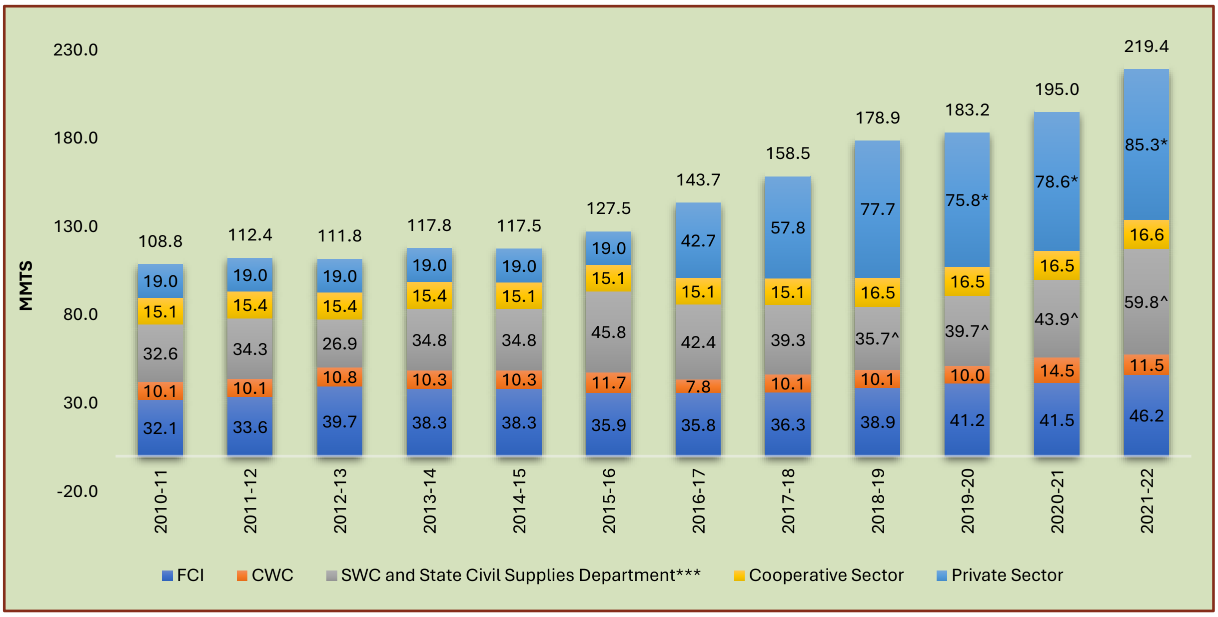


Source: FCI

The data presented in **Figure 2.4** underscores a significant trend over the last decade, revealing that the storage capacity utilized (utilization is the ratio of stored grain to capacity of storage) by the FCI has consistently exceeded the established buffer stocking norms[28]. Rice production during the period of 2021-2022 increased from 89.1 MMT to 130.8 MMT (Second advance estimates, 2022-23) (DES, 2023). This noteworthy surplus at the central level signifies a considerable challenge as a high volume of storage leads to use of poor infrastructure leading to higher losses. This is necessitating attention to expand the storage infrastructure across the country. Large volumes of FCI stocks follows growth in grain production.

[28] The FCI is mandated to hold a certain quantity of rice and wheat across the months of the year for ensuring food security, weather risk or any other emergency situation, which is defined as buffer stocking norms. For instance, as on April 1st, buffer stocking norms for rice and wheat are 13.6 MMT and 7.5 MMT, respectively.

Figure 2.5: Storage capacity available in India as per WDRA (2010-11 to 2021-22)



Source: Authors' calculations with data from Warehousing Development and Regulatory Development (WDRA) annual reports (various issues) and FCI annual reports (various issues)

** Includes capacity created under the support of Integrated Scheme for Agricultural Marketing (ISAM) scheme of Directorate of Agri Marketing and Inspection and Private Entrepreneurs Guarantee Scheme (PEGS) of FCI*

**** Includes 'state agencies' when state civil supplies department unavailable*

^ Excluding CAP storage

The storage capacity in India expanded from 108.8 MMT in 2010 to 219.4 MMT in 2021 due to increase in private warehouses renting-in by the government agencies (Figure 2.5). At FCI level, including owned and hired, the capacity marginally increased from 32.1 MMT to 46.2 MMT. Compared to FCI, state agencies storage capacity escalated from 32.6 MMT to 59.8 MMT. This increase is due to bumper cereal harvest in the country in last three years. India produced 329.5 MMT of cereals during 2020-2023 (DES, 2023). Also, we see a large reliance on private warehouses for cereal storage in the country, however, they are often hired by FCI. At warehouse level the storage capacity of the private sector leapt from 19.0 MMT in 2010 to 85.3 MMT in 2021-22. The growth of private sector storage can be traced to the GOI incentivising private warehouses through the implementation of Private Entrepreneurs Guarantee (PEG) Scheme[29].

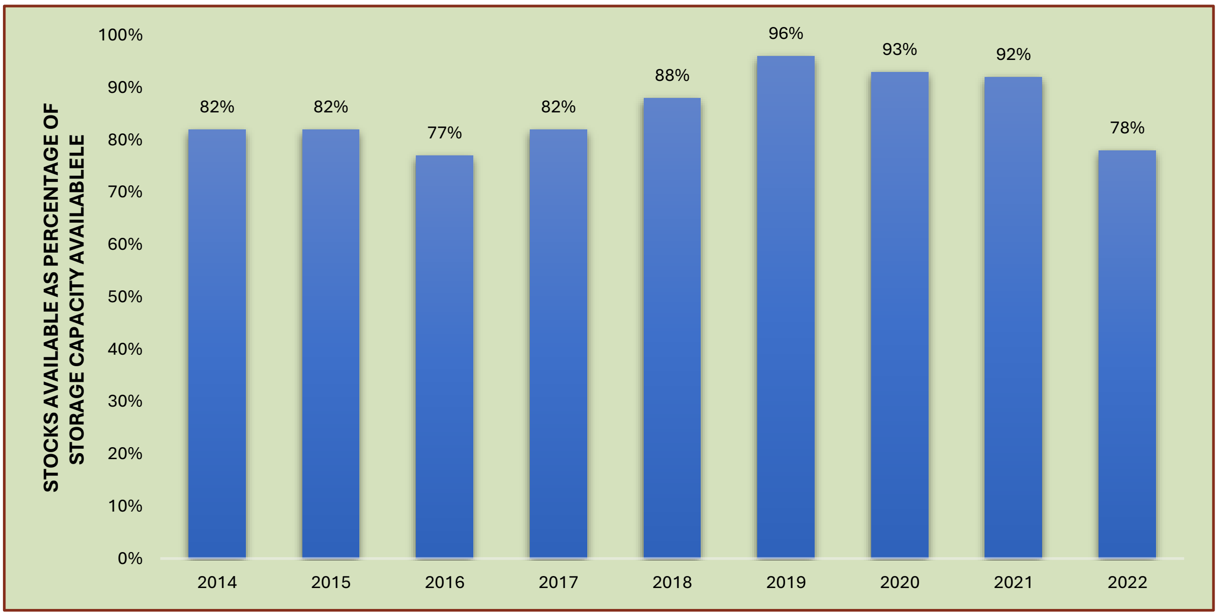
In the last decade the storage capacity of the cooperative sector has remained stagnant. The role of cooperative sectors in storage of grains is envisioned to be promontory by the Hon'ble Prime Minister Narendra Modi under the Agriculture Infrastructure Fund (AIF)[30] by PACs. The National

[29] Launched in 2008 to increase private participation in storage infrastructure, PEG scheme added 15.2 MMT of capacity from 2010 onwards.

[30] The Central Sector scheme was approved by Cabinet on 8.7.2020 to provide a medium - long term debt financing facility for investment in viable projects for post-harvest management Infrastructure and community farming assets through interest subvention and financial support. Under the scheme, 1 Lakh Crore will be provided by banks and financial institutions as loans to Primary Agricultural Credit Societies (PACS), Marketing Cooperative Societies, Farmer Producers Organizations (FPOs), Self Help Group (SHG), Farmers, Joint Liability Groups (JLG), Multipurpose Cooperative Societies, Agri-entrepreneurs, Start-ups and Central/State agency or Local Body sponsored Public Private Partnership Project. All loans under this financing facility will have interest subvention of 3 percent per annum up to a limit of Rs. 2 crores. This subvention will be available for a maximum period of 7 years. Further, credit guarantee coverage will be available for eligible borrowers from this financing facility under Credit Guarantee Fund Trust for Micro

Cooperative Grain Storage Project was launched in 2023 in order to expand cooperative sector storage facilities by 700 lakh tonnes. One of the major aims of this project is to reduce food grain transport and storage losses. Nonetheless, storage capacity of cooperatives increased only marginally in the last decade from 15.1 MMT in 2010-11 to 16.6 MMT in 2021-22. The utilization of storage capacity at all India level hovered around 90 percent during 2019-2022 indicating inadequacy of storage infrastructure (**Figure 2.6**).

Figure 2.6: Utilization percentage at FCI as on June 30 each year (2014-2022)



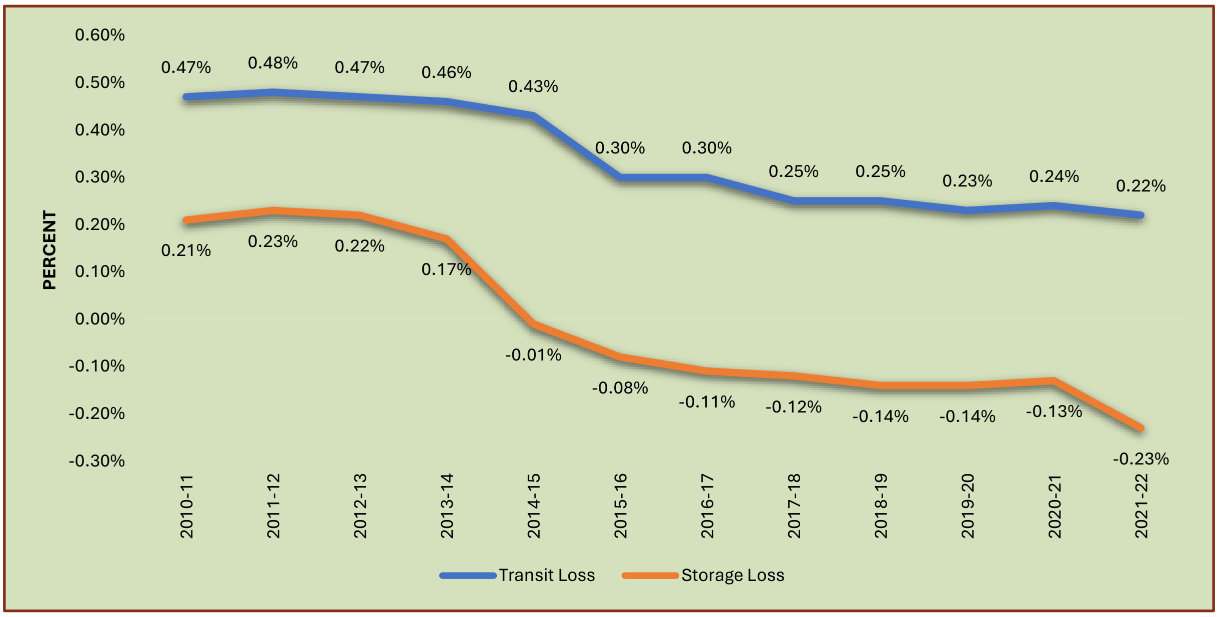
Source: DFPD Annual reports (various issues)

2.3 Regional dimension of storage

At all India level, storage loss has declined over the years for grains and due to moisture gain of wheat the graph shows a negative loss for total food grains (**Figure 2.7**). It is to note that at FCI, only quantity loss is measured by assessing the weight differences at the time of loading and offloading. The quantity losses may be measured inaccurately due to changes in moisture content which will affect weight, resulting in the apparent negative losses. Aside from quantity loss, during storage, quality loss of grain occurs with moisture migration and duration of storage. However, transit loss is at 0.22 percent at all India level in 2021-22, declined from 0.47 percent in 2010-11.

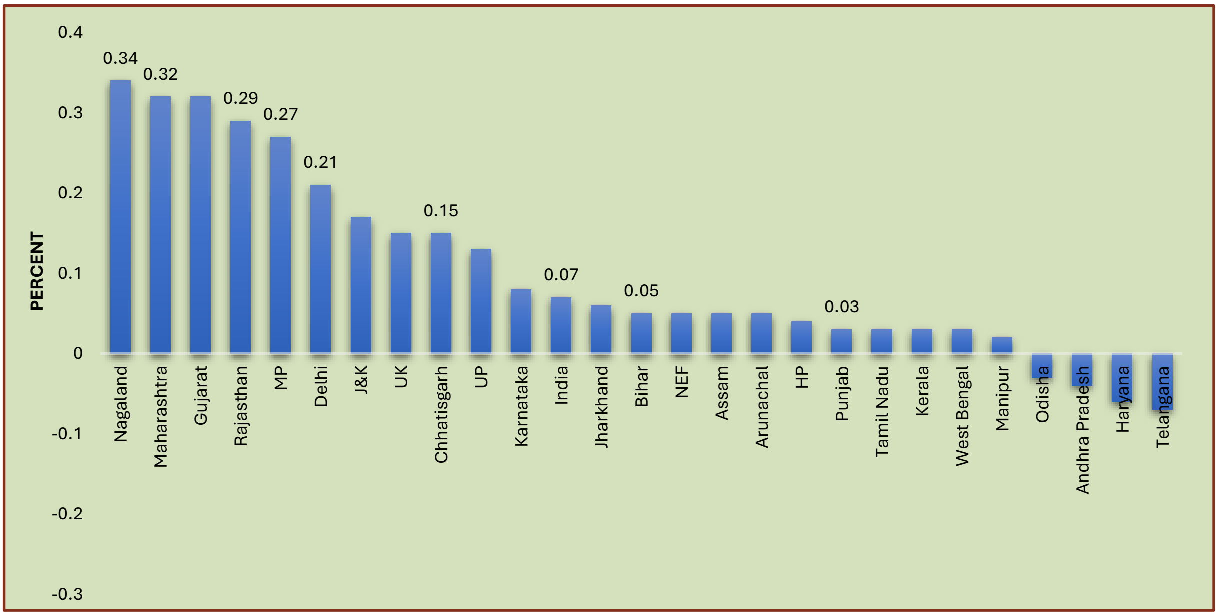
and Small Enterprises (CGTMSE) scheme for a loan up to Rs. 2 crores. The fee for this coverage will be paid by the Government. (Budget, 2023)

Figure 2.7: Transit and storage loss of food grains (percent of Quantity moved and issued) 2010-2022



