WRI INDIA

WORKING PAPER

# Tomato trail: Tracking food loss and food waste in Madhya Pradesh

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## HIGHLIGHTS

- Fruits and vegetables incur high food loss and food waste (FLFW) in India, leading to significant economic, environmental, and nutritional impacts.
- Existing literature shows a greater use of perception-based methods, such as interviews or surveys, than direct measurements of FLFW.
- We identified farm and retail levels as critical loss points in the tomato supply chain in Madhya Pradesh.
- Processing and storage of horticultural products, mainly tomatoes, are in the early stages in the region, with scope for minimizing FLFW by improving processing capacity at the farm and aggregator levels and leveraging clean energy solutions.
- The role of men and women is skewed across the supply chain, with men dominating wholesale activities, trading, and the transportation of tomatoes.
- To reduce FLFW, a food systems approach that is gender and socially inclusive should be adopted, with interventions that encourage participation from men, women, small and marginal farmers, and diverse social groups across the supply chain.

# EXECUTIVE SUMMARY

## Introduction

Despite India being among the top producers of fruits and vegetables, offering important supplements to the country's nutritional and food security, fruits and vegetables incur high food loss and food waste (FLFW). The latest estimates from a study undertaken by the Ministry of Food Processing Industries (MoFPI) indicate that fruits and vegetables incur highest postharvest losses in India. Tomato incurs the second highest postharvest losses (11.61 percent), after Guava (15 percent) (NABCONS 2022). Tomatoes are also one of the most important vegetables in the country because of their high nutritional and economic value to farmers and consumers and their role in local cuisines. The literature suggests that FLFW varies in different geographies and, depending on the methodologies adopted for assessment (Agarwal et al. 2021), there is a need for more focused geography-specific research.

This study aims to address the following critical issues: (1) assess the scale of FLFW in tomatoes, (2) identify critical loss points (CLP) and causes, (3) assess the role of energy and energy access, and (4) identify key solutions for reducing FLFW in the tomato supply chain. Additionally, this study provides a measurement-based methodology to measure FLFW and assesses the impact of the FLFW generated.

## About this working paper

This working paper aims to understand FLFW in the tomato supply chain in Madhya Pradesh (MP). This study was undertaken by WRI India in partnership with the Centre for Advanced Research and Development (CARD) for data collection to assess FLFW across the tomato supply chain. First, the study carried out a secondary review and identified potential CLPs in the tomato supply chain—farm, wholesale, and retail levels—followed by defining the scope of the study and assessing FLFW from harvest to retail levels, including the destination of discarded produce at each level. The study was conducted in three districts of MP—Dhar, Chhindwara, and Jhabua. The scope was limited to wholesale markets and retailers (mostly unorganized) in the selected geography. Next, the study adopted the supply chain approach with both qualitative and quantitative tools for data collection, including direct measurements, observations, focus group discussion, and interviews. The presence of men and women was mapped across the supply chain. Additionally, a stakeholder consultation at the state level was organized to validate findings and identify key interventions to reduce FLFW.

## Key findings

The supply chain actors measure losses primarily in economic terms. If the economic cost of tomato production or procurement is recovered, stakeholders, including farmers, wholesalers, and retailers, ignore the quantitative and qualitative losses in tomatoes. There is an overarching knowledge and awareness gap among supply chain actors regarding the scale and impact of FLFW. There are no storage or processing facilities for tomatoes available in the study region, and there are gaps in knowledge, infrastructure, and innovation in the sector. The findings are summarized as follows:

- In the tomato supply chain in MP, the farm level incurs the highest FLFW (15 percent), followed by the retail level (12 percent). These were identified as CLPs with FLFW translating into high economic, environmental, and nutritional impacts.
- The key causes for FLFW at the farm level in the tomato supply chain, as per the respondents, include poor production, harvesting, and postharvest practices at the farm level (such as harvesting time and method, packaging, and temporary storage); a lack of adequate infrastructure for storage, handling, and processing; and unforeseen weather conditions.
- The key causes of FLFW at the retail level, as per respondents, include poor farm-level practices leading to FLFW downstream (such as pests and infestation during production and poor harvesting practices); unforeseen weather conditions; and poor management practices (packaging and temporary storage, lack of storage alternatives, and consumer preferences that drive cosmetic specifications).
- The participation of men and women across the supply chain is skewed, with men dominating wholesale, trading, and transportation activities. Both men and women laborers are involved in harvesting activities; however, gender roles and differential wage rates are defined for both.

## Conclusion and recommendations

Key interventions were identified based on the findings of the study and stakeholder consultation (Lamba et al. 2022). We recommend adopting a food systems approach to address FLFW in the tomato supply chain; that is, taking an approach that looks at the entirety of food production, primary and secondary processing, distribution, consumption, and disposal to understand the complex interconnections and impacts within the system. The recommended interventions are grouped into three approaches, as summarized below, and a combination of interventions under different approaches that are locally

appropriate can be adopted. Specific to the study region, we recommend prioritizing interventions in consultation with district administrations based on available resources.

**A specific critical loss points approach** emphasizes the prioritization of FLFW at the identified CLPs—farm and retail levels.

- Develop best-practice modules for postharvest management for farmers and laborers, especially women and small and marginal farmers. These practices include improved harvesting methods and the use of maturity indices. Develop best practices (such as improved packaging and storage of perishables) for unorganized retailers.
- Promote the collectivization of tomato farmers at the farm level, such as through Farmer Producer Organizations and retailers in informal and formal groups. This provides stakeholders with opportunities to cross-learn, build capacities, and access financing to improve management practices.
- Diversify marketing channels, especially for small and marginal farmers, to minimize risks and help retailers avoid having surplus unsold produce.
- Adopt innovative low-cost solutions for storage and processing to minimize losses, such as evaporative cooling chambers; sheds for temporary storage, sorting, and grading; and solar dryers at the farm level. This would include solar refrigerators and other commodity solutions at the retail level.

**An enabling condition approach** supports building a favorable environment for continued progress in FLFW reduction in the tomato supply chain.

- Encourage research to overcome the gap in data on FLFW and thereby strengthen the development, implementation, monitoring, and evaluation of FLFW reduction strategies.
- Identify opportunities and barriers to adopting different practices by engaging directly with relevant stakeholders, including women and small and marginal farmers.
- Improve equitable access to information and technologies across the supply chain for weather forecasts, demand, supply, prices, and government schemes.
- Enable financing to reduce FLFW by increasing the financing available for programs, technologies, and enterprises that reduce FLFW in the tomato supply chain.

**A whole tomato supply chain approach** suggests engaging all supply chain stakeholders, including farmers, agricultural laborers, wholesalers, and retailers, to reduce FLFW in the tomato supply chain from production to consumption.

- Develop strategies guided by the "Target-Measure-Act" framework at the subnational level. This finding supports FLFW reduction as a key priority for research and action at all levels.
- Build capacity and create awareness of the scale, measurement, opportunities for reduction, and impact of FLFW across supply chains.
- Build stakeholder coalitions to bring all like-minded businesses and organizations to a common platform to cross-learn, collaborate, and act toward FLFW reduction.
- Create partnerships to build synergies between the public and private sectors to work toward a common goal and meet the growing domestic and international demands for fresh and processed tomatoes.

# INTRODUCTION

## Background

Globally, India is one of the major players in agriculture and allied sectors, especially horticulture. According to 2020–21 estimates, in the last decade (since 2012–13), horticulture production (335 million tonnes [Mt]) has outpaced food grain production (311 Mt) in India. The horticultural sector includes fruits, vegetables, plantations, flowers, spices, medicinal and aromatic crops, and honey. Fruits and vegetables are important sources of dietary fiber and minerals, vitamins, micronutrients, and antioxidants. In addition to providing nutritional benefits, the horticulture sector has the potential to improve farmers' incomes and diversify their livelihoods (Jha et al. 2019).

Although India is a leading agricultural producer, large quantities of food are lost or wasted between production and consumption. The economic value of postharvest losses was estimated at approximately ₹1,52,790 crore (US$18.5 billion)[i] in 2020–21, based on the average wholesale annual prices for three years (2019–20, 2020–21, and 2021–22). The agriculture sector contributes 19.9 percent of national gross domestic product (GDP) (2020–21) while the total monetary loss is 2.35 percent of national GDP (at current prices for the first quarter of 2022–23). Cereals, fruits, and vegetables account for more than half of this monetary loss. Fruits and vegetables contribute 37 percent (₹57,004 crore/$6.8 billion) of the total economic loss (NABCONS 2022), representing a significant loss of national wealth. These may be underestimates because the NABCONS assessment only accounts for quantitative losses and not qualitative losses in the selected supply chains.

Although a substantial quantity of food is lost or wasted, the country continues to grapple with challenges such as undernutrition and disproportionate access to food and nutrition. Additionally, postharvest losses in India lead to a carbon foot-

print of 64.1 ± 3.8 Mt $CO_2$eq per year (Kashyap & Agarwal 2020) for selected crops and 94 Mt $CO_2$eq per year from solid food waste (FAO 2021). Reducing FLFW offers multiple wins in terms of economic gains for farmers, wholesalers, and retailers: savings for consumers, supporting food and nutrition security, mitigating greenhouse gas emissions, and reducing pressure on land and water resources (Hawken 2017). Furthermore, reducing FLFW also helps in meeting multiple Sustainable Development Goals, mainly SDG 12 which seeks to "ensure sustainable consumption and production patterns" under which target 12.3, which calls for halving "per capita global food waste at the retail and consumer levels and reducing food losses along production and supply chains, including postharvest losses," by 2030 (UN 2017). Box 1 presents the definitions of food loss and food waste.

Box 1 | **Definition of food loss and food waste**

**Food loss** is the decrease in the quantity or quality of food resulting from the decisions and actions of food suppliers in the chain segments, (excluding retail), food service providers, and consumers. Also known as post-harvest losses, it includes losses during harvesting operations.

**Food waste** is defined as a decrease in the quantity or quality of food resulting from the decisions and actions of retailers, food services, and consumers.

**Quantitative food loss and food waste** is the amount or mass of food destined for human consumption that is removed from the food supply chain.

**Qualitative food loss and food waste** is the decrease in food attributes that reduces its value in terms of intended use. It can result in reduced nutritional value (e.g., smaller amounts of vitamin C in bruised fruits) and/or economic value of the food because of noncompliance with quality standards.

*Source:* Adapted from FAO (2019).

## Why tomatoes?

India is the second-largest producer of fruits and vegetables in the world after China and is among the largest producers of vegetables, with a production of 200 Mt in 2021–22 (FAO 2023). Globally, India is the second-largest producer of tomatoes, with Madhya Pradesh (MP) being the leading producer in the country. Figure 1 outlines the key statistics of tomato production and exports from India. As per the latest national-level postharvest assessment by MoFPI, tomatoes incur the highest postharvest losses in vegetables, with a total of 2.46 Mt (11.61 percent) of tomatoes lost annually (NABCONS 2022). Horticultural production has largely been undertaken by small and marginal farmers (0–2 hectares of land). As the 2015–16 agriculture census shows, 82 percent of tomato farmers in India are small and marginal, followed by semi-medium (12 percent), medium (4.9 percent), and large farmers (0.8 percent) (MoAFW 2020). They play an important role in overall horticultural growth. India has an enormous opportunity to reduce food losses while building a processing industry, improving livelihood especially of small and marginal farmers, and unveiling export potential for fresh and processed tomatoes.

