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WORKING PAPER

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Post-harvest losses in soyabean, custard apple, and onion in Madhya Pradesh and Maharashtra

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CONTENTS

Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback and to influence ongoing debate on emerging issues.

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Highlights

- India incurs a post-harvest loss of approximately INR 1.53 lakh crore (US$17.39 billion) annually, with onion and soyabean accounting for INR 5,156 crore ($0.59 billion) and INR 4,736 crore ($0.54 billion), respectively; a significant amount of greenhouse gas (GHG) emissions too is embedded in this loss.
- Periodically, India conducts comprehensive post-harvest loss assessments. Country-level studies provide useful, standardised estimates, but these estimates exclude losses incurred during long-haul transport (and associated handling and storage losses) to terminal markets, as well as the destinations of discarded produce.
- Using a mixed methods approach, and drawing on surveys, focus group discussions (FGDs), key informant interviews (KIIs), and direct measurements, this working paper assesses the impact of post-harvest losses (incurred in the supply chains of soyabean, custard apple, and onion) on the economy, climate, and nutrition in selected districts of Madhya Pradesh and Maharashtra.
- Post-harvest loss differs by crop and stage. The loss is highest in the harvesting, threshing, and collection stages for soyabean; in the harvesting (boundary/field edge and cultivated orchards), field sorting, and collection/aggregation stages (forest/common lands) for custard apple; and in the farm-level storage stage for onion.
- Targeted interventions, stronger infrastructure and advisory support, and improved use of stage-wise evidence in policy and investment are required to reduce post-harvest losses.

Executive summary

In Indian agriculture, post-harvest losses are caused by fragmented supply chains; inadequate infrastructure like moisture control and precooling facilities; and poor practices like incorrect timing of harvest and careless handling. Post-harvest losses lead to wastage of natural resources and reduce marketable produce, economic value, farm income, and nutritive value; affect the stability of food prices; and contribute to global greenhouse gas (GHG) emissions.

Because supply chains involve multiple actors across stages—production, harvesting, primary processing, storage, transportation, etc.—for each crop, losses are incurred at different stages and caused by varying factors. It is essential to determine where these losses occur and why to formulate and implement the appropriate solution for each problem.

Periodically, India assesses post-harvest loss at the country level up to 54 crops. Country-level studies provide standardised estimates. While these are useful, the current assessment excludes losses in long-haul transport (and the associated handling and storage losses) to terminal markets and the destination of produce discarded.

Conducted in partnership with BAIF Development Research Foundation, Samunnati, and Centre for Advanced Research and Development (CARD), this WRI India study uses a mixed methods approach to identify where losses occur in the soyabean, custard apple and onion. The rationale for selecting these crops for the study was that globally, India ranks among the leading producers of these crops (APEDA 2024; MoAFW 2023b; USDA 2024). The study also analyses how the losses vary across crops and contexts and what the climate, nutrition, and economic impacts of the losses are.

Post-harvest losses are high in all three crops, and there is both need and opportunity to reduce the losses. Reducing the losses offers economic gains for farmers, wholesalers, and retailers; savings for consumers; support in sustaining food, and nutrition security, and reduced pressure on energy, land and water resources. The study assesses and quantifies the post-harvest losses incurred between the years 2023 and 2024 during the harvesting, sorting, transportation, storage, and handling stages of the soyabean, custard apple, and onion supply chains in selected high production districts of Madhya Pradesh and Maharashtra.

The study combines farmer surveys, focus group discussions (FGDs), key informant interviews (KIIs), direct measurements (where feasible), and field observations to examine the critical loss points, the underlying causes of these losses, and the actionable prospects for reducing these at each stage. The study boundary, data collection, and estimation approach were guided by the FLW Accounting and Reporting Standard (FLW Protocol 2016).

We selected these states and specific clusters for their major production shares, agroecological relevance, and existing marketing channels. We based the estimates on one crop-specific post-harvest cycle for each crop. Therefore, the estimates capture seasonal conditions during the study period rather than the multiyear variation. To identify the critical loss point for each of these three crops in post-harvest stage, we triangulated quantitative loss estimates with information on infrastructure, climate, market conditions, and crop physiology.

Based on this methodology, this working paper attempts to answer the following research questions.

- What is the magnitude of post-harvest losses incurred across the soyabean, custard apple, and onion supply chains in Madhya Pradesh and Maharashtra? What are the critical loss points in each supply chain?
- What factors drive the post-harvest losses in different stages of the supply chains? What is the economic, climate, and nutrition impact of post-harvest losses?
- What are the interventions that can minimise these post-harvest losses in the supply chain of each of the three crops?

This working paper assesses stage-wise post-harvest losses incurred in the soyabean, custard apple, and onion supply chains in Madhya Pradesh and Maharashtra. By mapping supply chain actors, calculating stage-specific losses, and pinpointing critical loss points, it identifies where losses occur, how these losses vary across crops and contexts, and what these losses imply in climate, nutrition, and economic terms. It also recommends actionable strategies for reducing losses.

Key findings

The report maps post-harvest losses driven by structural, climatic, and infrastructural constraints in each stage of the three supply chains. We find that, at each stage, post-harvest loss differs by crop supply chains.

In the soyabean supply chain, harvesting and threshing constitute the critical loss points, exacerbated by unseasonal rainfall inducing moisture absorption, fungal infections, pod shattering, and miscalibrated combine harvesters. Collection is another critical loss point.

In the custard apple supply chain, harvesting is a critical loss point for the farm boundary/field edge and cultivated orchards whereas field sorting and collection/aggregation drive the highest losses for forest/common lands. Discards are driven primarily by improper physiological maturity at harvest; heat stress during unshaded aggregation; and mechanical damage during sorting and handling, packaging, and collection. The variation across production pathways is substantial.

In the rabi onion supply chain, the critical loss point is farm-level storage. Inadequate pre-storage curing and poorly ventilated structures—which are the primary drivers of physiological weight loss, sprouting, and rotting—lead to losses in storage.

When the study-derived loss rates were applied to the annual production across the selected districts—for onion, only to the estimated storage-relevant share of rabi production—the resulting indicative annualised quantities were 415,642 metric tonnes (MT) for soyabean, 7,793.42 MT for custard apple, and 1,689,697 MT for onion. We estimate the economic value of the loss at INR 2,087 crore (US$237.16 million) for soyabean, INR 20 crore ($2.27 million) for custard apple, and INR 2,711 crore ($308.07 million) for onion. The GHG emissions associated with these post-harvest losses are estimated at 92,206 tonnes of carbon dioxide equivalent (tCO_2e) for soyabean, 6,314 tCO_2e for custard apple, and 995,523 tCO_2e for onion. The macronutrient loss is substantial, including 147,885.42 tonnes of soyabean protein.

Addressing these issues requires

- improving access to viable post-harvest technologies and finance;
- strengthening advisory support via existing institutional and digital channels; and
- aligning policy and market incentives with specific critical loss points.

Introduction

Food loss and waste (FLW) is the decrease in the quantity or quality of food along the food supply chain. Food loss—also referred to as post-harvest loss in this working paper—occurs in supply chain segments excluding retail, food service, and consumers whereas food waste occurs at the retail, food service, and consumer levels (Agarwal et al. 2021; FAO 2019). Food loss and waste contributes 8–10 percent of global greenhouse gas (GHG) emissions and exacerbates near-term warming via emissions of methane (Geneva Environment Network 2024; UNEP 2024).

Reducing FLW offers multiple wins: economic gains for farmers, wholesalers, and retailers; savings for consumers; support in sustaining food and nutrition security; and reduced pressure on energy, land, and water resources (Hawken 2017; Karthick et al. 2023; Flores Rojas et al. 2024).

Globally, approximately, a third of food produced is lost or wasted from farm to plate (FAO 2019). In India, annually, post-harvest losses cost about INR 1.53 lakh crore (US$17.39 billion); onion accounts for INR 5,156 crore ($0.59 billion) and soyabean INR 4,736 crore ($0.54 billion) (NABCONS 2022). The key drivers include poor grading and packing systems; inadequate storage and cold chain infrastructure; fragmented supply chains; and limited farmer access to suitable technology, finance, and knowledge (Agarwal et al. 2021; Negi and Anand 2017; Karthick et al. 2023; Seshadri et al. 2026; Kalra et al. 2024).

Periodically, India undertakes national assessments of post-harvest losses for up to 54 crops. These assessments provide useful, periodic, standardised data on post-harvest losses. However, these estimates exclude losses in long-haul transport (and associated handling and storage losses) to terminal markets and the destination of the produce discarded (Agarwal et al. 2021). Additionally, the estimates account only for the economic impact of the post-harvest losses and not for the environmental or social impacts. Strengthening the existing assessment can support an improved problem-solution fit and improve the tracking of gains from loss reduction interventions (Miljkovic and Winter-Nelson 2021).

This WRI India study addresses that gap by assessing post-harvest losses incurred during 2023–24 in soyabean, custard apple, and onion supply chains in selected districts of Madhya Pradesh and Maharashtra. Together, the states of Madhya Pradesh and Maharashtra account for approximately 82.8 percent of the country's soyabean production, 56 percent of custard apple production, and 57.2 percent of onion production (Table 1). These crops capture the variation in crop type, perishability, market structure, and policy relevance, ranging from a relatively durable grain to a highly perishable fruit and a storage-sensitive staple vegetable (selected post-harvest loss estimates from the literature for soyabean, onion, and custard apple are summarised in Annexure B).

Table 1 summarises their production significance, concentration in the two study states, post-harvest loss, and trade context. Using mixed methods and direct measurement, where feasible, the paper assesses the scale and causes of post-harvest losses, identifies critical loss points, and discusses practical options for reduction.

Table 1 | **Area, production, state share (Madhya Pradesh and Maharashtra), post-harvest loss, and trade context for selected crops**

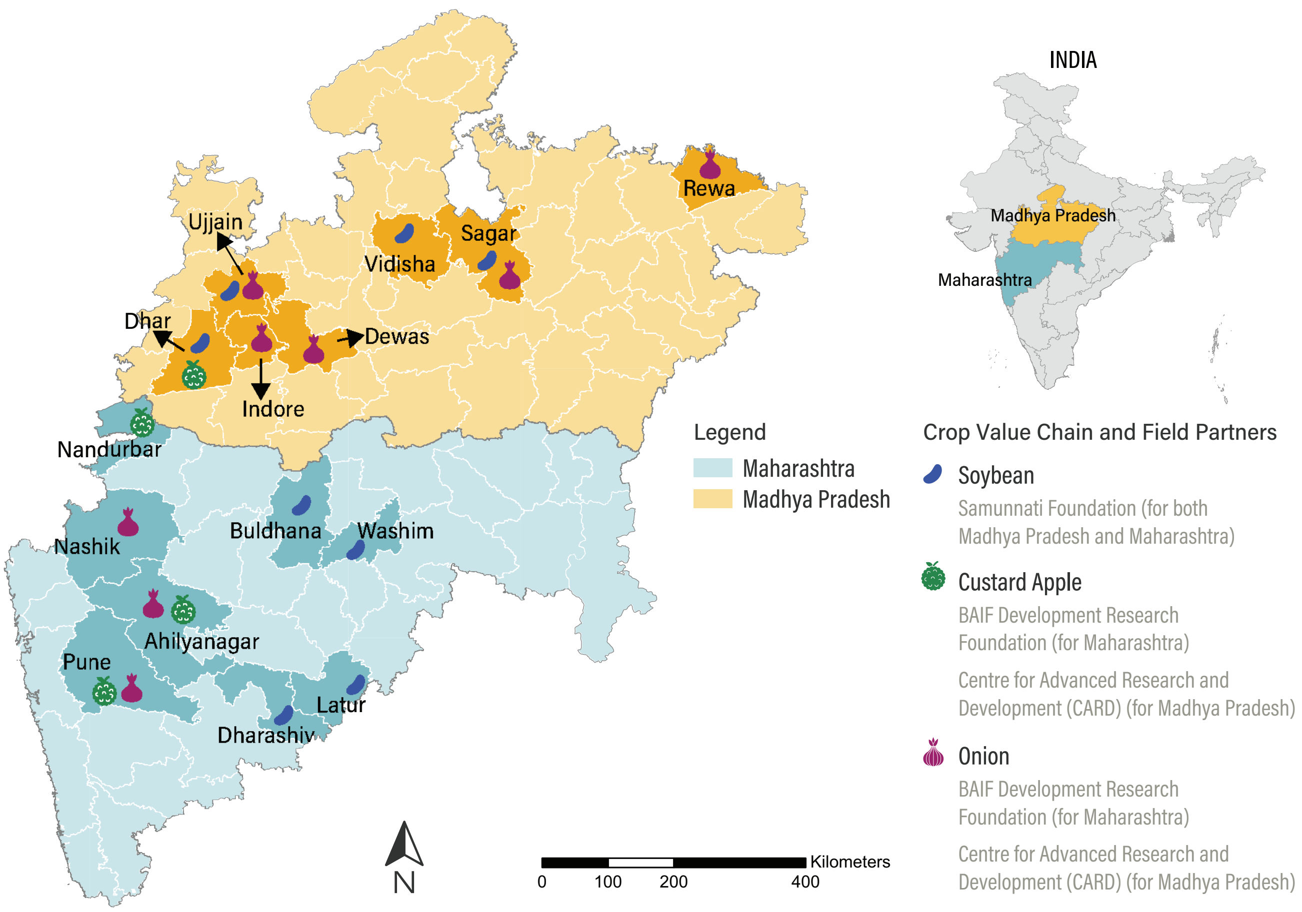
CROP (SCIENTIFIC NAME)	INDIA PRODUCTION (IN MMT; 2022-23)	AREA UNDER CULTIVATION (LAKH HECTARE)	SHARE IN GLOBAL PRODUCTION (%)	SHARE OF MADHYA PRADESH AND MAHARASHTRA IN INDIA'S PRODUCTION (%; 2022-23)	NATIONAL POST-HARVEST LOSS ESTIMATES (%)	POST-HARVEST LOSS (VALUE; INR/USD)	EXPORT VALUE (INR/USD; 2022-23)
Soyabean (Glycine max L.)	14.99	130.43 (2022–23)	3.3 (5th largest globally)	Madhya Pradesh (38.63); Maharashtra (44.14)	7.51	INR 4,700 crore ($0.53 billion) annually*	INR 487 crore ($55.3 million)
Custard apple (Annona squamosa L.)	0.46	Not available	Not available	Madhya Pradesh (25.77); Maharashtra (30.26)	Not available	Not available	Not available
Onion (Allium cepa)	30.23	17.4 (increased from 11.7 in 2014–15)	28.6 (largest producer)	Madhya Pradesh (17.41); Maharashtra (39.81)	7.21	INR 5,100 crore ($0.58 billion) annually	INR 4,525 crore ($514.2 million)

