Supply-side Problems in Food Loss and Waste

Issues in Mitigation through Cold Chain

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The food systems approach proposes reducing food loss and waste as a potential solution to achieve food and nutritional security. This is formalised in the Sustainable Development Goals of the United Nations. Despite the issue receiving such ubiquitous recognition, systematic efforts to measure and address FLW are absent in India. Our calculations show that one-sixth of agricultural production, accounting for one-tenth of the gross value added in agriculture, is lost. An efficient cold chain can reduce these losses substantially. However, the concept of an integrated cold chain is still in its infancy in the country, with greater emphasis being placed on single commodity cold storage. Promotional policies like the negotiable warehousing receipt system and the Agriculture Infrastructure Fund have not made an impact. Cold chain development will remain exclusive to export-oriented farmers and traders unless policies are introduced to enable small farmers, farmer producer organisations, and self-help groups to harness its benefits. Relevant start-up innovations can be scaled up through public support. A new institutional mechanism is needed to address the issue of FLW and achieve India's SDGs.

This paper is based on a larger study conducted by Chandra S R Nuthalapati for the Ministry of Agriculture and Farmers Welfare, New Delhi.

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The rise of the food systems approach to development issues in food and agriculture has been altering the ways and means of achieving food and nutrition security—an issue that has garnered immediate policy attention in the contemporary world (Pingali et al 2019). The Sustainable Development Goal (SDG) 12.3 calls for a commitment to halve food waste at the retail and consumer level and to reduce food loss across supply chains. As the food systems approach focuses on all the actors in the chain rather than only on production sites, the opportunity for increasing the supply of food is extended not only by spurring production but also by reducing losses through the entire chain and smoothening the production cycle by processing for longer preservation (Cattaneo et al 2021; FAO 2020). Loss reduction can have pronounced positive impacts on food security and the environment in low-income countries (Kuiper and Cui 2021).

Globally, around 14% of the food produced is lost between the post-harvest stage till, but excluding, the retail stage (FAO 2019). Developing countries, despite having high levels of hunger and starvation, account for 44% of the 1.3 billion tonnes of global food loss. While this results in direct welfare losses by reducing the food available for the needy, it has adverse environmental consequences too. The carbon footprint of food produced and not consumed due to loss or waste is estimated to be 3.3 gigatonnes of carbon dioxide equivalent (GoI 2018).

In India, studies have noted that reducing food loss and waste (FLW) through efficient logistics and cold chain can enhance farmers' incomes by leveraging lucrative markets in India and abroad (Chand 2017; Dev 2019). Possible pathways for realising higher farmer incomes through loss reduction include leveraging faraway markets by extending products' shelf life, diversifying to high-value crops, and enlarging buyer bases. For the consumer public, it helps normalise the price of fruits and vegetables temporally and geographically. A well-connected cold chain improves the availability of diversified foods, makes them affordable and accessible, and, most importantly, creates growth and employment opportunities through backward integration, including in the catalysed food processing sector (Chintada et al 2017). Theoretically, food loss reduction can have ambiguous effects on farmer producers and has to be assessed empirically (Rutten 2013). Farmers stand to gain from loss reduction in developing countries like India, as substantial losses are occurring in the midstream of the food chain in parallel with hunger and malnourishment.

Solutions to loss reduction in developing countries should take into consideration farmers' perspectives on education, harvest techniques, storage and cooling facilities, and social infrastructure (Ishangulyyev et al 2019). Improvements in the cold chain from production to consumption drive down food losses and improve welfare (Delgado et al 2021). Evidence from India, although scanty, demonstrates this. A large number of relatively small farmers participate in and directly benefit from cold storage by accessing better storage conditions for their seeds and selling directly after harvest (Minten et al 2014). The case studies from farmer producer companies (FPCs) in Haryana demonstrate the need for cold chain solutions to enable farmers to sell fruits and vegetables in new and rewarding markets (MPEnsystems and Shakti 2019). The lacklustre development of the food processing industry is attributed to infrastructural gaps in the integration of cold chains and their lopsided development (Singhal and Saxena 2018). The fruits supply chain at Azadpur *mandi,* one of the largest markets in the country, is handicapped due to the lack of cold chain infrastructure (Negi and Anand 2019). Pre-cooling and transport refrigeration can reduce food loss by 32% in open trucks, 9% in reefer trucks, and carbon dioxide equivalent emissions by 16% (Sodhi et al 2016).

This paper is organised as follows. The next section examines the loss estimations for downward bias, followed by statewise disaggregated loss estimates. The paper then examines welfare gains with loss reduction. The following section analyses the status of cold chain infrastructure in the country and reveals its lopsided nature. And finally, it critically analyses the policy framework vis-à-vis the evolution of the cold chain industry and concludes with policy suggestions.

Is There a Downward Bias in Estimating Food Losses?

Estimates of the actual magnitude of food losses in India vary widely between studies. Some argue that the losses are exaggerated and that most of the food produced is consumed with negligible losses. Official agencies seem to take this position, and the oft-cited Indian Council of Agricultural Research-Central Institute of Post-Harvest Engineering and Technology (ICAR-CIPHET) study by Jha et al (2015) legitimises this. However, the losses are much larger and need urgent action.

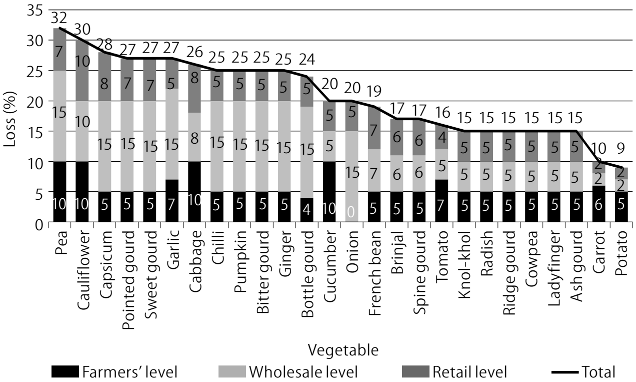
This paper attempts to estimate the losses using the widely cited ICAR-CIPHET study and builds alternative loss estimates (Table 1). Our estimates, using ICAR-CIPHET loss percentages, show that ₹1.68 lakh crore of food is wasted, which forms 5.2% of the gross value added (GVA) by agriculture as a whole and 1.52% of the fruits and vegetables in 2017–18. However, the ICAR-CIPHET study suffers from methodological errors due to which it cannot determine losses in the food value chain beyond the farm level. Aggregated self-reported measures usually underestimate losses (Delgado et al 2021), and this might be one reason for the lower estimates of their study. Further, their study does not track the same consignment of agricultural produce as it moves from the field (at the time of harvest) to the consumer. The CIPHET conducted this survey at the behest of the central government ministry

Table 1: Estimates of the Monetary Value of Harvest and Post-harvest Losses for Different Crops

