Indian Journal of Agricultural Economics
Vol.75, No.3, July-September 2020

Estimation of Harvest and Post-Harvest Losses of Cereals and Effect of Mechanisation in Different Agro-Climatic Zones of India

R.K. Vishwakarma*, S.N. Jha*, Anil K. Dixit*, Anil Rai†, Tauquir Ahmad†

ABSTRACT

A concurrent survey was conducted in India during 2012-14 to estimate the harvest and post-harvest losses of cereals covering 107 districts. The losses were recorded by personal interviews and observations in different farm operations and market points. The district-level data were pooled according to agro-climatic zones (ACZ). The loss at the national level was estimated by pooling the loss at ACZ level using production as credence. Total losses of cereals at the national level varied between 4.65 to 5.99 per cent. Loss in farm operations ranged between 3.90 to 4.78 per cent, while, loss during storage was between 0.75 per cent to1.21 per cent. Delay in harvesting followed by improper threshing and winnowing and inappropriate storage practices contributed more towards overall losses. Overall, the estimated monetary value of losses was to the tune of Rs. 20698 crore at the average annual price of 2014 and production of selected cereals in 2012-13.The role of mechanisation in preventing losses of cereals is evident from the results as there were significantly lower losses in the mechanised regions of India.

Keywords: Post-harvest losses, Harvest losses, Storage loss, Cereals.

JEL.: C83, Q11, Q13, Q16

I

INTRODUCTION

Cereals occupy an important place in human food diet, as they are the major source of energy. Paddy, wheat, maize, sorghum and pearl millet (*bajra*) are the most important cereals of India with a production of 245.50 million tonnes in 2013-14 (Government of India, 2015). Increasing agricultural production is one aspect of fulfilling food demand, while delivering food to the consumers by saving commodities from losses and without straining the fields, water and environment is considered to a better option. Each unit of operation at the harvest and post-harvest stages including storage results into some losses, which decrease food availability (Jha *et al*., 2015). Losses at farm level may depend on the methods of harvesting, maturity status of crop, moisture content at the time of harvest, type and method of

*ICAR-Central Institute of Post-Harvest Engineering and Technology, P.O. Punjab Agricultural University, Ludhiana. †ICAR-Indian Agriculture Statistical Research Institute, Pusa, New Delhi.

The Ministry of Food Processing Industries, Government of India is thankfully acknowledged for financial support to conduct the study. The contribution of former PC(PHT) and former Director, ICAR-CIPHET, Ludhiana, andResearch Engineers of ICAR-AICRP on PHET centres and their staff in data collection are duly acknowledged. The team of scientists and technical persons of Indian Agricultural Statistics Research Institute, New Delhi, are duly acknowledged for their assistance and support in data scrutiny and analysis. The authors also thank the anonymous referees for their constructive comments, which helped us in refining the manuscript.

threshing, cleaning/winnowing, type of threshing floor, mode of transportation, etc. Losses in post-harvest stages may depend upon handling, transportation, storage conditions, type of storage structure, insects, molds, fungi, birds, spillage, pilferage, rodents, etc. (Jha *et al*., 2015). Thus the information regarding reliable estimates of losses is very important for adopting efficient and economic control measures to minimise the losses at different stages.

Notable work of FAO (1977); Nawab Ali (1983); Narain and Khosla (1984) focussed on the estimation of the extent of harvest and post-harvest losses of cereals but limited to a geographical area and hardly covered post-harvest losses at the national level. A large-scale sample survey was conducted for the estimation of marketable surplus and post-harvest losses of major cereals in 1996-97 by enquiry method only (Government of India, 2002). Besides, Basappa *et al.* (2007) conducted a study during 2003-2004 in Karnataka to estimate the post-harvest loss of maize in different stages at farm level in two districts. Basavaraja *et al.* (2007) collected data by enquiry method from one district each for paddy and wheat. For the first time, Nanda *et al*. (2012) developed methodologies for a nationwide survey in 2005-07 to assess the harvest and post-harvest losses in India by both enquiry and observations. However, regional variations of losses were not reported. Hence, it would be pertinent to understand the regional variations and their sources to design the appropriate policy. Mechanisation is another factor affecting the extent of losses, in addition to time-invariant factors (topography).

Agricultural mechanisation implies the use of various power sources and improved farm tools and equipment, as it reduces the drudgery of the human beings and draught animals, precision and timeliness of efficiency of utilisation of various crop inputs and reduces the losses at different stages of crop production (Verma, 2008). A study done by Ajeigbe *et al*. (2010) asserted that productivity and income generation capacity are enhanced by the mechanisation of legume-cereal cropping systems in Nigeria. In less developed countries, larger losses are incurred during drying, storage, processing and in transportation as the supply chain is less mechanised (Aulakh and Regmi, 2013). In developed countries, food losses are generally low in the middle stages of the supply chain. For the low-income countries, pre-harvest management, processing, storage infrastructure and market facilities are either not available or inadequate (FAO, 2011). Hence agricultural mechanisation is a crucial factor for farm operations to prevent post-harvest losses. A comparison in the traditional post-harvest chain and mechanised post-harvest chain showed that the loss in the traditional post-harvest chain was significantly higher than the mechanised systems (Hodges *et al*., 2011), which clearly indicates that the mechanisation play an important role in reducing post-harvest losses.

In this backdrop, the present study was undertaken with the objective to assess the harvest and post-harvest losses of cereals at regional as well as at the national level. The present status of mechanisation as well as its roles on reduction in harvest and post-harvest losses have been explored.