Existing studies have assessed FLFW in different geographies; however, region-specific research on FLFW in India is scarce. WRI India's analysis indicates that available loss estimates vary and are not comparable because definitions, metrics used for measurement, and time frames vary, which makes it difficult to present consistent information on CLPs and to build systematic evidence for prioritizing action and resource allocation for decision-makers (Agarwal et al. 2021). Gender relations are a primary factor in the social and economic contexts that shape the functioning of food supply chains. They also influence the division of labor, roles, responsibilities, and access to and control over resources, services, knowledge, and technologies. Hence, gender relations have an impact on the overall efficiency of the food supply chain and, consequently, FLFW (FAO 2018b).

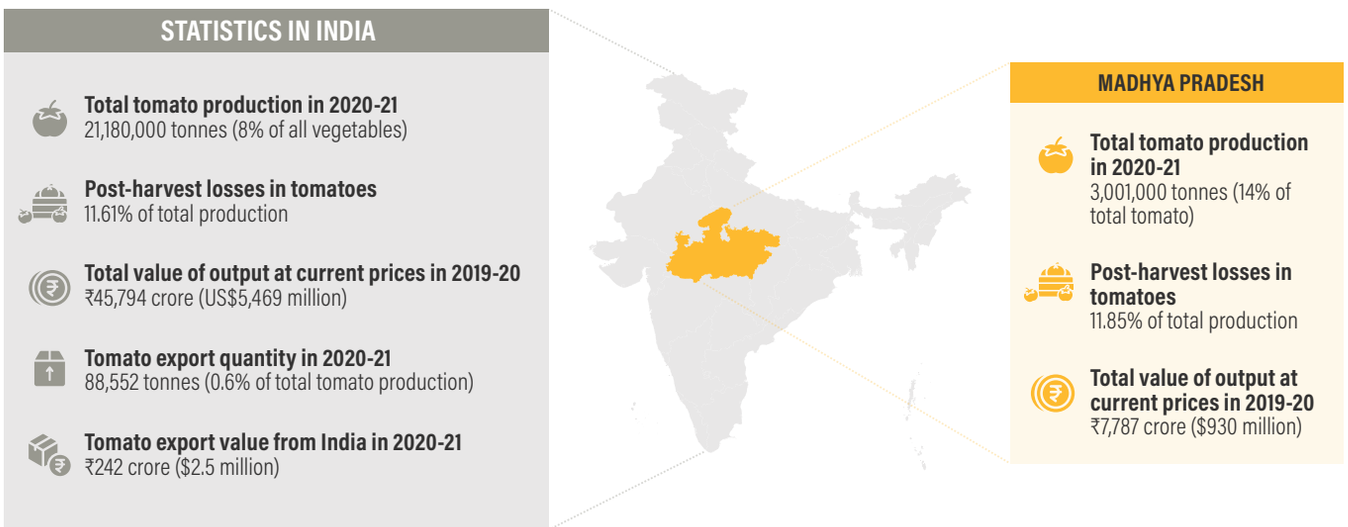
The current study aims to address the key research questions given below:

- What is the scale of FLFW in tomatoes?
- What are the CLPs, causes, and drivers of FLFW in tomatoes?
- What is the role of energy and energy access in reducing FLFW in tomatoes?
- What are the key solutions toward reducing FLFW in tomatoes?

Additionally, this study provides a robust methodology that includes direct measurements at multiple supply chain levels, studying the role of gender and social inclusion, and assessing qualitative losses in the supply chain.

The following sections discuss the methodology and rationale for the geography selection to identify CLPs, the scale of FLFW, and causes. Further, it discusses the economic, environmental, and social impacts of FLFW in the tomato supply chain. Finally, a conclusion and key recommendations are provided for reducing FLFW in the tomato supply chain.

Figure 1 | **Statistics at a glance**




*Source:* Data collated from reports by Ministry of Agriculture & Farmers' Welfare (MoAFW) 2018, 2023a, 2023b, and NABCONS 2022.

# METHODOLOGY

## Secondary review

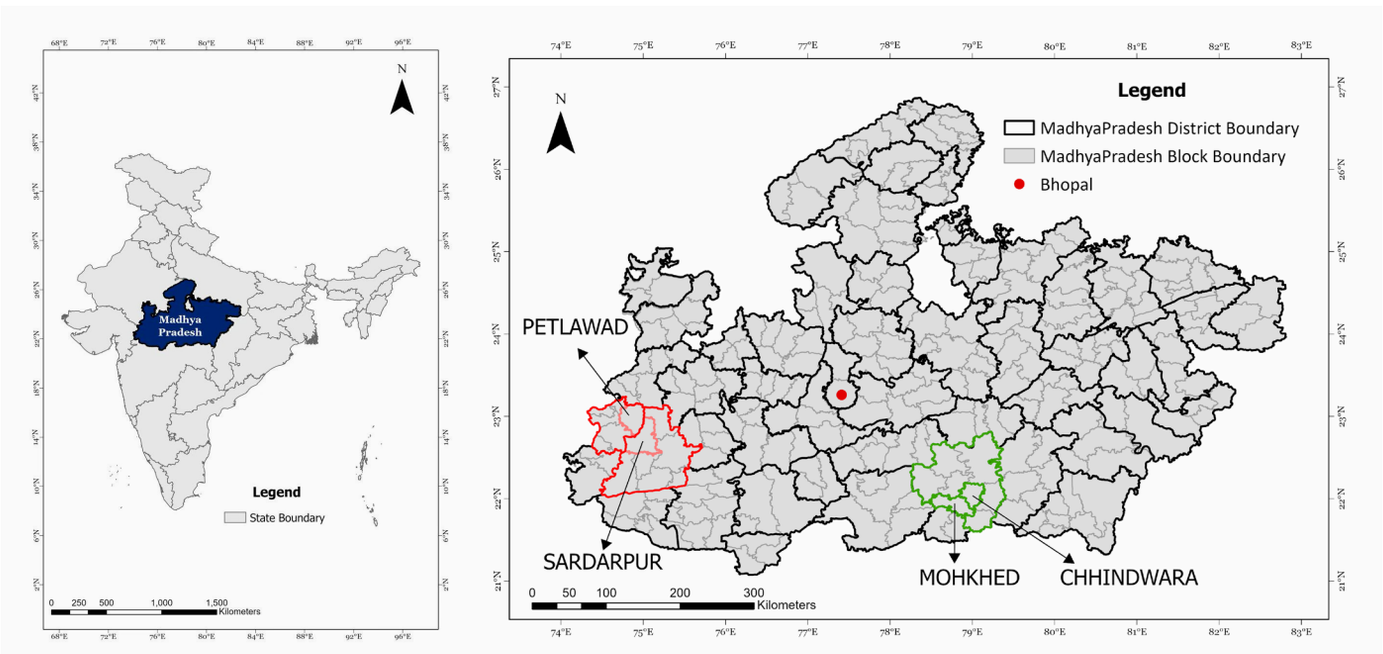
The study began by screening the existing literature on FLFW in the tomato supply chain, particularly in India, to gather data on the scale of FLFW, methodology, CLPs, causes, and key stakeholders. The key search terms for the reviews included "food loss," "postharvest loss," "tomato loss," "vegetable loss," "tomato waste," and "use of energy in FLFW." A literature search was conducted using online databases (Google Scholar and ScienceDirect). This was additionally complemented by grey literature, and the scope was expanded to a global level, given the limited research on FLFW in India. The latest reports were reviewed, and reports from 2010 were referred to in order to ensure uniformity. More than 40 studies were identified and reviewed. The output from the review was collated and synthesized to guide the next steps of the study (Appendix A). The tomato FLFW in different geographies varies from as low as 1 percent to as high as 60 percent. Very few studies have discussed the use of improved energy to minimize FLFW in the tomato supply chain, with most suggesting 'only' cold storage as an intervention. The literature indicates a greater use of perception-based methods, such as interviews or surveys, than direct measurements of FLFW. Based on a secondary review, the study team identified potential CLPs in the tomato supply chain are on farms, and at wholesale and retail levels. This study adopted mixed methods to capture quantitative and qualitative data using both perceptions and direct measurements.

### Study area

MP is a leading producer of tomatoes, with the highest production (14 percent) in India, followed by Andhra Pradesh (12 percent) and Karnataka (10 percent) in 2020–21 (DoAC&FW 2021). As of 2020–21, there was a 57 percent increase in the area under tomato cultivation with a 55 percent increase in production compared to 2013–14 in MP (MoAFW 2016, 2018). Despite this increase in overall production, MP's average yield (2020–21) remained stagnant at 29 tonnes/hectare. This is still marginally higher than the national average of 25 tonnes/hectare but lower than that of Andhra Pradesh (42 tonnes/hectare) and the global production leader, China, at 58 tonnes/hectare.

Based on its high production, yield, and common harvesting period, this study selected the state of MP and subsequently the districts of Chhindwara, Dhar, and Jhabua. The selected districts were grouped into two clusters (Figure 2) based on contiguity. Cluster one consists of Chhindwara, which is in the southern part of the state bordering Maharashtra and has access to the markets of both states. It is a major tomato-producing district in MP with a yield of 33 MT/hectare. The sampled blocks (district subdivisions comprising multiple villages) in the district include Chhindwara and Mohkhed. The second cluster includes two districts: Dhar and Jhabua. These districts are in the western part of the state, adjoining Gujarat, and reported the highest tomato yield (60 tonne/hectare) in MP, more than double the state average. A block from each district was selected for the second cluster, Sardarpur (Dhar) and Petlawad (Jhabua) (see Appendix B for details). Additionally, of all the selected districts, Jhabua has tomatoes as its one-district-one-product (ODOP), a recent government scheme that adopts the ODOP approach to build a selected value chain, scale in terms of the procurement of inputs, availability of common services, and marketing of products (MoFPI 2022).

Figure 2 | **Study area**

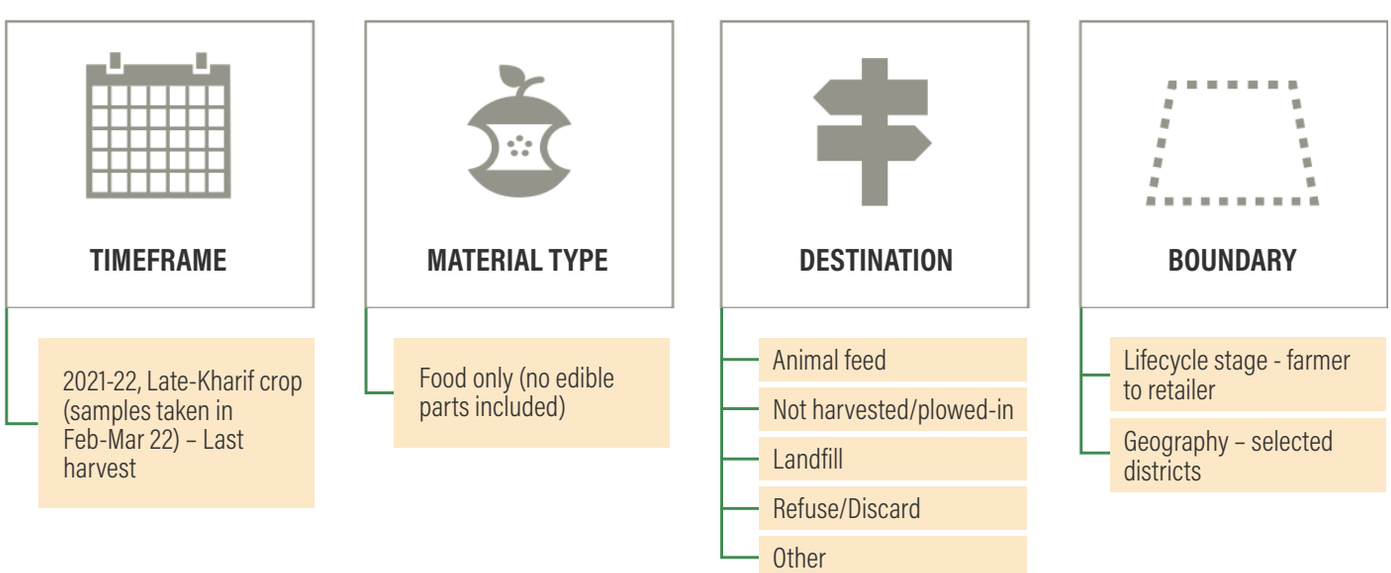



*Source:* Compilation by WRI India authors based on Horticulture Area Production Information System, Horticulture Statistics Division, Government of India for 2020–21.