Sr No	Crop	Production (million tonnes)	Price (₹/tonne)	As per Loss Estimates in Jha et al (2015): Overall Total Loss (%)*	As per Loss Estimates in Jha et al (2015): Value of the Losses (₹ crore)	Monetary Value of Loss (₹ crore) as per Food and Agriculture Organization (2018)#
Cereals					24,941	73,093
1	Paddy	112.76	19,381	5.53	12,085	33,655
2	Wheat	99.87	19,336	4.93	9,520	29,159
3	Maize	28.75	15,505	4.65	2,073	6,865
4	Pearl millet	9.21	14,381	5.23	693	1,987
5	Sorghum	4.8	19,817	5.99	570	1,427
Pulses					6,902	13,457
6	Pigeon pea	4.3	45,483	6.36	1,244	2,934
7	Chickpea	11.23	46,700	8.41	4,411	7,867
8	Black gram	3.56	47,319	7.07	1,191	2,527
9	Green gram	0.16	53,945	6.60	57	129
Oilseeds					9,070	9,493
10	Mustard	8.43	38,693	5.54	1,807	2,120
11	Cottonseed	11.62	33,802	3.08	1,210	2,475
12	Soybean	10.93	33,789	9.96	3,678	2,327
13	Safflower	0.06	28,979	3.24	6	12
14	Sunflower	0.22	32,442	5.26	38	46
15	Groundnut	9.25	41,808	6.03	2,332	2,514
Fruits					25,083	75,295
16	Apple	2.33	78,850	10.39	1,909	5,328
17	Banana	30.81	19,794	7.76	4,732	16,771
18	Citrus**	11.52	33,475	9.69	3,737	11,068
19	Grapes	2.92	57,930	8.63	1,460	4,635
20	Guava	4.05	28,598	15.88	1,839	3,127
21	Mango	21.82	51,645	9.16	10,322	30,426
22	Papaya	5.99	18,563	6.7	745	3,002
23	Sapota	1.18	29,455	9.73	338	938
Vegetables					17,374	54,615
24	Cabbage	9.04	10,843	9.37	918	2,647
25	Cauliflower	8.67	16,848	9.56	1,396	3,944
26	Green pea	5.42	37,555	7.45	1,516	5,699
27	Mushroom	0.49	1,08,493	9.51	506	1,329
28	Onion	23.26	18,857	8.2	3,597	11,974
29	Potato	51.31	13,843	7.32	5,199	19,036
30	Tomato	19.76	15,267	12.44	3,753	8,387
31	Tapioca	4.95	21,540	4.58	488	1,599
Plantation crops and spices					31,033	36,059
32	Areca nut	0.83	1,85,504	4.91	759	924
33	Black pepper	0.07	3,51,404	1.18	27	148
34	Cashew nut	0.82	3,63,514	4.17	1,238	1,788
35	Dry chillies	2.15	84,154	6.51	1,177	1,086
36	Coconut	16.41	2,74,455	4.77	21,487	27,023
37	Coriander	0.71	31,893	5.87	133	136
38	Sugar cane	379.9	1,941	7.89	5,818	4,424
39	Turmeric	1.13	78,260	4.44	393	531
Livestock					53,422	53,422
40	Egg	95.2	2,692	7.2	1,843	1,843
41	Fish	12.6	1,38,222	7.9	13,735	13,735
42	Meat	7.7	8,42,109	4.7	30,447	30,447
43	Milk	176.4	45,600	0.9	7,398	7,398
Total					1,67,825	3,15,434

* See Jha et al (2015).
** Includes lemon, sweet lime (mosambi), and orange.
\# Authors' calculations from the Food and Agriculture Organization database.
(1) Figures for production are for 2017–18 and prices are for 2018.
(2) Wholesale prices were used for loss value estimation.
Source: Compiled data from GoI (2018, 2019, 2020).

Figure 1: Food Loss Estimates in Vegetables in Remote Areas by Small Farmers' Agribusiness Consortium (%)



Source: GoI (2017).

and did not have the wherewithal to conceptualise and organise field surveys.

These estimates also do not corroborate with other studies. For example, another governmental agency called Small Farmers' Agribusiness Consortium (SFAC) conducted field surveys and found that 43% of all the losses happen in the midstream of the value chain from farmer to consumer, with the total losses ranging from 9% to 32% in vegetables (Figure 1). Our calculations from the Food and Agriculture Organization (FAO) database show similar findings—around 45% losses in vegetables in the midstream of value chains (Table 2). While

Table 2: Crop-wise Estimates of Edible Loss and Waste in Different Stages of Food Supply Chain

Crops	Production Level	Handling and Storage Level	Processing and Packaging Level	Distribution Level	Consumption Level	Total
Marine fish and other	8.2	6.0	0.0	14.2	1.9	30.2
Lemons and limes	13.6	6.9	1.9	6.1	0.9	29.5
Apples	13.6	6.9	0.1	7.9	0.4	29.0
Peas	13.6	6.9	0.0	6.1	1.4	28.0
Oranges	13.6	6.9	0.0	7.0	0.4	27.9
Tomatoes	13.6	6.9	0.0	6.9	0.4	27.8
Bananas	13.6	6.9	0.0	6.0	1.1	27.5
Grapes	13.6	6.9	0.0	6.5	0.4	27.4
Onions	13.6	6.9	0.0	6.4	0.4	27.3
Potatoes	13.6	6.9	0.0	4.6	1.7	26.8
Pelagic fish	8.2	6.0	0.0	6.6	0.5	21.3
Eggs	3.5	6.0	0.0	8.4	0.1	18.1
Milk-excluding butter	3.5	6.0	0.0	7.7	0.2	17.5
Pig meat	5.1	0.3	0.0	7.0	4.0	16.4
Mutton and goat meat	5.1	0.3	0.0	6.8	3.9	16.1
Rice	6.4	7.0	0.0	1.8	0.2	15.4
Maize	6.4	7.0	0.0	0.9	1.1	15.4
Wheat	6.4	7.0	0.0	1.4	0.3	15.1
Sorghum	6.4	7.0	0.0	1.4	0.3	15.0
Poultry meat	5.1	0.3	0.0	6.1	3.5	14.9
Bovine meat	5.1	0.3	0.0	3.8	2.2	11.3
Butter, ghee	5.1	0.3	0.0	5.9	0.0	11.3
Sunflower seed	1.8	2.9	1.8	0.0	0.2	6.7
Groundnuts	1.8	2.9	1.6	0.0	0.2	6.5
Rapeseed and mustard	1.8	2.9	1.5	0.1	0.2	6.5
Soya beans	1.8	2.9	1.2	0.2	0.2	6.3
Cottonseed	1.8	2.9	1.4	0.0	0.2	6.3

Source: Authors' calculations based on a data set from the FAO (2019).

these studies report substantial food losses in the handling, storage, and transportation of fruits and vegetables, the ICAR-CIPHET study shows negligible food losses at this level. This does not lend much credibility to the findings of the official losses report.

The Committee on Doubling Farmers' Income questioned the estimates of the ICAR-CIPHET and felt that the losses were too low to be representative of far-flung areas in the country. On the contrary, the committee regarded the SFAC's estimates of 9%–32% losses in vegetables to be true for most parts of the country (GoI 2017). The committee also pointed out a unique problem in India: the proportion of unsold produce with farmers—especially of fruits and vegetables that are stored for long periods in anticipation of marketing avenues that may emerge at a later point—that cannot be added directly to the proportion of FLW.