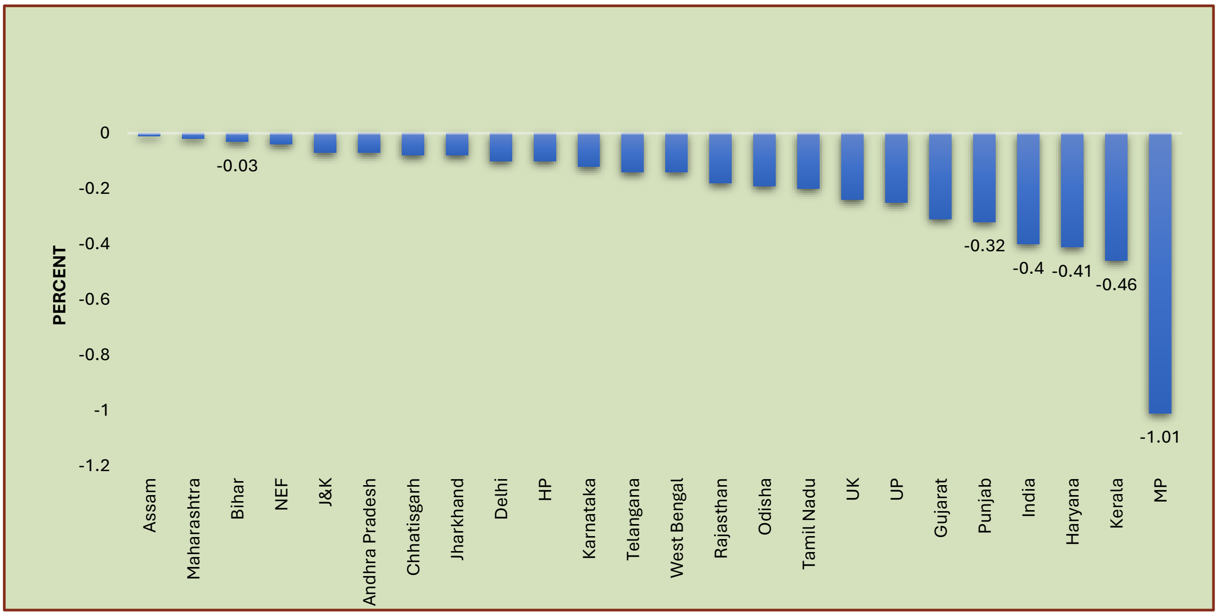
Source: FCI various issues

Figure 2.8: Storage loss in rice at FCI warehouses for Apr-Sep 2023



Source: FCI

Figure 2.9: Storage loss in wheat at FCI warehouses for Apr-Sep 2023

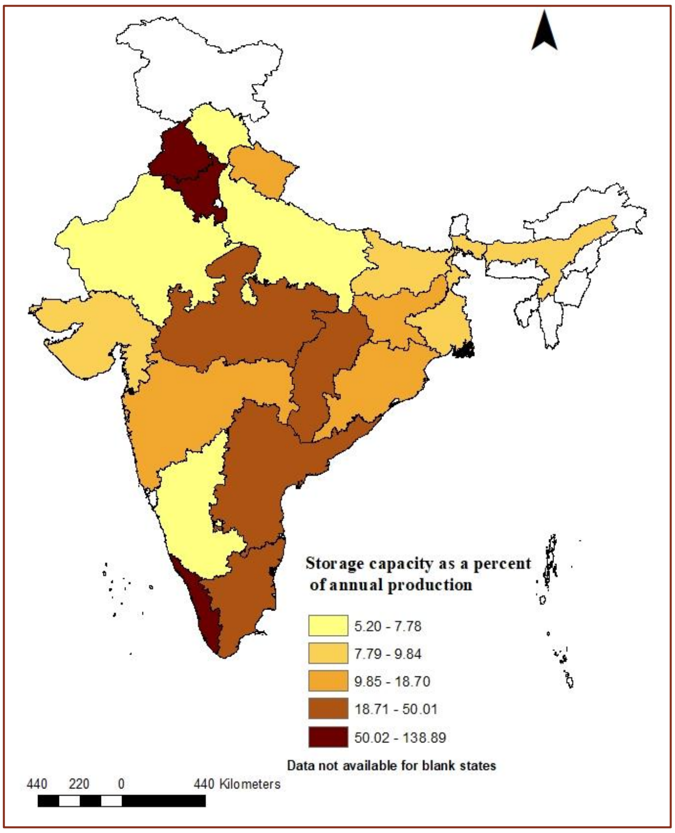


Source: FCI

As **Figure 2.8** and **Figure 2.9** show, storage loss varies across states and between rice and wheat, which is related to the climatic condition, storage infrastructure, the efficiency of storage system. At the FCI level, the assessment of storage losses reveals notable disparities between rice and wheat during the period of April-September 2023. Across various states, rice demonstrates a positive storage outcome, with the most substantial percentage observed in Nagaland, a north-eastern state, reaching 0.34 percent (**Figure *2.8***). Conversely, wheat exhibits a contrasting trend owing to the proliferation of private storage facilities and silos, resulting in a decline in storage losses since 2015. The hygroscopic nature of the wheat crop, characterized by its ability to absorb moisture and gain weight over time, contributes to the nuanced storage loss trend. Despite this inherent feature of gain due to moisture absorption, the extent of storage losses for wheat varies significantly among states. To note that, Bihar, a key wheat-producing state, registers comparatively higher storage losses in comparison to other major wheat-producing regions.

Figure 2.10 represents the storage capacity of the state as a percent of annual food grain production. The figure starkly portrays a pronounced regional bias in the development of storage capacity, with a notable concentration in Punjab (56.32 percent), Haryana (53.99 percent), Madhya Pradesh (50.01 percent). In Kerala, despite relatively low absolute food grain production (0.63 MMT), the storage capacity is more than production (0.88 MMT) leading to high percentage of storage capacity as percent to total food grain production. This could be attributed to Kerala's status as a prominent consumer of rice, driving the need for storage infrastructure. The skewed distribution of government storage infrastructure in India highlights a disparity in the allocation of resources. There exists a distinct inadequacy of storage capacity in eastern and north-eastern states. Despite being the leading food grain producer in the country, with a production of 56.11 MMT, Uttar Pradesh faces a storage capacity constraint, with only 7 percent of its food grain having adequate storage facilities. Similarly, West Bengal, another prominent food grain producer with a production of 20.5 MMT, possesses a mere 1.93 MMT of storage capacity, indicating a pressing need for infrastructure development. This deficiency raises questions about the equitable distribution of resources and the accessibility of storage facilities for agricultural produce in these regions.

Figure 2.10: State-wise storage capacity of FCI and state agencies to annual food grain production (Excluding hired CAP storage) as on Jan 01 2023

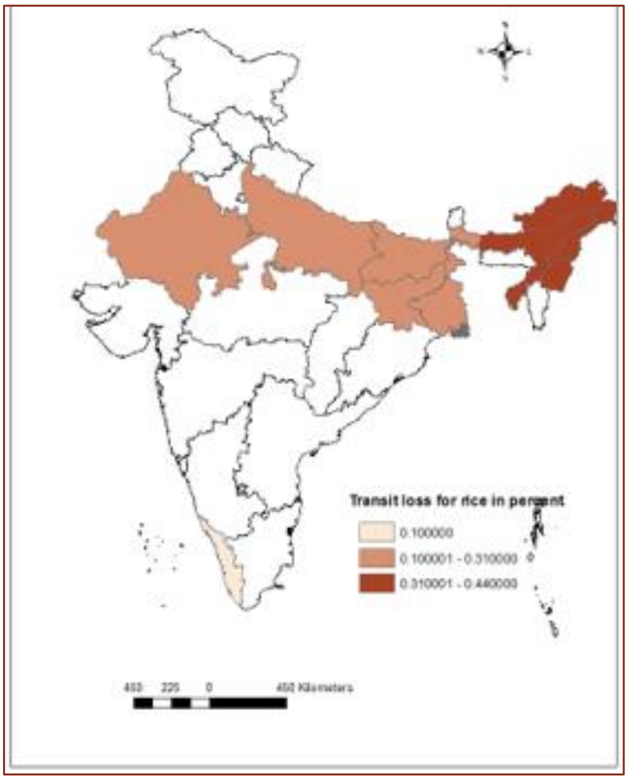


Source: Agriculture Statistics at a Glance, 2022. Department of Food and Public Distribution (DFPD) annual reports (various issues)

2.4 Distribution

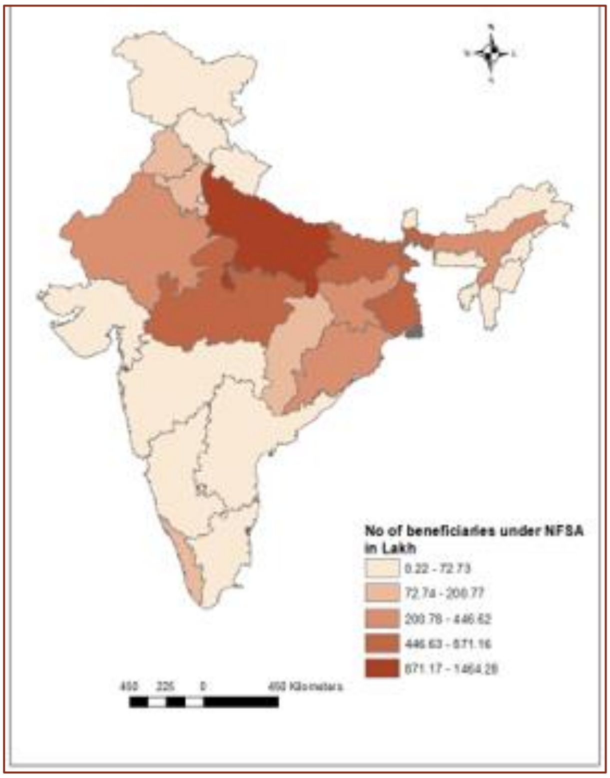
Approximately 800 million beneficiaries under the National Food Security Act (NFSA), are receiving assistance through the PDS across India. This aid is facilitated through a network of 5.45 lakh Fair Price Shops (FPSs) throughout the country. Verdhan et al. (2020) study on transit losses in PDS based on the field survey in Andhra Pradesh estimated an economic loss of Rs. 182.11 million per year for total transit and handling loss at state level. The major factors of transit losses are due to poor infrastructure at the mandal level buffer storage facilities, spillage of rice, re-bagging, pilferage or siphonic of rice, seized rice stocks for litigation issues, distant transportation before it reaches to Fair Price shops. Lower procurement leads to higher transit losses in eastern and north-eastern states (**Figure 2.11** and **Figure 2.12**).

Figure 2.11: Transit loss (in percent) for rice across states (Apr-Sep 2023)



Source: Data on request from FCI

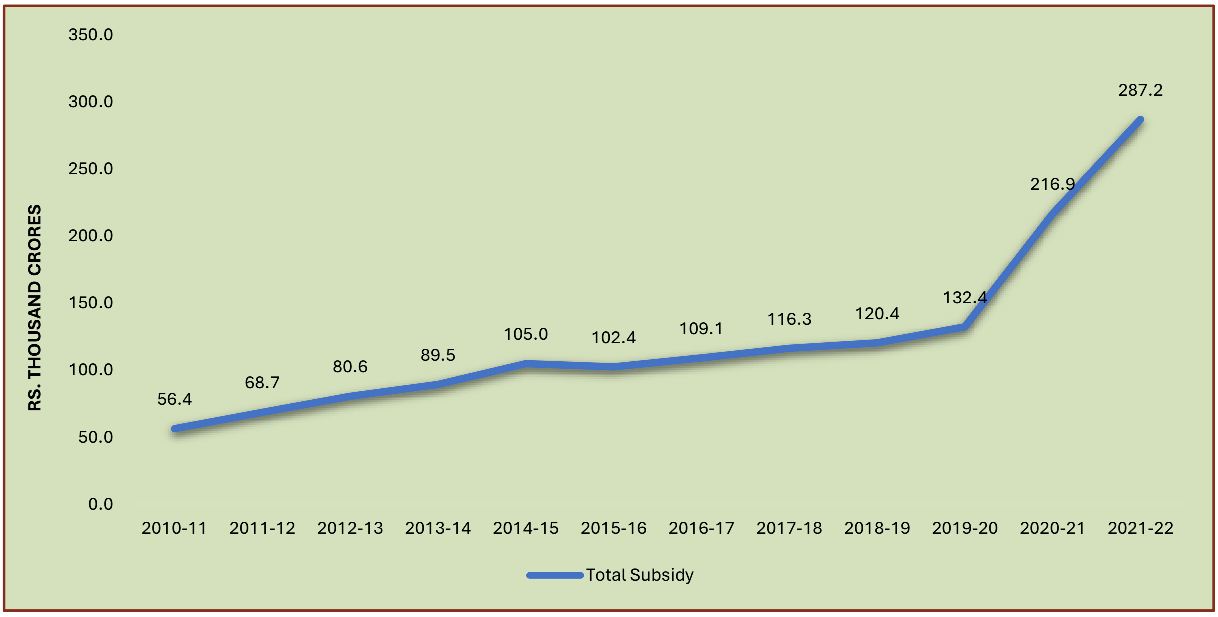
Figure 2.12: Number of NFSA beneficiaries across states 2023



Source: Foodgrain bulletin (October 2023), DFPD

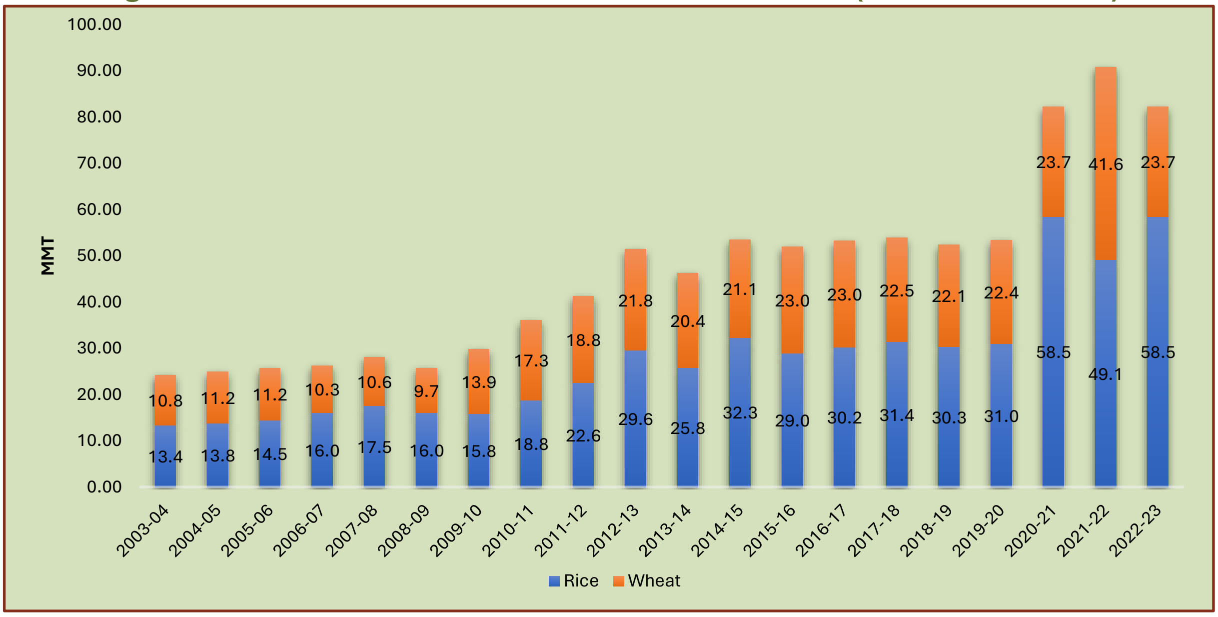
PDS schemes including Antyodaya Annapurna Yojana, Annapurna yojana and other food security schemes, represent the biggest welfare scheme in India. These welfare schemes comprise 8.3 percent of total budgeted revenue expenditure of GOI (GoI, 2023) and has been increasing over the years due to expansion of the program by providing additional 5 kg of rice/wheat per person per month during the COVID-19 period and making it free January 2023 onwards for the next five years (**Figure 2.13**). Hence, tackling transit and handling losses in the PDS is of cruical importance. The report of the Standing Committee on Food Consumer Affairs and Public Distribution (2021-22) highlighted that there have been losses of 4.11 lakh tonnes of grains (wheat and rice) with an economic losses of Rs. 1109.82 crores in the last four years. Multiple handling of grain results in high transit losses during distribution process. Over the period the transit losses have declined, however, it has a distinct value of 0.22 percent as of 2021-22 (see **Annex *2***). The offtake of grain increased from the implementation of NFSA in 2013, and the figures rose to a height in last four years, from 53.4 MMT in 2019-20 to 82.23 MMT in 2022-23 (**Figure 2.14**).