+ MMT is million metric tonnes; 1 MMT = 1,000,000 metric tonnes (MT)

** Using the exchange rate USD 1 = INR 88*

Source: NABCONS (2022); MoAFW (2023a, 2023b, 2023c); USDA Foreign Agricultural Service (n.d.); Department of Commerce (n.d.); DES (n.d.); APEDA (2024).

Figure 1 | **Study districts and field partners for soyabean, custard apple, and onion**



Source: WRI India authors.

Methodology

This study aims to estimate the scale and identify the causes of post-harvest losses, determine critical loss points, and discuss practical options for reducing losses. The study is guided by three research questions.

1. What is the magnitude of post-harvest losses across the soyabean, custard apple, and onion supply chains in Madhya Pradesh and Maharashtra? What are the critical loss points in each supply chain?
2. What factors drive post-harvest losses across the different stages of the supply chains? What is the economic, climate, and nutrition impact of post-harvest losses?
3. What are the interventions that can minimise these post-harvest losses in the supply chain of each of the three crops?

Geographical scope and sampling approach

Three civil society organisations (CSOs) – BAIF Development Research Foundation, Samunnati, and Centre for Advanced Research and Development (CARD) – supported stakeholder engagement, data collection, and validation of findings from analysis. We selected districts based on production and representation of production systems (Figure 1).

Analytical framework

In order to define the scope of the study and enable the systematic measurement and reporting on post-harvest losses, the FLW Accounting and Reporting Standard (FLW Protocol 2016), a standardised measurement framework, was adopted (Figure 2).

Data collection design and tools

To assess post-harvest losses, we used crop-specific mixed methods approach. First, we conducted a secondary desk review and exploratory field visits – which included consultations with farmers, traders, and retailers – that helped to map supply chains and identify potential critical loss points in selected study districts. These findings directly informed the subsequent data collection methods and timelines.

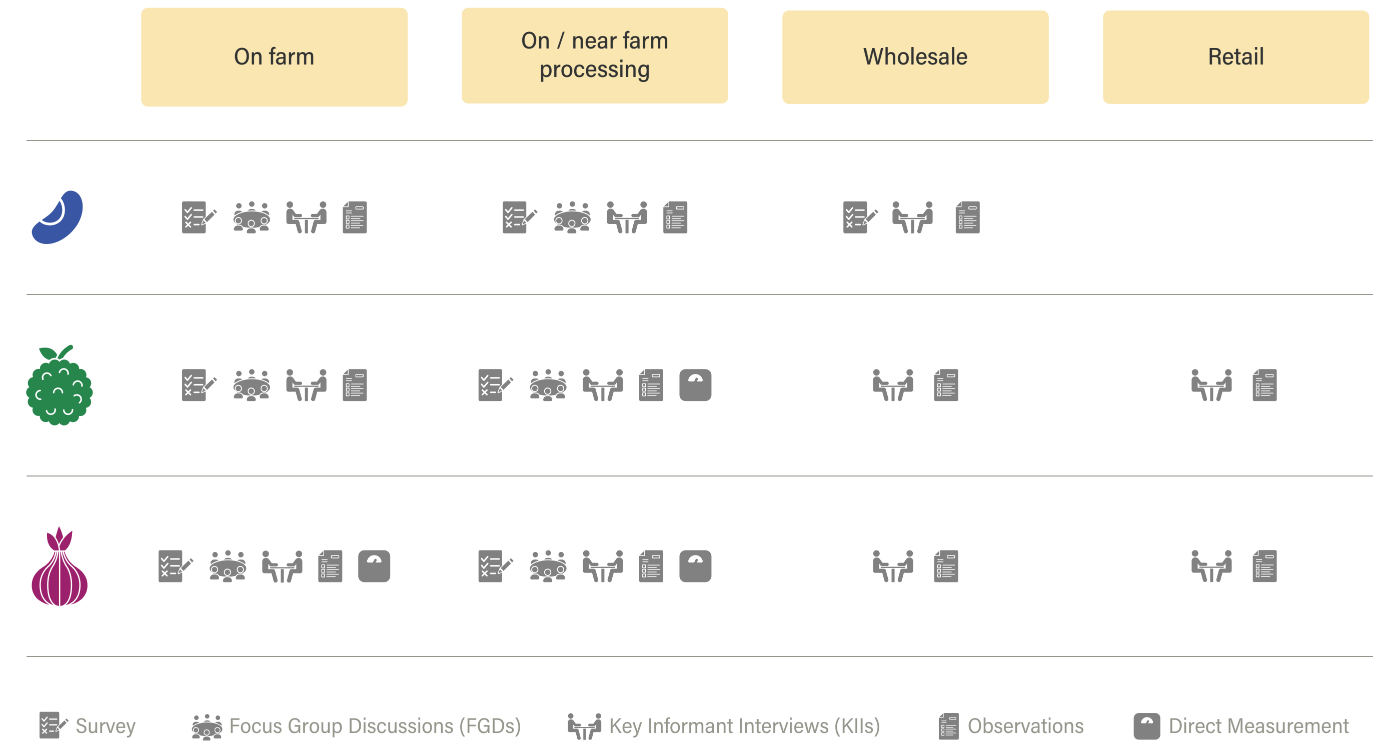
Across the assessments, data collection included structured farmer surveys, focus group discussions (FGDs), key informant interviews (KIIs), direct measurement, and field observations (Figure 3, Table 2). The sampling strategy ensured the inclusion and representation of women as well as large, medium, small, and marginal farmers[1] (for details on the data collection tools, see Annexure A).

Figure 2 | **Scope of the study for onion, soyabean, and custard apple (aligned with the FLW Accounting and Reporting Standard)**

	TIMEFRAME	MATERIAL TYPE	DESTINATION	BOUNDARY
Soyabean Kharif crop	From October to December 2024	Kharif soyabean kernels	• Animal feed • Composting/aerobic processes • Land application • Not harvested/plowed-in • Refuse/discards/litter • Other (human consumption; used as seed)	**SUPPLY CHAIN** Farm to wholesale **GEOGRPAHY** Madhya Pradesh: *Ujjain, Sagar, Dhar, Vidisha* Maharashtra: *Buldhana, Washim, Latur, Dharashiv*
Custard Apple	From August to November 2024	Custard apple fruits	• Animal feed • Composting/aerobic processes • Open dump • Not harvested/plowed-in • Refuse/discards/litter • Other	**SUPPLY CHAIN** Farm to retail **GEOGRPAHY** Madhya Pradesh: *Dhar* Maharashtra: *Pune, Ahilyanagar, Nandurbar*
Onion Rabi crop	From November 2023 to October 2024	Whole bulbs of rabi onion	• Animal feed • Open dump • Not harvested/plowed-in • Refuse/discards/litter • Other	**SUPPLY CHAIN** Farm to retail **GEOGRPAHY** Madhya Pradesh: *Dewas, Indore, Ujjain, Sagar, Rewa* Maharashtra: *Pune, Ahilyanagar, Nashik*

Source: FLW Protocol (2016); WRI India authors.

Figure 3 | **Crop-specific supply chain stages and data collection tools used**



Source: WRI India authors.

Table 2 | **Overview of crop-wise data collection tools and sample sizes**

DATA COLLECTION TOOL	OBJECTIVE	SOYABEAN	CUSTARD APPLE	ONION
Supply chain mapping	Identify crop-specific post-harvest stages, actors, handling practices, marketing channels, and likely loss points to guide tool design and measurement points	Harvesting, collection, threshing, winnowing/ cleaning, drying, packaging, storage, transport/market arrival	Harvesting, field sorting, collection, aggregation, and first mile handling across forest collection, farm boundary, and orchard systems	Harvesting, curing, sorting/grading, packaging, farm-level storage, and transportation
Structured farmer surveys	Capture crop practices, farmer profile, perceived losses, and loss drivers. Stages differed by crop: Soyabean covered near-farm stages from harvesting to transport/market arrival; onion covered harvesting, curing, sorting/grading, packaging, storage, and transport; and custard apple covered harvest, field sorting, collection, aggregation, and handling practices through the load-tracking tool.	421 farmers	60 farmers/ collectors	900 farmers
Key informant interviews (KIIs)	Map post-harvest processes and supply chain actors; understand stage-specific loss drivers.	57 (9 farmer groups, 16 traders, 16 transporters, 16 combine harvester operators)	40 (20 traders, 20 retailers)	60 (20 traders, 20 wholesalers, 15 retailers, 5 processors)

Table 2 | **Overview of crop-wise data collection tools and sample sizes**

DATA COLLECTION TOOL	OBJECTIVE	SOYABEAN	CUSTARD APPLE	ONION
Focus group discussions (FGDs)	Validate loss points, understand shared practices and constraints, and identify solution pathways.	24 (farmers)	20 (10 forest fruit collectors, 10 orchard growers)	90 (45 farmers, 45 agricultural labourers)
Direct measurement	Quantify losses using standard units (weight/ unit count/ volume), recorded digitally. All loss estimates were calculated on a fresh weight basis using commodity weights recorded at the time of measurement.	Not conducted	60 tagged fruit batches weighed at three stages (harvest; field sorting; village aggregation)	150 onion lots weighed before and after farm-level storage over 100–165 days for both quantitative and qualitative changes
Observations	Triangulate reported information and document post-harvest handling practices.	District-wise: harvesting, collection, threshing, drying, packaging, storage, and transportation practices	Production-system wise: forest, farm boundary, and orchard systems, including harvest maturity, harvesting method, cushioning, shade, sorting surface, container type, aggregation time, sun exposure, repacking, and transport handling	District-wise: harvesting, curing, sorting/grading, storage structure, ventilation, stacking, sprouting, rotting, and transportation practices

Note: 1. Sample sizes were determined based on crop-specific study design; production concentration in selected districts and blocks; field feasibility; and the need to capture variation across farmer categories, production systems, and post-harvest practices.

2. For soyabean and onion, the farmer survey samples were designed to provide sufficient observations across selected high-production districts and key post-harvest stages but not to be statistically representative at the state or national level.