## Approach

This study adopts the supply chain approach and refers to the Food Loss and Waste Accounting and Reporting Standard (FLWS) as a guiding framework and global standard (FLW Protocol 2016). Figure 3 summarizes the scope of the entire study using FLWS.The study was undertaken for the late-Kharif tomato season, with data collection in February and March 2022. As shown in Figure 3, tomatoes produced for human consumption but discarded or diverted for purposes other than human consumption were considered FLFW. Furthermore, district administrative boundaries were considered as the boundaries of the study for collecting data from stakeholders identified.

Figure 3 | **Scope of the study**




*Source:* WRI India authors based on FLW Protocol (2016).

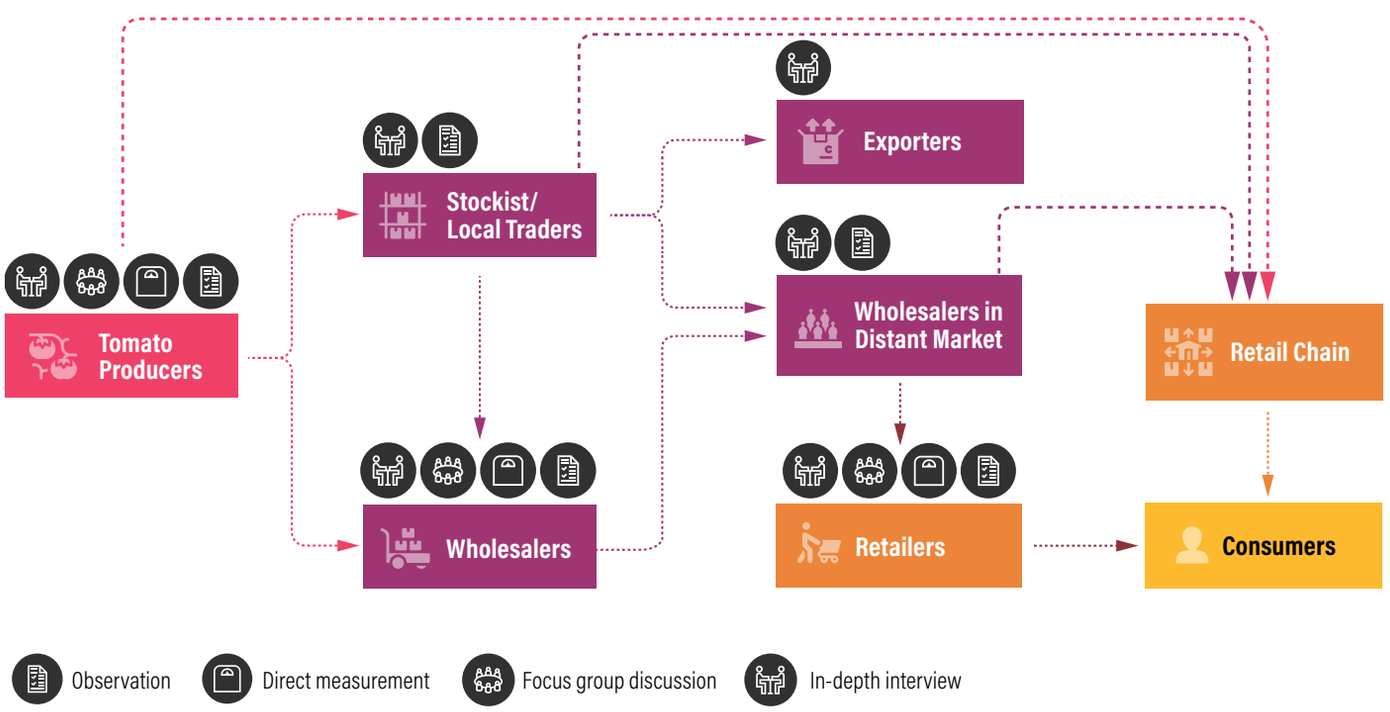
The study team identified a regional partner organization, the Center for Advanced Research and Development (CARD), in the selected geography that already engages with farmers in the region.

## Data collection

WRI India partnered with CARD, which has regional offices in the selected geography, for the duration of this study. The partner supported the gathering of information in the local context, facilitated a preliminary field visit and data collection, and later supported the conducting of a stakeholder consultation to validate the findings.

1. Preliminary visit: A preliminary field visit to the selected geography and interactions with key tomato supply chain actors was conducted. The visit helped in understanding the geography and significance of key stakeholders, especially the roles of women and small and marginal farmers, and to gauge the understanding of FLFW.
2. Selection of blocks and villages: A total of four blocks, with two blocks in each cluster, were selected for the study. The blocks selected were those with the highest production levels. Blockwise data were collected from district horticulture officials and triangulated using partner insights.
3. Tool development: The measurement tool was developed on an open-source mobile data collection platform, the Open Data Kit (ODK), and synced online for the study team to monitor. The data collection tools went through WRI's human subject protection process to ensure the confidentiality and privacy of participant details during the research (See Appendix C for tool). The data collection tools were translated into a regional language (Hindi), and verbal informed consent was obtained before data collection.
4. Training and capacity building: Awareness and capacity for the measurement of FLFW is at a nascent stage among development organizations in India. Despite having worked with farmers for decades, the partner had not carried out any assessment of FLFW. This study offered an opportunity to build the partner organization's capacity to understand the significance and scale of the problem. Two days of training for the partner organization representatives on the project background, objectives, data collection tools, and pilot testing was conducted in each cluster. Their inputs and feedback were incorporated into the tools before the actual data collection. The data collection team was composed of equal numbers of women and men to ensure favorable conditions for interacting with men and women.
5. Primary data collection: The partner organization supported primary data collection, which included direct measurement, focus group discussions, semi-structured interviews, and observations, as detailed in Appendix D. Figure 4 illustrates the overarching tomato supply chain and the types of data collection tools deployed.

Figure 4 | **Overarching tomato supply chain & data collection methods used**




*Source:* WRI India authors.

### SAMPLE SIZE

The study used both quantitative and qualitative data collection tools. Snowball sampling was used to select farmers, wholesalers, traders, and retailers for data collection. Data were collected from 80 farmers, comprising 32 percent marginal and small farmers (< 2 hectare), 33 percent semi-medium farmers (2–4 hectare), 29 percent medium farmers (4–10 ha), and 6 percent large farmers (> 10 hectare; see Table 1). Of the total responses received, 84 percent indicated land ownership by men only, 15 percent indicated land ownership by both men and women, while only 1 percent indicated land ownership by women. Data could be collected from very few women farmers because of factors such as higher participation of men, cultural issues, and unavailability.

### STAKEHOLDER CONSULTATION TO VALIDATE FINDINGS AND DISCUSS WAYS FORWARD

Following preliminary analysis of data collected from the field, a stakeholder consultation— "Co-creating pathways to reduce food losses in the tomato supply chain in Madhya Pradesh"—was conducted to validate findings and seek inputs on interventions from experts. The consultative approach actively engaged diverse supply chain stakeholders (including farmers, processors, government officials, and retailers) working together to design potential solutions (Lamba et al. 2022).

The study encountered a few limitations across the project duration, as follows:

- Unforeseen events such as COVID-19 led to nationwide travel restrictions, postponing the data collection process. This resulted in the study team only measuring tomato losses during one round of picking, which was closer to the end of the harvesting cycle.
- The tomato FLFW reported at wholesale markets is restricted to wholesale markets at the block level, close to farmers' fields, and the findings cannot be generalized to wholesale markets at longer distances.
- The instances where a marketable surplus could not enter the market supply chain owing to the non-availability of the market were not evaluated, which would be an added food loss.

## FINDINGS

Tomatoes, a cash crop, are largely grown during the Kharif season, with only a small percentage of farmers in the study area growing them in the Rabi season. The crop is input-intensive, with farmers practicing improved agricultural practices, such as drip irrigation and mulching. The selected districts represent 19 percent (0.57 million tonnes) of the total tomato production in the state. The major tomato varieties grown in this region are Abhilash, Rishika, and Meghdoot. The tomatoes are primarily consumed fresh, and no processing facilities were observed. All farmers had access to grid electricity with an average of 10 hours of availability for irrigation purposes. No electricity-related challenges were reported in the study area. All the surveyed farmers practiced staking (a method that supports tomato plants off the ground while assisting in upward growth), more than 90 percent used drip irrigation, and about 82 percent practiced mulching in tomato cultivation. Use of drip irrigation and mulching helps build farmers' resilience in case of climate variability and optimizes the use of resources.

The following section details the CLPs and their major causes.