Figure 2.13: Total Food Subsidy including consumer subsidy, carrying cost of buffer stocks and subsidy on coarse grains (2010-11 to 2021-22)



Source: FCI Annual reports (various issues)

Figure 2.14: Offtake of Rice and Wheat from Central Pool (2003-04 to 2022-23)



Source: Foodgrain bulletin (various issues), DFPD, GoI

The spells of rain, availability of transport facilities also impact transit losses of grains. As we have shown that stock at FCI was much above the buffer stocking norms and it has been the case for rice in last four years, increased the need for expansion of storage and handling infrastructure. The demand for excess ration under PMGKAY[31] escalated the distribution pressure. Hence, modernisation of transport and distribution will reduce post-harvest losses.

[31] Pradhan Mantri Garib Kalyan Anna Yojana (PMGKAY) was launched amidst Covid-19 pandemic induced lockdown in April 2020 and was discontinued from Jan 2023 onwards. Under this scheme, all the NFSA beneficiaries were distributed additional 5 kg per person of food grains

3 Factors of losses

The multiple factors contributing to storage losses of grains have been well-known for some time. First is duration. Sarid et al. (1965) determined that with increase in storage duration, the occurrence of storage infestation increases. However, the range of grain infestation varies across storage infrastructure with variation in weight loss of 8 to 15 percent. Early studies and later literature highlight the importance of moisture control and show that bulk storage has smaller losses compared to bag storage due to better aeration and lower, more stable moisture content. Ramavisan et al. (1967) studied storage loss of wheat in one of the districts of Punjab and found that 75 percent of farmers stored in bags and suggested that metal bins are better storage to reduce losses. Almost 40 years later, Sinha and Sharma (2004) identified that wheat storage loss in jute bag can be as high as 6.6 percent and can be brought down to 2 percent by storing in metal bins. Despite the technical advantages of bulk storage, bag handling remains the primary method of grain storage in India with a rising trend of bulk storage.

The physical factors for storage loss of grains include environmental, structure of storage, duration, treatment during storage, relative humidity, rainfall during harvest, air velocity, exposure to direct sunlight etc. The biological factors of loss during storage include moisture content, insect infestation, micro-organisms, and rodents. There are primary and secondary pests in the storage; primary pests impact the whole grain and secondary pests damage if the grain is processed or broken. The examples of primary pests are weevils (Sitophilus spp.), Rhyzopertha dominica, Khapra beetle (Trogoderma granarium). The Khapra beetle is one of the major infestations in wheat in Punjab. Moisture can contribute to grain loss by promoting microbial and fungal activity. Unlike grain stored in silos or hermetic bags, grain stored in jute bags will absorb moisture from the outside air. This can both contribute to losses and impede measurement of loss. For example, estimation of storage loss in the government godowns between the time of receipt and offloading can be misleading in the absence of moisture content information. During procurement time of wheat in March-April, the weather condition is dry and grain moisture content tends to be lower than in the rainy season of July-September when grain is off-loaded. Due to absorption of moisture, the weight of the grain increases, obscuring weight loss due to insect damage (Ahmed, 1983).

Losses during storage can be of both types: quantitative loss which means reduction in grains due to improper handling, insects, rodents attack and quality loss due to mold damage shrivelled grain, discolouration, and lustre loss. Moisture content during storage is the major cause of losses. Rodents, storage fungi are also the major cause of grain spoilage and impacts the price of the product due to deterioration of the quality (Jain et al., 1994). Regarding the factors of losses, there are biotic and abiotic factors which are dependent on storage technology and practices. Nutritional condition of wheat is also largely affected by the storage condition, any fungi attack, infestation of grain leads to affect constituents of grains.

3.1 Moisture content

Moisture quantity of grain is one of the critical factors during storage, for optimal milling yield and quality of grain, paddy is procured at 14 percent of moisture content. According to FCI quality norms, the maximum limit of moisture content for common and A grade paddy is at 17 percent and for rice, parboiled or raw it is fixed at 14 percent. During the harvest the moisture level of paddy hovers around 20-22 percent and drying of grain is required before storage. Improper drying increases the probability of infestation in the grain and mold creation. Storage at 30 degrees below 65 percent RH keeps the grain equilibrium of SMC of 12-14 percent. Therefore, proper drying of grain is required before the procurement. As rice harvesting period is already hot-and humid period in the tropical countries, the probability of growth of toxigenic fungi and release of mycotoxin are also high. Due to short harvest window, it is very less time for farmers to dry the produce properly. Storage of un-milled rice is more susceptible to loss due to higher protein and fat concentration (Atungulu et al., 2019). Hence, proper storage before milling is important to reduce storage losses and to get optimal paddy to rice conversion rate, which is at 67 percent.

3.2 Mixture of foreign matters, broken grains and dust

According to the FCI quality norms, the maximum limit for broken grains in raw rice is at 25 percent and for parboiled rice it is at 16 percent. Mixture of foreign matters increases the probability of fungus attack during storage.

3.3 Impact of harvesting technology on storage losses

Harvesting technologies and handling of the harvest produce impact the storage loss. In combine harvesters the mixture of dust, foreign matters are higher due to crashing of grains. Hence, proper gradation is required before storage to reduce losses. Also, the environmental condition affects the grain quality, rainfall during harvest already increases the moisture level in wheat and during storage the grain cannot absorb more moisture and reduces quality of the produce. Treatment of grains before storage is important to reduce losses. There are different methods of drying techniques impacting the moisture content of grains. Mechanical drying reduces the moisture content but it is difficult to reduce the content in given time.

3.4 Aeration

Aeration is important to cool and dry the grain in the storage to control the infestation. In conventional storage system, jute bags are stacked, however the temperature varies across stacks resulting in moisture migration. Generally, air is heavier at the bottom and lack of aeration creates dampening of grains at the bottom. Also, within the bag, the ambient temperature is lower than the inside, resulting in damage in outer layer due to lack of aeration. In silos, aeration is done as required by the sensors' data on moisture from different locations of grain storage.

3.5 Biotic factors

To control infestation, literature show that fumigation is done with Aluminium phosphide (Kumar et al., 1981). The major pests in store grains are beetles, weevils, moths, and rodents. **Storage Pests: Red Flour Beetle** (Tribolium Castaneum), **Sursari/Lesser grain borer** (Rhyzopertha Dominica), **Rice weevil** (Sitophilus Oryzae), **Saw teethed grain beetle** (Oryzaephilus surinamensis), **Flat grain beetle** (Laemophloeus), **Khapra beetle** (Trogoderma Granarium). To control infestation, there are two kinds of fumigation, preventive and curative. Aluminium phosphide is majorly used insecticides; however, the hermetic storage condition increases the CO_2 concentration and reduce dependants on fumigation.

4 Post-harvest loss in different storage system of the government: Assessment based on Case studies

4.1 CAP storage

CAP storage is traditional method of storing grains. One of the primary challenges associated with CAP storage is its susceptibility to environmental factors such as humidity and temperature fluctuations. In regions with high humidity levels, condensation can occur beneath the covering, leading to moisture accumulation and subsequent mold growth, which can spoil the stored grains. In our case study of CAP, it was used at shellers' level in the procurement channel of paddy in Moga district of Punjab (**Figure *4.1***).

In 1955, a committee was set up for assessing the rice milling industry in India and based on the recommendations the Rice Milling Act was forwarded, with improved infrastructures at shellers by mechanical drying and parboiling machines. In 1965-66 "Save grain" campaign was launched to improve storage infrastructure in India. Our FGD with sheller managers found out that controlling moistures in grains is the major challenge. After the procurement, due to short time period for rice processing, the moisture level reduction to FAQ norms is difficult. However strict mandates exist for the shellers for the quantity they deliver to the FCI.

- Government agencies have a contract with the paddy sheller, which has a capacity to store 160000 jute bags at the facility out of which 1 lakh bags were stored in the open area through CAP storage.

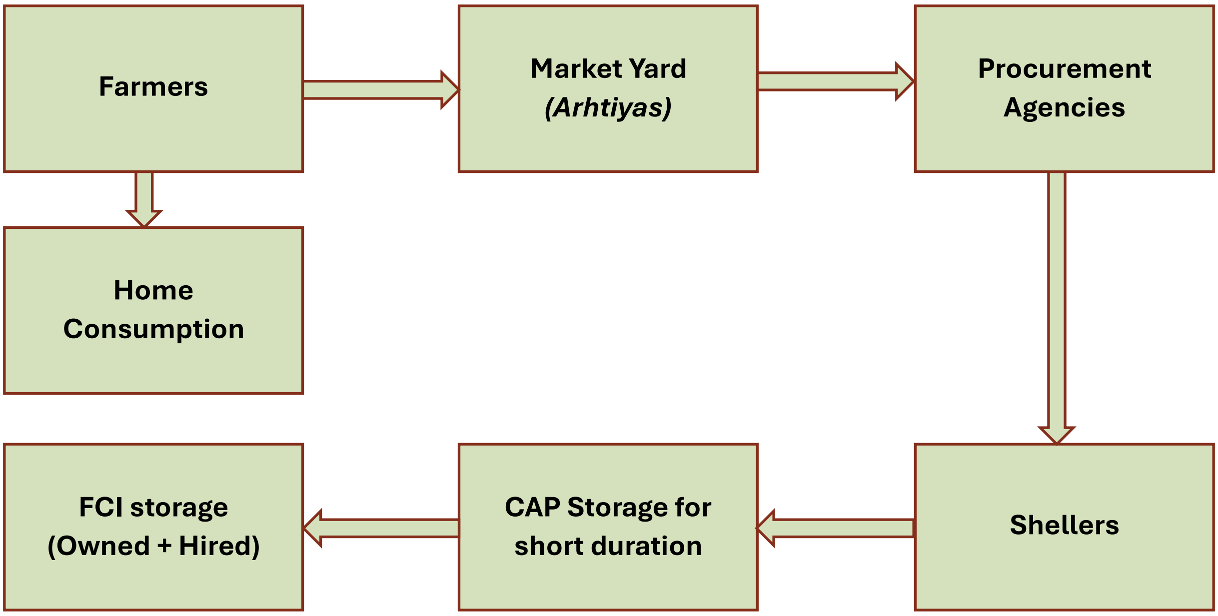
- The CAP storage is spread over an area of 3 to 3.5 acres using a wooden plinth and no cover. Stacks of jute bags are made with a height of 20-25 bags depending upon the requirement. In case of rains the storage gets covered within minutes as per the owner using large plastic covers.

- The sheller receives paddy from the government agencies that procure for the government, PSWC, PUNGRAIN, MARKFED and PUNSUP.

- Paddy so received by the sheller contains 20 to 22 percent moisture. As per the FCI mandate, it has to be heated and dried to meet the government standards of 14 percent moisture.

As per the contract the sheller has to follow the FCI mandate of delivering 67 percent of the weight of the paddy received as shelled and polished rice to be further stored by the FCI for the central pool.

Figure 4.1: Procurement channel in Punjab

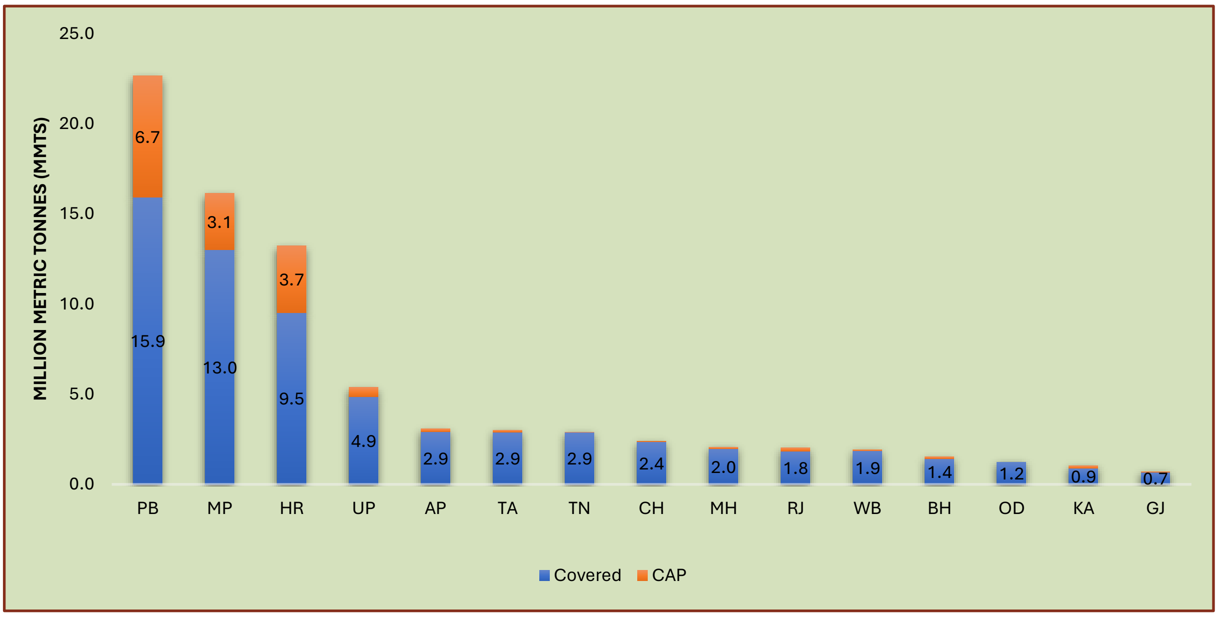


Source: Authors' depiction

In CAP storage, the storage of food grains is in the open space for short-term periods, typically ranging from 3 to 6 months, represents a practical approach to address the challenges of storage capacity during peak harvest periods. This method involves utilizing a concrete plinth and wooden dunnage for aeration, with protective plastic covers placed on top. This approach is considered both cost and time-effective, serving as a temporary solution when conventional covered storages become exhausted during periods of high agricultural activity.