3. For custard apple, the tagged batches were selected to capture variation across production ecotypes and to enable direct tracking of losses across first-mile handling stages.

4. Direct measurement was not feasible for soyabean because harvesting occurs through combine harvester machines rapidly over a very short duration, making data collection difficult due challenges in tracking when and where harvesting occurs on the farm.

5. Quantitative findings were triangulated with FGDs, KIIs, direct measurements, and field observations to improve interpretation and reduce reliance on any single data source.

6. For custard apple, qualitative data from FGDs and KIIs were analysed using thematic coding to identify recurring loss-driver themes, including technology and infrastructure, skills and institutions, climate and natural shocks, and policy and market incentives.

7. All data collection tools were reviewed through WRI's Human Subjects' Protection process to safeguard confidentiality and privacy of participant information during data collection.

Source: WRI India authors.

Estimation of GHG emissions, nutrition losses, and economic losses

We estimate the total quantity lost[2] to translate post-harvest losses into three indicative impact metrics: GHG emissions, nutritive value losses, and economic losses (we report the results as indicative magnitudes alongside the post-harvest loss findings, along with a detailed methodology, in Annexure C).

Estimating total quantity lost

We estimate the total quantity of post-harvest loss of each crop in metric tonnes within the study boundary by applying the study-derived loss percentage to the total quantity.

For soyabean and custard apple, we calculate the total quantity as the sum of production in the selected study districts.

For onion, we limited the total quantity to the storage-relevant quantity—the estimated share of rabi onion that was stored—because direct measurement captures farm-level storage losses.

We apply the loss percentages to the total production of the selected districts because we purposively selected the study districts from important production belts; and we triangulate the reported losses with FGDs, KIIs, field observations, and secondary literature (see Annexures A and B).

We calculate the total quantity as the sum of production in all the districts included in the study. These estimates are indicative and limited to the selected districts.

$$\textit{Total quantity lost (MT)} = \textit{Total quantity considered (MT)} \times \textit{loss (\%)}$$

Estimating GHG emissions

We estimate total GHG emissions in tonnes carbon dioxide equivalent (tCO_2e) as the sum of the production-phase emissions from the quantity of the crop/produce that is ultimately lost and the emissions from disposal pathways of the discarded produce, based on destination shares.

We select this approach because the study aims to provide an indicative estimate of the climate implications of post-harvest losses rather than a full life cycle assessment. It follows the FLW Accounting and Reporting Standard (FLW Protocol 2016), wherein FLW quantities are linked to upstream production emissions and downstream treatment and disposal emissions.

We take crop-specific production emission factors from the available India-relevant secondary literature: Sah and Devakumar (2018) and Vetter et al. (2017) for onion and soyabean crop production emission factors; and CEE (2023) for custard apple related estimates (see the emission factors and destination assumptions in Annexure C).

The calculation assumes that crop-specific emission factors (kg CO_2e/kg of fresh produce) are constant across the study districts and that the destination shares in Annexure C apply uniformly to the total quantity lost. The calculation includes embodied production phase and specified disposal emissions and excludes emissions outside this boundary and avoided emission credits.

Estimating nutrient losses

We estimate nutritive value losses by applying nutrient composition conversion factors to the same total quantity lost (in MT) used in the GHG calculations, translating post-harvest losses into energy loss (reported as billion kilo calorie (kcal)) and macronutrient losses (protein, fat, and carbohydrate, reported as tonnes).

We take the nutrient composition values (per 100 gram raw edible portion) from the Indian Food Composition Tables (IFCT) for the raw edible form of each crop (Longvah et al. 2017) (for the corresponding IFCT food codes and nutrient values we use in our calculations, see Annexure C).

We assume that the lost quantity has the same average nutrient composition as the raw edible portion reported in IFCT; therefore, these estimates should be interpreted as indicative nutrition equivalent losses.

Estimating the economic value of post-harvest losses

We estimate the economic value of post-harvest losses using the equation (NABCONS 2022):

$$\textit{Economic loss (INR)} = \textit{Total quantity lost (MT)} \times \textit{Average price (INR/MT)}$$

We derive the average prices from mandi (wholesale market) price data and computed as multi-year averages to smooth the year-to-year price variability. To reflect regional market differences, we use mandi prices from the selected study areas. Consistent, grade-specific price data is absent; therefore, the estimates capture only physical quantity losses.

Based on the availability of crop-specific price data, the price averaging periods are 2022–2024 for soyabean, 2022–2025 for onion, and 2018–2022 for custard apple.

Where arrivals data are available, we estimate prices as arrival weighted averages to better reflect the effective price when larger volumes are traded.

Limitations of the study

This study has four key limitations.

POST-HARVEST LOSS ESTIMATES ARE NOT AVAILABLE FOR CUSTARD APPLE

National post-harvest loss estimates and comparable benchmarks are available for onion and soyabean (NABCONS 2022) but not for custard apple, limiting external comparison and validation of the estimates of the loss of custard apple.

SOYABEAN SURVEYS MAY HAVE RECALL BIAS

Soyabean estimates rely on farmer recall of losses across post-harvest stages, which may introduce bias. We use a larger sample size to mitigate this and triangulate findings using FGDs and KIIs.

ALL ESTIMATES ARE APPROXIMATE AND INDICATIVE AND SHOW THE LIKELY ORDER OF MAGNITUDE

We use standard conversion factors (Annexure C) and simplified assumptions to compute GHG emissions estimates and nutritive value losses. These values are indicative estimations representing the likely order of magnitude rather than exact measurements.

POST-HARVEST LOSS PERCENTAGES ACROSS CROPS MAY NOT BE DIRECTLY COMPARABLE

The supply chain stages differ for the three crops, as does the methodology of our study; therefore, the loss percentages may not be directly comparable.

Findings

This section maps the scale of post-harvest losses in the soyabean, custard apple, and onion supply chains, as revealed in our survey, and presents the climate, nutrition, and economic impacts of the losses; their causes; and the opportunities for reducing these losses.

Mapping the soyabean supply chain

Typically, the soyabean supply chain near the farm begins after physiological maturity and progresses through interlinked operations: harvesting; collection, stacking, and bundling; transport to the threshing floor; threshing, dehusking, and stripping; winnowing and cleaning; drying; bagging/handling and packaging; farm-level storage; and transport to aggregation points and markets (NABCONS 2022). Figure 4 summarises the near farm post-harvest stages and the key actors involved at each stage of the soyabean supply chain.

From harvesting to market arrival, the post-harvest process averages 13.6 days in Madhya Pradesh and 29 days in Maharashtra, according to our survey findings. Farmers report post-harvest losses having occurred at multiple stages, from harvesting until market arrival.

The literature suggests that loss risks vary substantially across these steps, occurring particularly during harvesting and threshing, where grain breakage, scattering, and delays can increase quantitative and quality losses (NABCONS 2022; Patrey and Deshmukh 2022; Sharma et al. 2019).

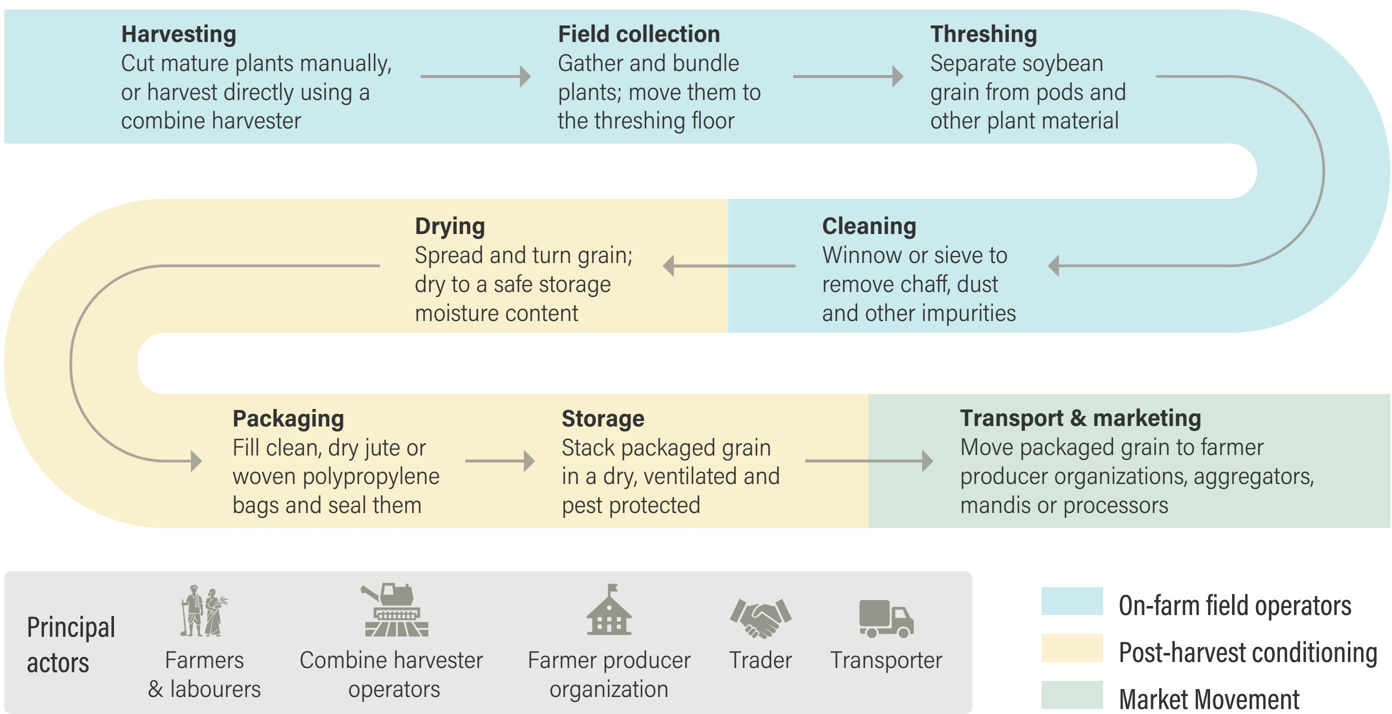
Harvesting and collection Farmers and hired labour undertake harvesting—following physiological maturity of the crop—and then collection, stacking, bundling, and initial handling. Where mechanised services are used, machinery owners and operators and custom hiring providers support harvesting and collection.

Transport, threshing, cleaning, and winnowing The harvested produce is transported to the threshing floor for threshing, dehusking, or stripping. Farmers, hired labour, machinery owners and operators, and custom hiring providers are involved in threshing and subsequent winnowing and cleaning.

Drying, packaging, and farm-level storage At the farm level—following threshing and cleaning—soyabean grains are dried, bagged, handled, packaged, and stored. Farmers and hired labour undertake these operations while traders and aggregators are involved in packaging and storage, if the produce is procured near the farm.

Transport to aggregation points and markets Local aggregators and traders procure and move the produce from farms while transporters support the movement to

Figure 4 | **Soyabean near-farm post-harvest stages and key actors in the supply chain**



Source: WRI India authors, informed by NABCONS (2022) and exploratory fieldwork conducted for this study.

aggregation points and markets. Mandi-linked actors are involved in weighing, auctioning, and onward dispatch. Scale of post-harvest losses and critical loss points in the soyabean supply chain

Table 3 summarises the time taken, flow of produce, and post-harvest losses reported at each stage and presents the post-harvest losses reported by farmers by district. The losses average 10.07 percent of the overall sample produce: 10.43 percent in Madhya Pradesh and 9.69 percent in Maharashtra. Across the districts surveyed, the post-harvest loss varied from 0.19 percent (in Ujjain, Madhya Pradesh) to 25.9 percent (in Sagar, Maharashtra).

At the supply chain stage, the highest average losses reported across the overall sample were during harvesting (2.18 percent), threshing (2.16 percent), and collection (1.81 percent). Together, these stages account for approximately 61 percent of the total reported stage-wise post-harvest loss. Therefore, the most critical loss points within the study boundary are harvesting, threshing, and collection.

The remaining average losses occurred during the stages of drying (1.06 percent), transportation (0.90 percent), storage (0.78 percent), winnowing and cleaning (0.59 percent), and packaging (0.54 percent). These stage-wise patterns differ between the two states: in Madhya Pradesh, higher average losses are recorded during threshing, winnowing and cleaning, drying, and packaging; in Maharashtra, higher average losses are recorded during harvesting, collection, storage, and transportation. However, these differences reflect the characteristics of the districts surveyed; the differences should not be interpreted as uniform, state-level differences.