Therefore, alternate estimates have been drawn from the FAO database to arrive at the food losses in the value chain (Table 1). These estimates are lower than those of the SFAC but higher than that of the ICAR-CIPHET study—food losses in the crop sector account for 8.2% of the GVA in agriculture, and fruits and vegetables constitute 50% of the losses in the crop sector. If we add food loss in livestock and dairy, the total food loss in the country comes to ₹3.15 lakh crore and 10% of the GVA in agriculture. This size of FLW—amounting to $45 billion and 1.74% of the gross domestic product—is huge by any standard and warrants urgent policy action. This is apart from the loss of 68 million tonnes of food at the household level and approximately 29 million tonnes of wastage at the food services stage, as given in the food waste index of the United Nations Environment Programme (UNEP 2021). It is also important to note that food loss and waste are dynamic concepts, and the numbers may be higher than the estimates and may go up as households prefer food with higher sanitary and safety standards when their income increases (Barrera and Hertel 2021; Cattaneo et al 2021).

It is worth mentioning here that losses in fruits and vegetables are disproportionately higher (50%) than their share in the net sown area (12%). On the other hand, food inflation in recent times is tied to the higher prices of these foods, which is a consequence of their supply shortages (Patnaik and Hatekar 2019). Therefore, this presents a good opportunity to ramp up cold chain facilities to make food available as per the changing consumer food basket.

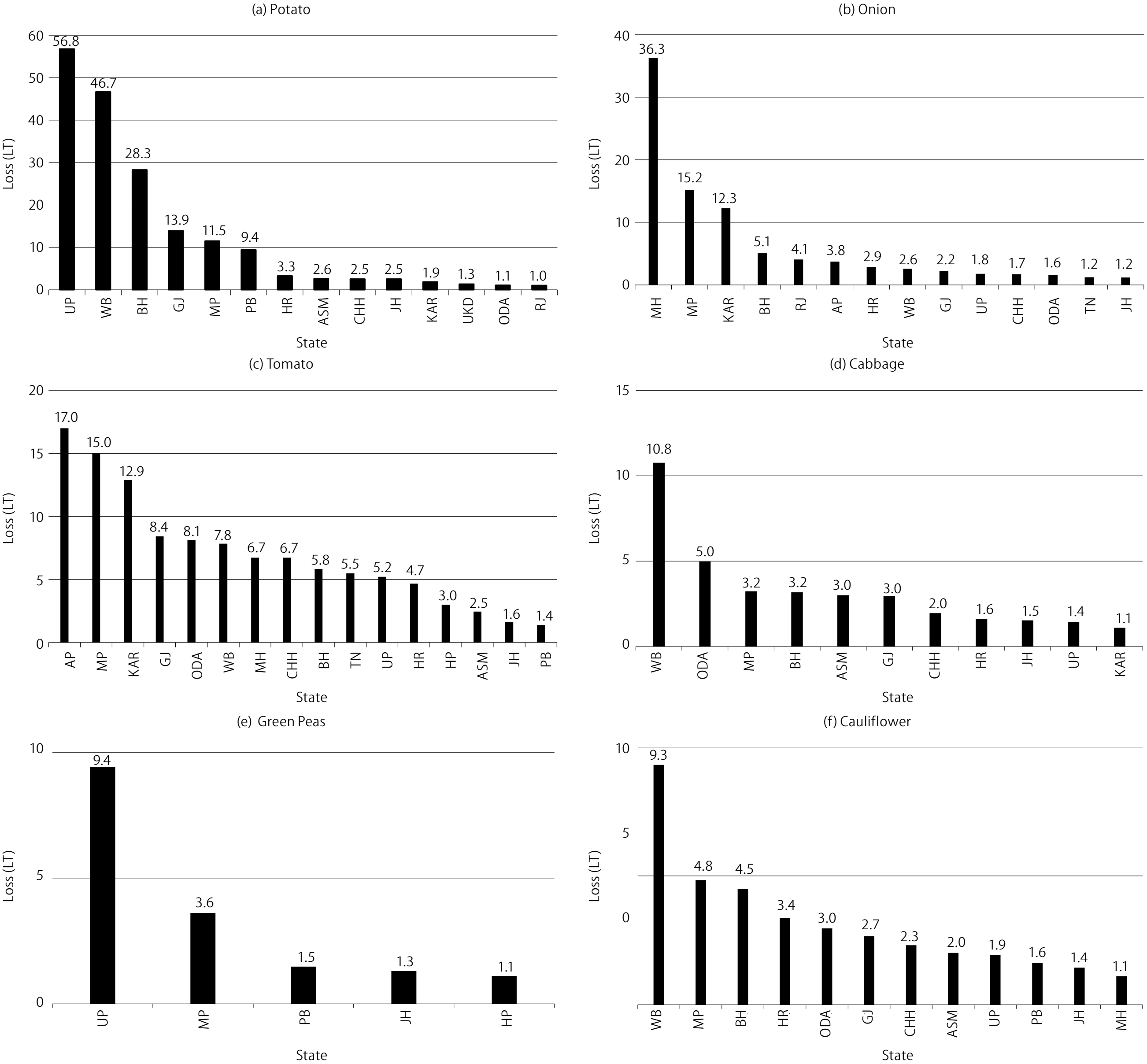
Food Loss and Waste across States and Crops

FLW estimations across various states show the enormity of this problem despite using conservative loss proportions in the ICAR-CIPHET study. The states with the highest losses for vegetables, fruits, and food crops are shown in Figures 2, 3, and 4 (pp 54–56), respectively. These figures reveal that the losses are the highest among vegetables, followed by fruits and food crops.

The losses in vegetables are found to be highest in Uttar Pradesh (UP), Madhya Pradesh (MP), West Bengal, Maharashtra, Bihar, and Andhra Pradesh (AP) (Figure 2). Further, the losses

Figure 2: Losses in Vegetables across States in India, 2018

(lakh tonnes)



LT = lakh tonnes, UP = Uttar Pradesh, WB = West Bengal, BH = Bihar, GJ = Gujarat, MP = Madhya Pradesh, PB = Punjab, HR = Haryana, ASM = Assam, AP = Andhra Pradesh, CHH = Chhattisgarh, JH = Jharkhand, KAR = Karnataka, UKD = Uttarakhand, ODA = Odisha, RJ = Rajasthan, TN = Tamil Nadu, HP = Himachal Pradesh, and MH = Maharashtra.
Source: Calculated by the authors using the loss estimates of Jha et al (2015) and crop production figures taken from GoI (2018).