### Critical loss points

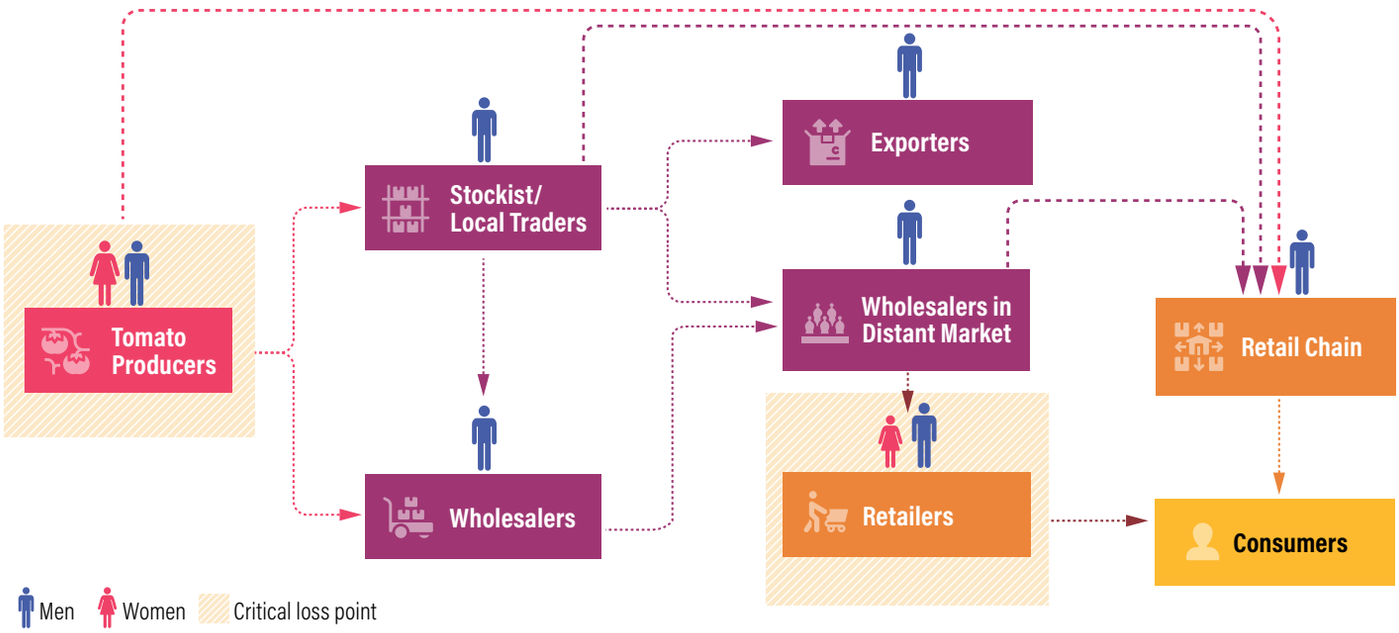
Secondary analysis indicated three potential CLPs in the tomato supply chain: (i) farm level, (ii) wholesale level, and (iii) retail level. These points in the supply chain involve harvesting, trading, sorting and grading, and temporary storage. Based on direct measurements, this study identified the farm and retail levels as CLPs. In addition, the presence of men and women was mapped across the supply chain (Figure 5) to assess their roles.

Table 1 | **Sample size**

| DATA COLLECTION TOOLS | SUPPLY CHAIN STAKEHOLDERS (NUMBER) | | |
|---|---|---|---|
| | FARMER | INTERMEDIARY (TRADER, WHOLESALER, TRANSPORTER) | RETAILER |
| Measurement | 80 | 20 | 20 |
| In-depth interview | 20 | 20 | 8 |
| Focus group discussion | 10 | 4 | 4 |

*Source:* WRI India authors.

Figure 5 | **Mapping presence of men and women and critical loss points in the tomato supply chain**




*Notes:* Gender symbols indicate the quantitative participation of women and men in each supply chain level. When both symbols are used, the bigger symbol indicates the gender of the group that is the main actor at that level.

*Source:* WRI India authors.

The FLFW at each potential CLP identified during the study is summarized in Table 2, with details of each supply chain level in the following section.

## Farm level

In the study area, tomatoes were harvested manually, with a high dependency on hired labor. The tomatoes were harvested and collected from a common spot using plastic crates, buckets, or baskets. At the collection point, a cloth or plastic sheet was laid to dump tomatoes in a heap and to perform sorting and grading activities (see Appendix E). Some farmers try to situate this collection point under trees or in shade. Few farmers in Jhabua district have sheds, which protect the freshly harvested produce from direct sunlight exposure, in which sorting and grading could be performed. Next, cleaning, sorting, and grading were performed based on parameters such as damage, rot, size, shine, color, and market requirements, as described below (see also Appendix F).

- **Grade I:** Locally termed "best quality," also referred to as "super" in the study region. These are medium to large tomatoes that are shiny, spotless, and of uniform ripeness. These fetch the highest market returns. During the study period, Grade I tomatoes fetched ₹350 ($4.18) per crate (25 kg/crate).

Table 2 | **Scale of food loss and food waste at different levels**

| POTENTIAL CRITICAL LOSS POINTS | SAMPLE SIZE | PERCEPTION | MEASUREMENT (MEAN) | | |
|---|---|---|---|---|---|
| | | PERCENTAGE LOSS | GRADE I | GRADE II (QUALITATIVE LOSS) | GRADE III (QUANTITATIVE LOSS) |
| Farm level | 80 | 5–10% | 58% | 27% | 15% |
| Wholesale level | 20 | 1–2% | 73% | 26% | 1% |
| Retail level | 20 | 5–10% | 77% | 11% | 12% |

*Source:* WRI India authors

- **Grade II:** Locally termed "medium quality," these include a mix of big-medium size tomatoes but with cosmetic defects, and small tomatoes, the size of a golf ball or smaller with no defects. They are edible, shiny, and spotless with uniform ripeness, but do not fetch the highest returns (43 percent less than Grade I) due to their size, which is less preferred by buyers. A product categorized as Grade II, which is marketable but fetches a lower price, is considered a qualitative loss.
- **Grade III:** Damaged or rotten tomatoes, which are a mix of edible (not marketable; ugly produce) and inedible tomatoes that are either used for household consumption or discarded on the farm or nearby. It is important to note that when the market has a supply shortage, this category fetches the minimum returns (80-100 percent lower than Grade I). Grade III tomatoes are considered quantitative FLFW.

After sorting and grading, tomato crates were stacked or covered with newspapers and tied using thread or tape on most farms, especially in Dhar and Jhabua. According to the respondents, this helps protect them from the sun and from movement during transportation and ensures hygienic protection from other crates stacked on top. This practice adds to farmers' costs but is demanded by the market. Farmers store tomatoes only temporarily, mostly in the case of a delay at the buyer's end. Temporary storage is either in the open or in sheds in the field for 1–3 days. Farm-level processing was not observed, and all activities conducted postharvest were manual with no observed use of technologies requiring energy. Both men and women laborers were involved in harvesting activities; however, gender roles were defined, with men usually carrying harvested tomato crates, while women were more involved in harvesting by picking, cleaning, sorting, and grading tomatoes. Hired labor has differential wage rates, with men receiving 25 percent higher wage rates than women for the same hours of work.

## SCALE OF TOMATO LOSSES

Fifteen percent of the harvested tomatoes were lost or discarded, based on direct measurements at the farm. The produce categorized as "lost" consists of produce that is not marketable and either inedible or only partially edible and is hence discarded. It includes products with defects, discoloration, physical damage, of inappropriate size, and decay. The perceptions of farmers and other stakeholders vary regarding the scale of food loss at the farm, taking into consideration various prevailing factors such as yield, market rates, and the role of individuals in tomato cultivation and postharvest activities. For instance, individuals involved in overseeing farming operations might have a different understanding of losses than those who engage in other activities. A qualitative loss of 27 percent of produce was measured at the farm level, either fetching a lower price or having reduced nutritional value.

The produce discarded at the farm level is largely thrown back into the open field or on a nearby farm to decompose (96 percent); only 4 percent of farmers reported feeding discarded produce to livestock.

## CAUSES OF TOMATO LOSSES

Food losses at the farm level are largely attributable to the production stage, such as damage from pests, diseases, unseasonal rain, or frost. However, a range of other practices can also lead to FLFW, such as plant variety, time of sowing, and mulching. Outside the scope of this study, a less understood but potential source of significant losses are crops that are never harvested for a range of reasons, including lack of buyers, lack of access to a market, or quality concerns (WWF-UK 2021). Box 2 briefly summarizes the findings from the study of FLFW from unharvested tomatoes.

**Harvesting practices:** The stage of harvesting, harvesting method, and harvesting time are considered crucial factors that determine the shelf life and FLFW of tomatoes. According to the respondents, the harvesting stage is based on the availability of laborers, buyers' demands, and preferences. Farmers harvest tomatoes after receiving an order, and travel distance determines the maturity stage of the tomatoes to be harvested. For shorter distances or for sale in local markets, ripe tomatoes are harvested for immediate sale and consumption. For long-distance transport, tomatoes are harvested at the half-ripe stage, when they are green, firm, and less prone to damage during shipment. However, harvesting a mix of different maturity stages often led to FLFW and rejection by buyers later downstream because they did not meet the desired quality standards. This poor sorting by quality specifications is largely due to time constraints, poor guidelines for laborers, and lack of supervision of laborers engaged in harvesting.

The unavailability of labor for harvesting tomatoes sometimes leads to a delay in harvesting, which in turn leads to overripening or decay and a subsequently shorter shelf life. Harvesting is conducted from sunrise to sunset, which is the time preferred by hired laborers. This is contrary to the recommended time, which is to harvest during the cooler time of the day (up to noon), as an increase in fruit temperature occurs when the fruits are left exposed to the sun, resulting in accelerated ripening (FAO 2018c).

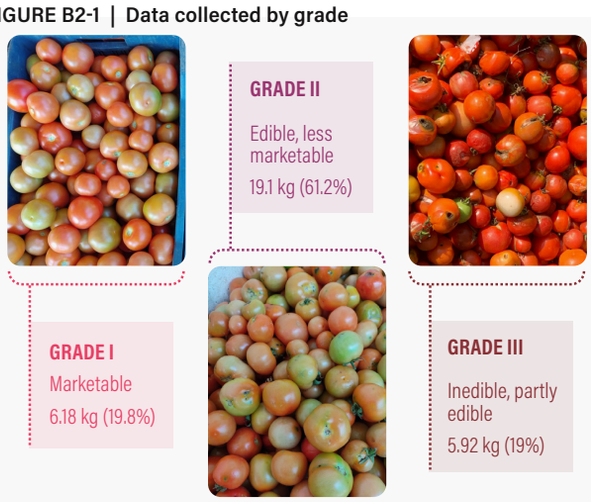
In this harvesting method, hired or household workers receive no training in harvesting practices. To reduce losses, tomatoes in this region are only picked by hand, with workers wearing gloves to minimize damage to the fruit. Some farmers recognized the significance of plucking tomatoes with a portion of the stem and calyx; however, no attention was paid to this while harvesting tomatoes. This technique has the potential to extend shelf life but also increases the risk of damaging

## Box 2 | Tomatoes left unharvested

Some farmers leave ripe and edible tomatoes unharvested. This may be due to labor unavailability, avoidance of additional harvesting costs, input costs already being recovered, or inability to estimate the scale of unharvested produce.

To estimate the scale of unharvested tomatoes in the field, the study team conducted an experiment on a tomato farm being cleared for the preparation of the next crop. From the unharvested tomatoes, we sampled 3 rows of 50 feet each with a row spacing of 5 feet, covering an area of 750 square feet of about a hectare farm (91,127 sq feet). The unharvested tomatoes were harvested, sorted into three grades, weighed, and analyzed using the SISC Food Loss Metric tool. Had the unharvested tomatoes been harvested, an additional 145 crates (25 kg/crate) per hectare of tomatoes could have been sold. Given an average yield of 50 tonnes/hectare, this would represent a 7 percent increase in the total output per hectare (Figure B2-1).

**FIGURE B2-1 | Data collected by grade**




*Source:* WRI India authors.

Measuring row length for data collection

*Photo credit* – Shweta Lamba/WRI India

other tomatoes during transit and storage (MIDH, personal communication, 2017). During harvesting, baskets and plastic crates and buckets were used as field containers.

**Washing/cleaning:** Tomato farmers did not wash/sanitize tomatoes to remove dirt or foreign materials. Only in some places did laborers wipe the tomatoes with a cloth or their gloves while sorting and grading. Plastic crates were also not cleaned before use, which can become a source of contamination (FAO 2018c).