This study identifies harvesting and threshing as the critical loss points in the soyabean supply chain, consistent with previous studies conducted in the region (Ahmad et al. 2021; Directorate of Marketing and Inspection 2021; NABCONS 2022; Sharma et al. 2019). Previous studies report threshing and related processing losses ranging from 0.32 percent to 2.35 percent in Madhya Pradesh (Sharma et al. 2013; Sharma et al. 2019) to 2.3 percent in Maharashtra (Kannan 2014).

The farm-level storage loss of 0.52 percent reported in Madhya Pradesh is broadly comparable with previous estimates of 0.62–0.82 percent (Sharma et al. 2019). Similarly, transport losses were estimated at 0.56% in Madhya Pradesh, compared with the earlier estimate of 0.16%, and at 1.23%

Table 3 | **Farmer-reported soyabean post-harvest losses across stages and districts, and associated causes (survey conducted from October to December 2024)**

CATEGORY	HARVESTING	COLLECTION	THRESHING	WINNOWING / CLEANING	DRYING	PACKAGING	STORAGE	TRANS-PORTATION	TOTAL
Madhya Pradesh									
Vidisha (kg per 100 kg)	0.50	0.07	0.13	0.26	0.01	0.15	0.00	0.37	1.5
Sagar (kg per 100 kg)	5.60	3.90	5.90	2.30	2.90	1.90	1.50	1.60	25.6
Dhar (kg per 100 kg)	2.00	2.70	3.80	1.50	2.50	0.60	0.50	0.20	13.8
Ujjain (kg per 100 kg)	0.05	0.05	0.01	0.05	0.01	0.01	0.01	0.00	0.19
Average time taken (days)	2.00	1.84	1.73	1.91	1.91	1.74	1.20	1.30	13.66
Average loss (kg per 100 kg)	2.03	1.69	2.49	1.06	1.37	0.68	0.52	0.56	10.43
Maharashtra									
Buldhana (kg per 100 kg)	3.20	2.40	2.40	0.00	0.30	0.20	1.70	1.60	11.8
Latur (kg per 100 kg)	1.40	1.00	0.90	0.03	0.50	0.40	0.07	0.40	4.7

CATEGORY	HARVESTING	COLLECTION	THRESHING	WINNOWING / CLEANING	DRYING	PACKAGING	STORAGE	TRANS-PORTATION	TOTAL
Dharashiv (kg per 100 kg)	1.50	1.20	1.20	0.50	1.40	0.80	0.30	1.07	7.97
Washim (kg per 100 kg)	3.10	2.90	2.70	0.00	0.70	0.00	2.00	1.70	13.1
Average time taken (days)	2.63	7.50	1.32	0.16	1.39	0.72	14.05	1.25	29.03
Average loss (kg per 100 kg)	2.33	1.93	1.83	0.14	0.76	0.41	1.03	1.23	9.69
Overall sample									
Average loss (kg per 100 kg)	2.18	1.81	2.16	0.59	1.06	0.54	0.78	0.90	10.02
Key causes reported for quantity loss	Unseasonal rainfall; fallen grains; weed infestation	Inattention; stray animals; uneven land	Improper thresher speed; late harvesting	Weight loss; seed dispersion	Moisture loss; seed scattering	Poor-quality bags; mould growth	Moisture loss; rodent attack	Poor loading/unloading; manual transfer	—
Key causes reported for quality loss	Moisture; weed infestation; fungal infection	Fungal infection; untimely rain; pod germination	Foreign matter; seeds bursting	Foreign matter	Untimely rain; sunlight exposure	Colour change; fungal growth	Colour change; poor aeration	Hook damage; sharp sampling tools	—

*Note * Loss values represent farmer-reported quantities lost, expressed as kilograms lost per 100 kg of produce entering the respective stage. These values are perception- and recall-based estimates rather than direct measurements.*

 # "Average time taken" represents the reported time spent at each post-harvest stage. State totals represent the sum of the stage wise durations.

Source: WRI India authors.

in Maharashtra, compared with the earlier estimate of 2.7% (Kannan 2014; Sharma et al. 2019).

Discussion on causes and opportunities

Farmers report that quantitative and qualitative losses incurred during the post-harvest stages are caused by awareness, knowledge, and post-harvest practices; infrastructure, technology, and mechanisation; climate and natural shocks; and markets, institutions, and incentives. We discuss these causes in this subsection, along with field insights and evidence from the literature, and identify opportunities for reducing these losses.

AWARENESS, KNOWLEDGE, AND POST-HARVEST PRACTICES

Across the overall sample, 98 percent of respondents report that they practise manual harvesting; it is particularly common where landholdings are small, fields are fragmented or intercropped, and farmers have limited access to machinery. Respondents associate harvesting and collection losses with fallen grains, weed infestation, delayed harvesting, uneven land, stray animals, and insufficient attention during the collection of harvested produce.

After farmers thresh soyabean, they clean and sort it to remove foreign materials and damaged grains, thereby improving the quality of the final produce. However, sometimes, farmers discard edible grains along with damaged grains and foreign matter because of poor sorting and grading or inadequate machinery and equipment.

Another commonly reported cause of quantitative and qualitative loss is inappropriate handling during loading and unloading: 59 percent of respondents reported that they use sharp lifting hooks for handling gunny bags, which could puncture bags and damage grains.

Opportunities

These findings indicate that farmers and labourers need practical training on appropriate harvest timing, collection, sorting, bag handling, and loading and unloading practices. Farmers can also be trained to identify the moisture levels that are suitable for grain and to adjust practices when the weather changes.

INFRASTRUCTURE, TECHNOLOGY, AND MECHANISATION

In Sagar and Dhar, respondents associate losses with poorly calibrated harvesting and threshing machinery, rainfall-related delays, dependence on manual operations, and limited timely access to mechanisation. Similarly, previous studies attribute losses at this stage to inappropriate thresher settings, excessive beating, and delays in moving the harvested crop to the threshing floor (Sharma 2013; Kannan 2014; Sharma et al. 2019).

In Washim and Buldhana, the prevalence of small and semi-medium landholdings and limited access to mechanisation keep harvesting and threshing labour-intensive. Farmer dependence on custom hiring services limits access to the machinery required; and the small and fragmented size of landholdings limit the use of machinery.

The slightly higher overall average loss reported in Madhya Pradesh reflects higher losses at particular stages, especially threshing, winnowing and cleaning, and drying. In Maharashtra, the pattern is different. Losses during harvesting, collection, storage, and transportation are greater; these differences may reflect variations across the surveyed districts in landholding structure, access to labour and machinery, rainfall exposure, storage duration, and handling arrangements.

Respondents linked losses during storage to inadequate drying, substandard or torn gunny bags, poor aeration, and rodent and insect infestation. About 16 percent of the respondents reported that beetles and weevils attack soyabean during drying and storage and rodents cause physical damage and contamination. During harvesting, collection, packaging, and storage, fungal infestation reduces grain quality.

Opportunities

The findings point to the need for appropriately calibrated harvesting and threshing machinery, timely access to custom hiring services, upgraded cleaning and drying equipment, improved quality of bags, and adopting rodent-resistant storage at the farm level. Shared access models—including farmer producer organisation (FPO)–led machinery leasing and Custom Hiring Centres—may be particularly relevant for small and marginal farmers (Ahmad et al. 2021; Gulati et al. 2024; NABCONS 2022).

CLIMATE AND NATURAL SHOCKS

Unseasonal rainfall after harvesting but before drying results in excessive absorption of moisture, making grains prone to mould growth, spoilage, and blackening, thereby reducing their quality. Unseasonal rainfall causes pod cracking, germination, and seed loss. More than 70 percent of the farmers surveyed report that unseasonal rainfall is a cause of losses experienced during harvesting.

In the post-harvest management of soyabean, sun drying in the open is a crucial stage because it helps minimise fungal growth and spoilage during storage. However, unexpected rainfall, prolonged field exposure, and inadequate removal of moisture affect grain quality and market prices. Extended drying periods under unsuitable weather conditions raise the risk of fungal infection.

Opportunities

Practical opportunities include improving access to weather information, harvesting and threshing timely, using clean tarpaulin sheets or raised drying surfaces, accessing sheltered drying facilities, and using simple moisture testing equipment. These measures could reduce exposure to unexpected rainfall and help ensure that the moisture level of soyabean is appropriate before it is packaged and stored.

MARKETS, INSTITUTIONS, AND INCENTIVES

Respondents associate transportation losses with poor handling, leakage from inadequate packaging, delays in shifting produce, and manual loading and unloading. Sharp hooks and sampling tools damage bags and grains during transportation and market handling.

After soyabean is dried and sorted, it is transported to the nearest Agricultural Produce Market Committee (APMC) markets, such as Udgir (in Maharashtra) and Ujjain (in Madhya Pradesh). Inadequate packaging results in spillage and weight loss during transportation while moisture absorption reduces grain quality and affects market prices. At the mandi level, respondents associated losses with delayed auctions, poor handling during weighing and loading, and moisture loss. However, this study does not separately assess losses at mandis or quantify these.

Opportunities

Opportunities include improving packaging and loading practices, ensuring timely collection and transportation of produce, increasing the availability of handling facilities at aggregation points and mandis, and formulating and implementing market incentives that reward grain quality. Farmer producer organisations and other farmers' collectives can facilitate shared access to machinery, drying and storage infrastructure, market information, and coordinated transportation, particularly for farmers with small or fragmented landholdings.

Mapping the custard apple supply chain

The study tracks the custard apple supply chain from harvest to the first wholesale stage across the sampled regions of Madhya Pradesh and Maharashtra. We identify three distinct production and sourcing settings: trees in forests and on common lands; trees growing along farm boundaries, field edges, or bunds; and cultivated custard apple orchards on farms. The associated supply chain pathways differ in labour-dependent activities, packaging, market access, and the timing of sorting and aggregation.

Harvesting In Nandurbar's forests and common lands, women collectors harvest Stage 2 fruits at dawn (Figure 5).

Women account for about 70 percent of the labour in collection, first sorting, and roadside sales, underscoring the gendered nature of forest-based collection (Arya and Ashok 2019; Nordhagen 2021; Tandon, n.d.).

In Nalchha, Dhar district, Madhya Pradesh, mixed-gender members of households pick fruits that are in Stage 2 of physiological maturity and growing along farm boundaries, field edges, or bunds. These are picked by either twisting or clipping the fruit. At times, children adept at climbing branches are engaged. The fruits are picked at dawn.

In the orchards of Pune and Ahilyanagar districts of Maharashtra, household members and hired labourers pick custard apple that are in either Stage 2 or Stage 3 of physiological maturity. The fruit is clipped or handpicked, usually during the early hours of the day, to avoid direct sunlight and heat.

In the Dhar-Indore corridor in Madhya Pradesh, orchards are mostly drip-irrigated and trees are regularly pruned. Mixed-gender labourers employed on daily contracts harvest most fruit at physiological maturity Stages 2–3. Clippers are used to pick the fruit. This activity is performed at dawn.

Sorting and grading After the custard apple is harvested, farmers or labourers sort and grade it, depending on whether the trees are in forests or in common lands; growing along farm boundaries, field edges, or bunds; or cultivated in orchards on farms.

In Nandurbar, fruits on trees in forests and on common lands that are bruised, split, or fungus-infested are quickly sorted on tarpaulin sheets. Farmers either discard rejected fruits or feed it to the cattle.

For trees growing along farm boundaries, field edges, or bunds, at the collection point—typically a shaded open space near the hamlet—women conduct a rapid hand sort, removing underripe, overmature, insect-stung, or split fruits. These fruits are either ripened for home consumption or fed to goats.

Figure 5 | **Custard apple maturity classification. Custard apple maturity was classified into four stages for the study**

Stage 1
Raw and firm

Stage 2
Medium ripe

Stage 3
Fully ripe

Stage 4
Over ripe

Source: WRI India authors, based on Wakchaure et al. (2024) and the stage classification documented during the study.

In cultivated custard apple orchards in Maharashtra, defective or damaged fruits, including those affected by animals, are sorted and discarded along orchard boundaries. In orchards in Madhya Pradesh, on-farm grading removes fruit that is either undersized or broken.

First-mile collection and aggregation Once the sorting, and in some cases grading, is complete, the next steps in the supply chain follow.