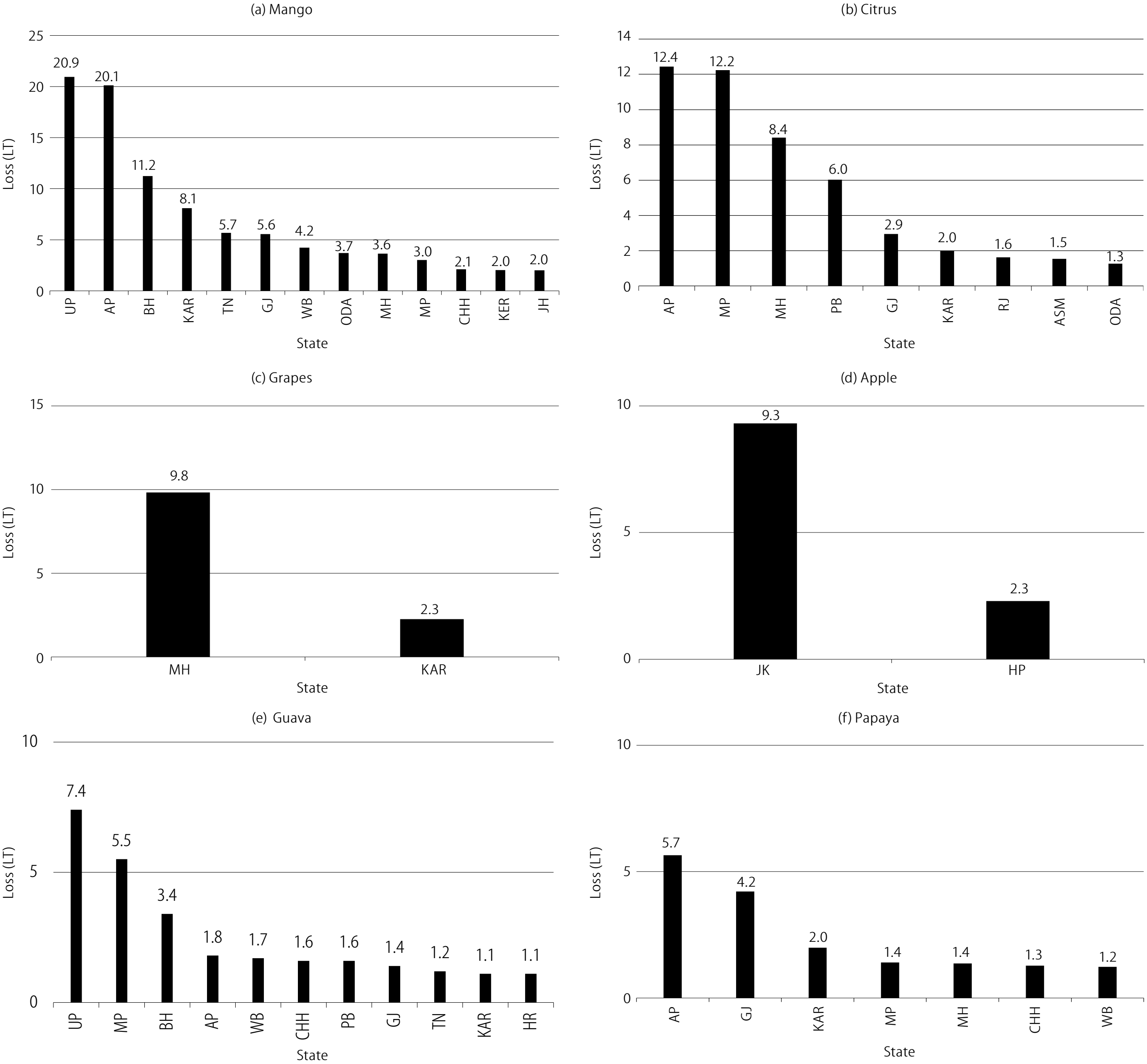
are larger in potatoes followed by onions, tomatoes, cabbages, green peas, and cauliflowers. The losses (in lakh tonnes) are highest in UP (57), West Bengal (47), and Bihar (28) for potatoes; in Maharashtra (36.3), and MP (15.2) for onions; in AP (17), and MP (15) for tomatoes; in West Bengal (11), and Odisha (5) for cabbages; in UP (9.4), and MP (3.6) for green peas, and in West Bengal (9.3), and MP (4.8) for cauliflower.

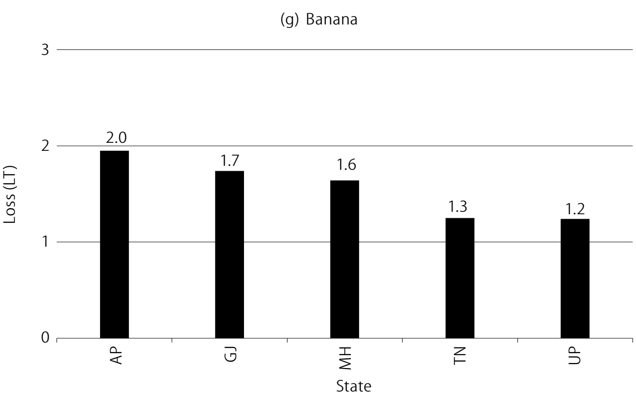
Substantial losses in fruits occur in AP, UP, MP, Bihar, Maharashtra, and Jammu and Kashmir (J&K) (Figure 3). The magnitude of food loss is highest in mangoes followed by citrus fruits, grapes, apples, guavas, papayas, and bananas. While (in lakh tonnes) UP (21), AP (20), and Bihar (11) have the highest losses in mangoes, citrus fruits are wasted the most in AP (12) and MP (12). Other leading states with major losses include Maharashtra for grapes (10), J&K for apples (9.3), UP for guavas (7.4), and AP for papayas (6) and bananas (2).

Paradoxically, more food is wasted in minor crops like millets and pulses than the most cultivated crops, rice, and wheat in India (Figure 4). This indicates the lackadaisical manner in which these crops are treated. In other words, post-harvest care, including storage facilities, is reserved for rice and wheat, leading to minor millets and pulses being relatively neglected. Therefore, improving post-harvest handling can save a lot of these crops. States with large food losses in the case of food crops are UP, Maharashtra, Rajasthan, and MP. Substantial losses are found in the case of pearl millets in (in lakh tonnes) Rajasthan (11); sorghum in Maharashtra (10) and Karnataka (7); wheat in UP (8); chickpeas in Maharashtra (6)

Figure 3: Losses in Fruits across States in India, 2018

(lakh tonnes)





LT = lakh tonnes, UP = Uttar Pradesh, WB = West Bengal, BH = Bihar, GJ = Gujarat, MP = Madhya Pradesh, PB = Punjab, HR = Haryana, ASM = Assam, AP = Andhra Pradesh, CHH = Chhattisgarh, JH = Jharkhand, KAR = Karnataka, KER= Kerala, ODA = Odisha, RJ = Rajasthan, TN = Tamil Nadu, HP = Himachal Pradesh, and MH = Maharashtra.
Source: Calculated by the authors using the loss estimates of Jha et al (2015) and crop production figures taken from GoI (2018).

and Rajasthan (5); pigeon peas in MP (5); and rice in West Bengal (4), UP (4), and Punjab (3).