**Sorting and grading:** After harvesting, all farmers in the study area sorted and graded tomatoes. This was predominantly carried out by women, both hired laborers and household members. The major reasons for discarding tomatoes during sorting included fruit being rotten, damaged, or diseased. They also discarded produce that could contaminate other tomatoes stored in the same container. This activity took place during the second half of the day when a considerable quantity of harvested tomatoes is ready for sorting and grading. It is largely carried out under trees partially exposed to sunlight, which risks exposing the harvested tomatoes to direct heat. Sorting and grading tomatoes directly on the ground increases the risk of contamination and subsequent qualitative losses in the supply chain. In addition, offloading tomatoes from a height into heaps for sorting and grading often puts pressure on those tomatoes at the bottom of the heap, physically damaging the produce (See in Appendix E). Furthermore, several farmers reported that if a family member or other individual does not oversee the sorting and grading practice, there are considerably more discards.

**Packaging:** Plastic crates of a standard size were used for packaging the tomatoes. However, the weight of the crate varied from 1 kg to 2 kg, and the weight of the packed crate ranged from 21 kg to 30 kg. Approximately 51 percent of the farmers surveyed used newspapers and tape to cover the crates, to protect tomatoes from bruises, and to protect against damage from other crates during stacking. However, using paper can also create heat, ripening the tomatoes more quickly, which is overlooked by farmers. To attract higher prices, farmers pack the bruised or poor-quality tomatoes at the bottom, with the best quality layer on the top. This practice puts more

pressure on the tomatoes at the bottom of the crate, leading to higher FLFW downstream. In many cases, where the buyer/trader sends staff to carry out sorting, grading, and packaging, the staff tend to overstuff crates, as the price paid is based on the number of crates and not the actual weight at the farm gate. Overpacking results in compression bruising and FLFW downstream. Other key causes include unskilled labor, lack of supervision, and poor guidelines from traders during transit.

**Storage:** Tomatoes have a very high moisture content and are very difficult to store at ambient temperatures for a long time, especially during peak temperature hours in summer. On the farm, tomatoes are temporarily stored in an open field or under shade until the evening, late at night, or for a day. Because market trading takes place in the morning, if farmers intend to sell in the local market, the produce is stored overnight on the farm, leading to marginal quality loss. There are no alternatives available for storage on farms, often leading to distress selling. Because most farmers cultivate tomatoes during the Kharif season, the temperature during the harvesting period provides comparatively favorable conditions for temporary storage. However, unforeseen weather and theft are also risks.

**Transportation:** The transportation of tomatoes from the farm to the market is largely carried out by covered vehicles and by road, with no accessible railway connectivity for the transportation of perishables. No refrigerated vehicles were used for transporting tomatoes in the study area; this was largely attributed to proximity to large markets, the additional cost, and lack of collectivization. Losses during transportation are due to excessive heat, vibration from poor road conditions, delays in transportation (driver negligence, interstate permits, waiting time outside the market, traffic, and vehicle breakdowns), and unforeseen weather conditions.

**Secondary processing:** Secondary processing occurs when the primary product is changed to another product, for example, turning tomatoes into tomato ketchup. No processing was performed at the farm level. This is attributed to various factors, including lack of awareness, unavailability of processing varieties, high cost of cultivation, price volatility, and lack of market linkage. Farmers are unaware of processing opportunities for tomatoes, especially processing specific varieties of tomatoes.

**Marketing:** Unavailability of a favorable market price or buyers owing to factors such as glut, trade restrictions, and climatic conditions leads to food loss for farmers. When the market price is not profitable, farmers will leave the crop unharvested to avoid additional labor and transportation costs, as shown in Box 2. This leads to considerable losses on the farms with unharvested produce and postharvest losses. In the case of sales to big retail companies, products of inferior quality, in terms of appearance, are discarded as they do not fetch profitable returns to farmers leading to higher discards during sorting and grading. There were no farmer producer organizations (FPOs) or groups of tomato farmers in the region; however, some informal groups led by a large farmer aggregated produce to sell in big markets. The marketing of produce and the wholesale market itself are dominated by men, and women's roles are very limited.

In addition, there is an overarching lack of awareness among farmers and hired laborers regarding the scale and impact of food losses on their livelihoods and the environment. There are various government schemes (for example, ODOP, the Mission on Integrated Development of Horticulture, and Operation Greens) that support improvements in postharvest management, especially for small and marginal farmers, but farmers have limited access to these benefits. If the economic cost of tomato production is recovered, farmers ignore the scale of quantitative and qualitative losses in tomatoes.

## Wholesaler level

The wholesale level plays a critical role in marketing the produce locally, as well as transporting it over longer distances. Most tomato farmers (decision-makers, mostly men) preferred selling produce at the farm gate, considering the shorter shelf life, for convenience and to avoid transportation costs and risk. However, small and marginal farmers with smaller quantities of produce sell together with other farmers informally, in the wholesale market, or directly to consumers in local markets. Data from one wholesale market in each block (Sausar, Guriya, Chhindwara, Petlawad, and Rajgarh) were studied. The wholesale markets visited during the study sourced tomatoes from nearby villages (from an average distance of 25–30 km) which were immediately sold during the early morning hours. Only buying and selling among farmers, traders, wholesalers, and retailers takes place at the wholesale market. It is dominated by men, with very few women involved in marketing operations, and then mostly engaged in cleanliness or retail. This also acts as a barrier to women farmers wishing to engage in marketing activities at the wholesale level.

### SCALE OF TOMATO LOSSES

Wholesalers take tomatoes that are sorted and graded according to their requirements or pay lower prices for tomatoes that do not meet their criteria. At the time of sale, wholesalers do not allow further sorting to buyers and only sell the crate on a weight basis. In the local wholesale market, a marginal 1 percent quantitative loss was reported during direct measurements. However, 26 percent of the tomatoes were Grade II, indicating a qualitative loss and nutritional and economic impacts. The percentage of losses varies with the prevailing

prices in the wholesale market. It is important to note that the wholesale markets in this study are block-level markets, mostly sourcing tomatoes locally during the harvesting season.

### CAUSES OF TOMATO LOSSES

Wholesalers indicate that the primary causes for losses at the wholesale level are production and postharvest management practices at the farm. For example, poor sorting and grading can lead to transportation losses. At the market level, factors such as unforeseen weather conditions during marketing, delayed sales, poor handling by hired laborers, and lack of infrastructure play a significant role. It is also important to note that if the produce brought to the market has been damaged, it usually remains unsold or is sold at a comparatively lower price, and that economic loss is mostly borne by farmers. The burden of economic loss is therefore shifted to farmers/traders who bring produce to sell in the market.

**Storage:** There are no storage facilities at the wholesale market level for farmers to store surplus produce if it is not sold, leading to distress selling and subsequent economic losses. These food losses at the wholesale market are mostly borne by the farmers who are unwilling to incur additional return transport costs for the produce. Some wholesalers were observed storing tomatoes at room temperature in their shops; this is a temporary arrangement for only a few days until they find a buyer, or prices are more favorable, but this incurs food losses. In discussions with stakeholders, cold storage is not considered a feasible storage solution for tomatoes because of factors such as high cost, consumer preference for fresh produce, and year-round availability of tomatoes from different regions of the country, which adds to price competitiveness. Furthermore, the literature recognizes the limited role of cold chains in climatic fruits and vegetables, such as tomatoes, in domestic markets (Oosteweche et al. 2022).

**Operation hours:** Wholesale markets are restricted to morning hours. Because harvesting is carried out throughout the day, farmers wait until the next day to sell at their local wholesale markets.

**Handling:** The handling of produce at the wholesale level is performed by hired laborers. The produce arrives in crates and is sold in the same crates, with only the loading and unloading of the crates carried out. However, it was observed that the traders sometimes discard tomatoes on top of the crates to fetch good returns from buyers. The discarded produce remains unaccounted.

In addition, the wholesale level plays a critical role in determining shelf life in the supply chain; for instance, packaging materials and destination distance should be appropriate for the quality of procured tomatoes.

## Retailer level

Most fresh produce is sold through unorganized retailers, including street vendors, roadside daily vendors, fruit and vegetable outlets, and community markets. This study targeted unorganized retailers to examine tomato FLFW. Retailers, comprising both men and women, hope to sell their tomatoes on the same day as purchase given their perishability, harsh weather conditions, high value, and unavailability of storage.

### SCALE OF TOMATO WASTAGE

At retail level, a quantitative food waste of 12 percent was measured at the end of the day of sale. This may not include a significant proportion of the discarded tomatoes received from wholesalers at the start of the day. Upon assessing the qualitative losses, approximately 11 percent of the produce was categorized as Grade II and sold in the retail market at a price 50 percent lower than Grade I. The perceptions of retailers vary, with an average waste of 1 kg per crate, and sometimes 2–3 kg per crate, which translates to a percentage wastage of 5–10 percent.

Food waste generated by retail outlets is generally discarded as municipal waste or fed to stray cattle. If municipal waste is not segregated and processed responsibly, it ends up in landfill where it produces methane, negatively impacting the environment.

### CAUSES OF TOMATO WASTAGE

Retailers report that agricultural practices during production and postharvest at the farm and wholesaler levels play a critical role in determining the shelf life of tomatoes and eventual wastage at retail. For instance, frost or excessive heat during production may affect the shelf life of the produce. Other factors contributing to food waste in retail stores include unforeseen weather conditions, customer demands, and supply shortages, which impact consumers' purchasing power. Most consumers demand a standard size, uniform color, and without any marks, meaning part of the edible produce will not meet the desired criteria. However, retailers cope with the changing demand by adjusting their pricing to sell before the end of the day. Distress selling at a lower price led to an economic loss for the retailer. If a surplus remains by the end of the day, they store it at home for sale the next day, usually in polythene bag or in a basket under a fan, if available. No cold storage facilities were available at the retail level and no training was provided to retailers. The knowledge required to ensure the quality of produce comes from first-hand experience and/or working with experienced retailers.

Retailers source from an average distance of 5 km, a wholesale market or a farm, using either a rented vehicle or their own vehicle. The packaging during transportation consists of plastic crates (50 percent) or polythene bags (50 percent). However,

transportation in polythene bag leads to increased wastage. Furthermore, keeping tomatoes with other produce and exposed to direct sunlight can accelerate ripening and increase subsequent wastage. Retailers have no standard protocol for handling or storing tomatoes. It was observed that tomatoes were often kept under other vegetables during transportation and were not stored with due precautions.

Box 3 | **Processing and storage**

While India is the second-largest producer of tomatoes, with a 10.7 percent share of global production, it has only a 0.3 percent share of the tomato (fresh and chilled) export industry as of 2021 (FAO 2023) and is a net importer of processed tomatoes. Tomato processing has also been identified as a key solution by stakeholders, particularly farmers. Processing requires suitable tomato varieties, though these varieties are not preferred for sale in markets. To make this economically viable, sourcing tomatoes at ₹4/kg ($ 0.05/kg) or less is required. China processes tomato paste at a much cheaper rate, making it the global leader. Indian ketchup manufacturers find it cheaper to import Chinese tomato paste than to procure it in India (Gulati et al. 2022). Imports of cheap foreign produce disrupt local production. Over the last three years (2019–22), the demand for **processed tomatoes** has increased at a rate of 30 percent each year. This growth has been triggered by an increase in the domestic consumption of products derived from processed tomatoes in hotels, restaurants, and catering and the volatility of fresh tomatoes (Sasidharan & Colvine 2020). In addition, it is important to note that although the domestic demand for processed tomatoes is increasing, the size of the market is such that about 8,000 hectares (out of about 840,000 hectares under tomato cultivation in India) of tomatoes will suffice to service the processing requirement. There is therefore a need to build export potential for tomato value added products along with processing (Sasidharan & Colvine 2020).