From the trees in forests and on common lands in Nandurbar, collectors carry the harvested fruit in a container to shaded village collection points that are at a distance of 2–3 km. Traders collect fruit from 150–200 collectors over 2–3 days. They combine the produce into truckloads of 8–10 tonnes, waiting until enough fruit has accumulated to cover freight costs.

From the trees growing along farm boundaries, field edges, or bunds, picking continues until 50–80 kg of fruit is pooled at a hamlet collection point within a radius of 1 km of the trees. Local traders purchase fruit in cash, usually on the same day.

In cultivated custard apple orchards on farms in Maharashtra, after the crates are filled, traders aggregate and grade the fruit before repacking it for dispatch to Pune, Mumbai, and destinations out of the state. In orchards in Madhya Pradesh, the fruit is taken to village collection points, where commission agents auction the lots.

Packaging and transportation Usually, custard apple is packaged after farmers or labourers sort and grade the fruit. Transportation depends on the marketing channel, distance to market, and, available transportation alternatives.

From the trees in forests and on common lands in Nandurbar, collectors carry 25–30 kg of fruit in bamboo baskets or crates lined with neem or custard apple leaves, a practice observed in 94 percent of the monitored batches. The produce passes through several handling points during transportation.

Collectors use bamboo baskets to carry about 15 kg of fruits collected from trees growing along farm boundaries, field edges, or bunds in Nalchha. Fruit is transported across a distance of 30–40 km to markets in Dhar or Jhabua in plastic crates lined with paper or weed grass.

From cultivated orchards on farms in Maharashtra, custard apple is packed in 20-kg high density polyethylene (HDPE) crates lined with dried grass or fresh leaves. Traders repacked the fruit into 1–5 kg corrugated fibreboard cartons for dispatch. In Madhya Pradesh orchards, fresh fruit is transported in 20-kg HDPE crates covered with paper or leaves. Produce is delivered on the same day or overnight in cushioned crates to local and distant markets.

Figure 6 summarises the three custard apple production and supply chain stages, their main actors, and loss risk points. The mapping shows that labour roles vary by setting and that women play a particularly important role in forest-based collection and first-mile sorting.

Figure 6 | **Custard apple production systems, supply chain stages, and gendered labour roles documented in the study across Maharashtra and Madhya Pradesh**

Source: WRI India authors.

Scale of post-harvest losses across critical loss points in the custard apple supply chain

Overall, across the 60 tagged batches, the cumulative loss averages 9.50 percent. Losses vary substantially across the four state-specific supply chains within the three production and sourcing settings, from 2.5 percent in cultivated orchards in Madhya Pradesh to 22.1 percent for fruit collected from forests and common lands in Maharashtra (Table 4).

The cumulative loss of 22.1 percent is the highest among the fruit collected from forests and common lands in Maharashtra. Stage-specific losses average 6.9 percent during harvesting, 8.7 percent during field sorting, and 8.7 percent at village collection points; therefore, the largest stage-specific losses are recorded during field sorting and village aggregation. Broadly, the cumulative estimate is consistent with the loss patterns reported by Shailza et al. (2020).

Fruit from cultivated orchards in Maharashtra shows a cumulative loss of 9.8 percent, with losses concentrated at the harvest stage. Among the batches monitored, those harvested at Stage 2 maturity show losses of approximately 3–5 percent, whereas batches harvested late or at an overripe stage show losses of approximately 15–25 percent. This pattern is broadly consistent with Jethva et al. (2014), who document harvest rejection of 3–6 percent in Gujarat orchards, and Deepthi et al. (2025), who report farm-level losses of 7.65 percent in orchard systems in Andhra Pradesh.

In Madhya Pradesh, the loss of fruit collected from trees growing along farm boundaries, field edges, or bunds was 5.0 percent at the harvest stage and 1.4 percent at collection points; and the intermediate cumulative loss was 6.1 percent. The cumulative loss was the lowest in orchards, at 2.5 percent: losses averaged 0.9 percent at the harvest stage, 1.4 percent during field sorting, and 0.5 percent at collection points. The cumulative estimate, 2.5 percent, was substantially lower than the total loss of 29.98 percent reported in Andhra Pradesh (Deepthi et al. 2025) and at the lower end of the 13–25 percent range reported for Gujarat orchards (Jethva et al. 2014). The transit loss observed during the monitored deliveries is under 1 percent.

Based on the magnitude and location of the measured losses, the critical loss points differ across the three production and sourcing systems. In the forest/common land pathway, losses are concentrated during field sorting. In the farm boundary/field edge pathway, harvesting is the primary critical loss point. In cultivated orchard systems, harvesting is the main critical loss point, particularly in Maharashtra, while field sorting is the largest measured stage-specific loss in the Madhya Pradesh orchards.

Discussion on causes and opportunities

The findings indicate that post-harvest losses across the custard apple supply chain are shaped by four broad groups of factors: awareness, knowledge, and post-harvest practices; infrastructure and technology; climate and natural shocks; and markets, institutions, and incentives. The relative importance of these factors differs across production and sourcing systems.

Table 4 | **Stage-wise and cumulative post-harvest losses (%) in the custard apple supply chain**

SUPPLY CHAIN STAGE	MADHYA PRADESH - FARM BOUNDARY/ FIELD EDGE (% LOSS)	MADHYA PRADESH - CULTIVATED ORCHARD (% LOSS)	MAHARASHTRA - FOREST/ COMMON LAND (% LOSS)	MAHARASHTRA - CULTIVATED ORCHARD (% LOSS)
Harvest	5.0	0.9	6.9	9.8
Field sorting	0	1.4	8.7	0
Collection point	1.4	0.5	8.7	0
Cumulative	6.1	2.5	22.1	9.8

Note: Stage-specific losses are calculated as discarded weight divided by the weight entering that stage. Cumulative loss is calculated separately for each batch against its initial harvested weight and then averaged across batches; it therefore cannot be derived by adding the displayed stage averages.

Source: WRI India authors.

Table 5 | **Salience of loss driver themes in custard apple FGDs and KIIs**

LOSS DRIVER CATEGORY	MADHYA PRADESH - FARM BOUNDARY/ FIELD EDGE	MADHYA PRADESH - CULTIVATED ORCHARD	MAHARASHTRA - FOREST/ COMMON LAND	MAHARASHTRA - CULTIVATED ORCHARD
Technology and infrastructure	11 (13.1%)	35 (13.9%)	25 (11.8%)	27 (11.4%)
Skills and institution	29 (34.5%)	66 (26.3%)	96 (45.3%)	160 (67.5%)
Climate/natural shocks	3 (3.6%)	18 (7.2%)	5 (2.4%)	10 (4.2%)
Policy/market incentives	41 (48.8%)	132 (52.6%)	86 (40.6%)	40 (16.9%)

Note: *Driver categories were are developed through thematic coding of FGDs and KIIs. Values represent the number of coded references, with their percentage share of all coded references for the respective pathway shown in parentheses; they do not represent the percentage of respondents.

#Technology and infrastructure include references to crates, cushioning, shade, storage, packhouse facilities, transport, and handling equipment. Skills and institutions include harvesting knowledge, maturity identification, sorting and grading practices, labour organisation, training, collective action, and institutional support. Climate and natural shocks include heat exposure, rainfall, humidity, pest or disease incidence, and other weather related weather related factors affecting fruit quality. Policy and market incentives include price volatility, buyer preferences, market access, aggregation delays, credit, subsidies, and incentives for improved handling or processing.

Source: WRI India authors.

Thematic coding of transcripts from FGDs and KIIs shows that in Madhya Pradesh, the most frequently coded themes were policy and market incentives in the farm boundary/ field edge pathway (48.8 percent), cultivated orchards (52.6 percent), and farm boundaries/field edges (52.6 percent). In Maharashtra, the most frequently coded themes were skills and institutional constraints in forest/common land collection (45.3 percent) and cultivated orchards (67.5 percent). Also, respondents repeatedly noted technology gaps, such as limited access to crates, shade, and packhouse infrastructure (Table 5).

AWARENESS, KNOWLEDGE, AND POST-HARVEST PRACTICES

Across all three production and sourcing settings, harvesting is carried out generally before dawn or during early morning hours to reduce exposure to direct sunlight and slow the softening of fruit after harvest. Therefore, timing the harvests correctly and identifying maturity are particularly important for reducing losses. Limited extension support can make it harder to apply these practices consistently.

Opportunities

The findings point to the need for better harvest and improved primary handling as practical priorities, particularly for forests/common land and farm boundary/field edge production pathways. These priorities involve practical, low-cost improvements rather than new interventions. Using simple cutting tools, village-level training on harvest windows, and improved sorting and handling practices can reduce damage before the fruit reaches wholesale markets.

INFRASTRUCTURE AND TECHNOLOGY

Most collection points lack precooling or packhouse facilities, making shade, cushioning, and rapid aggregation the main ways to reduce heat stress and handling damage. Respondents repeatedly noted technology gaps, such as limited access to crates, shade, and packhouse infrastructure. Limited access to shared handling facilities is especially consequential in the forest/common land pathway, where traders assemble fruit from many collectors over 2–3 days before transport.

Opportunities

Low-cost ventilated crates, shade, sorting mats, cushioning, and faster pick-up can reduce damage before the fruit reaches wholesale markets. Improving access to shared handling infrastructure could support adoption, particularly where affordability is a constraint.

CLIMATE AND NATURAL SHOCKS

Climate and natural shocks account for 2.4–7.2 percent of recorded references to loss drivers across the four custard apple pathways (Table 5). Heat exposure can accelerate custard apple softening after harvest, particularly when collection or aggregation is delayed. Softer fruit is more vulnerable to damage during handling and transport. This is especially important because most collection points lack precooling and packhouse facilities.

Opportunities

Harvesting during cooler hours, providing shade, using cushioning, and reducing waiting time at aggregation points can help reduce heat stress and handling damage.

MARKETS, INSTITUTIONS, AND INCENTIVES

Policy and market incentives are the most frequently mentioned loss drivers in the two Madhya Pradesh production pathways, while skills and institutional constraints are the most frequently mentioned in the two production pathways in Maharashtra. Affordability constraints, particularly the upfront cost of crates and other handling equipment, can also limit the adoption of improved practices.

Opportunities

Women play a central role in collection and first sorting. Women-led marketing groups or savings-linked cooperatives can help improve access to finance and support the adoption of better handling practices. In orchard systems, the main priorities are improved harvest maturity, cushioning, field-heat reduction, and market incentives that reward careful handling and rapid dispatch.

Initiatives such as Ghoomar Mahila Producer Company, Jovaki Agro Food India Pvt. Ltd., and TRIFED's Van Dhan clusters illustrate institutional arrangements through which training, aggregation, small-scale processing, market linkages, and access to institutional schemes can be provided. Although not evaluated as part of this study, these initiatives are relevant to the skills, institutions, and policy and market-incentive constraints identified (Table 5) (Arya and Ashok 2019; Suman et al. 2024).