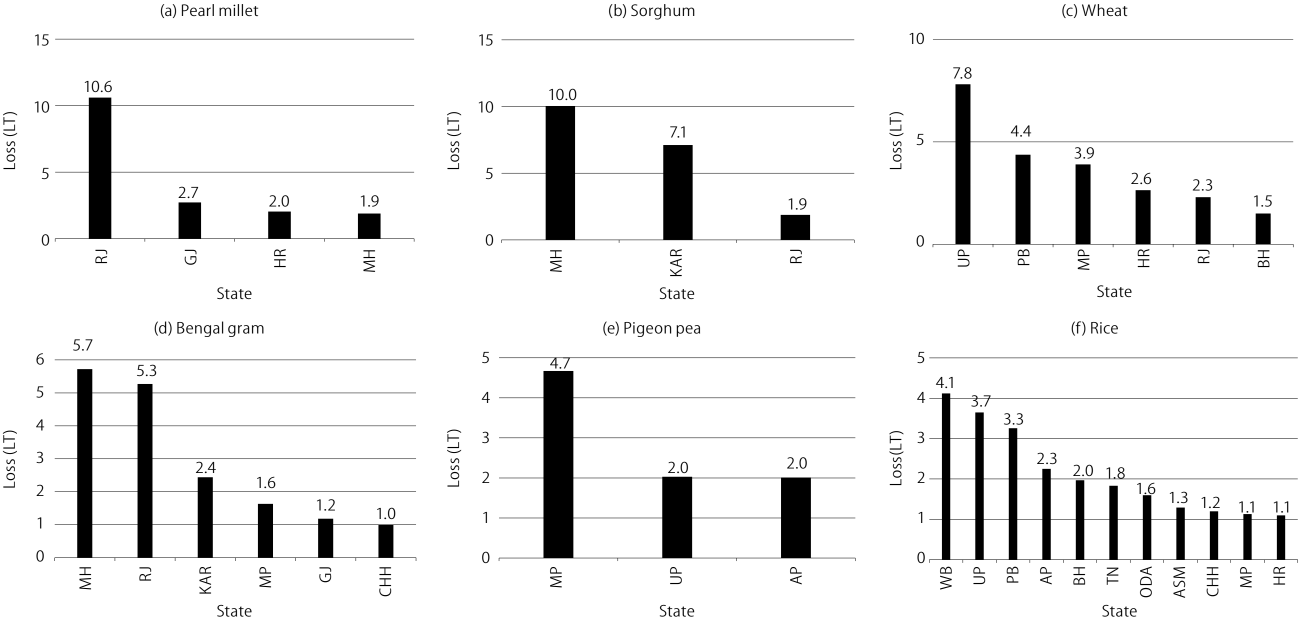
Does Loss Reduction Improve Welfare Gains?

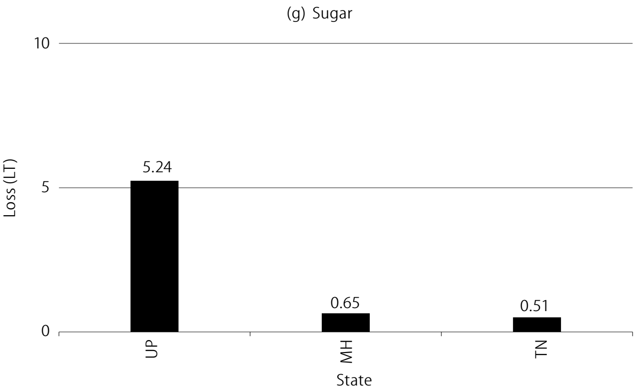
The main question that arises in the debate on FLW is whether there can be net welfare gains if the losses are reduced. Theoretically, the net gains are ambiguous and depend on the kind of loss (Rutten 2013). The outcomes will be very different for developing countries that have supply-driven food loss and developed countries that have demand-driven food waste. In developing countries such as India, promoting improved growing and post-harvest technologies and practices might prove effective since there are people to consume these foods, especially since the consumption of fruits and vegetables in the country is quite low relative to the recommended levels.

There are direct and indirect causes of FLW. The former comprises the direct actions (or lack thereof) of individual

Figure 4: Losses among Food Crops across States in India, 2018

(lakh tonnes)



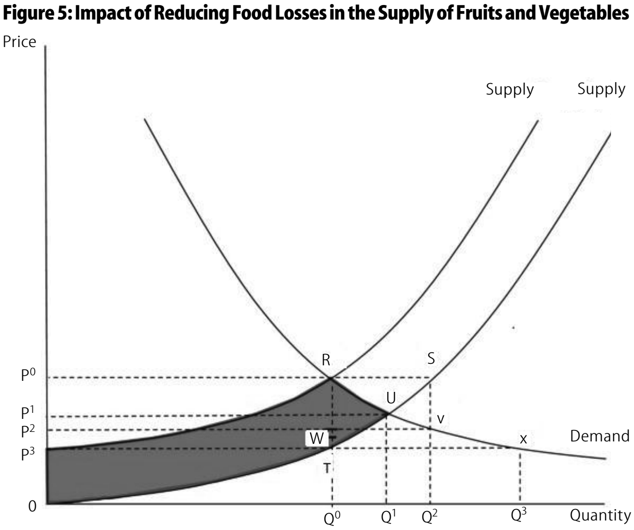


Only states where loss in sugar production is more than 0.50 lakh tonnes are considered. For other crops, it is 1.0 lakh tonnes and more.

LT = lakh tonnes, UP = Uttar Pradesh, WB = West Bengal, BH = Bihar, GJ = Gujarat, MP = Madhya Pradesh, PB = Punjab, HR = Haryana, ASM = Assam, AP = Andhra Pradesh, CHH = Chhattisgarh, KAR = Karnataka, ODA = Odisha, RJ = Rajasthan, TN = Tamil Nadu, and MH = Maharashtra.

Source: Calculated by the authors using the loss estimates of Jha et al (2015) and crop production figures taken from GoI (2018).

Figure 5: Impact of Reducing Food Losses in the Supply of Fruits and Vegetables



Source: Rutten (2013).

actors in the food value chain that lead to FLW while the latter refers to the economic, cultural, and political environment of the food system in which these actors operate. Typically, small households and high-income households waste more food because the amount of food they buy and prepare is usually more than what they can consume, especially when they have cooling infrastructure. In some cultural settings, food may function as a symbol of prosperity.

The capacity to enhance food and nutrition security through food loss reduction depends on the loss reduction setting, the stage of the value chain, and the location of food-insecure groups. Studies show that loss reduction in fruit and vegetable value chains has the potential to improve food security, while reducing loss in animal products helps in cutting down greenhouse gas emissions (Kuiper and Cui 2021). Loss reduction does not necessarily lead to greater food security and may harm farmer producers as they can also lead to lower prices. However, the net buyers of food stand to gain from these lower food prices. Food recovery and redistribution programmes and better on-farm storage structures can improve the food security status of farming households. The likelihood that a reduction in losses or waste will improve the food security status of groups located far away from the point of reduction is small (FAO 2019).

When losses are reduced, the socially optimal supply curve on the right side of the initial supply curve is possible, allowing higher production at the given price or the original production at a lower price (Figure 5). As a result, there can be an increase in the overall welfare gain (P^3RUO), which equals the sum of the change in the producer and consumer surplus as shown by Rutten (2013). However, it is simplistic to limit the analysis to one stage of the value chain, as reducing loss in one stage of the food chain may trigger losses in other nodes (Bellemare et al 2017). The net effect will depend on the degree of price adjustments, which is contingent on the price elasticity of supply and demand and the price transmissions from one stage of the food chain to another (Cattaneo et al 2021). Environmental issues must also be factored into the scenario to understand the total impact.