Source: Adapted from FAO (2019).

## Impact of tomato loss and waste

The findings show there is FLFW across the tomato supply chain: a 15 percent loss at farm level, a marginal 1 percent at wholesale, and 12 percent at retail level. The scale of FLFW is important because of its impact on the environment, the economy, and food and nutrition security. The selected districts in 2020-21 produced 557,329 tonnes (19 percent) of total tomato production in the state, of which FLFW was 83,614 tonnes at the farm level, 4,738 tonnes at the wholesale level, and 56,289 tonnes at the retail level.

**Environmental:** FLFW has a huge impact on the environment, putting pressure on various resources such as land, water, and fertilizer, and leading to emissions from the improper management of discarded produce. The production impact upstream of FLFW is 29,393 tonnes of $CO_2$ equivalent/year, based on the calculation of an emission factor of 0.15 $CO_2e$ per kilogram of waste produced (Vetter et al. 2017). The destination footprint is not considered in the calculation. However, using the FLW Value Calculator (FLW Protocol 2021), the quantity loss at wholesale and retail levels (61,027 tonnes) of tomato FLFW leads to 6,824 tonnes of $CO_2e$/year of emissions from increased landfill and 28,995 tonnes of $CO_2e$/year from the agricultural production impact. This gives a total of 65,212 tonnes of $CO_2e$/year.

**Economic:** All stakeholders across the supply chain experience significant economic losses as a result of FLFW, especially small and marginal farmers dependent on agriculture as their primary source of livelihood.

For farmers, the average cost of tomato cultivation is ₹129,000/hectare ($1,545/hectare) (Solidaridad Regional Expertise Centre 2022) with an average yield in the study region being 50 tonnes/hectare. A 15 percent loss at farm level translates to a quantity loss of 7.5 tonnes/hectare and cost-of-cultivation loss of ₹19,350 ($232) per hectare per season. If the quantity lost was sold, it would have fetched an average additional ₹9000/tonne ($107/tonne) resulting in ₹67,500 ($806) per hectare. In India, the economic loss from FLFW forms a significant portion of the income of small and marginal farmers (82 percent of all tomato farmers), restricting their potential to improve incomes and diversify their agricultural livelihoods.

A wholesaler only incurs economic losses in unforeseen scenarios, such as rainfall during trading or transportation, when produce is spoiled or fetches lower returns. The wholesaler recovers the cost of FLFW in the long run by charging higher margins.

An unorganized small retailer, on average, buys one crate (25 kg/crate) of tomatoes per day. A 12 percent loss of produce translates to 3 kg of tomato waste and ₹17,200 per year ($205/year) of input cost and ₹32,400 per year ($387/year) if the produce was sold at the rate of ₹30/kg prevailing during the study period. The assessment of wastage at the consumer level was outside the scope of this study; however, there is scope for increasing consumer savings by reducing wastage at the consumption level.

**Nutrition:** The tomato is one of the most important "protective foods" because of its special nutritive value. It is an important source of dietary fiber, minerals, vitamins, micronutrients, and antioxidants. A total FLFW of 1,44,641 tonnes results in significant nutrient losses; specifically, 4,594 tonnes of carbohydrates, 4,586 tonnes of dietary fiber, 1,110 tonnes of protein, 629 tonnes of minerals, 37 tonnes of vitamin C, and 8 tonnes of carotenoids. These nutrient losses are distributed across different levels, with 58 percent occurring at the

farm level, 3 percent at the wholesale level, and 38 percent at the retail level (Longvah et al. 2017). If the avoided FLFW were redirected to feed the needy, it could help support and improve food and nutrition security.

## CONCLUSION AND RECOMMENDATIONS

Based on the findings, the study team identified three broad categories of interventions to reduce FLFW: (i) behavioral change and capacity building, (ii) infrastructure and innovation, and (iii) policy and incentives for inputs from stakeholders. Stakeholder consultation identified interventions and actors to undertake solutions to reduce FLFW in tomatoes (Lamba et al. 2022). The key interventions identified included creating awareness and capacity to reduce FLFW, improving infrastructure and innovation, such as solar dehydrators and sheds at the farm level, and improving access to existing policies and schemes that support FLFW reduction. Furthermore, it was concluded that no single intervention would solve FLFW in the tomato supply chain. Rather, it requires a variety of interventions implemented at different stages of the food supply chain and by different actors. The following subsections build on the findings of this study to provide recommendations for reducing FLFW.

We recommend adopting a food systems approach that considers the entirety of food production, primary and secondary processing, distribution, consumption, and disposal to address complex interconnections and achieve impacts within the system. Specific to the study region, we recommend prioritizing interventions (Tables 3, 4, and 5) following a cluster approach in consultation and anchored with district administration, where strategies to reduce FLFW for tomatoes and other crops can be designed. The focus of strategic discussion at the district level could also be on identifying potential public funding sources through existing schemes that can enable the establishment of innovation and infrastructure, advice for farmers on harvesting practices, and better connections with the market.

The recommended interventions at the identified CLPs are summarized below in Table 3. Access to financing, information, data, and energy is the cornerstone of sustainable progress in FLFW reduction in the tomato supply chain. Table 4 lists the enabling conditions critical for achieving FLFW reduction. It also supports building an enabling ecosystem to promote FLFW reduction in other crops and commodities.

Table 3 | **Specific interventions at identified critical loss points to reduce FLFW**

| INTERVENTION | AT FARM LEVEL | AT RETAIL LEVEL |
|---|---|---|
| Best practices for target stakeholders | Develop best practice modules for harvest and postharvest management that include maturity indices for right harvesting stage, harvesting time, use of shade during temporary storage, and adoption of climate-resilient varieties. | Develop best retail practice modules, that include use of shade, use of plastic crates during transit, air circulation, and appropriate storage. |
| Collectivization of stakeholders | Promote and incentivize the collectivization of tomato farmers and agricultural laborers to form groups or farmer producer organizations (FPOs), especially women and small and marginal farmers, to achieve economy of scale, competitive rates, benefits from schemes, finance, and access to resources. | Encourage formation of retailer associations/unions to address retailer-level challenges and enable knowledge sharing across retailers about the latest technologies and practices to reduce wastage. |
| Diversification of marketing channels | Diversify marketing channels to minimize risks and maximize profits by selling all grades of tomatoes through portals such as e-NAM. | Diversify marketing channels and build relationships/ contracts to sell surplus produce, such as with hotels, restaurants, businesses, and processors. |
| Innovative technology | Adopt low-cost technology for processing and storage of multiple commodities, including tomatoes, such as evaporative cooling chambers, pre-cooling methods, sun sheds, and solar dryers, with buy-back of processed material. Ensure access for women and small and marginal farmers. | Adopt small-scale refrigeration solutions for short-term storage of surplus produce, such as solar refrigerators. Ensure access for unorganized small retailers, especially women who may be at higher economic risk. |
| Management of human resource | Create awareness and training for farmers and tomato laborers to reduce FLFW.<br>Encourage farmers to oversee on-farm practices such as sorting, grading, and farmgate sales. | Build trust-based relationships with wholesalers or directly with producers to source quality produce with longer shelf life. Encourage informed purchase and oversee proper handling during sales. |

*Source:* WRI India authors.

Table 4 | **Interventions to support building enabling conditions to reduce FLFW**

| INTERVENTION | DESCRIPTION |
|---|---|
| Information symmetry | Improve access to information across the supply chain, especially the marginalized, including women and small and marginal farmers. Timely information on the weather, forecasts, projected demand, quality standards, market price, processing, and export standards play an important role in decision-making. |
| Finance | Develop funds and financial products or leverage existing schemes and policies dedicated to investing in innovation and scaling up enterprises and technologies, such as drip irrigation, processing facilities, and marketing. |
| Research | Engage in more geography-specific research to identify localized solutions. Study the role of women, small and marginal farmers, and social classes in food loss and food waste and identify opportunities for and barriers to adopting different practices. Build business cases, cost-benefit analyses of recommended solutions, and effective monitoring and evaluation mechanisms that will guide further research. |
| Access to energy | Improve continuous access to reliable and affordable energy during production and subsequently enable opportunities for storage, transport, and processing of tomatoes. Clean energy solutions may be adopted where feasible and economic to meet region-specific requirements. |

*Source:* WRI India authors.

Building enabling conditions complements efforts toward interventions across the tomato supply chain and at CLPs to reduce FLFW as discussed in Table 5. The Target-Measure-Act approach is important in guiding FLFW reduction by national and subnational governments (Singh et al. 2023). This encourages the government to set targets for FLFW reduction, measure and monitor progress over time, and identify specific interventions to achieve these targets.

Box 4 | **Role of clean energy**

Clean energy, along with other interventions, can be a part of the solution for reducing FLFW. Various clean energy solutions have been identified in secondary literature and stakeholder consultations; however, these require tailoring for local implementation. For instance, evaporative cooling chambers are successful in minimizing losses at the farm (Singh et al. 2022) but their limited capacity is a constraint. A standard evaporative cooling chamber has an average capacity of 6–8 crates. For a crop such as tomatoes, which has multiple harvests, each ranging from 1.2 tonnes to more than 1,000 tonnes (1.2 tonnes would require approximately 50 crates), this poses significant storage challenges. However, evaporative cooling chambers can be leveraged for the storage of surplus produce, or their capacity can be expanded. Solutions such as evaporative cooling chambers and solar refrigerators require initial investment, training in usage, and continuous monitoring for sustainable adoption. Such solutions can therefore be useful for small and marginal farmers on farms in the study region, with handholding support for the initial season to enable adoption.

*Source:* WRI India authors.

Table 5 | **Interventions across the supply chain to reduce FLFW**

| INTERVENTION | DESCRIPTION |
|---|---|
| Develop state strategies | Adopt the Target-Measure-Act approach at sub-national levels to ensure target setting, periodic measurement, and identification of hotspots and solutions. Food loss and food waste (FLFW) reduction to be incorporated as a priority as a part of a State Action Plan on climate change and food waste in respective city plans. |
| Awareness and capacity building | Adopt a gender and socially inclusive approach to create awareness among key stakeholders (e.g., women, small and marginal farmers, agricultural laborers, wholesalers, retailers, civil society organizations) regarding FLFW and its social, economic, and environmental impacts and build their capacity to take appropriate action. |
| Stakeholder coalition | Build or leverage existing stakeholder coalitions to cross-learn and collaborate on key developments to reduce FLFW across the supply chains of tomatoes and other perishables. An example is the Friends of Champions 12.3 India network, where some member organizations are working on innovative solutions such as solar dryers and packaging alternatives to improve shelf life. |
| Create public-private partnerships | Encourage partnerships across the supply chain to meet the growing domestic and international demand. The public and private sectors need to come together to provide funding, policies, improved varieties, infrastructure, and incentives to encourage adoption of improved practices, promotion of tomato varieties suitable for processing, and improved market linkages for small and marginal farmers. |

*Source:* WRI India authors.

In summary, FLFW reduction requires localized solutions that prioritize CLPs but also requires target setting and spearheading action by the government at the sub-national level. It is important for interventions to be evidence-based and gender-inclusive and socially inclusive to achieve equitable and sustainable FLFW reduction across the supply chain.