While the open storage technique offers advantages in terms of quick implementation and reduced costs, it comes with inherent risks (Chaturvedi and Raj, 2015). The exposure to the elements, including moisture, rain, and waterlogging, poses a significant threat to the stored grains. Consequently, storage losses are more pronounced in these open storages compared to conventional covered facilities. This increased vulnerability underscores the need for careful consideration and management during the storage period. In CAP storage compared to jute bag, hermetic bags lead to lesser grain losses (Bharadwaj, 2015).

Figure 4.2: Covered and CAP share in storage with FCI and state agencies for top selected states as on Jan 01 '21



Source: DFPD Annual Reports (various issues)

Note: Data for state-wise CAP storage is not available post 2021 as FCI is trying to gradually phase it out

As of January 1, 2021, the FCI operated 15 million metric tonnes (MMTs) of CAP storage capacity (**Figure *4.2***). This represents approximately 18 percent of the total storage capacity under the purview of FCI, as reported by the Department of Food and Public Distribution in 2022. Notably, the north zone accounts for a substantial portion of the total CAP storage capacity in the country, with 94 percent distributed across states such as Punjab (45 percent), Haryana (25 percent), Madhya Pradesh (21 percent), and Uttar Pradesh (3 percent).

Recognizing the limitations and challenges associated with open storage, the Shanta Kumar Committee recommended a phased approach to gradually eliminate these storages in January 2015. The committee suggested that no grains should remain in CAP storage for more than three months, emphasizing the importance of transitioning to more secure and sustainable storage methods. This recommendation reflects a strategic effort to enhance the efficiency and resilience of the food grain storage infrastructure, aligning with broader goals of minimizing storage losses and ensuring food security.

4.2 Conventional Covered Warehouse

The conventional covered warehouse in Moga District owned by the CWC and hired by the FCI with a capacity of 17300 MT has been studied as a case study. The capacity utilization at this facility can go up to 100 percent during peak procurement time. A rough estimate provided by the management of the losses (storage and transit) stand at 0.3 to 0.4 percent. The facility provides the estimated loss quantity to the FCI on a monthly basis. The methodology of measuring the storage losses is the same as the FCI since the warehouse is hired by FCI and operated under its mandates. The storage losses equal to the difference between the quantity by weight at book value and the quantity by weight at dispatch. Wheat is accepted at this facility at 14 percent moisture level and even at relaxed norms unlike at silos where wheat with more than 12 percent moisture is not accepted.

The grains in this facility are stored in jute bags of 50 kg for wheat and rice stacked up to a height of 22-25 bags depending upon requirement. One stack is of 1740 quintals comprising of 3480 bags. Like other FCI facilities, pre-monsoon treatment for infestation is mandatory. The storage losses in these conventional covered warehouses primarily depend upon the moisture content at which the produce is received and the duration for which the grains are stored. If the moisture content at receiving is high, the probability of infestation increases. Wooden dunnage is used in these warehouses for aeration from the floor for the bottom of the stack. There have been instances of grains spilled to the floor from the bags at the lowest of the stack. The management reports that such spillage is minimal and can be vacuumed, collected, and put back. The leakage may have been due to the use of hooks for moving bags as there were hook marks in the jute bags.

The management verifies that in wheat, weight increases during storage due to moisture changes and thus the measured storage losses are negative. For rice, the moisture content determines the losses. Overall, the storage losses are minimal in the facility since the FCI mandates are followed strictly but transit losses exist. The CWC is responsible for delivering the quantity of the stored produce after adjusting for transit losses permissible by the FCI.

When the height of the stack is increased due to storage demand, the moisture in the bags at the top decreases compared to lower stacks. This difference in weight of the bags in the same stack has been stressed by the management. The heat waves have amplified these effects. Aeration happens through the ventilators at the top of the ceiling bringing in hot air and drying the bags at the top of the stacks. This phenomenon is dependent upon the season. In winter, the relative humidity is comparatively low. So, the amount of weight that the grains will gain depends upon the season and duration for which it has been stored.

4.3 Steel Silos

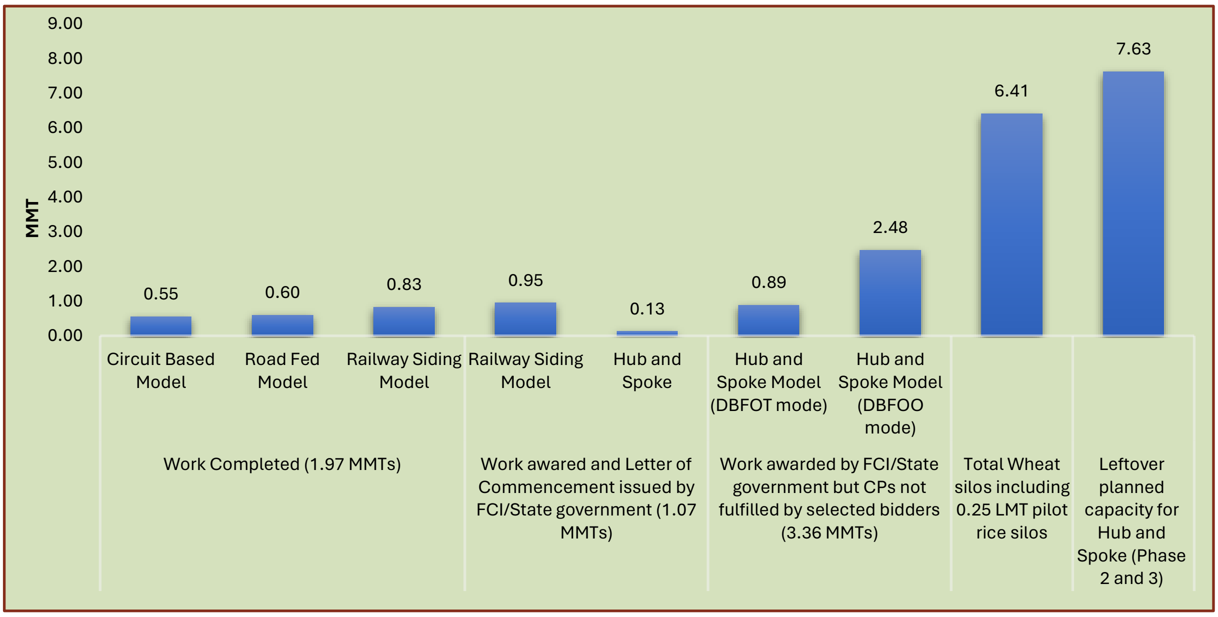
There have been many studies on the efficiency of steel silos compared to conventional warehouses for grain storage and the agro-processing units find the bulk storage more favourable (Dhingra, 2016; Kumar et al., 2021). Silos not only ensure better preservation of food grains but also enhance their shelf-life. There are different structure types of silos: concrete silos, steel silos, bag silos, bunk silos etc. Concrete silos are of cement structure and of cylindrical shape, however this structure has issues of moisture absorption from the atmosphere. In the context of innovative grain storage practices, Madhya Pradesh has emerged as a pioneer in utilizing silo bags adopted from Argentina for on-field storage, contributing to a reduction in the reliance on chemical fumigants. This approach, particularly implemented during periods of bumper production, also serves as a means for short-term credit advancement (Gulati et al., 2021).

On a broader scale, the public grain management strategy in India has emphasized the expansion of steel silo facilities. Since January 2016, entities such as FCI, CWC, and other State Government agencies were tasked with achieving a collective capacity target of 10 MMT. Private investors, CWC, SWC, or other state agencies have played a pivotal role in funding these capacities. The

Department of Food and Public Distribution (DFPD) has granted 'in-principal approval' for silo construction under the Hub & Spoke model proposed by FCI. The transportation of food grains stored in silos are planned to use silo railways, to carry in bulk to minimize losses resulting from theft and pilferage (FCI, 2022).

Despite these initiatives, the completion of steel silo capacity work has reached only 1.97 MMT out of the planned 14.03 MMT. As of September 30th, 2023, assignments or completions account for 6.4 MMT of capacity, inclusive of a 0.25 MMT pilot for rice silos, leaving 7.63 MMT yet to be allocated (**Figure *4.3***). This discrepancy highlights the existing challenges and underscores the need for continued efforts to meet the targeted expansion of steel silo infrastructure in India.

Figure 4.3: Status of silo construction as on September 30 2023

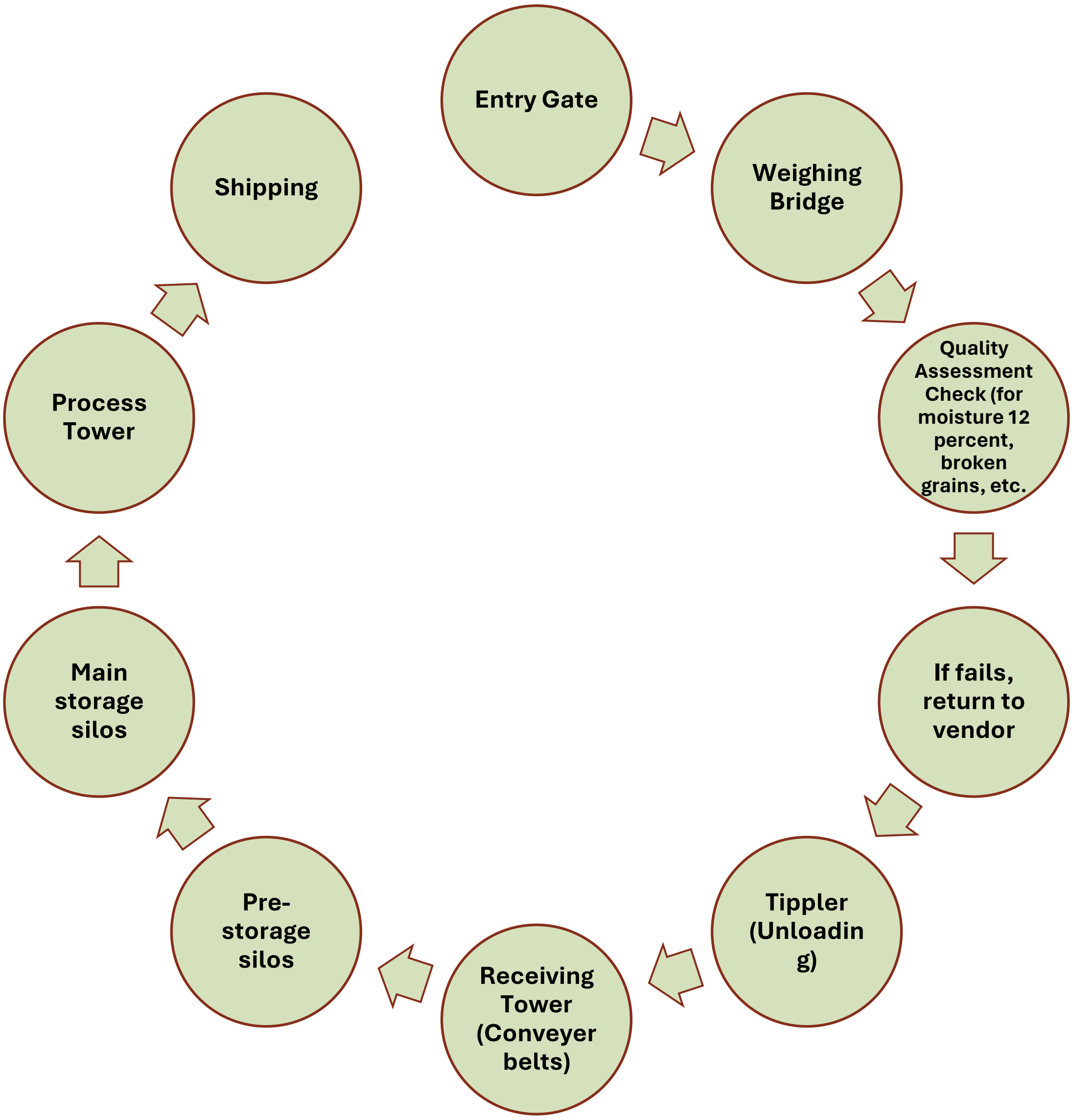


Source: FCI

A case study for silo storage was made through a visit to silos owned by Adani Agri Logistics Limited (AALL), a private logistic infrastructure company at Moga, Punjab. Total capacity of the storage unit is 2 lakh tonnes with 16 Silos of 12.5 thousand tonnes each. Additionally, there are 4 silos of 4500 tonnes each for pre-silo storage purposes. Grain storage operations in this modern silo infrastructure started in 2007. Only URS (Under reduced specification) quality wheat is stored in these silos. This storage facility has a railway siding. The facility is almost fully mechanized and less labour intensive.

There exists a defined procedure of collecting food grains from the farmers for storage (**Figure *4.4***):

Figure 4.4: Process of grain management in silos



Source: Stakeholders' Interview at Adani Silos, Punjab, 2023

The *arhtiyas/*commission agents at mandi issue a purchase slip to the farmers after the quality/moisture checks at the mandi but the produce is not collected there. The farmers bring the produce along with the purchase slip to the silos for the grain to go directly to the storage which is hired by the FCI. The produce is weighed at the gate. The produce goes through various checks through a sampling procedure. Sample is taken from the trolley and categorized into four samples – reference sample, dockage testing, moisture testing and manual testing. The value of the produce is then decided through the various measures from the sample of the produce. If the produce fails the moisture check at the sampling gate, the produce is declined. If accepted, the produce is then unloaded at the unloading dock and through conveyer belts transferred to the smaller silos for pre-silo storage.

FCI hires the storage from Adani at no gain/no loss basis in storage. There is no loss or gain in storage according to the person interviewed. The quality and quantity are not affected in silo storage. However, there is very minimal loss in the process of procuring the grains from the farmers which go through a process of quality/moisture/grading check. This loss gets covered in the 0.25 percent of transit loss permissible by the FCI. The grains stored in the silos remain the property of FCI.

The delivery of the grains is undertaken on request from the FCI and done on a bulk basis only through railway sidings. FCI allows for 0.25 percent quantity loss in the transit of the food grains from the silos to the allotted state.

4.4 SWOT analysis of different storage types based on case studies

Table 4.1: SWOT analysis of CAP storages

CAP	
Strength *What is working well with this storage type?*	Weakness *What is the disadvantageousness with this storage type?*
Low investment, economical, time effective	Larger losses, prone to waterlogging and rains, more rodent attacks, and infestation
Opportunities *What new frontiers can be explored?*	Threats *What are the issues with this storage type?*
Short duration storage less than 3 months with good management practices	Probability of larger losses in events of rains and flooding

Table 4.2: SWOT analysis of conventional covered warehouses

Conventional warehouse	
Strength	Lower construction costs
Weakness	This storage type is labor intensive (Annex 6). Ambient temperature fluctuates due to older structures. The temperature and moisture content of the outer layer of jute bag is more susceptible to outside temperature. Due to higher moisture absorption, the condensation happens in wheat grains. The quantitative loss is also higher compared to steel silos.
Opportunities	Reduction of transit loss is possible by expanding the procurement and storage facilities in consumption regions.
Threats	Technologies are conventional and backward. Storage of older crops are susceptible to more damage.