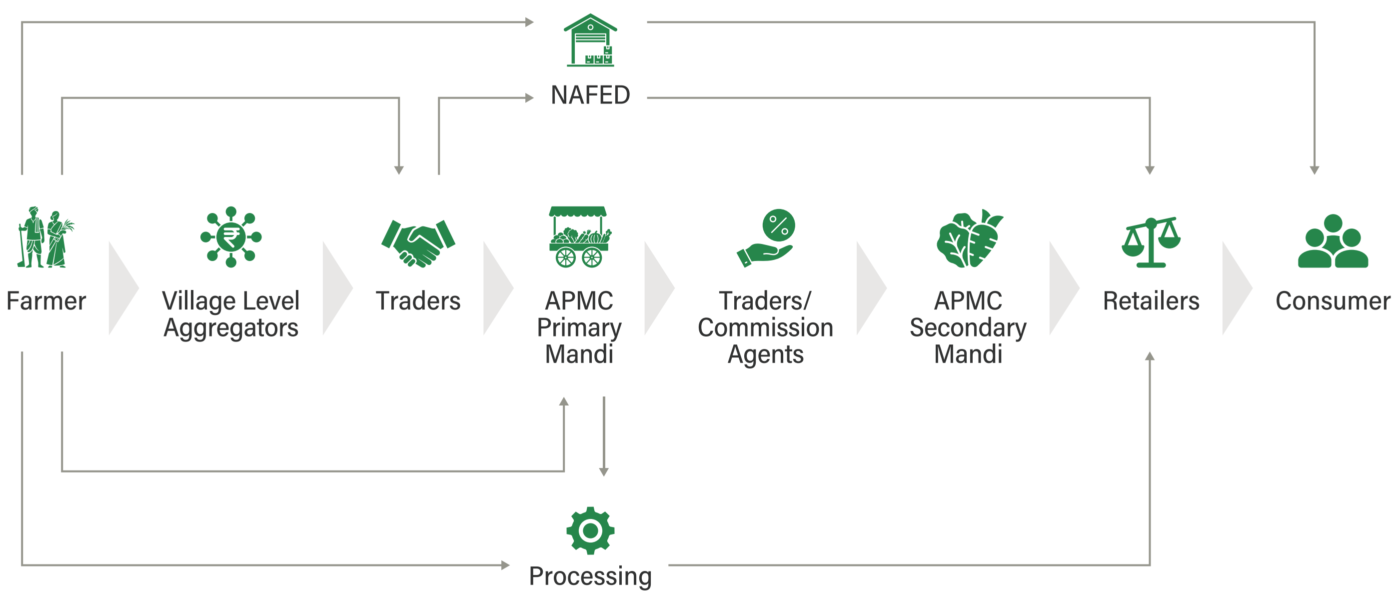
Mapping the onion supply chain

In the study area, the agricultural land is owned mostly by men (75 percent), women (11 percent), and both men and women jointly (14 percent); nonetheless, women are equally involved in all aspects of the supply chain. More women work on farms on average during the harvesting activity; however, both men and women participated in the initial processing after harvest. In marketing activities, trading and mandi activities are largely undertaken by men, with very limited participation by women

Of the onion farmers interviewed, 28.78 percent are marginal, 38.67 percent small, 32.11 percent medium, and 0.44 percent are large farmers. The reliance on loans for growing onion—mostly for labour, fertiliser, and seed costs—is higher among farmers in Maharashtra (31 percent) than in Madhya Pradesh (13 percent). Institutional sources—banks, cooperatives, societies, and self-help groups (SHGs)—are the main sources of credit, followed by informal sources (friends, family, and others), according to the respondents; only 8 percent of the farmers reported being part of any farmer group, FPO, or cooperative.

Rabi onion is transplanted in either December or January. It takes 110–150 days to attain maturity. Usually, harvesting begins in late March or early May. Farmers decide when and how onion is harvested, cured, sometimes sorted and graded, stored, and marketed (Lamba and Sharma 2026). Figure 7 shows the post-harvest handling and marketing process, from harvest to farm-level storage and subsequent market transfer.

Figure 7 | **Onion supply chain in Maharashtra and Madhya Pradesh**



Note: NAFED (National Agricultural Cooperative Marketing Federation of India Ltd); APMC (Agricultural Produce Market Committee)
Source: Roy et al. (2024).

Harvesting Farmers practise manual harvesting primarily using hired labour and hand tools such as sickles and knives. Farmers determine the harvest timing mainly by using their experience in visual inspection. The study finds that 95 percent of farmers harvest crops based on visual cues (leaf toppling, bulb size, and weather); only 8 percent rely on multiple factors such as calendar period and buyer demand. Harvesting at the right stage of maturity influences shelf life and post-harvest outcomes; premature harvesting can increase physiological weight loss, decay, and sprouting (Kale et al. 2022). Survey responses indicate that the primary reasons for losses at harvesting are pre-harvest/production practices (53 percent), unskilled labour (30 percent), rainfall during harvesting (27 percent), poor harvesting practices (16 percent), and labour shortages (9 percent).

Curing Curing is a drying process that removes excess moisture from the outer skin, root, and neck tissue of the harvested onion (Gorrepati et al. 2017); usually, depending on the weather, it takes 5–15 days. Curing reduces post-harvest losses by sealing the neck and forming a barrier to water loss and enhances the visual appeal required for marketing. Proper curing can reduce storage diseases and rots (Gorrepati et al. 2025).

In the study area, after the onion is harvested, it is dried for 10–15 days in direct sunlight, though variations are observed across farmers. Inadequate curing increases susceptibility to weight loss, sprouting, and rotting during storage, indicating that pre-storage management significantly influences storage. In this study, curing served as a crucial preparatory step for storage and marketing.

Sorting and grading Farmers use manual grading before either marketing or storage. To improve the appearance, farmers direct labourers to remove the outer layers of dry scales before marketing the crop. Based on bulb size, onion bulbs are divided into four grades: A (>80 mm), B (50–80 mm), C (30–50 mm) (Kale et al. 2022), and Grade D (<30 mm and jointed) (Figure 8). Usually, right after harvesting, Grade D is sorted and sold in markets or used for home consumption. Higher returns and a longer shelf life can be achieved through proper sorting and grading.

Packaging and storage In Maharashtra, 76 percent of farmers store onion for sale at a later date as compared with only 34 percent in Madhya Pradesh. The study assesses the composition of onion at the start of the storage period, usually after grade D is sorted and sold in nearby markets. Based on weight, about 10 percent of onion is Grade A, 57 percent Grade B, 28 percent Grade C, and 5 percent Grade D.

Onion is stored at the farm level, usually for four to six months, depending on factors such as favourable market price, availability of storage, weather conditions, risk, and the need for money. Inadequate or poor storage conditions leading to rotting, sprouting, and moisture loss are responsible for the largest post-harvest losses.

Storage structures differ by farm size, income, region, and access to government schemes. The structures depend on income, produce volume, availability of space, and level of farmer expertise (Gorrepati et al. 2025).

In Maharashtra, most farmers use iron mesh storage (50 percent), followed by traditional bamboo storage (31 percent) and stone storage (11 percent); only 3 percent reported concrete structures. In Madhya Pradesh, most farmers store onion in houses/concrete storage rooms (56 percent), followed by iron mesh storage (20 percent), godowns (9 percent), and bamboo storage (5 percent) (Figure 9).

Figure 8 | **Onion bulb grades used in the study based on bulb size and form**

Grade A: >80 mm

Grade B: 50–80 mm

Grade C: 30–50 mm

Grade D: <30 mm and joint bulbs

Note: mm=millimetre

Source: WRI India authors, based on Kale et al. (2022) and the grading classification documented during the study.

Figure 9 | **Representative farm-level onion storage structures observed in Maharashtra and Madhya Pradesh**

Iron mesh storage

Concrete storage for onion

Stone storage usually practiced by marginal farmers

Traditional bamboo storage for onion

Photo credits: BAIF and CARD.

Table 6 | **Scale of post-harvest losses in the onion supply chain**

STATE	PRODUCTION (%)	HARVESTING (%)	PRIMARY PROCESSING (%)	TRANSPORTATION (%)	STORAGE	
					(DIRECT MEASUREMENT %)	STORAGE (FARMER PERCEPTION %)
Madhya Pradesh	14	4	5	1	19	16
Maharashtra	9	5	4	3	37	22
Average	12	4	5	2	27	21

Source: WRI India authors.

When structures are located away from the house, typically, male household members oversee storage; when the crop is stored inside the house, men and women share oversight responsibilities.

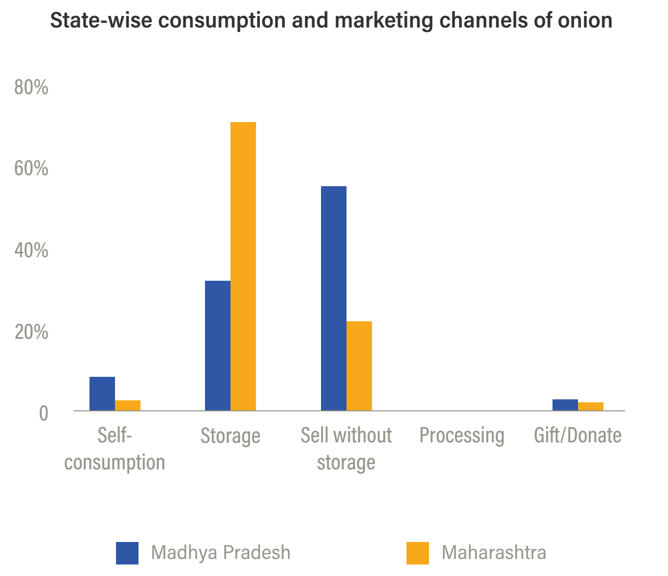
Some farmers reported temporary arrangements (open field, hut, others) before selling. Others did not store onion because of factors such as - unavailability of space, knowledge, need for urgent money, favourable market prices, or high losses during storage.

Transportation Prompt movement minimises the occurence of damages during handing and spoiling; therefore, efficient transportation is crucial for marketing onion. Traders utilise vehicles and rail/road wagons for greater distances; and, usually, farmers employ bullock carts or tractor trolleys to deliver onion to local markets including APMC mandis (Kale et al. 2022). Farmers reported negligible losses during this stage except when unforeseen rain damages the crop during open transportation.

Scale of post-harvest losses and critical loss points in the onion supply chain

In the onion supply chain, post-harvest losses include rotting, sprouting, and physiological weight loss. Storage is the critical loss point by both storage-level direct measurement (27 percent) and perception-based surveys (21 percent) (Table 6). Better storage conditions can reduce avoidable post-harvest losses substantially.

Figure 10 | **Consumption and marketing pattern of onion farmers by state**



Source: WRI India authors.

Onion storage is less common in Madhya Pradesh than in Maharashtra. Storage averaged 165 days in Maharashtra and 101 days in Madhya Pradesh. Storage duration is shaped by weather conditions, prevailing market prices, inadequate household income, and the need for money. Figure 10 shows the main consumption and marketing channels reported by onion farmers in Madhya Pradesh and Maharashtra, including self-consumption, storage, sale without storage, processing, and gifting/donation.

Post-harvest loss drivers vary by supply chain stage, but farmers consistently link downstream losses to production practices that affect initial quality. The key contributors to production-stage losses that farmers cite most frequently are erratic climatic conditions like hailstorms (50 percent), unforeseen rainfall (41 percent), and excessive heat (35 percent). The key contributors to storage-stage losses are weather conditions like excessive heat (33 percent) and excessive rainfall (24 percent). Other factors are pest and fungal infestation (24 percent), poor storage facilities (9 percent), and sorting and grading (6 percent); market prices also play a key role in post-harvest losses across the onion supply chain.

Discussion on causes and opportunities

Post-harvest losses in onion during storage, the critical loss point, reflect multiple, interacting constraints: awareness and knowledge; infrastructure and technology; policies and incentives; and market access.

AWARENESS AND KNOWLEDGE

For around two decades, farmers in Madhya Pradesh and Maharashtra have relied mostly on traditional knowledge for cultivating onion. Since 2016, they have observed improvements in access to irrigation as well as changes in temperature, rainfall patterns, and operations such as sowing, yield, and post-harvest management.

Nonetheless, our study reveals disparities in post-harvest practices and knowledge. For instance, in practices related to curing, sorting and grading, and storage, 22 percent of farmers have received some training on the onion supply chain while 78 percent have not.The participation rate in training is higher in Maharashtra (35 percent) than in Madhya Pradesh (8 percent), though the training focuses more on pre-production and production practices than on post-harvest management.

Women farmers play a key role in onion cultivation but only 14 percent of the total farmers trained are women; and 91 percent of farmers, including women farmers, said they need more training, especially on post-harvest and storage management. Inclusive training sessions on improved storage methods have the potential to improve storage uptake and decrease distress selling, particularly for smallholder farmers in Madhya Pradesh.

INFRASTRUCTURE AND TECHNOLOGY

Farmers store onion at the farm level; storage-level direct measurement reveals significant loss (27 percent) due to factors like poor storage structures and inadequate storage space. Improving storage practices and access to finance for storage can catalyse the reduction of post-harvest loss.

In the study area, farmers have access to irrigation; however, only 4 percent reported using drip irrigation and most employed flood irrigation. Production practices also play a critical role in determining the quality of produce after harvest.

All supply chain processes—harvesting, sorting, grading, and packaging—are manual and require labour. The farm-level opportunity for integrating technology that is accessible by women farmers and that reduces their drudgery and dependence on labour is significant.

Farmers sell most of their produce at mandis; secondary processing was not observed. The results reveal unrealised potential for value addition (especially for Grade C and Grade D onion) storage enhancement, and raising farmer income.

POLICIES AND INCENTIVES

In India, agriculture is a state subject. Therefore, budgetary allocations differ based on importance, scale, and farmer needs.

Farmers' access to government subsidies related to managing onion after harvest are limited in both Madhya Pradesh and Maharashtra, though more farmers in Maharashtra (5 percent) obtained storage subsidies than in Madhya Pradesh (<1 percent). Additionally, Madhya Pradesh lacked funding for subsidies related to onion storage, and the lack of funding which reduced coverage.