How much food can be saved and how many people can be fed through loss reduction? We assume a loss reduction of one-third in the medium term, though SDG 12.3 states a commitment to reduce FLW by 50% by 2030. An effort was made to calculate the number of additional people who can likely be fed with a food savings of one-third loss reduction by taking the per capita consumption of these foods from the National Sample Survey Office (NSSO) and the conservative loss estimates of ICAR-CIPHET (Table 3). Approximately 165 lakh tonnes vegetables, 78 lakh tonnes fruits, and 45 lakh tonnes foodgrains could be spared for human consumption. A synthesis of this is provided in Table 3. By reducing food losses by only one-third, large quantities of food can be saved—potato (62 lakh tonnes), tomato (38 lakh tonnes), mango (32 lakh tonnes), onion (31 lakh tonnes), citruses (17 lakh tonnes), cabbage (13 lakh tonnes), and guava (11 lakh tonnes).

As shown in Table 3, driving down losses by one-third can feed a large number of people. Substantial gains are possible in the case of loss reduction in mango, papaya, guava, sorghum, green peas, and grapes. It is important to mention here that the per capita consumption of these commodities is very low and is likely to go up with an increase in income. Nevertheless, the NSSO data provides a benchmark to assess the number of people who can be fed with the savings generated by the reductions in food losses.

What Ails the Cold Chain?

The concept of an integrated cold chain is only a decade old in the country and is relatively new. Until recently, cold chains were considered synonymous with cold storage. In 1990, India's cold storage capacity was only 7 million tonnes. These cold storages stored farm production at production sites without any regard for requirements at other nodes of the food value chain. Gradually, the policy focus shifted to recognising the need for cold storage at market hubs to store the supply to retailers. The establishment of the National Centre for Cold-chain Development (NCCD) in 2013 by the Ministry of Agriculture marked the dawn of establishing an integrated cold chain from harvests through pre-cooling units to refrigerated transport, pack houses, market hub cold storages, and so on.

Three-fourths of the cold storage in India is meant for horticultural produce, while the rest is for livestock products. Most cold storage units (72%) are single-commodity units. Of the horticultural units, 68% are being used to store potatoes, mainly through obsolete technologies such as bunker coil systems. Only 40% of them have sorting, grading, and pack house facilities (NHB 2014). Two-thirds of the cold storage solutions are located at the farmgate near production sites, and the need for market hub cold storage is catching up. There is a need to develop modern cold storage solutions with additional services as they can propel production and profitability as shown in Bihar by Minten et al (2014). The development of cold storage units with a higher capacity than the national average is shown to be associated with a higher potato production in West Bengal.

The number and capacity of cold storage units have increased across all Indian states (Table 4). Undivided AP is an exception in this regard—it witnessed an absolute reduction in capacity during this period, 2015–20. The total cold storage capacity created grew at around 1 million tonnes per year between 2015

Table 3: Loss Reduction by One-third, Crop-wise Total Savings, and the Number of Additional People That Can be Fed

Crops	Total Savings per Annum Lakh Tonnes (33.3%)	Per Capita Consumption Kilogram/Annum	Number of Additional People That Can be Fed/ Annum Crore
Mango	31.65	3.20	98.92
Papaya	6.51	1.09	59.75
Guava	10.55	1.58	66.79
Sorghum	6.75	10.17	6.64
Green peas	6.62	1.98	33.43
Citrus	17.03	6.84	24.89
Grapes	4.15	1.57	26.45
Tomato	38.03	16.11	23.61
Chickpea	6.18	2.65	23.32
Cabbage	13.39	7.68	17.44
Onion	31.23	19.54	15.98
Cauliflower	13.53	8.79	15.39
Pearl millet	6.24	9.80	6.37
Potato	61.77	34.33	17.99
Pigeon pea	3.29	6.95	4.74
Apple	3.99	4.77	8.37
Banana	3.91	12.91	3.03
Sugar	2.47	21.29	1.16
Rice	7.80	160.43	0.49
Wheat	8.02	156.73	0.51

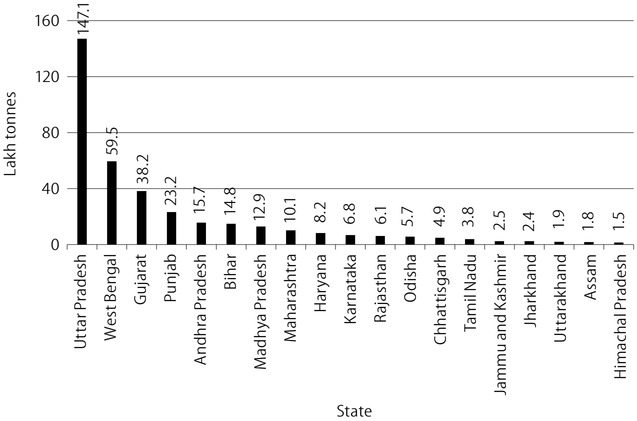
Source: (1) Per capita consumption figures are taken from NSSO (2012). (2) Loss estimates are calculated using Jha et al (2015). (3) Crop production figures are taken from GoI (2018).

Table 4: Statewise Cold Storage Capacity, 2015–20

State	2015		2020		Change in 2020–15 (%)	
	No	Capacity (lakh tonnes)	No	Capacity (lakh tonnes)	No	Capacity
Andhra Pradesh	404	15.8	405	15.7	0.3	-0.6
Assam	34	1.2	39	1.8	14.7	48.8
Bihar	303	14.1	311	14.8	2.6	5.2
Chhattisgarh	89	4.3	99	4.9	11.2	13.9
Delhi	97	1.3	97	1.3	0.0	0.0
Goa	29	0.1	29	0.1	0.0	0.0
Gujarat	560	20.3	969	38.2	73.0	88.2
Haryana	295	5.9	359	8.2	21.7	39.3
Himachal Pradesh	30	0.4	76	1.5	153.3	280.7
Jammu and Kashmir	28	0.6	69	2.5	146.4	286.3
Jharkhand	55	2.2	58	2.4	5.5	8.9
Karnataka	189	5.3	223	6.8	18.0	28.5
Kerala	197	0.8	199	0.8	1.0	4.3
Madhya Pradesh	260	11.0	302	12.9	16.2	17.9
Maharashtra	540	7.1	619	10.1	14.6	43.0
Odisha	111	3.3	179	5.7	61.3	75.4
Punjab	606	20.0	697	23.2	15.0	15.5
Rajasthan	154	4.8	180	6.1	16.9	27.5
Tamil Nadu	163	3.0	183	3.8	12.3	29.4
Tripura	13	0.4	14	0.5	7.7	18.3
Uttar Pradesh	2,176	136.3	2,406	147.1	10.6	7.9
Uttarakhand	28	0.8	55	1.9	96.4	137.5
West Bengal	502	59.0	514	59.5	2.4	0.8
Total	6,863	317.8	8,082	369.7	17.8	16.3

Data for 2020 ends in September.
Source: Compiled from GoI (2015) and Ministry of Agriculture and Farmers Welfare (2020).