Table 4.3: SWOT analysis of steel silos

Steel Silos	
Strength	**Weakness**
Wheat can be stored in huge quantity, no loss/gain for wheat and it is a better-quality storage method. Modern technology facilities like conveyer belts and IoT sensors are used. Storage cost per tonne is lower than conventional and it has less transit loss due to railway sidings. Less fumigation is required and moisture migration can be controlled through aeration.	Capital intensive and dust quantity is more. There is no segregation of produce. Distance to mandi is more, transit cost for farmers increases due to double transport from field to mandi (*arhtiyas*) and then to silo. Moisture quantity is restricted to 12 percent which is lower than what is required at mandi.
Opportunities	**Threats**
Expanding silos facilities to procurement centers will reduce the transit loss, Construction for rice storage is yet to put to scale.	Proper precautions need to be taken. Inspection and management are required, bulk storage is suspectable to huge risk in case of large-scale grain damage.

Table 4.4: SWOT analysis of private warehouses

Private warehouse	
Strength	Clean and well managed warehousing system compared to conventional warehouses This storage type had modern vacuum cleaners. This storage type can be hired on need basis, and it reduces dependence on CAP storage.
Weakness	No modern technological facilities like conveyor belts, IoT censors to check the temperature and moisture were available. Fumigation for the entire stack happens together and no system were there to trace the source of infestation, The case study private warehouse is still dependent on labour. Farmers do not directly sell to private agencies, double transport increases transit loss.
Opportunities	Reducing government interventions and direct selling to private warehouses through NWR will reduce the transaction costs.
Threats	Lack of incentive to invest in infrastructure because of contractual relation. Uncertainty in profit because of the controlled grain markets and the owners have less incentive to invest in technological change.

Source: Stakeholders case study at Punjab, 2023

5 Effectiveness of Private Warehouses on postharvest losses

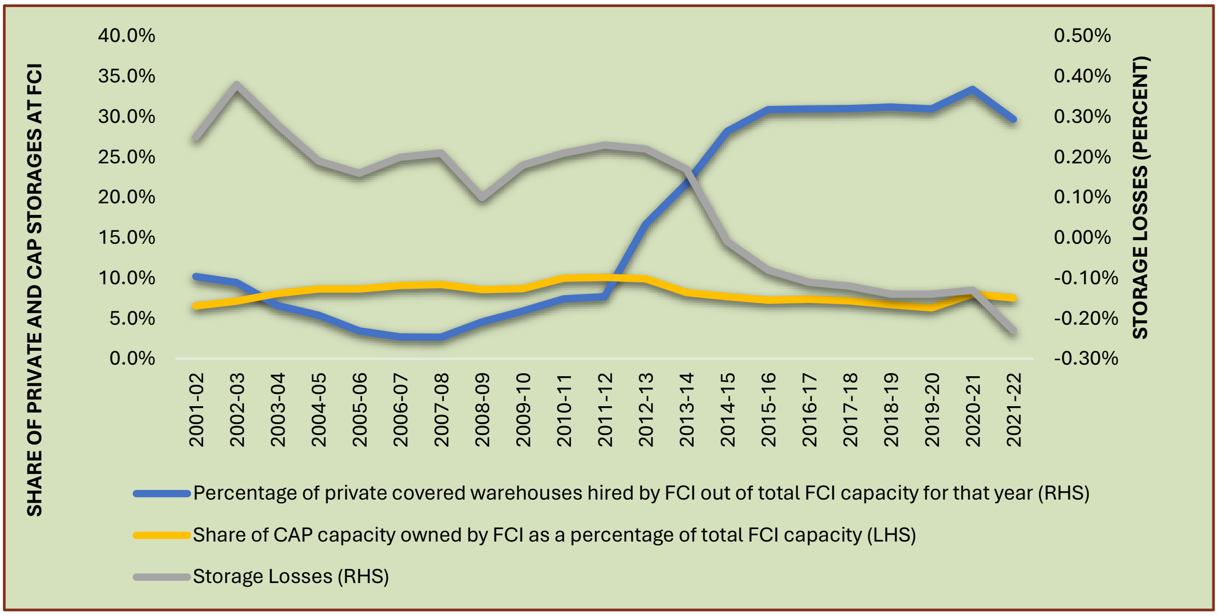
There have been many recommendations from earlier government formed committees to increase the private participation into the country's grain management system including storage systems to increase efficiency and lower storage losses. And also, to decrease the role of the FCI which was formed during times of much needed government role for country's food security. But the functioning of the corporation has not been near optimal due to its increasing role requiring larger bureaucratic apparatus and subsequently inducing greater inefficiencies. The studies include Expenditure Reforms Commission's Report on Food Subsidy (2000), Excess Food Stocks, PDS and Procurement Policy (2001 b), Long Term Grain Policy (2002) and among the latest being the Shanta Kumar report on restructuring FCI (Kumar 2015). But the pace of implementing recommendations had been very sluggish till 2010. The government then introduced schemes like PEG in 2008 and Private Warehousing Scheme (PWS) 2010 to increase private sector participation in storage and handling of the grains. The schemes were based on a guarantee of hiring of the warehouses by the FCI, thus incentivizing investments (more on the schemes in the next sections).

These schemes have successfully increased private participation (**Figure 5.1**). The capacity of covered warehouses hired by FCI from private sector for 2001-02 to 2021-22 has grown at a CAGR of 6.5 percent as compared to the CAGR of 1.2 percent of the increase in the FCI storage capacity. This has been achieved by not increasing dependence on the CAP storage owned and hired by FCI over the years. The share of private sector warehouses hired by FCI as a percent of total FCI storage capacity (not including state capacities) was as low as 2.7 percent in 2006-08 which increased to 7.7 percent in 2011-12. After the introduction of PEG 2008 and PWS 2010 schemes and their successful implementation over the years, the share has significantly increased to 30 percent in 2021-22 (excluding the private hired silos). The rest being the share of FCI owned warehouses and hired from state government/agencies.

Has the private participation played a role in reducing storage and transit losses? The losses were larger for the FCI a decade ago and have declined in the last decade. The private sector participation took pace from 2011-14 when a total of 11.62 MMTs of private covered capacity was added through PEG scheme alone. The share increased from 7.7 percent in 2011-12 to 21.7 percent in 2013-14. Storage losses as a percentage of quantity issued fell from 0.23 percent in 2011-12 to 0.17 percent in 2013-14 to minus 0.01 percent in 2014-15 on account of weight gain due to moisture. It has further fallen to minus 0.23 percent in 2021-22. The correlation between the private covered warehouse capacity hired by FCI and storage loss percent during the period of 2010 to 2022 indicates a value of -0.86. The increase in the demand of storage capacity over the years due to increasing food grain production and procurement has been supplied through private sector participation and by not increasing dependence on more CAP storages. The share of CAP storages owned by FCI as a percentage of total FCI capacity has just increased from 6.6 percent in 2001-02 to 7.5 percent in 2021-22 and which now is being used by the government as a last resort and for shorter time periods.

There are other contributors as well to the factors responsible for falling storage losses. Adoption of better storage methods, better practices, technology upgradation and investments in research are some other factors either adopted by FCI or brought in by the private sector. Nonetheless it is safe to say a strong negative relationship exists between private sector participation in the handling and storage of food grains in India and the storage losses incurred with increase of private participation in the Indian government's grain management system (**Figure 5.1**).

Figure 5.1: Trend in private and CAP storages as percentage of total FCI capacity and trend in storage losses (2001-02 to 2021-22)

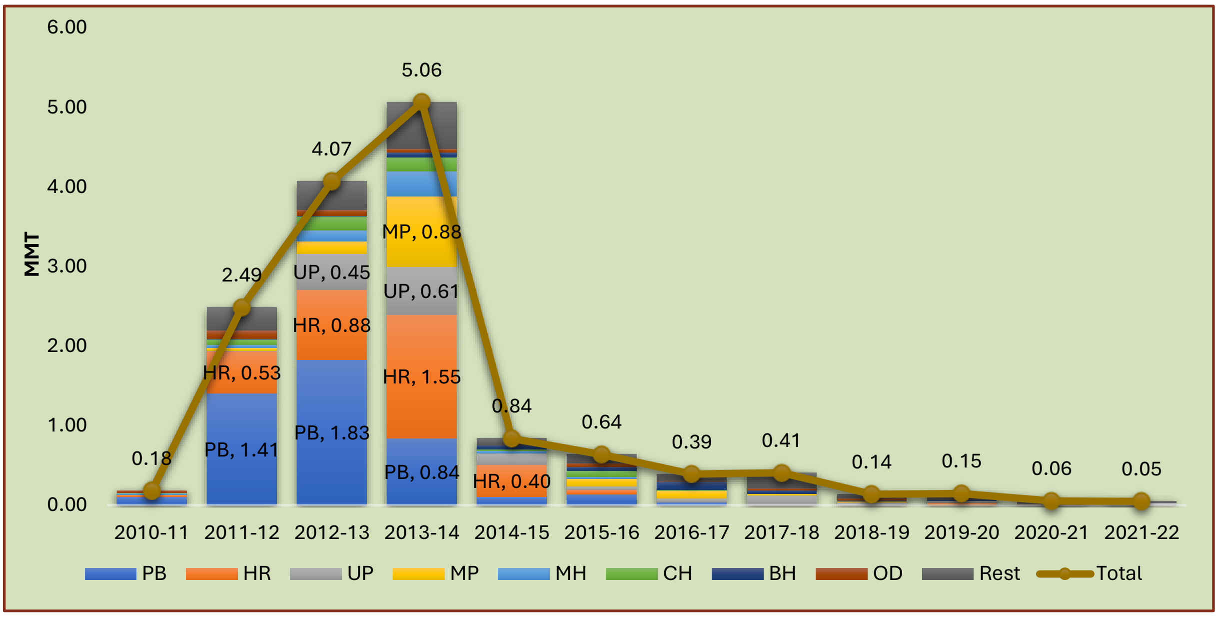


Source: Authors' calculations; data on storage from DFPD and FCI Annual reports (various issues); data on storage losses from FCI Annual reports

5.1 Private Entrepreneurs Guarantee Scheme (PEG Scheme)

Private Entrepreneurs Guarantee Scheme was formulated in 2008, for construction of warehouses in Public Private Partnership (PPP) mode through private entrepreneurs, Central Warehousing Corporation (CWC) and State Warehousing Corporations (SWCs). Under this scheme the government does not allocate funds for the construction. After a warehouse is constructed and taken over, FCI gives a guarantee of rent for 10 years in the case of private investors and for 9 years in case of CWC/SWCs/State Agencies, irrespective of quantum of food grain stored. Under this scheme, the respective agency/party will have full responsibility for the storage losses in food grains stocks in excess of limits prescribed for FCI during the relevant period shall be deducted from the total rentals payable to the party. As on Oct 31 2023, 18.9 MMTs of capacity has been approved and 14.6 MMTs has been completed. The graph below gives the status of this scheme as on Mar 31 2022 (**Figure 5.2**). Under this scheme, three states, Punjab (31 percent), Haryana (24 percent) and Uttar Pradesh (11 percent) made up 65 percent of the total capacity of 14.5 MMT created, followed by Madhya Pradesh (9 percent), Maharashtra (4 percent) and Chhattisgarh (4 percent).

Figure 5.2: State-wise and year-wise details of the PEG capacity created under PEG scheme as on 31.03.2022



Source: FCI website

The warehousing capacity under this scheme has been concentrated in the north region as per the demand since the procurement of food grains is concentrated in that region. The capacity so created has contributed in the reduction of the post-harvest storage losses through reducing the dependence on the CAP storage. And since the FCI hires and operated these storages, the FCI mandates for storages are followed. These storage mandates ensure uniform methods, rules, and practices to be followed across all the warehouses hired, owned or operated by FCI, thereby reducing storage losses.

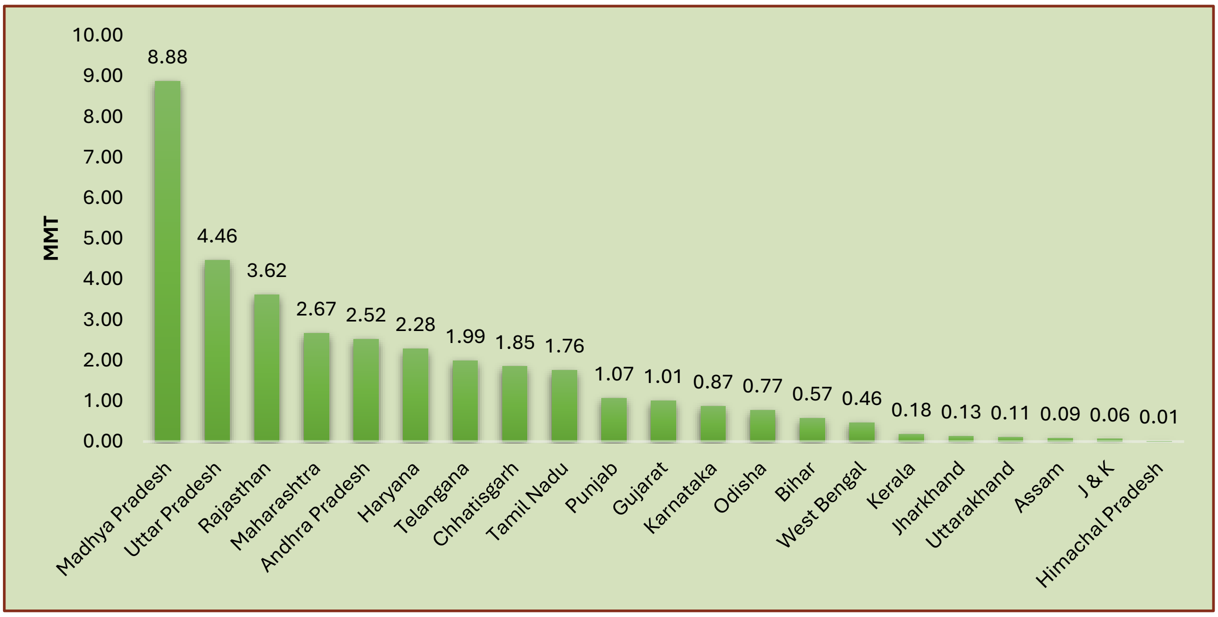
5.2 Role of Negotiable Warehousing Receipts (NWRs) in reducing postharvest losses

Negotiable warehousing receipts (NWR) work as instruments for the farmers to access financial credit on their produce providing a system whereby their stored produce serves as collateral and can be sold or traded. Farmers store their produce after the harvest and receive a receipt from the warehouse which can then be used to for short-term borrowing to obtain working capital. In India, where there are major government interventions in the market for food grains in the form of procurement, storage, price support and stabilisation, have disincentivizing private sector storage and consequently NWR system has not able to function (RBI, 2005). Warehousing receipts apart from providing the farmer access to credit, can also ensure better price realisation for the farmers as farmers can choose to sell their produce well beyond the harvesting period. Most farmers sell their produce just after harvest in India due to capital requirement for the next crop.

Currently with the presence of the procurement system and guaranteed price support in India, most farmers do not store wheat or rice to sell in the post-harvest months when higher prices prevail in the market. With a system of NWR in place farmers can ensure better prices for themselves by storing their produce, accessing credit on that produce to sow the next crop and sell the produce at their will when prices seem suitable. This system also ensures price smoothing and reduces risks to some degree in the agricultural market through expanded access to storage (Giovannucci, Varangis, & Larson, 2001).