In the study, only a small portion of farmers reported receiving subsidy support for storage. However, in the state, schemes like Rashtriya Krishi Vikas Yojana have been key in encouraging farmers to adopt scientific storage structures. The facility can be scaled to other states as well. The Indian Council for Agricultural Research (ICAR) and the Directorate of Onion and Garlic Research have been key in enabling farmers to adopt practices that improve post-harvest management.

MARKET ACCESS

Market price is a driving factor for decisions on duration of onion storage, sale, sorting and grading, and other post-harvest practices. In the study area, farmers travel 37 km on average to sell onion at the nearest wholesale market.

Farmers who store onion secured better prices in the market, and they negotiate more effectively if storage space and infrastructure are available. Farmers sell only at wholesale or retail markets. They are either not aware of other marketing channels that can reduce post-harvest losses or do not have access to those channels.

Since women farmers play a negligible role at markets and women do not work as traders, selling at the farm gate can offer women an opportunity to participate in marketing and decision-making.

In addition, diversifying marketing channels to include more processing at the farm level can improve shelf life, provide women livelihood opportunities, reduce losses, and support in stabilising prices.

Translating post-harvest losses in all the three supply chains into climate, nutrition, and economic impacts

This subsection presents the climate, nutrition, and economic impacts of the post-harvest loss in the soyabean, custard apple, and onion supply chains (Table 7).

Climate impacts

Across all three supply chains, the GHG emissions associated with the estimated post-harvest losses reflect both the emissions embodied in the production of food lost and the emissions from disposal pathways.

The total annual GHG emissions linked to the food lost are estimated at 92,206 tCO_2e for soyabean, 6,314 tCO_2e for custard apple, and 995,523 tCO_2e for onion (Table 7). These estimates reflect both the quantity lost and the assumed destination pathways reported in the study (Annexure C).

Table 7 | **Total quantities lost and associated GHG emissions, nutrition losses, and economic value of losses per year**

CROP	TOTAL PRODUCTION (MT)	TOTAL QUANTITY CONSIDERED (MT)	LOSS (%)+	TOTAL QUANTITY LOST (MT)	TOTAL GHG EMISSIONS (TCO_2E)	ENERGY LOSS (BILLION KCAL)	PROTEIN LOSS (TONNES)	FAT LOSS (TONNES)	CARBO-HYDRATE LOSS (TONNES)	ECONOMIC VALUE OF LOSS (INR BILLION)
Soya-bean	4,127,529	4,127,529	10.07%	415,642	92,206	1,585.48	147,885.42	82,380.24	53,160.61	20.87
Custard apple	82,036	82,036	9.50%	7,793.42	6,314	7.71	126.25	52.22	1,588.30	0.20
Onion (in storage)	11,778,917	6,258,139	27%	1,689,697	995,523	811.73	25,345.46	4,055.27	161,535.03	27.11

Note: Metric tonnes (MT).

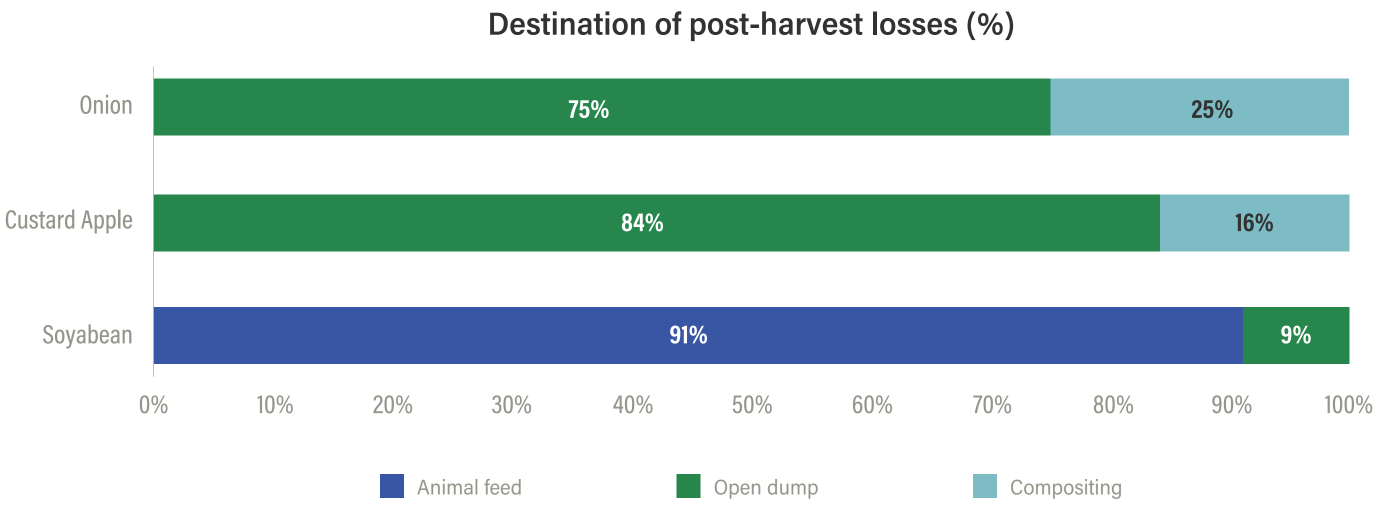
**For onion, the total quantity considered includes only rabi onion (77 percent of the total onion production) that is stored (69 percent of total rabi onions are stored), based on study learnings.*

**For soyabean and custard apple, the total quantity considered represents the sum of production across all study districts. For onion, the total quantity considered includes only the share of total production relevant to the storage-focused assessment.*

+Storage loss represents measurable physical quantity loss, including physiological weight loss and discarded produce due to spoilage or damage. Quality deterioration without measurable weight loss was excluded. GHG impacts were estimated by applying the relevant production and destination-specific emission factors to the total physical quantity lost.

Source: WRI India authors' calculations.

Figure 11 | **Reported destination shares of post-harvest losses by crop**



Source: WRI India authors.

Figure 11 presents the reported destination shares of discarded produce used in the GHG calculations. Onion accounts for the largest total emissions because of the scale and post-harvest losses. Although custard apple also has a high open-dump share, its total emissions are lower because the quantity lost is substantially smaller. Soyabean emissions are moderated by the large share directed to animal feed, although its greater loss volume results in higher total emissions than that of custard apple.

Nutrition impacts

Applying IFCT (Longvah et al. 2017) nutrient composition factors (Annexure C) to the total quantity lost (Table 7) indicates that the nutrition loss in all three crops is sizeable.

The protein lost for soyabean (147,885.42 tonnes) far exceeds that for onion (25,345.46 tonnes) and custard apple (126.25 tonnes). The energy lost is 1,585.48 billion kilo calories (kcal) for soyabean, 7.71 billion kcal for custard apple, and 811.73 billion kcal for onion. The estimated carbohydrate losses are 53,160.61 tonnes for soyabean, 1,588.30 tonnes for custard apple, and 161,535.03 tonnes for onion.

Soyabean accounts for the biggest portion of protein lost despite losing a lower volume, as shown in IFCT food code B024 (Annexure C). Even a little decrease in post-harvest losses can protect a disproportionately high fraction of nutritional value; therefore, interventions in the soyabean supply chain should be given top priority

On the other hand, the carbohydrate lost during storage (161,535.03 tonnes) is relatively high for onion and accounts for a major portion of energy loss.

Economic impacts

The economic value of post-harvest loss, which is calculated by multiplying the total quantity lost by the average mandi wholesale prices, is significant for all three crops (Annexure C). We use multi-year average prices to smooth inter-annual variability in accordance with the national valuation logic.

Where arrivals data are available, we weight average prices by market arrivals so that prices from higher-volume markets contribute more to the final average (NABCONS 2022). We estimate the annual loss at INR 2,087 crore ($237.16 million) for soyabean, INR 20 crore ($2.27 million) for custard apple, and INR 2,711 crore ($308.07 million) for onion (Table 8). Across crops, the contrast is driven primarily by the interaction of loss volumes and price levels.

The onion and soyabean supply chains represent very large aggregate value losses because the loss quantities are large at the assessed scale and the prices are substantial across the multi-year period. The aggregate value of custard apple lost is smaller at the scale assessed, but this lower value should not be interpreted as being low-priority. Losses in custard apple are concentrated in first-mile handling and, therefore, likely to be highly responsive to targeted improvements in harvest timing, shading, cushioning, and rapid aggregation, all measures that can generate meaningful returns for collectors and smallholders despite a smaller aggregate production base.

Conclusions and way forward

This report assesses stage-wise post-harvest losses in the soyabean, custard apple, and onion supply chains in Madhya Pradesh and Maharashtra. Using a mixed methods approach, it identifies where losses occur; how they vary across crops and contexts; and what they imply in climate, nutrition, and economic terms.

For soyabean, major losses occur during harvesting, threshing, and collection. For custard apple, critical loss points vary by production pathway: harvesting is critical at the farm boundary/field edge and in cultivated orchards, while field sorting and collection/aggregation are critical in forest and common land supply chains. For onion, the dominant critical loss point is storage.

The findings show that losses are shaped not only by crop physiology and post-harvest practices but also by access to finance, infrastructure, advisory support, machinery, aggregation arrangements, and markets. Looking ahead, three priorities stand out:

- Access to post-harvest technologies, infrastructure, and finance must be improved.
- Post-harvest management practices should be integrated more strongly into existing extension and farmer support systems.
- Policy and market support should be aligned with the post-harvest stages and production and sourcing.

Access to post-harvest technologies, infrastructure, and finance must be improved

First, access to post-harvest technologies, infrastructure, and finance must be improved in ways that are viable for small and marginal farmers, women farmers, and forest collectors. Viability should be assessed in terms of affordability, expected reduction in losses, labour requirements, ease of maintenance, suitability to local practices, and ease of adoption, including improving storage structures for onion, expanding access to appropriate harvesting and threshing support for soyabean, and strengthening low-cost handling, shading, packaging, and aggregation practices for custard apple.

Financing pathways could include formal credit, concessional loans, equipment leasing, custom hiring services, buyer-supported models, FPO- or cooperative-managed assets, targeted public support, and public-private partnerships. Therefore, community-level, women-led, and FPO-led models should be understood not as substitutes for formal finance but as possible institutional pathways through which farmers and collectors can access technical assistance, credit, tools, infrastructure, and markets on more favourable terms.

Post-harvest management practices should be integrated more strongly into existing extension and farmer support systems

Second, better post-harvest management practices should be integrated more strongly into existing extension and farmer-support systems. Advisory support can be delivered through FPOs, Krishi Vigyan Kendras,[3] Agricultural Technology Management Agency[4] platforms, horticulture departments, equipment providers, trader networks, and digital or open-access training tools. Digital and peer-learning formats should complement appropriately designed in-person demonstrations, particularly where practical skills such as machine calibration, maturity identification, curing and storage management are required.

Policy and market support should be aligned with the post-harvest stages and with production and sourcing

Third, policy and market support should be aligned with post-harvest stages and production/sourcing systems identified in this study. For soyabean, incentives that reward grain quality, alongside market information and coordinated transport through farmer collectives, can support better drying and handling. For custard apple, market arrangements should account for variety, produce quality, the time needed to reach buyers, and farmers' and collectors' access to storage and aggregation. Women have a central role in forest/common land collection and first sorting, women-led groups should be included in training, finance, aggregation, and market-linkage interventions. For onion, targeted storage support, suitable finance, market information, and access to other marketing channels can help farmers make storage and sale decisions.

Continued improvement in crop and stage-wise loss tracking should distinguish between physical edible material loss, physiological moisture loss, quality downgrading, and produce redirected to other uses. Integrating climate and nutrition assessment can strengthen investment decisions, provided consistent material boundaries, units, moisture bases, and destination definitions are used. Overall, reducing post-harvest losses can support farmer income stability, conserve edible produce and nutrients, and lower emissions from food that is produced but not consumed.

Appendices

Appendix A: Data collection tools for soyabean, custard apple, and onion supply chains

This study used mixed methods—surveys and/or direct measurement with semi-structured interviews, FGDs, and field observation—to capture post-harvest practices, losses, causes, and solutions in the soyabean, custard apple, and onion supply chains.

Survey

For soyabean and onion, structured farmer questionnaires captured household and farm characteristics, harvesting, post-harvest handling, storage, transport, marketing, and perceived losses. Tools were translated into Hindi and Marathi, and verbal consent was obtained.