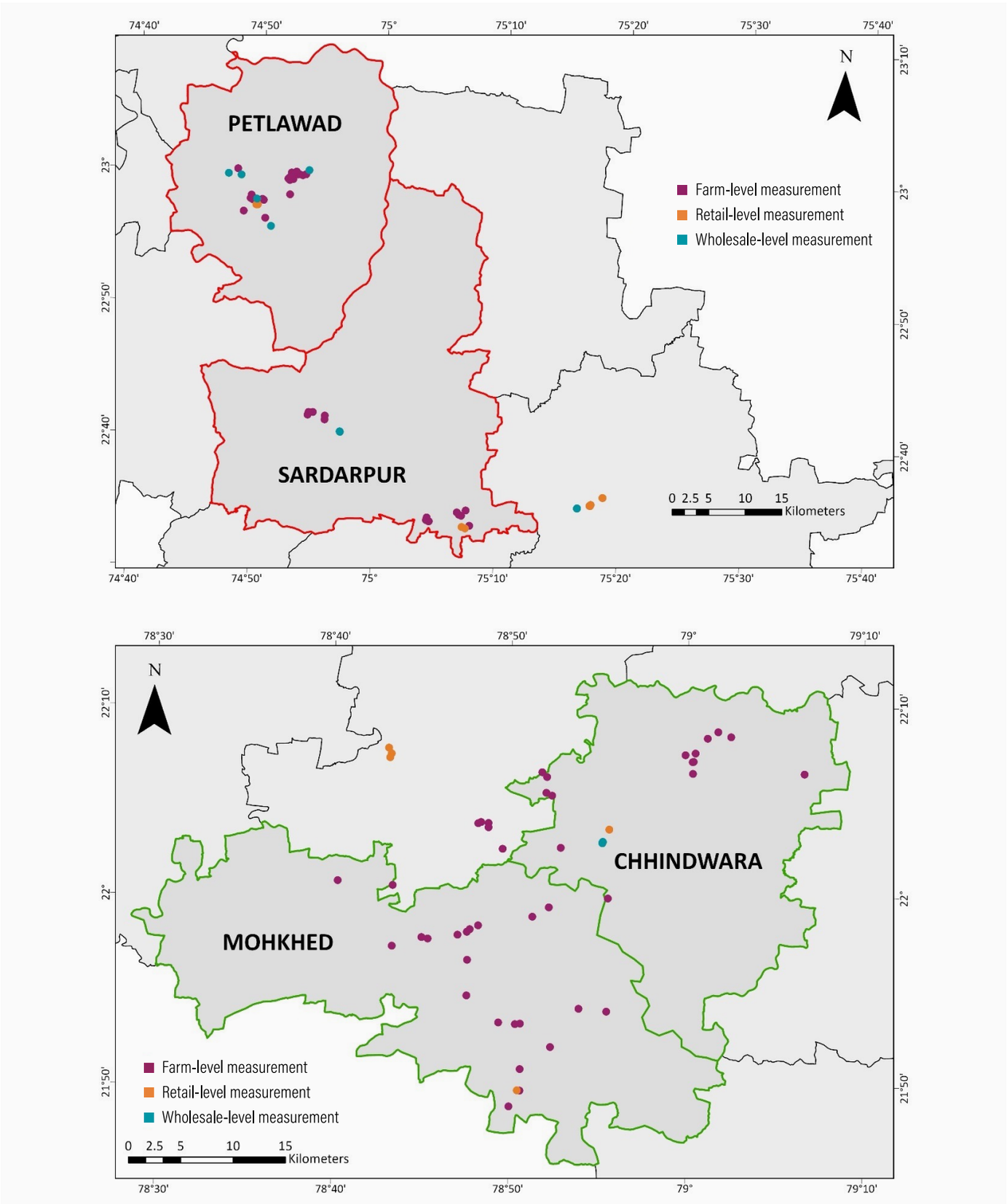
# APPENDIX A. SECONDARY REVIEW OF FLFW IN THE TOMATO SUPPLY CHAIN AND USE OF ENERGY

| GEOGRAPHY | EXTENT OF FOOD LOSS AND FOOD WASTE (FLFW) REPORTED | ROLE OF ENERGY IN REDUCING FLFW | SOURCE |
|---|---|---|---|
| Ethiopia | Losses of 20.5%, 8.6%, 2.9%, and 7.3% were recorded at the producer, wholesaler, retailer, and hotel and café levels, respectively, with a total loss of 39.3%. | Not discussed. | (Abera et al. 2020) |
| | Losses are 3.7% at the producer level, 2.8% at the collector level, 3% at the wholesale level. | Potential for improved cooling systems, forced ventilation evaporative cooling system. | (Emana et al. 2017) |
| Sweden | Total loss during harvesting, sorting, and packaging could vary from 1% to 20%. Losses during transport to wholesaler and handling at warehouse could vary from 1% to 5%. | Evidence that the drying process increased energy demand and reduced climate change impact. | (Bosona & Gebresenbet 2018) |
| Andhra Pradesh, India | Aggregate postharvest food loss and waste from farm to retail totaled between 9.1% to 13.4% of the total tomato quantity, based on the destination food loss and waste and declared methods. | Without adequate cold storage, mature produce quickly deteriorates as bruising, over-ripeness, excessive softening, and biological spoilage cause quality and postharvest losses. | (Boiteau & Pingali 2022) |
| Nigeria | Annual loss is 45-60%. Food loss in production and consumption of about <15%; 30% during processing, packaging, transportation, and distribution; and 20% at the markets. | Potential local solutions with minimal energy cost – Evaporative Cool Chamber, solar dryer, and ColdHubs. | (CBI & SureChain 2021) |
| Colombia | Losses of 11.2% of tomatoes at the farm level, 0.5% at the trader level, and 1.7% wastage at the retailer level. | Not discussed. | (Chaboud & Moustier 2021) |
| Trinidad and Tobago | Quality loss of 5% in farm harvest, 10% in ripening and storage, 2% in transportation and unloading, 4% in the municipal market, 2% at the roadside market, 10% in packing houses, 5% each in retail and wholesale markets.<br>Quantity loss of 7% in harvesting, 8% in packing house operations, and 12% in marketing. | Lack of cold storage facilities, equipment, and unreliable electricity supply hinder cold chain development for fruits and vegetables. | (FAO 2018a) |
| Nigeria, Rwanda, and India | In India, farm level losses range from 7–18%, wholesale level 2–8%, and retail level 1–10%. | Not discussed. | (Kitinoja et al. 2019) |
| Zimbabwe | Postharvest losses range from 1% to 4.9%. | Modern storage (cold room) facilities generated less FLFW as compared to subsistence farmers, who typically use traditional storage facilities. | (Macheka et al. 2018) |
| Jharkhand, India | Losses of 9.86% at the farmer level, 5.23% at the cleaning, grading, weighing, and packaging stage, 3.02% at harvesting and aggregation, and 1.61% during transportation.<br>Losses of 2% at the commission agents (arhtiya) and local trader level, 9.38% at the wholesale level, and 11.25% at the retailer level. | Lack of cold chain, reefer vehicles to maintain quality during transportation. | (NHRDF 2018b) |
| Haryana, India | Losses of 4.80% at harvesting, 2.33% during transportation, and 6.21% at the cleaning, grading, weighing, and packaging stages. | Recommends integrated pack house with facilities, including cold storage and processing. | (NHRDF 2018a) |
| Madhya Pradesh, India | Losses of 6% at the farm level, which included harvesting, grading, packing, and aggregation; losses of 3.4% at local trader and wholesale level. The remaining losses of about 8% occurred at the retailer level. | Recommended establishment of controlled atmosphere storage, evaporative cooling chambers, cold storage, and cold rooms at a cluster level. | (Solidaridad Regional Expertise Centre 2022) |
| Nepal | Total losses of 10% were found from harvesting to marketing: 2% during harvesting, 2% during packaging, 4% during transportation, and 2% during storage. | Not discussed. | (Tiwari et al. 2020) |

| GEOGRAPHY | EXTENT OF FOOD LOSS AND FOOD WASTE (FLFW) REPORTED | ROLE OF ENERGY IN REDUCING FLFW | SOURCE |
|---|---|---|---|
| Fiji | Total commercial postharvest loss was 32.9%. Losses were due to decay (8.8%), failure to ripen (8.9%), cartons insufficiently filled (7.8%), physical damage during transport (0.1%), and over-ripeness (6.4%). | Not discussed. | (Underhill & Kumar 2015) |
| Gujarat, India | Losses during sorting observed to be 8–10%, whereas physical loss in weight observed was 2–3% during transport. | Not discussed. | (Vala et al. 2021) |
| European Union | Of the total fresh tomatoes produced, 49% were lost or wasted. The majority of loss and waste was generated at processing stage (43%) and consumption stage (20%) followed by losses of 8% at retailing and 5% at distribution. | Not discussed . | (Xue et al. 2021) |

*Source:* WRI India authors.

# APPENDIX B. DATA COLLECTION MAPPED IN STUDY BLOCK




*Source:* WRI India authors.

# APPENDIX C. MEASUREMENT TOOL AT FARM LEVEL

| **TOMATO** | Name of data collector: Text | | | |
|---|---|---|---|---|
| Code farm: Numeric | Variety name: Text | | | |
| **QUESTIONS AND OBSERVATIONS** | **AT HARVEST** | | **FARM GATE** | |
| Date | Date format | | | |
| Location of farm | Text (village, block, district) | | | |
| Size of total land owned (in hectares) | Numeric | | | |
| Ownership of land | Man/Woman/Both | | | |
| Social group | Select one - SC/ST/General/OBC | | | |
| Type of ration card | Select one – APL/BPL/Antyodya/none | | | |
| Crops produced | Text | | | |
| Size of tomato farm (in ha) | Numeric | | | |
| Use of irrigation _____(yes/no) | Use of mulching (yes/no) | | Use of staking (yes/no) _____ | |
| Use of drip irrigation – yes/no | Do you have a government (or grid) electricity supply – yes/no | | | |
| How many hours per day is electricity usually available? | numeric (max 24) | | | |
| Stage of harvesting (using the scale) | Numeric | | | |
| Selling to/buyer | Text | | | |
| Name of destination market if known | Text | | | |
| Distance from wholesale market | ____ Numeric _____km | | _____ Numeric _____hours | |
| Sorting - selecting out that produce which will not be sent to the market | Was sorting done at harvest? yes/No | If Yes, estimate waste (discarded) _____% or left on the tree _____% Reason for sorting out: Text | Was sorting done before farm gate sale? yes/no | If Yes, estimate waste (discarded): % Reason for sorting out: Text |
| Size grading: is there any grading into different sizes on the farm? | If Yes, estimate % in each category: numeric Large _____% ; Medium _____% Small _____% Damaged_____% _____ ____% | | If yes, estimate % in each category: numeric Large _____% Medium _____ % Small _____ % Damaged_____% _____ _____% | |
| Does the price offered vary by quality grade? | Describe grading criteria: Text | | If yes, what is the price offered for each quality grade? numeric Highest_____ Middle_____ Lowest _____ | |
| Expected farm gate price: | | | Price offered _____text/drop down of options (by weight? by volume? by number of crates? Price per kg: _____ Numeric | |
| **MEASUREMENT** | **AT HARVEST** | | **FARM GATE (TO BE MEASURED AGAIN IF POSSIBLE)** | |