The implementation of the NWR system requires availability of private warehouses, legal and institutional environment, and reduced government interventions in the market. With availability of an option with the farmer to store his produce with maintained quality standards in storage and receive warehousing receipts, the post-harvest losses can be minimised especially in the regions where the procurement system is not as strong as in the northern region of the country. With the NWR system in place with its required environment, the small holder farmers can store their produce in the private registered warehouses with better handling and storage standards instead of storing at their houses. This will help drastically reduce the losses incurred when compared to storing at farmers' own place. At present a very small percentage of warehouses are registered with the WDRA which makes the first base unavailable for the NWR system to grow (**Figure 5.3**).

Figure 5.3: State-wise total capacity of registered warehouses



Source: WDRA dataset

This system has a high potential of reducing marketing level postharvest losses in the chain. It can also reduce transactions cost for the dealers. After the farmer has received a receipt from the warehouse, the stored produce can change hands without any transit of goods requirement. Hence reducing the probability of any transit losses till the produce is finally sold in the retail market. The storage regulation standards required by the regulatory authority for NWR issuing warehouses can ensure market integration through grading and committing on the receipt the standards to be maintained throughout storage period. Even the government can procure food grains through these receipts without having to run the inefficient bureaucratic apparatus for procurement (Kumar A., Gulati A., Cummings Jr. R., 2007).

But the use of WRS is low in India. Various reasons have been established for farmers in India not availing NWR facilities including: lack of awareness, lack of storage facilities, transportation cost, documentation involved and immediate need of money (Shalendra, Jairath, Haque, & V., 2016). In the same study the authors found that 75 percent of the sampled farmers stated an absence of warehousing facilities in the vicinity as their reason for immediate disposal of the commodity. The Essential Commodity Act gives the GOI the power to put the stocking limits on grain which disincentivizes the private sector to invest in the storage infrastructure. With government playing the major role in storing the food grains in the country through FCI and other government agencies have left little gap for private players to enter. The role is limited to assured hiring of private infrastructure against fixed rent for the private players. Since 2010 the government has promoted private warehouses on a model where the FCI hires them to store the produce for the government leaving no room for NWR system to grow. At present the bulk of receipts issued are to the traders or large farmers who can bear the transactions cost involved. For this system to be implemented, the first step will be ensuring availability of private warehouses where the produce is. Most farmers in India are smallholders and hence information flow is required among them to utilise this tool that can enhance their incomes. Our FGD highlights that there is a lack of warehouse receipt system by private warehouses for rice-wheat as most of the farmers sell during harvest due to credit advancement from arhtiyas. Also, the focused group discussion found out that they have lack of options to store their produce for rice and wheat in private warehouses that they can sell after the peak harvest period, when price goes up.

6 Role of FPOs in reducing PHL

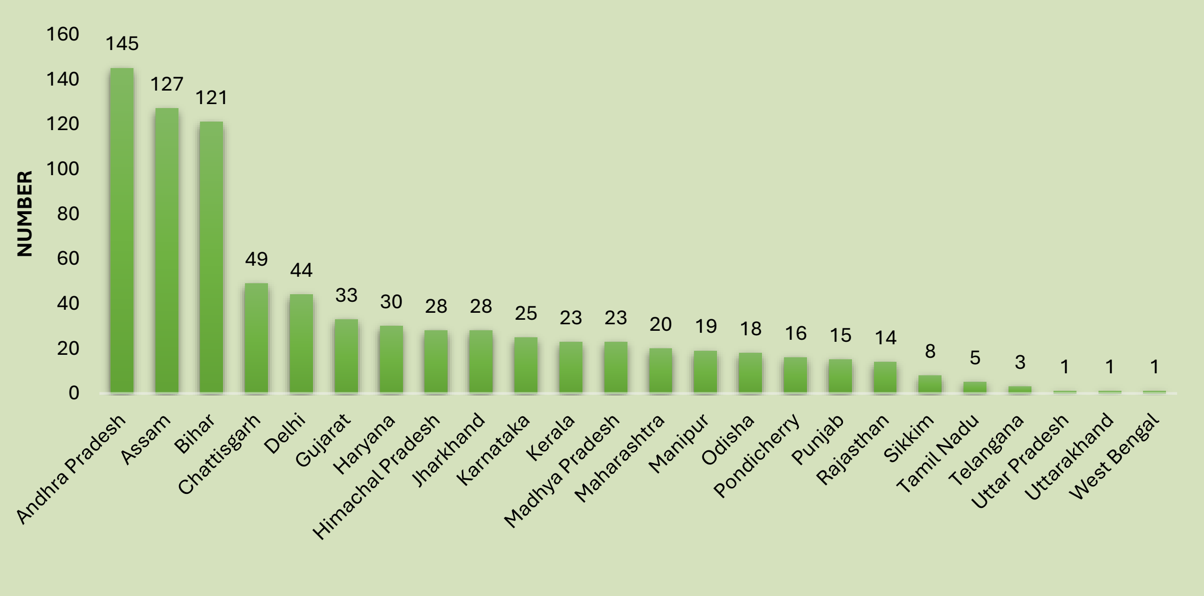
The marketed surplus for rice at all India level is at 81.51 percent for rice and 73.78 percent for wheat (Agriculture Market at glance, 2018). With increase in production and share of marketed surplus, farmers need to expand their storage facilities to fetch a higher price after the peak harvest period. Developing storage infrastructure at farmers' level is crucial to reduce quantity and quality losses of their produce. Large and medium farmers have higher share of marketed surplus (Parthasarathy and Rao, 1964), and they have better bargaining position in the market. Small farmers are more susceptible to price risk and distressed sale of their produce due to interlinkage in output-credit market and due to lack of access to storage infrastructure. Storage at farmers level also determine the price realization of the farmers, due to quality deterioration.

The extent of storage infrastructure varies across states. Traditionally in India, the storage structure at farmers' level is low cost, permanent or need based construction (Said and Pradhan, 2014). However, these domestic storage types are susceptible for losses particularly for longer duration (Rath et al., 2021). Transport loss of farmers from field to mandi due to open grain movement and the loss increases with longer distance. APMC market density is 116 per sq km. as contrary to 496 per sq km. at all India level. The Prime Minister Narendra Modi announced doubling farmers' income under NITI Aayog and to do that reducing post-harvest losses through expanding storage infrastructure has been one of the major objectives.

In this context, farmer producer organisations (FPO) were developed to be an interface between farmers and markets. FPOs play a key role to aggregate small and marginal farmers produce to reduce post-harvest losses by increasing efficiency in the value-chain. As over 80 percent of Indian farmers are marginal and small producers, agri-business approach through FPOs can increase investment to minimise losses at farmers' level (Singh and Khanna,2019). Producing Companies Act 2002 anchored the aggregation of small and marginal farmers with companies to strengthen market integration.

This paper would examine the role of Farmer Producer Organizations, their effectiveness and performance in reducing postharvest losses at an organizational level. Even though production has increased over the years, lack of transport, storage facilities lead to lower price realization by the farmers. In this regard, there has been increased investment in Agriculture Infrastructure Fund (AIF) to develop post-harvest infrastructure at FPO, SHGs level. However, the share of AIF in total agriculture expenditure budget remained a meagre 0.13 percent. Formation and Promotion of 10,000 Farmer Produce Organizations (FPOs) with a budgetary allocation of Rs 6,865 crores was announced by the central government in February 2021. At all India level, there are 33,711 FPOs and out of which only 797 FPOs are for rice and wheat comprising 3,95,181 farmers. Farmers at individual level have lack of affordability to invest in storage technologies. Also, FPOs play key role creating awareness among farmers to reduce losses. Andhra Pradesh has the highest number of FPOs in the country followed by Assam and Bihar. Whereas, other major rice producing states West Bengal, Uttar Pradesh, Telangana have almost no presence of FPOs (**Figure 6.1**). In grain market, in many instances FPOs have organized for market linkage of speciality grain like aromatic rice or provider of inputs at favourable price as an alternative to cooperative societies.

Figure 6.1: Number of FPOs for wheat and paddy across states



Source: FPO platform for India, Tata-Cornell Institute

Case study on FPC in Moga, Punjab

This FPO started in 2022 and has a member of 400 from 6 villages. At village level, farmers have individual level storage capacities and mostly they sell to public procurement agencies. From the FGD, farmers intended to directly sell to private agencies if credit advancement through private warehouse system is available. However, for storage infrastructure, at individual level farmers use steel drums, jute bags, polypropylene bags for wheat and only jute bags for basmati rice. Farmers generally sell the paddy directly after the harvest. Whereas, for wheat farmers store to fetch better price and for home consumption and for next year seed usage. One farmer reported to have a wooden bunker storage with a capacity of 500 quintal, out of which 425 quintal was utilized with sealing of the room by cello tapes. Comparing to bag storage types, the storage loss was reported to be lower in bulk bunker storage. At village level, hermetic storage bags of higher capacity can be expanded through FPOs that farmers can store the produce for better price realization and for home consumption.

Source: FGD with Sukmani Women FPCL Members, Punjab, 2023

The procurement is lower in eastern states and due to lack of storage facilities farmers are engaged in distress sales. Prices remain much lower than the minimum support price in these states. For instance, in 2018-19, wholesale mandi (market) price of paddy in the harvest months in West Bengal remained around Rs. 1552 which is much lower than MSP of Rs.1750 announced by CACP for that year. In contrast, wholesale mandi price of paddy for Punjab and Haryana, during harvest months were Rs. 2383 and Rs.2908 respectively Hence, storage infrastructure by FPOs can reduce the distress sales particularly for marginal and small farmers.

7 Conclusion

Given the lengthy processes of procurement, storage, public distribution the transition losses of grains are significant. India has gone through technological change of storage to some extent in terms of expansion of silos, however, largely the storage system is under conventional warehouses. There is a lack of inclusivity in grain procurement in India leading to transit losses for rice and wheat. Hence expanding procurement infrastructure in consuming region will reduce the transit losses. Even though FCI has an objective to phase out CAP storage types, it comprises 28 percent share in Punjab and 20 percent in Madhya Pradesh in 2020.

The storage infrastructure by FCI is regionally concentrated in procuring region, hence farmers in non-procuring states experience distress sales. Also, in states with rise in procurement in recent years, do not have adequate infrastructure of rice storage. For e.g in Chhattisgarh, the storage loss for rice is at 0.15 percent, whereas in Punjab it is at 0.03 percent. In terms of storage techniques, bulk storage is more efficient than bag storage (storage cost is also lesser that warehouses), but it requires capital investment and infrastructural development. In terms of storage bag types, for rice, hermetic bags are suitable, because rice is processed from paddy, and it does not need respiration. However, for wheat grain bulk storage is more viable from post-harvest loss point of view. The rice-wheat market is very much controlled by government policies, and FCI has to pay heavy rent to silos and private warehouses. The public-private partnership through implementation of PEG scheme has been beneficial to expand the storage capacity. However, it has not promoted substantial technological investment like use of conveyor belt to reduce handling losses, modernisation of storage techniques like different kinds of hermetic bags due to control on storage and movement of grains by the government. Instead, de-regulating the rice-wheat market by promoting private sector participation in grain market would lead to technological change in storage infrastructure. Direct selling to private warehouses through warehouse receipt system will reduce the interlinkage in credit market and would reduce storage losses particularly in regions where public procurement is not efficient.

7.1 Policy Implications

We recommend some policy options to not only further increase private participation but also to make it more efficient, market determined, farmer welfare centric and cost effective thereby further contributing to lowering postharvest losses.

Reforming PDS and to boost direct cash transfer to reduce transit and handling loss of grain

At present the Indian grain management system is strongly tied with the country's public procurement and distribution (PDS system) apparatus. Almost all of the grain procurement, handling, storage and distribution operations lie with the FCI. In 2020-21, 81.35 crores beneficiaries were estimated under the NFSA act which is expected to increase over time as it has been the case. Increase in beneficiaries require increase in procurement, storage and distribution operations and thereby increase in FCI role. This is a highly inefficient system which involves multiple transit requirements, bigger bureaucratic apparatus leaving room for corruption and deters private investments through policy uncertainties. While the PDS system is required for the poor population of the country, it can be targeted like it was before the NFSA. The mechanisms used for this objective however can be reformed. Food stamps are one way. Food stamps can be used in the usual retail stores for buying anything from a pre-determined set of commodities. This can also have positive effects on the nutrition as nutrient-rich food can be bought such as eggs. Direct income transfers are another way through which the poor can buy from the market at market prices the bundle of commodities they prefer. These mechanisms do not distort the market, having minimal or no effect on price determination in the market, do not crowd out private sector investments and help reduce the postharvest losses in the marketing channels.

Lowering operational inefficiencies

As on Aug 01 2023, India held 52 MMTs of grain stocks well above the buffer stocks requirements. Handling these stocks have large costs. In 2021-22, the carrying cost of buffer stocks for FCI stood at 4.88 thousand crores which included handling expenses (7.3 percent of total carrying costs), storage charges (22.8 percent), interest paid (42 percent), freight (19.3 percent), administrative overheads (4 percent) and transit and storage shortages (4.6 percent) **(Annex *1*)**. FCI can move to a system of tenders whereby desired quantity and quality can be delivered where required. Competitive bidding can be sought from private sector for procurement, handling, transit, and distribution to the desired location consequently reducing operational inefficiencies in the system.

Direct selling to private warehouses: and NWR system

The government has been working towards and incentivizing private participation in the agricultural storage infrastructure of the country. This push has been significant after the PEG 2008 and PWS 2010 schemes which has added significant private capacity to the total storage capacity in the country. However, these warehouses are mostly hired by the FCI itself for their storage requirements. And this has also been the reason for the geographical concentration of the warehouses constructed under these schemes where the FCI operations and need for storage is in the procurement region of the country i.e., in Punjab and Haryana.

NWR system can overhaul the grains market in India. Government should promote the registration of the warehouses and set up regulatory standards through which produce can be stored in private warehouses. The receipts can then be sold, traded and used as collateral for accessing finance from banks. The NWR system can also help banks have a record of farmers' and traders' credit worthiness which is non-existent in India as of now. This system if implemented properly can drastically reduce the storage burden on FCI as then the produce can be hold through receipts without the commodity changing hands and incurring losses.

Expanding bulk storage (steel silos)

More bulk storage can be planned in the short term. There are obvious benefits of bulk storage through steel silos. They incur almost no losses in storage and minimal in transit. Silos use one-third of the space used by conventional covered warehouses for the same storage capacity. Labour cost is significantly reduced as compared to conventional storages. The bulk storages should be further expanded through identifying districts with storage needs. The regulatory standards should be further streamlined to reduce the existing transit losses from silos to other state storages. On bulk storage, the work has been completed or towards near completion for 3 MMTs capacity of steel silos from private sector. Another 11 MMTs of steel silos capacity is yet in its stages of bidding or planned. Under phase one of the Hub and Spoke model, 12 locations have been identified for DBFOT mode (Design Build Finance Operate Transfer) and 66 locations for DBFOO model (Design Build Finance Own Operate).

The Government of China implemented "Scientific Grain Storage Project" (SGSP) to boost farmers to storage their produce in bulk metal silos through cooperative memberships. According to the study Luo (2021), adoption of metal silos can save 86,000 hectares of land, 29400 tonnes of fertilizers, 0.82 billion cubic meters of water, reduce carbon emissions by 232,000 tonnes, and can provide the grain to 1.39 million of population per year.