Direct measurement

For custard apple, losses were measured using a load-tracking approach based on guidance from the Food and Agriculture Organization (FAO) and the FLW Standard, adapted for perishable produce. A tagged sub-batch (comprising 30 percent of consignment) was tracked across four stages: harvesting, field exit, village aggregation/segregation, and the next handling point within the block boundary. Measurements included weight, fruit count, grade, maturity, rejects, causes of rejection, packaging, labour, and transport.

POST-HARVEST LOSS METRICS (FAO 2018)

For each handling stage i, the stage-specific physical loss (by weight) was computed as

$$L_i = \frac{D_i}{W_i} \times 100$$

Where,

W_i = total weight/number of fruit carried into stage i (kg)

D_i = weight/number discarded at stage i (kg)

Cumulative loss after the last stage n was calculated as

$$CL_n = \frac{\Sigma_{n=1}^{n} D_k}{W_0} \times 100$$

Where,

W_0 = initial harvested weight/number at the field gate

Digital scales were calibrated daily; duplicate weighing was conducted for 10 percent of observations; analysis was done in Stata 18.

For onion, direct measurement focused on storage. Readings were taken at inward storage and outward storage. The tool recorded quantity, sprouting, rotting, colour, storage type, capacity, and utilisation. Four grades were used: A (>80 mm), B (50–80 mm), C (30–50 mm), and D (<30 mm and/or double/joint onions).

The average of all readings was used to estimate mean quantitative loss, using the following formula:

$$\text{Mean loss (\%)} = \left(\frac{1}{n}\right) \times \sum_{1}^{n} \left[\frac{W_{1i} - W_{2i}}{W_{1i}}\right] \times 100$$

Where,

W_{1i} = Initial weight of sample i (inward storage)

W_{2i} = Final weight of sample i (outward storage)

n = Total number of samples

Initial and final weights included rotted and sprouted onions and moisture loss; changes in colour and size were treated as qualitative loss.

Semi-structured interviews, FGDs, and observation

Semi-structured interviews were conducted with stakeholders across the three supply chains to identify loss points, causes, and solutions. We used FGDs to validate survey and measurement findings and understand shared practices and regional constraints. Field teams used checklists and photographs to record harvesting, handling, storage and transport practices, hygiene conditions, and any visible loss or damage to the produce.

Appendix B: Literature reviewed across soyabean, custard apple, and onion supply chains

Table B1 | **Post-harvest loss estimates in soyabean supply chains reported in the selected literature**

REGION	HARVESTING TO THRESHING (%)	THRESHING TO WINNOWING (%)	DRYING AND STORAGE (%)	TRANSPORTATION AND STORAGE (%)	MARKET YARD (%)	SOURCE
Central Narmada Valley and Malwa Plateau	5.97	3.48	0.66	0.33	0.97	Gulati et al. (2024)
Rajasthan	1-2	NA	1–2	NA	NA	Grant Thornton (2016)
Madhya Pradesh	3.54	0.32	0.62-0.82	0.16	0.47	Sharma et al. (2019)
Madhya Pradesh	7.08	2.35	NA	NA	NA	Sharma et al. (2013)
Chhattisgarh (Mungeli district)	18	22	20–25	NA	NA	Patrey and Deshmukh (2022)
Central Plateau	7.63	NA	NA	NA	NA	Ahmad et al. (2021)
Maharashtra	5.3	1.6-2.3	NA	2.7	NA	Kannan (2014)
National	2.68	0.22–1.21	0.07-0.08	0.88	0.15-0.34	Directorate of Marketing and Inspection (2021)
Latur, Maharashtra	8.84	NA	NA	NA	NA	NABCONS (2022)
Madhya Pradesh	3.24	NA	NA	NA	NA	NABCONS (2022)
Maharashtra	2.62	NA	NA	NA	NA	NABCONS (2022)
Paraná, Brazil	4	NA	2	0.75	NA	Arends-Kuenning et al. (2022)

Source: WRI India authors.

Table B2 | **Post-harvest loss estimates in onion supply chains reported in the selected literature**

REGION	KEY LOSS ESTIMATE / FINDING	SOURCE
Karnataka	2% field, 0.1% transport/packaging, 13.4% storage	Bondita (2023)
India	Field curing losses 5–17%	Gorrepati et al. (2017)
Pune and Nashik	16% farm, 3.85% wholesale, 1.83% retail; cumulative 21.72%	Sahu et al. (2021)
Varanasi	6.98% farm; highest shares in transport and storage	Singh et al. (2024)
Bihar	Storage loss in selected genotypes: 5.80–6.83%	Rani et al. (2024)
Nashik	20–25% due to decay, sprouting, shrinkage	Setiya and Muthuselvan (2018)

Source: WRI India authors.

Table B3 | **Post-harvest loss estimates and key drivers in custard apple supply chains reported in the selected literature**

INDICATOR	ORCHARD FARMS	FOREST/ COMMON LAND	SOURCE
Recorded area under production	Maharashtra ≈ 15,929 ha; Madhya Pradesh ≈ 8,896 ha	Not officially enumerated; trees dispersed on common or forest land	MAGNET (2023)
Mean productivity	7.6 t ha^{-1} (Maharashtra); 12.3 t ha^{-1} (Madhya Pradesh)	25–40 kg per tree (approximately 3–5 metric tonnes per hectare)	Jethva et al. (2014); MAGNET (2023)

INDICATOR	ORCHARD FARMS	FOREST/ COMMON LAND	SOURCE
Bearing age (first commercial crop)	Begins in the third year under managed orchards	Trees reach stable bearing after about 8–10 years	CEE (2023); Jethva et al. (2014); Praveen et al. (n.d.)
Labour share	Family and hired male labour dominate harvesting and pruning; women are involved in, mainly, grading and retail tasks	Collection, head-loading, and road-side sales are carried out chiefly by tribal women (>70% of labour time)	CEE (2023); Shailza (2020); Singh and Kumar (2023)
Gender roles in income and decisions	Produce and price decisions are largely controlled by male land-holders; women's role is limited more to post-harvest operations	Women collectors directly negotiate prices but margins remain low	CEE (2023); Shailza (2020); Singh and Kumar (2023)

Note: Systematic data on custard apple post-harvest losses is limited. Available studies indicate cumulative losses of about 30 percent from farm to retail in Andhra Pradesh, 13–25 percent in Gujarat orchard systems, and around 20 percent in Rajasthan tribal supply chains without cooling or pulping. Common drivers include late harvesting, transport in uncushioned containers, compression during storage, and high ambient temperatures (CEE 2023; Deepthi et al. 2025; Jethva et al. 2014; Shailza 2020; Singh and Kumar 2023).

Table C1 | **Emission factors used in the GHG calculations (tCO_2e per tonne of produce or material)**

CROP	PRODUCTION	OPEN DUMPING	COMPOSTING	NON-HUMAN CONSUMPTION/ANIMAL FEED
Soyabean	0.070	0.61695	0.10584	0.10584
Custard apple	0.275	0.61695	0.10584	0.10584
Onion	0.100	0.61695	0.10584	0.10584

Source: CEE 2023 (for custard apple); Sah and Devakumar 2018 (for soyabean); Vetter et al. 2017 (for onion).

Appendix C: Estimating GHG emissions, nutrition losses, and economic value associated with post-harvest losses in the soyabean, custard apple, and onion supply chains

This annexure presents the approach used to estimate the GHG emissions, nutrition losses, and economic value of losses associated with the post-harvest losses quantified in this study for soyabean, custard apple, and onion.

We estimated the total quantity lost (in MT) of each crop by applying the study derived loss percentage to the total quantity considered within the study boundary and translated the post-harvest losses into broader impacts.

Approach used to estimate GHG emissions

We calculated total GHG emissions by adding the emissions embodied in producing the quantity of produce lost to the emissions associated with its destination pathways. The destination pathways included open dumping, composting, and non-human consumption or animal feed. For soyabean, the animal feed shares were grouped for the GHG calculation and assigned the non-human consumption emission factor. We used the following equation

$$GHG = Q_{lost} \times EF_{production} + \sum_{1} Q_d \times EF_d$$

The methodology is based on the available data. The study reviewed the literature on methodologies to assess GHG emissions from food loss and followed guidance from the FLW Protocol.

Table C1 shows the emission factors used for these calculations. Table C2 provides the assumed destination shares of the discarded produce. All factors were harmonised to tonnes CO_2e per tonne of fresh or wet material before multiplication. Where treatment or disposal factors were reported per tonne of dry matter, the dry matter conversion assumption was applied explicitly.

Table C2 | **Destination of total quantity lost**

CROP	DESTINATION ASSUMPTIONS FOR DISCARDED PRODUCE
Onion	75% open dump and 25% composting
Custard apple	84% open dump and 16% composting
Soyabean	91% animal feed, 9% open dump

Source: CEE 2023 (for custard apple); Sah and Devakumar 2018 (for soyabean); Vetter et al. 2017 (for onion).

Approach for estimating nutritive value losses

We estimated nutritive value losses by applying nutrient composition conversion factors to the same total quantity lost (MT) used in the GHG calculations. We drew nutrient composition values from the IFCT for raw produce (crop-specific food codes) (Longvah et al. 2017), and report these here as energy loss (in billion kcal) and as macronutrient losses (in tonnes of protein, fat, and carbohydrates). Where IFCT values are provided per 100 g (Table C 3), they are scaled to tonnes lost using standard unit conversions; energy is converted from kilo Joules (kJ) to kcal using kcal = kJ / 4.184.

Approach for estimating the economic value of losses

We estimated the economic value of post-harvest losses by multiplying the total quantity lost by the average mandi wholesale price for each crop (NABCONS 2022) (Table C4).

Table C3 | **Nutrition conversion factors used**

CROP	IFCT FOOD CODE	ENERGY (kJ/100g)	PROTEIN (g/100g)	FAT (g/100g)	AVAILABLE CARBOHYDRATE (g/100g)
Onion (big)	G017	201	1.50	0.24	9.56
Custard apple	E016	414	1.62	0.67	20.38
Soyabean (brown)	B024	1596	35.58	19.82	12.79

Source: Longvah et al. (2017).

Table C4 | **Price series used for estimating economic value of losses**

CROP	PRICE SOURCE USED	GEOGRAPHICAL SCOPE COVERED (DISTRICTS/ MARKETS/ MANDIS)	TIME WINDOW USED FOR AVERAGING	AVERAGE PRICE USED (INR/quintal)	AVERAGE PRICE USED (INR/MT)*
Soyabean	CEDA (Agmarknet-based mandi prices)	Madhya Pradesh (Ujjain, Sagar, Dhar, Vidisha) and Maharashtra (Buldhana, Washim, Latur, Dharashiv)	2022-2024	5,022.12	50,221.20
Onion	CEDA (Agmarknet-based mandi prices)	Madhya Pradesh (Dewas, Indore, Ujjain, Sagar, Rewa) and Maharashtra (Ahily-anagar, Pune, Nashik)	2022-2025	1,604.23	16,042.27
Custard apple	Agmarknet modal prices and arrivals compiled in MAGNET plan	Major custard apple mandis in India listed (Gaddiannaram, Jodhpur, Durg, Faizabad, Vadodara)	2018-2022	2,591.26	25,912.57

Note All price series were converted into the units required for valuation (INR/kg or INR/MT) using standard conversions (1 quintal = 100 kg; 1 MT = 1,000 kg).*
Source: CEDA n.d.; MAGNET 2023.

Endnotes

1. The Agriculture Census classifies operational holdings (in hectare) as follows: marginal = below 1; small = 12; semi-medium = 24; medium = 410; and large = 10 and above (GoI 2019).

2. For soyabean and custard apple, the total quantity considered corresponds to the total crop production for the relevant region within the study boundary and the study's loss percentage was applied directly to this total to estimate the quantity lost. For onion, the total quantity considered reflects the subset relevant to the storage focused assessment, specifically rabi onion (77 percent of the total production) that is stored (69 percent of rabi onion), based on study learnings, before applying the loss percentage.

3. A Krishi Vigyan Kendra is an agricultural science centre established by ICAR to serve as a frontline extension system, providing localised technology transfer, hands-on training, and advisory support directly to farmers.

4. The Agricultural Technology Management Agency is a decentralised, district-level platform in India that integrates agricultural research and extension services to facilitate the dissemination of new technologies and farming practices directly to farmers.

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