Figure 6: Statewise Cold Storage Capacity, 2020



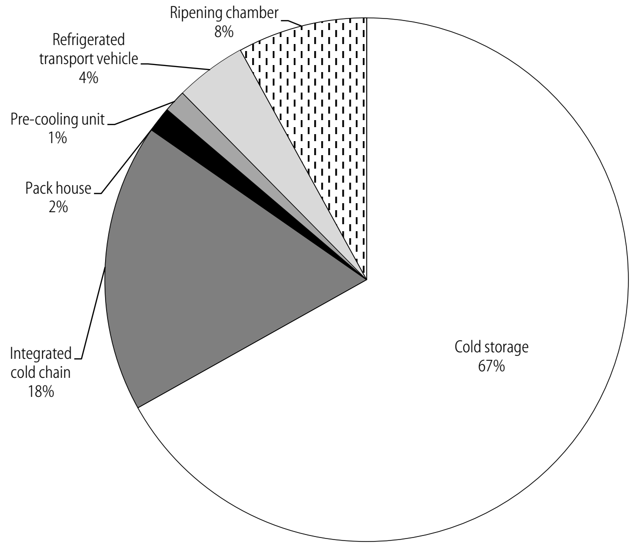
Source: Based on the data presented in Table 4.

and 2020, from 32 million tonnes to 38 million tonnes, posting a growth rate of 16% per year. The average size of cold storage units is relatively small—4,574 tonnes each—with no indication of change in the last five years. The average capacity does not reflect the small capacity of most cold stores—they usually have capacities of less than 1,000 tonnes, are single commodity units, and are from the unorganised sector (Arora 2018). India's 37-million tonne cold storage chain belongs to 3,500 entities, while 20 companies handle 125 million tonnes of capacity in the United States, leaving scope for some consolidation in the years to come (Ramesh 2020).

The cold storage infrastructure development in India is skewed in favour of the few states producing potatoes except Gujarat (Figure 6). Four states—UP, West Bengal, Gujarat, and Punjab—possess 72% of all cold storage units in the country, while Himachal Pradesh, Assam, Uttarakhand, Jharkhand, J&K, Tamil Nadu, Chhattisgarh, Rajasthan, Karnataka, Haryana, Maharashtra, MP, Bihar, and AP have severely underdeveloped infrastructure. UP alone accounts for 30% of the total cold storage units and 40% of the total capacity, while the average cold store capacity in West Bengal is the highest at 11,500 tonnes per unit.

The lopsided development of cold chains can be seen in the public support given to different components—two-thirds of the funding has gone to cold storage development (Figure 7). Refrigerated transport, pack houses, and pre-cooling units get 4%, 2%, and 1% of the funding, respectively. On the other hand, according to a study commissioned by the NCCD and the National Bank for Agriculture and Rural Development Consultancy Services (NCCD-NABCONS 2015), there are large gaps in the availability of pack houses, ripening chambers, and reefer trucks—99.6%, 91.1%, and 85.4%, respectively. Despite these market gaps, the

Figure 7: Cold Chain Projects Supported by Various Government Agencies, 2006–07 to 2020–21



Source: Based on the data presented in Table 5.

fact that these studies are being published indicates that the need for an integrated cold chain has been getting increasing attention as policymakers get a clearer view of the challenges involved in reducing losses and improving social welfare.

Notwithstanding the delayed start, the wheels of cold chain development have been moving in the country, albeit at a slow pace (Table 5). During 2006–21, 3,973 cold chain projects were funded by different agencies in the country. UP has

Table 5: Cold Chain Projects Supported by Various Government Agencies in India, 2006–07 to 2020–21

State(s)	Cold Storage	Integrated Cold Chain	Pack House	Pre-cooling Unit	Refrigerated Transport Vehicle	Ripening Chamber	All Components	
							Number	Crore
Andhra Pradesh	145	11	3	0	2	32	193	208
Assam	10	2	2	0	0	0	14	45
Bihar	106	6	0	1	3	0	116	63
Chhattisgarh	23	3	0	1	0	2	29	36
Delhi	9	0	0	0	30	0	39	15
Gujarat	282	35	3	15	12	50	397	443
Haryana	73	14	0	0	8	11	106	147
Himachal Pradesh	12	237	13	0	3	1	266	183
Jammu and Kashmir	10	48	0	0	29	1	88	155
Jharkhand	28	0	0	1	1	0	30	14
Karnataka	69	20	3	0	17	11	120	145
Kerala	5	7	3	0	1	0	16	40
Madhya Pradesh	85	4	2	0	0	11	102	107
Maharashtra	99	108	17	18	12	71	325	473
Odisha	27	4	1	6	17	2	57	36
Punjab	277	55	2	3	1	16	354	297
Rajasthan	54	27	4	1	9	26	121	141
Tamil Nadu	16	18	1	5	3	32	75	106
Telangana	69	8	4	0	6	16	103	112
Uttar Pradesh	1,162	34	2	0	13	34	1,245	755
Uttarakhand	3	37	0	4	7	1	52	173
West Bengal	93	29	2	0	0	1	125	100
Total (number)	2,657	707	62	55	174	318	3,973	–
Total (financial support) in crore	1,809	1,628	206	18	40	92	–	3,794

(1) Cold storage includes controlled atmosphere storage; integrated cold chain includes cold room, conveyor belt, and grading packing unit.
(2) Compiled from the NHB (nd).

the highest percentage of cold chain projects (31.3%), followed by Gujarat (9.9%). This figure is less than 9% for the rest of the states. Of the total cold chain projects in the country, two-thirds are related to cold storage. This is true in almost all the states except for Himachal Pradesh, J&K, Uttarakhand, Maharashtra, and Tamil Nadu.

Cold Chain and State Support: A Critical Assessment

Presently, small farmers growing fruits and vegetables cannot harness cold chain as the bulk of cold storage units and refrigerated transport are used by potato farmers and corporate entities for livestock products and dairy. As outlined above, the concept of an integrated cold chain is still new. Green logistics systems, as per the India Cooling Action Plan (2019), must be incorporated to reach the target levels of emissions through energy efficiency to comply with multilateral climate accords. The scope of cold chain has grown to include increasing the efficiency, precision, and speed of transportation and parameters for protecting quality, texture, and freshness of the produce. This comes with the emergence of cutting-edge technologies that enable food tracking, create real-time data on the movement of refrigerated cargo, and use blockchain for transparency in the movement of produce. Further, existing cold storages must be technologically upgraded to include thermal integrity, refrigeration installation handling systems, etc. According to the NCCD-NABCONS (2015) estimates, there are gaping holes in the cold chain infrastructure, with shortages of more than 50% in cold storage capacity, 85% in refrigerated trucks, 99% in pack houses, and 90% in ripening chambers.

To play its part, the central government has enacted several promotional measures like allowing foreign direct investments (FDIs) of up to 100%, providing viability gap funding of up to 40% of the project, and providing the cold chain industry with infrastructure status, profit-linked tax holidays, priority sector benefits, and lower goods and services tax (GST). It has also removed the service tax on cold chain services such as preconditioning, pre-cooling, ripening, waxing, and retail packaging. Excise duty exemption was given for refrigeration machinery and parts used for the installation of cold storage or refrigerated vehicles. On the other hand, several demand-side factors are propelling cold chain development, such as changes in consumer demand with regard to quality and diversified food and the need for last-mile delivery of e-commerce and organised food retail. These organised retailers have strengthened the backend infrastructure to procure directly from farmers (Nuthalapati et al 2020a). The supply of cold chain components has gotten a fillip with the emergence of third party logistics providers in the form of start-ups that have managed to mobilise large amounts of funding. Both e-commerce and delivery intermediaries, like third party logistic providers, have risen with pandemic-related restrictions on grocery shopping (Reardon et al 2021).