Paucity of data at macro level on losses in grain management system

There are storage and transit losses at data in FCI storages, however, data is not provided across different types of storage facilities and along the duration of storages. Another, major overlook of FCI data is lack of attention towards quality losses. FCI provides standard quality norms of various grades for rice and wheat (A, B, C, D), however, norms are at met at the time of procurement. This means due to lack of storage infrastructure; portion of grains are deteriorated in terms of quality. There is no data available on different grades of grains offloaded from the storage. The C and the D category are not fit for human consumption without upgradation of the quality. Also, storage loss only captures quantity losses at FCI owned or hired go-downs, however, it does indicate any loss assessment at CAP before shelling, or grains lying in mandi. Hence, strengthening national level survey on grain storage losses across the value-chain would be beneficial to target the loopholes.

Table 7.1: Categorization of Wheat/Paddy (20cc of representative sample)

Category Wheat/Paddy	Weevilled Grains only	Designation Paddy	Damaged Discoloured grains
A	Up to 1 percent	1	Up to 5 percent
B	Above 1 percent to 4 percent	2	Above 5 percent to 10 percent
C	Above 4 percent to 7 percent	3	Above 10 percent to 15 percent
D	Above 7 percent to 10 percent	4	Above 15 percent to 20 percent
Method: Volumetric for both categorization and designation			
Volumetric up to 3.5 percent and then by count in case of wheat			

Source: FCI

The Road to increase storage capacity at grass-root level through PACs

As we see losses at shellers, mandi for rice at market in Punjab due to huge harvest of the produce and MSP driven increasing area under paddy in the state, the use of CAP has not phased out. Self-sufficiency in production and consumption will reduce the flow of surplus procurement to deficit procurement states and so the transit losses.

GOI has announced in 2020 the Agriculture Investment Fund to promote post-harvest technological development through PACs, FPOs for interest subvention of 3 percent to invest in infrastructure. However, at FPO level, the role is limited to input distribution rather than village level construction of storage infrastructure. The Union Cabinet on May 31 2023 approved the construction of warehouses for agricultural produce through Primary Agricultural Credit Societies (PACS) which can also serve as custom hiring centers, processing units and Fair Price Shops (FPS), etc. FCI is implementing a pilot project in 24 PACS of 24 states/union territories. The objective of this scheme is to decentralize the warehousing infrastructure in the country allowing small holder farmers to reap its benefits by storing their produce and realizing better prices and avoiding distress sale. The planned capacity of a storage unit at PACS level is planned to be around warehouses of 500 to 2000 MTs each. These warehouses will be geographically distributed for maximum reach of the farmers and will help in reducing storage and transit losses among other benefits. It has been rolled out as 'World's largest grain storage plan in cooperative sector'.

Expanding storage capacity in consuming region

For better preservation of grains, bulk capacity through steel silos needs to be expanded in the country. FCI has plans to expand silo facilities in consuming regions to reduce transit losses. However, as of now, 14 percent of the 10 MMT target capacity has been met. Rice silos are yet under experiment, which need to be expanded in eastern and southern states (major consuming centres). Even in the proposed plan of rice silos, there is no target of construction of rice silos in Chhattisgarh, West Bengal.

Relaxation on storage bags to reduce losses

As per our study storage for public distribution and at farmer level, jute bags are most widely used packaging material. The use of hermetic bag is limited for the post-harvest storages.

There are many kinds of hermetic containers commercially available including: SuperGrain bags with a capacity of 60 kg to 2 tonnes portable containers, Grainsafe for 1 tonne to 2.5 tonne capacity, Coccons with about 1000 tonnes capacity designed for storage at cooperative or trader level. Hermetic bunkers for long term storage with 10,000-20,000 tonnes of grain capacity and fifth is TranSafeliner for shipment of grains. Hermetic bags are safe chemical free 'green' technology for storage for rice to avoid insect infestation, prevention of mould growth, to maintain storage quality, and for longer durability. The case study on paddy storage in Bangladesh exhibits that hermetic GrainPro bag and Cocoon bag technologies have reduced paddy losses and economically more feasible compared to traditional storage technologies (Alam et al., 2022).

In case of possibility of using hermetic bag in India, there is **Jute Packaging Material (JPM Act, 1987)** for mandatory use of jute bags by GOI for packaging rice, wheat grains. Even though jute is bio-degradable, jute is a water guzzler, hydrophilic, and labour-intensive crop and the usage leads to frequent rodent attack, pilferage, infestation due to tropical climate. Hence, expansion of usage of hermetic bags requires policy changes to reduce storage and transit losses of grains.

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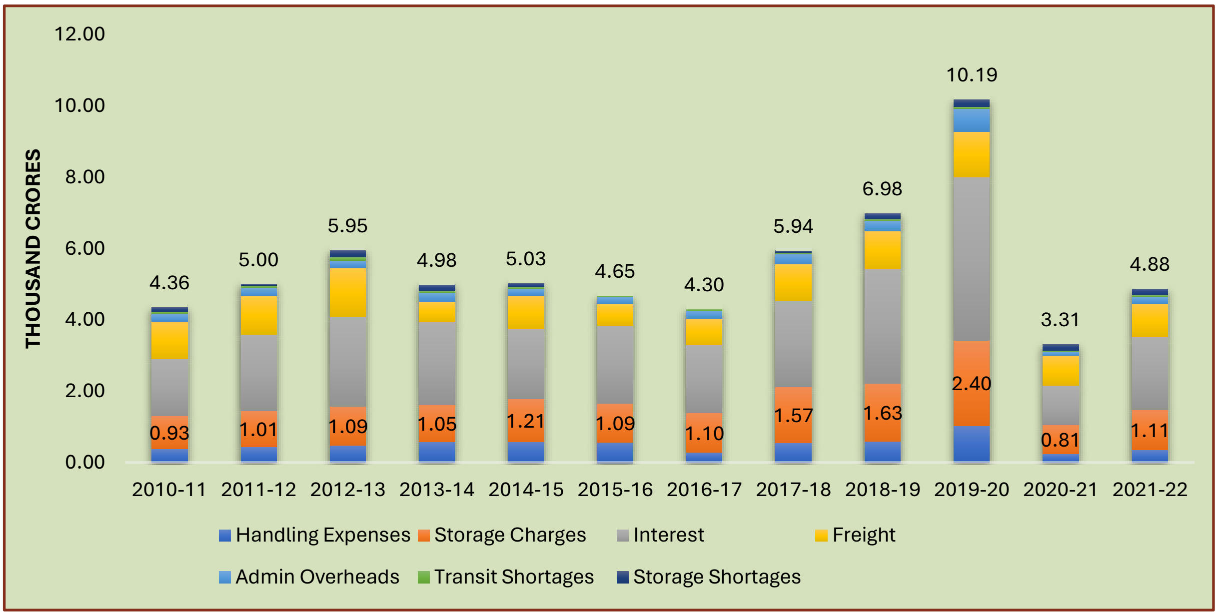
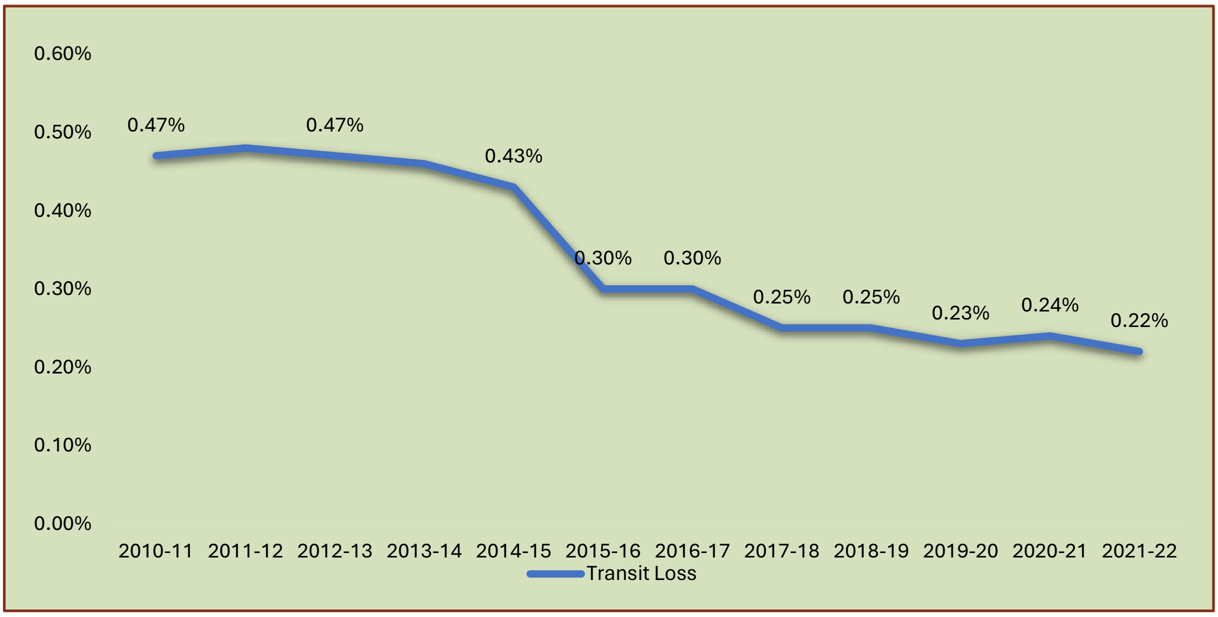
9 Annexures

Annex 1: Carrying cost of buffer stocks (2010-11 to 2021-22)



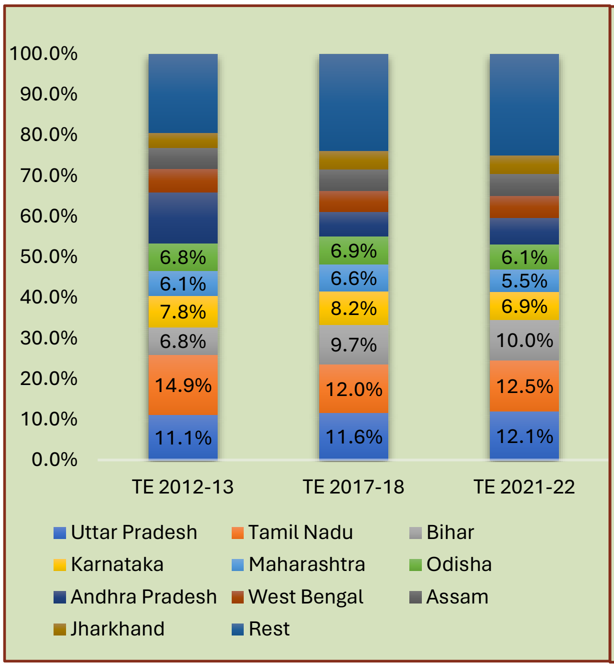
Source: FCI Annual reports (various issues)

Annex 2: Transit loss of food grains at FCI (as percent of quantity moved) (2010-11 to 2021-22)

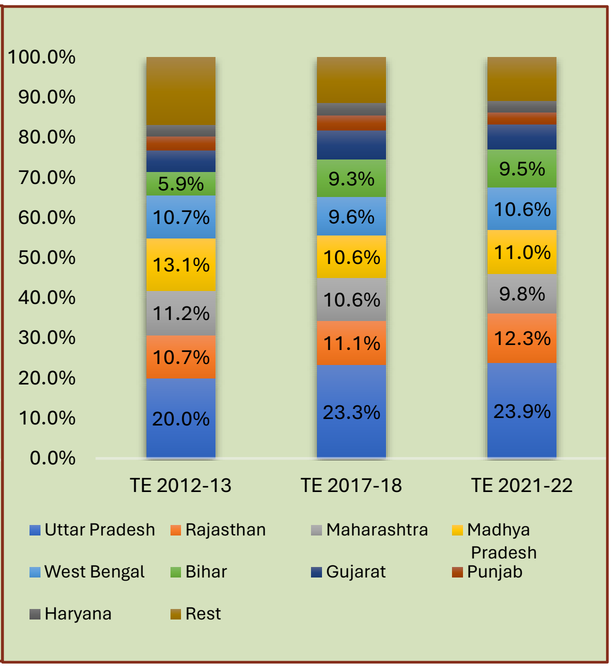


Source: FCI Annual reports (various issues)

Annex 4: State-wise share of rice offtake under NFSA (Percent)

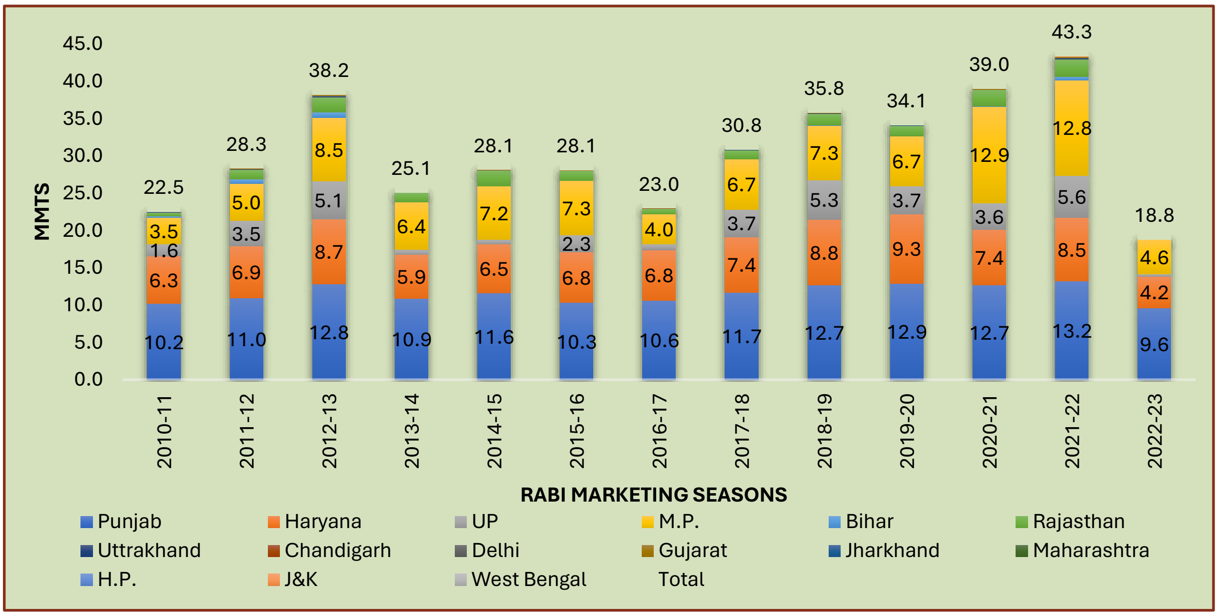


Annex 3: State-wise share of wheat offtake under NFSA (Percent)



Note: Total offtake as percentage of total allocation under NFSA only; Years based on rabi marketing season for wheat and kharif marketing season for rice; Source: Food grain Bulletins, DFPD

Annex 5: State-wise procurement of wheat (2010-11 to 2022-23)



Source: Food grain Bulletins (DFPD)