| | | |
|---|---|---|
| Sample size (this should show as guideline) | 1 plastic crate (approx. 25kg) | 1 plastic crate (approx. 25kg) |
| Time from harvest | ____ Numeric _____ minutes | |
| Time of day | Time format | |
| Temperature | Numeric | |
| Humidity | Numeric | |
| Quality sort for defects, decay, damage<br>(Weight) Ratings from 5 = Extreme defects, decay, or damage; 3 = moderate; 1 = none | Numeric<br>Number of rating 5 _____<br>Number of rating 3 _____<br>Number of rating 1 _____ | Numeric<br>Number of rating 5 _____<br>Number of rating 3 _____<br>Number of rating 1 _____ |
| Weight of the produce with obvious defects; i.e., cracks, sunburn, misshapen, etc. (will still be sold) | Numeric | Numeric |
| Describe defects found (take photos) | Text + photo | Text + photo |
| **MEASUREMENT** | **AT HARVEST** | **FARM GATE (TO BE MEASURED AGAIN IF POSSIBLE)** |
| Weight with decay symptoms | Numeric | Numeric |
| Describe decay found (take photos) | Text + photo | Text + photo |
| Weight damaged; i.e., bruises, cuts, mechanical injury, sap burn, insect damage. | Numeric | Numeric |
| Describe damage found (take photos) | Text + photo | Text + photo |
| Ripeness rating:<br>5 = external full color*, full ripe<br>4 = 3/4 color<br>3 = 1/2 color<br>2 = 1/4 color<br>1= green | Number full color Numeric<br>Number 3/4<br>Number 1/2<br>Number 1/4<br>green | Number full color Numeric<br>Number 3/4<br>Number 1/2<br>Number 1/4<br>green |
| Rate packaging protection<br>Numeric/drop down | _____5 = very strong, protective<br>_____4 = strong, moderately protective<br>_____3 = somewhat strong, protective<br>_____2 = weak, not very protective<br>_____1 = no packaging or very weak, no protection | _____5 = very strong, protective<br>_____4 = strong, moderately protective<br>_____3 = somewhat strong, protective<br>_____2 = weak, not very protective<br>_____1 = no packaging or very weak, no protection |
| Describe packaging or container: type, material, dimensions, cooling efficiency, etc. (take photos) | Text | Use of newspaper/paper in packaging? (Yes/No) |
| Size and/or weight of package or container | Numeric | Numeric |
| Destination of discarded tomatoes | Text | Text |

Harvesting stage maturity scale used

1.  **GREEN** The tomato surface is completely green. The shade of green may vary from light to dark.
2.  **BREAKERS** There is a definite break of color from green to bruised fruit Tannish-yellow, pink or red or 10% or less of the tomato surface.
3.  **TURNING** Tannish-yellow, pink, or red color shows on over 10% but not more than 30% of the tomato surface.
4.  **PINK** Pink or red color shows on over 30% but not more than 90% of the tomato surface.
5.  **LIGHT** RED Pinkish-red or red color shows on over 60% but red color covers not more than 90% of the tomato surface.
6.  **RED** Red means that more than 90% of the tomato surface, in aggregate, is red.

*Source:* WRI India authors.

# APPENDIX D. DATA COLLECTION TOOLS

## Primary data collection tools

**Direct measurement:** Direct measurement uses a measurement device to determine the weight of FLFW. A weighing scale was used to measure FLFW at three stages of the supply chain: farming, wholesale, and retail. An average unit of one crate (approximately 25 kg) was taken for sampling, and the contents sorted into three categories for measurement: marketable (e.g., high quality and fetches best returns), marketable but lower rates (e.g., not highest quality but edible), and inedible (e.g., insect damage, disease, decay, and over-maturity). These grades were determined based on size, color, and shape. A scale for measuring the maturity/ripeness of tomatoes was used to assess the quality of the sampled tomatoes (see Appendix C which includes harvesting stage maturity scale).

**Semi-structured interviews:** Semi-structured interviews with open-ended questions were framed to collect information through conversational and two-way communications. A list of general questions to identify key causes, sources, and potential solutions for FLFW was prepared ahead of time, with scope for additional questions during the interview through probing. Interviews were conducted with targeted stakeholders across the supply chain.

**Focus group discussion (FGD):** FGDs with target stakeholders across the supply chain were conducted to obtain an overview of the tomato supply chain in the region and possible solutions to reduce FLFW. A mixed-group (both men and women participating in the same FGD) discussion approach was adopted; however, it was observed that women were reluctant to speak in the presence of men from the village. To ensure the participation of women stakeholders, gender-disaggregated FGDs were later conducted.

**Observation:** The study team made observations throughout the data collection process in the field using a checklist based on observations of handling practices during the events. The key activities and practices were captured using photographs. The key areas for observation included agricultural practices, food safety measures, hygiene, cultural factors, and the extent of FLFW. Furthermore, the study team captured the role and involvement of small and marginal farmers, agricultural laborers, and women and men at different stages of the supply chain.

# APPENDIX E. SORTING AND GRADING PRACTICE

*Photo credit:* Shweta Lamba/WRI India

# APPENDIX F. TOMATO GRADES

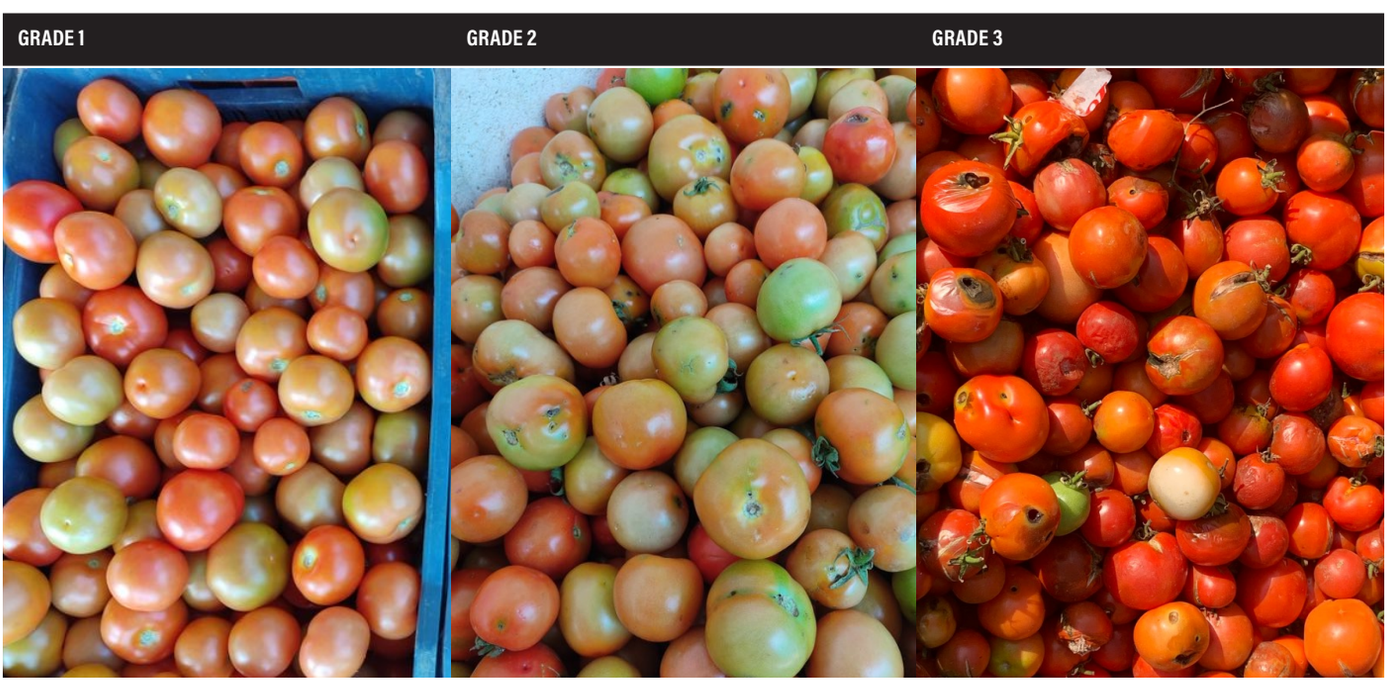



*Photo credit:* Shweta Lamba/WRI India

# LIST OF ABBREVIATIONS

| | |
|---|---|
| **CARD** | Centre for Advanced Research and Development |
| **CLP** | Critical Loss Point |
| **DoAC&FW** | Department of Agriculture, Cooperation and Farmers' Welfare |
| **FGD** | Focus Group Discussion |
| **FLFW** | Food Loss and Food Waste |
| **FLW** | Food Loss and Waste |
| **FLWS** | Food Loss and Waste Accounting and Reporting Standard |
| **FPO** | Farmer Producer Organization |
| **GDP** | Gross Domestic Product |
| **GHG** | Greenhouse Gas |
| **IDI** | In-depth Interview |
| **KG** | Kilogram |
| **MOAFW** | Ministry of Agriculture & Farmers' Welfare |
| **MOFPI** | Ministry of Food Processing Industries |
| **MP** | Madhya Pradesh |
| **NABCONS** | NABARD Consultancy Services |
| **NGO** | Non-governmental Organization |
| **NHB** | National Horticulture Board |
| **ODK** | Open Data Kit |
| **ODOP** | One District One Product |
| **SDG** | Sustainable Development Goal |

# GLOSSARY

Block: Development planning unit within a district. Blocks typically comprise clusters of villages.

Crore: A unit in the Indian numbering system equal to ten million (10,000,000).

District: A district (zila) is an administrative division of an Indian state or territory. In some cases, districts are further subdivided into subdivisions, and in others, they are directly subdivided into tehsils or talukas.

Evaporative cooling chambers are a simple and inexpensive way to keep vegetables fresh without the use of electricity. Evaporation of water from the surface removes heat, creating a cooling effect that can improve the shelf life of vegetables.

Food loss: Food loss is the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in chain segments, excluding retail, food service providers, and consumers. This is also known as postharvest loss.

Food supply chain: The food supply chain consists of the following segments: agricultural production and harvest, slaughter, or catch; postharvest, slaughter, and catch operations; storage; transportation; processing; wholesale and retail; household consumption; and food services.

Food waste: Food waste is the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food services, and consumers.

Kharif season: The agricultural season in India that begins with the onset of the monsoon and ends with the beginning of winter. The crops are sown around June and harvested between September and October.

Late Kharif Season: This is a subcategory of the Kharif season in India, where crops are sown later in the monsoon period, typically around August, and harvested later in the year, often extending into December and January.

Rabi season: The agricultural season in India that begins in winter and ends in the spring. Crops are sown around October and harvested between April and May.

## ENDNOTE

i. Average exchange rate in 2023: 82.298 Indian rupees.

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# ABOUT WRI INDIA

WRI India, an independent charity legally registered as the India Resources Trust, provides objective information and practical proposals to foster environmentally sound and socially equitable development. Our work focuses on building sustainable and liveable cities and working towards a low carbon economy. Through research, analysis, and recommendations, WRI India puts ideas into action to build transformative solutions to protect the earth, promote livelihoods, and enhance human well-being. We are inspired by and associated with World Resources Institute (WRI), a global research organization. Know more: www.wri-india.org

**Our challenge**

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

**Our vision**

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

**Our approach**

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to inform government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.