The country is witnessing a virtual explosion of innovative start-ups aiming to address several problems across production and marketing as well as create services for diversified consumer needs (Nuthalapati et al 2020b). Pune-based Ecozen Solutions has developed a solar-powered, small-size cold storage unit for pre-cooling in the field. SaptKrishi Scientific launched a cold storage-cum-transportation device called Sabjikothi for both pre-cooling and transporting produce to the next destination. Santa Barbara-based Apeel Sciences has launched an innovative natural technique to coat fresh fruits and vegetables with a thin peel of edible plant materials to slow down water loss and oxidation and extend produce life span with lesser mechanical damage (FAO 2019). Gurugram-based Arya Collateral Warehousing Services aggregates warehouses through its digital platform AZZ Godaam. Stellapps has developed solutions for cooling milk in the value chain and provides other services like credit and insurance; it is used by 2 million farmers in 30,000 villages, handling over 10 million litres of milk a day.

Apart from these direct innovations, start-ups that connect farmers with customers directly have been building state-of-the-art cold chains either on their own or through third party logistic providers like Delhivery. In the food and agriculture sector, Big Basket, Zomato, Swiggy, Udaan, Grofers, and Ninjacart have mobilised $5.5 billion in funding in the last few years and are strengthening their backend infrastructure. Licious and Fresh-to-Home are the two major start-ups in the livestock products market with considerable investments in cold chains.

The central government invested ₹3,794 crore between 2006–07 and 2020–21 in the promotion of cold chain in the country at an average of ₹253 crore per annum. This may not be a big sum but combined with tax breaks, tariff reductions, and an enabling environment, it has helped the cold chain develop critical mass and emerge as a fledgling industry. However, several of the schemes for this purpose are concentrated in a few geographies. The Pradhan Mantri Kisan Sampada Yojana (PMKSY) fund releases were skewed toward the southern and western states. While Maharashtra recieved ₹1,164 crore as of May 2019, Bihar was given a paltry ₹41 crore (Hussain 2020). This skewed fund allotment can come in the way of infrastructural development, which in turn stifles the growth of fruit exports as shown by Kulkarni (2020). There are no clear implementation guidelines for the well-intentioned ₹1 lakh crore Agriculture Infrastructure Fund (AIF) introduced in 2020 to give loans with interest subvention of 3% to primary agricultural credit societies (PACS), farmer producer organisations (FPOs), self-help groups (SHGs), and other cooperatives (Gulati 2020). The negotiable warehouse receipt (NWR) system under the Warehousing Development and Regulatory Authority (WDRA) could not take off because of the poor availability of registered warehouses, complicated procedures, and the lack of awareness (Shalendra et al 2016; Hussain 2018). Additionally, several of the incentives meant for cold storage do not extend to those with multi-commodity and other support services (NCCD 2020).

There is a need to incentivise resource-poor farmers, FPOs, and SHGs to harness cold chain facilities to maximise returns from farming. Farmers need training on scientific post-harvest management techniques such as good cultural practices, harvesting at maturity, grading, pre-cooling, packaging, and storage practices (Hegde and Madhuri 2013). Putting in place an effective cold chain needs interventions on the supply side like nurturing professional skills and developing quality and safety control measures, information systems, and standardisation and on the demand side like education and training at the farmer level (Gligor et al 2018). The moot point, however, is how much the emerging cold chain facilities will lead to food loss reduction.

Cold chain infrastructure will be effective and expand and fructify only when it moves beyond the current clientele of exporting farmers and traders in well-endowed states and regions to resource-poor farmers who are struggling to create better livelihood opportunities by cultivating high-value crops. As food loss is concentrated in the midstream of the value chain in the country, upgrading cold chain facilities will improve welfare by benefiting both producers and consumers. This is also the most appropriate way to improve food security through the evolving food systems approach.

Conclusions

In the last decade, there has been an increasing realisation worldwide that food saved is of enormous significance and can be considered as food produced without adverse environmental consequences. This has led to commitments in the SDGs to halve FLW by 2030. This is especially significant as the world battles food insecurity and malnutrition during the COVID-19 outbreak. Despite the ubiquitous recognition of the need to reduce food loss, systematic efforts in this regard are non-existent in India. Even less effort has been made to define and assess the extent of losses across the food value chain. This paper examines the available estimates and tries to critically assess the efforts to build cold chain as the way forward.

Around 100 million tonnes of fruits, vegetables, and foodgrains—amounting to nearly one-sixth of the production and one-tenth of the GVA in agriculture—are lost. These losses are the highest in vegetables followed by fruits, livestock products, and foodgrain crops. The chief cause is the underdeveloped value chain, especially the poor quality of logistics, cold chain, storage structures, and transport. Better techniques of harvesting and mechanisation will also go a long way in addressing FLW. While being a second-order problem relative to food loss, food waste is also an issue, especially due to the wasteful lifestyles of the rich.

The loss estimates in the country do not factor in the quality of the food loss. Further, it should be understood that FLW is a dynamic concept. As income increases, people's health consciousness increases and they change their food consumption, thereby increasing food loss. Rising food safety concerns among those with higher incomes also drive up food loss estimates, precisely for this reason. On the one hand, the rise of supermarkets may help in building cold chains and reducing losses, and on the other, their quality premiums may exacerbate food losses. Market integration plays a positive role in tackling the problem of food loss.

An efficient cold chain can mitigate FLW effectively and ensure higher farmer incomes by leveraging lucrative markets, enlarging the buyer base, and diversifying towards high value crops, apart from promoting social welfare through enhanced consumption. With the existence of mostly single commodity cold storages, the relative absence of multi-commodity storages with additional services and gaps of around 90% in the availability of refrigerated vehicles, pack houses, and ripening chambers, cold chain development is in its infancy. Even the available cooling infrastructure is beset with regional concentration, with it being practically non-existent in many states. Governmental investments coupled with tariff reductions and enabling environments have helped create a critical mass of cold chain networks to attract private initiatives. The rise of organised retail and e-commerce and the lengthening of food chains from rural to urban areas collectively create a demand for an integrated cold chain. However, the cold chain must be in the green logistics framework, duly follow emissions reduction standards, and leverage new technologies in information and communication.

In this regard, it is critical to involve small farmers, FPOs, SHGs, and cooperative societies in leveraging cold chain benefits through credit support as well as demand creation through demonstrations and pilot projects. Recent government initiatives such as e-negotiable warehousing receipts and the AIF should be amended towards this goal. Encouraging innovative start-ups through the promotion of venture capital can augment these efforts.

Achieving FLW commitments as part of SDG 12.3 requires commitment and action agendas. Almost all countries are moving in this direction. Following the Malabo Declaration, the African Union has been implementing Strategic Action Area 1 in association with the FAO for loss reduction. On the other hand, developed countries have been enacting policies, like the Waste and Resources Action Programme in the United Kingdom, to tackle food waste. India needs to deal with FLW by establishing institutions, like a task force, to define and standardise the estimation of losses and initiate policies to incentivise loss reduction, behavioural changes, etc. Further research is required on the determinants and distributional effects of cold chains, the cascading effects of different stages of the food value chain with cold chain development, technological options for cold chain development, and measurement methodologies for FLW.

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