Annex 6: Trend of labour dependence of FCI grain management system

	Departmental		Direct Payment System		No work no pay		Total	
	No. of Depots	No. of labourers	No. of Depots	No. of labourers	No. of Depots	No. of labourers	No. of Depots	No. of labourers
2010-11	162	19979	223	30907	12	1337	397	52223
2011-12	162	19234	221	28452	66	5159	449	52845
2012-13	162	18376	219	28803	83	6272	464	53451
2013-14	162	17555	219	27696	83	6290	464	51541
2014-15	162	16381	219	26722	92	7640	473	50743
2015-16	145	15203	206	25283	94	7426	445	47912
2016-17	64	13919	169	23715	90	6992	323	44626
2017-18	56	12612	154	21370	88	6752	298	41094
2018-19	54	11610	152	20407	88	6725	294	38742
2019-20	56	10600	155	19052	85	6322	296	35974
2020-21	49	9532	148	16898	83	6066	280	32496
2021-22	30	7841	131	15053	82	6268	243	29162

Source: FCI Annual reports

Annex 7: Storage loss, storage capacity and market density for selected states

S. No.	States	Storage loss (percent)		Storage Capacity with FCI Jan 01 2023 (MMT)	Total No of APMC Markets (Regulated PMYs + SMYs)	Area served by one APMC Market in sq.km
		Wheat	Paddy			
1	Gujarat	0.05	0.05	0.84	400	490
2	Haryana	0.13	NA	8.82	281	157
3	Himachal Pradesh	0.03	NA	0.09	56	994
4	Madhya Pradesh	0.02	0.04	19.53	545	565
5	Punjab	0.08	0.07	15.89	435	116
6	Rajasthan	0.00	NA	1.10	454	754
7	Uttarakhand	0.01	0.07	0.36	67	798
8	Uttar Pradesh	0.12	0.05	4.37	623	387
9	West Bengal	0.02	0.08	1.93	475	187
10	Andhra Pradesh	NA	0.02	2.81	191	853
11	Assam	NA	0.06	0.55	226	347
12	Bihar	NA	0.07	1.50	0	NA
13	Chhattisgarh	NA	0.04	2.83	187	727
14	Maharashtra	NA	0.00	1.95	902	341
15	Odisha	NA	0.06	1.13	436	357
16	Tamil Nadu	NA	0.06	2.92	283	460
17	India	0.02	0.06	71.40	6630	496

Source: APMC data from SIXTY SECOND REPORT "AGRICULTURE MARKETING AND ROLE OF WEEKLY GRAMIN HAATS", STANDING COMMITTEE ON AGRICULTURE (2018-2019) SIXTEENTH LOK SABHA; Storage loss from FCI on request; Storage capacity from DFPD

Annex 8: Economic costs and MSP for Wheat (2011-12 to 2021-22)

	Wheat			
	Acquisition Cost	Distribution Cost	Economic Cost	MSP Wheat
2011-12	1355	240	1595	1170
2012-13	1483	270	1753	1285
2013-14	1558	351	1908	1350
2014-15	1664	387	2051	1450
2015-16	1773	354	2127	1525
2016-17	1835	362	2197	1625
2017-18	1892	406	2298	1735
2018-19	1957	403	2360	1840
2019-20	2071	552	2623	1925
2020-21	2132	600	2732	1975
2021-22	2202	266	2468	2015

Source: FCI Annual reports

Annex 9: Economic Cost and MSP for Paddy/Rice (2011-12 to 2021-22)

	Paddy + Rice			
	Acquisition Cost	Distribution Cost	Economic Cost	MSP Paddy Common
2011-12	1862	261	2123	1080
2012-13	2018	287	2305	1250
2013-14	2226	390	2616	1310
2014-15	2446	497	2944	1360
2015-16	2622	503	3125	1410
2016-17	2672	433	3105	1470
2017-18	2773	508	3280	1550
2018-19	2894	550	3444	1750
2019-20	3023	697	3720	1815
2020-21	3145	794	3939	1868
2021-22	3248	314	3562	1940

Source: FCI Annual reports

Annex 10: Losses at various levels for wheat for selected states (NABCONS study 2022)

Wheat				
Major Producing States	Farm-level aggregate	Market level aggregate loss	Overall total loss	Godown loss
All India	3.61	0.56	4.17	0.02
Uttar Pradesh	3.37	2.94	6.31	0.12
Madhya Pradesh	3.77	0.43	4.2	0.024
Punjab	2.75	1.77	4.52	0.08
Haryana	3.51	0.74	4.24	0.13
Rajasthan	4.46	1.78	6.25	0.002
Himachal Pradesh	2.81	0.5	3.31	0.03
Uttarakhand	0.79	1.72	2.52	0.013

Source: NABCONS study 2022

Annex 11: Losses at various levels for paddy for selected states (NABCONS study 2022)

Paddy				
Major Producing States	Total loss at farm-level	Total loss at market level	Overall total loss	Godown Loss
All India	4.17	0.6	4.77	0.06
West Bengal	4.63	0.53	5.16	0.08
Uttar Pradesh	3.41	0.49	3.9	0.05
Punjab	2.63	0.42	3.05	0.07
Odisha	3.4	0.55	3.95	0.06
Chhattisgarh	3.54	0.38	3.92	0.04
Tamil Nadu	5.36	0.62	5.98	0.06
Andhra Pradesh	4.98	0.76	5.74	0.02
Bihar	4.05	0.6	4.65	0.07
Madhya Pradesh	3.77	0.43	4.2	0.04
Assam	5.48	0.6	6.08	0.06
Maharashtra	3.86	0.57	4.43	0.001
Gujarat	4.04	0.52	4.56	0.05
Uttarakhand	2.33	0.55	2.88	0.07

Source: NABCONS study 2022

Annex 12: State-wise area, production, and yield for rice (2018-19 to 2020-21)

Area, Production and Yield for Rice										
State/ UT	Season	Area ('000 Hectares)			Production ('000 Tonnes)			Yield (Kg./Hectare)		
		2018-19	2019-20	2020-21	2018-19	2019-20	2020-21	2018-19	2019-20	2020-21
Andhra Pradesh	Kharif	1564	1526	1496	5243	5117	4211	3353	3353	2815
	Rabi	644	774	828	2991	3542	3672	4645	4576	4437
	Total	2208	2300	2324	8235	8659	7883	3729	3765	3393
Assam	Kharif	2024	1895	1980	4075	3959	4143	2013	2089	2092
	Rabi	401	396	380	1146	1026	1072	2858	2593	2820
	Total	2425	2291	2360	5221	4985	5215	2153	2176	2209
Bihar	Kharif	3099	2826	2962	6019	6169	6611	1942	2183	2232
	Rabi	60	60	59	136	129	136	2256	2133	2307
	Total	3160	2886	3021	6156	6298	6747	1948	2182	2233
Chhattisgarh	Kharif	3606	3666	3791	6527	6775	7161	1810	1848	1889
Gujarat	Kharif	809	850	837	1819	1822	1937	2248	2144	2314
	Rabi	30	55	70	93	162	209	3131	2950	2999
	Total	839	904	907	1912	1983	2146	2279	2193	2367
Haryana	Kharif	1447	1447	1327	4516	4824	4425	3121	3334	3334
Jharkhand	Total	1527	1358	1411	2894	3013	2753	1895	2219	1951
Karnataka	Kharif	985	916	1038	2945	2775	3145	2989	3030	3030
	Rabi	154	269	359	486	859	1147	3160	3193	3193
	Total	1139	1185	1397	3431	3634	4292	3012	3067	3072

Kerala	Kharif	152	152	157	430	449	470	2826	2947	2985
	Rabi	46	46	48	149	157	164	3232	3416	3441
	Total	198	198	205	578	606	634	2920	3056	3091
Madhya Pradesh	Kharif	2373	1982	2080	4450	4684	4287	1875	2363	2061
	Rabi	18	34	37	45	94	127	2493	2765	3430
	Total	2391	2016	2117	4495	4778	4414	1880	2370	2085
Maharashtra	Kharif	1417	1478	1473	3144	2702	3028	2218	1828	2056
	Rabi	48	75	88	132	196	264	2778	2612	3001
	Total	1465	1553	1561	3276	2898	3292	2236	1866	2109
Odisha	Kharif	3585	3648	3690	6808	7428	7657	1899	2036	2075
	Rabi	274	293	348	926	933	1153	3376	3188	3313
	Total	3859	3941	4038	7734	8360	8810	2004	2122	2182
Punjab	Kharif	3103	2920	2928	12822	11779	12784	4132	4034	4366
Rajasthan	Kharif	198	220	231	453	481	634	2291	2189	2739
Tamil Nadu	Kharif	1573	1742	1860	5470	6388	6137	3478	3666	3300
	Rabi	149	165	177	661	783	744	4450	4748	4215
	Total	1721	1907	2036	6131	7171	6881	3562	3760	3379
Telangana	Kharif	1189	1096	1800	4134	4021	5440	3477	3669	3022
	Rabi	743	915	1386	2536	3407	4778	3413	3723	3446
	Total	1932	2011	3186	6670	7428	10217	3452	3694	3206
Tripura	Kharif	199	197	198	561	582	585	2822	2959	2953
	Rabi	71	71	66	233	228	218	3287	3232	3321
	Total	269	267	264	793	810	803	2944	3031	3045
Uttar Pradesh	Kharif	5719	5711	5652	15458	15437	15430	2703	2703	2730
	Rabi	29	26	26	87	81	90	2994	3114	3464
	Total	5748	5737	5678	15545	15518	15520	2704	2705	2733
Uttarakhand	Kharif	239	230	238	562	598	657	2350	2599	2762
	Rabi	17	17	16	56	61	58	3289	3565	3595
	Total	256	247	254	618	658	715	2412	2665	2814
West Bengal	Kharif	4233	4219	4300	11892	11341	11855	2809	2688	2757
	Rabi	1280	1272	1286	4350	4540	4669	3400	3570	3632
	Total	5513	5491	5586	16242	15881	16524	2946	2892	2958
All India	Kharif	39964	39013	40358	102040	102277	105208	2553	2622	2607
	Rabi	4192	4649	5411	14438	16594	19160	3444	3569	3541
	Total	44156	43662	45769	116478	118870	124368	2638	2722	2717

Annex 13: State-wise area, production and yield for Wheat (2018-19 to 2020-21)

Area, Production and Yield for Wheat									
State/ UT	Area ('000 Hectares)			Production ('000 Tonnes)			Yield (Kg./Hectare)		
	2018-19	2019-20	2020-21	2018-19	2019-20	2020-21	2018-19	2019-20	2020-21
Bihar	2157	2150	2223	6466	5580	6150	2998	2595	2767
Chhattisgarh	105	110	160	163	115	248	1548	1050	1551
Gujarat	797	1018	1017	2407	3327	3259	3020	3268	3205
Haryana	2553	2534	2564	12574	11876	12394	4925	4687	4834
Himachal Pradesh	319	286	333	565	563	570	1770	1970	1712
Jammu & Kashmir	288	244	244	672	488	484	2330	2002	1985
Jharkhand	164	215	233	303	439	544	1847	2046	2337
Karnataka	150	150	203	164	180	262	1090	1198	1291
Madhya Pradesh	5520	6551	6083	16521	19607	18182	2993	2993	2989
Maharashtra	834	1057	1126	1249	1794	2071	1497	1697	1839
Punjab	3520	3521	3530	18262	17616	17186	5188	5003	4868
Rajasthan	2880	3118	3002	10083	10916	11035	3501	3501	3676
Uttar Pradesh	9540	9853	9852	32741	33815	35507	3432	3432	3604
Uttarakhand	327	316	312	952	904	955	2910	2861	3062
West Bengal	112	188	193	338	510	595	3012	2708	3077
All India	29319	31357	31125	103596	107861	109586	3533	3440	3521

Questionnaire

Questionnaire for postharvest grain management system FCI

1. Introduction
    a. Type of storage facilities CAP/ Covered warehouses/ Modern silos
    b. Size
    c. Utilization
    d. Commodities stored:
    e. Type of storage
    f. Ownership type: Owned/Hired; if hired organisation:
    g. No. of labourers
    h. Distance from mandi
    i. Mode of transport:
    j. Profile of depositors (farmer/ Trader/others)
    k. Operating expenditure for running the warehouse

Type of storage with FCI: Owned/ hired

Operations	Methods of operation	Equipment used	Quantity handled	Quantity loss	Quality loss	Causes of losses
CAP						
Covered warehouse						
Silos						
Private warehouse						

Type of operations and associated losses

Operations	Methods of operation	Equipment used	Quantity handled	Quantity loss	Quality loss	Causes of losses
Procurement						
Storage						
Transport						
Distribution						

Storage techniques:

1. What are additives used to control infestation?
2. Fumigation method
3. How does the FCI manage grain storage, including the use of storage facilities, labour use, techniques, and management practices? How can it be more efficient in terms of technological advancement to reduce post-harvest losses?
4. What are the primary factors contributing to post-harvest losses in traditional warehouses, CAP storage facilities vis-à-vis modern silo facilities in India?

5. What are the common causes of losses during the procurement process of major grains in mandis (agricultural markets) in India?
6. How do these losses vary across different regions and grains?
7. What strategies can be implemented to minimize losses during procurement?
8. How do storage conditions, transportation, and handling practices impact the quality and quantity of grains?
9. What are the key stages in the distribution process of grains in India in public distribution?
10. What is the extent of grain loss during storage, and to what extent does the use of hermetic storage methods reduce these losses when compared to traditional gunny bags?

Questionnaire for postharvest grain management system private warehouse

- Name of the private warehouse
- Capacity
- Quantity handled in last one year
- Number of farmers/traders linked
    1. Methods of operation
    2. Equipment/technology used
    3. Usage of hermetic storage
    4. Cost of storage
    5. Storage loss
    6. Causes of losses

Questionnaire for postharvest grain management system FPO

Questionnaire for FPOs
General Information on FPOs:
Name of FPO: ____________________________
Date of Registration: _________________________
Location/Address: ___________________________
Contact Person: _____________________________
Contact Email: ______________________________
Contact Phone Number: _______________________
Number of Registered Members: _______________
Proportion of Small Farmers (percentage): _______
Proportion of Medium Farmers (percentage): ______
FPOs Commodity Basket: (Please specify the types of agricultural products your FPO deals with)

a. _____________________________
b. _____________________________
c. _____________________________
d. _____________________________

Annual Turnover (for the most recent year): ____________

Profit Sharing Mechanisms with Members: (Please describe how profits are shared among FPO members)

Prominent Commodity Sales Platforms: (Where does your FPO primarily sell its products? Check all that apply)

a. Local Markets
b. Cooperative Outlets
c. Online Platforms
d. Export Markets
e. Others (Please specify): ______________________

Which type of storage do you use for rice, wheat, maize, and soybean?

Storage conditions and structure

Duration of storage and offtake pattern

Has participation to FPOs reduced farmers' post-harvest loss?

Do farmers avail warehouse receipt for any crop? Has that changed their storage pattern?

Do you face any specific challenges or opportunities that you would like to highlight regarding your FPO's operations?

Are there any recent initiatives or projects your FPO is involved in, or plans to undertake in the near future to reduce post-harvest loss?

What support or resources do you feel would benefit your FPO to reduce storage and transit losses?

What are the interventions required to reduce post-harvest losses both in terms of quantity and quality?

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