II

MATERIALS AND METHODS

The estimation of quantitative losses have been considered, which is defined as a reduction in weight of the edible available for human consumption. The estimates of harvest and post-harvest losses were obtained through an all India survey from which the data was collected both, (i) by enquiry and (ii) by actual observations in different operations and market points from production to consumption of selected cereals, viz., bajra, maize, paddy, sorghum and wheat.

Sampling Design

The survey covered 14 of the 15 agro-climatic zones (ACZs) in India (Basu and Guha, 1996). The survey was carried out in 120 districts covering 14 ACZs (except island region) of India (Jha *et al*., 2015) but data of 107 districts has been retained for the analysis in this study (Appendix I). The stratified multi-stage random sampling without replacement (SRSWOR) method was employed (Ahmad *et al*. 2016; Vishwakarma *et al*., 2019), considering the ACZs as strata, to select the respondents for collecting data on losses. The allocation of the number of districts for data collection in each of the ACZ was based on their contribution towards the total production of the selected crops in the country. Two blocks from each of the identified districts; five villages from each opted block and ten farmers from each identified village were selected randomly using SRSWOR for data collection by enquiry at the farm level. Further, two farmers from the list of already 10 selected farmers of each village were taken randomly for data collection by observation for each crop.

The estimation of losses with respect to storage in market points, two units of each point, i.e., wholesaler, retailer, *godown*, and processing unit were taken using SRSWOR from the respective lists prepared after complete enumeration of each units in selected districts. The data by enquiry as well as by observation were collected from all selected units. For primary data collection, a set of seven schedules were prepared based on existing studies conducted by FAO (1980); Government of India (2002) and Nanda *et al*. (2012). The data collection started in December 2012 and completed in June 2014 covering one crop cycle for each selected cereal.

Data Collection Method by Enquiry

Information regarding the losses in farm operations and prior to storage was collected at the time of operation. Data was collected for each harvest. The data to estimate losses during storage at the farm, *mandi*, retailer, processing units and *godowns* were collected once every month and continued for one year. In the case of processing units, the data of loss was collected for the produce until it was stored and not processed.

Data Collection by Observation

The estimates of losses by observation in farm operations were recorded for harvesting, threshing and cleaning/winnowing operations. A pro forma (Nanda *et al*., 2012) was modified for each selected crop in this study and used to collect data on losses based on observations. To estimate the losses in farm-level manual operations harvesting, a plot of 5 m×5 m (for plain regions) or 2 m×10 m (for hilly regions) was selected in the identified field (Vishwakarma *et al*., 2019). While, in the case of combine harvest, the production of selected field was recorded after harvesting.

To estimate the loss during threshing and cleaning/winnowing, the harvested crop of the selected plot was threshed with the usual practice adopted by the farmer and grains and straw were weighed separately.

Data Analysis

The data were analysed using statistical analysis software (SAS) by incorporating sampling design in the estimation process. Data were analysed for different operations of each selected district separately for enquiry and observation records and then the results were pooled by assigning appropriate weights to get the estimated losses of produce at higher levels (i.e., ACZ and national level). The losses at ACZ level was estimated using the production of districts as weights. Similarly, losses at the national level were estimated by assigning weightage on the basis of the production of a specific crop/commodity in the ACZs. The estimates of enquiry and observation of particular operations were optimally combined through inverse variance method to obtain the total per cent loss at ACZ and national levels.

To estimate the overall total loss of selected crops at the national level, the estimates of quantity for produce retained/handled in each market points during storage were used. Since the complete produce was handled in each selected farm operations; the total loss of a crop in all farm operations was taken as the arithmetic sum of losses in individual operations. Information on per cent retention estimates during storage in each market point was adopted from Nanda *et al*. (2012).

Overall loss in a crop at the national level was calculated by adding the total loss in farm operations and total loss during storage in different market points (Vishwakarma *et al*., 2019).

III

RESULTS AND DISCUSSION

Present Status of Farm Mechanisation in India

The farm mechanisation scenario in India is entirely different from other countries due to its diverse requirements as per climatic conditions, socio-economic structure and crop diversity. The data of availability of harvest and post-harvest implements with farmers were taken from *Input Survey 2011-12* (Government of

India, 2016) and arranged ACZ-wise *(*Appendix II). It may be observed that only tractor has penetrated to all parts of India as a farm power source. It is interesting that more than 70 per cent farmers in Zone 4 and 5 (i.e. Bihar and Uttar Pradesh) owned tractors where average land holding is less than 1 ha. There is a lack of mechanical harvesting and threshing equipment in most parts of the country except Zone 6 (trans-Gangetic plain region comprising Punjab, Haryana and Delhi). In Zone 14, 55.8 per cent of farmers own power threshers for wheat, which is the highest among all other zones in the country (Appendix II). The socio-economic characteristics such as small land holdings and abundant farm labour might be the main reason for less use of combine harvesters in Zone 2, 3, 4 and 5. Manually operated pedal threshers are commonly used in Zone 2 (Eastern Himalayan region comprising all 8 North East states) and Zone 3 (Lower Gangetic plain region, i.e., West Bengal). It may, therefore, be inferred that the farm power is available in most parts of the country but machines for harvesting, threshing, and cleaning, which are efficient and suitable for small size holdings are lacking in most of the agro-climatic zones of India, which needs due attention.

Extent of Harvest and Post-Harvest Losses in Cereals at the Agro-Climatic Zone Level

The number of districts surveyed in each ACZ, the number of respondents in the farm operations as well as in market points are reported in Appendix I. The extent of harvest and post-harvest losses were estimated at ACZ level. Some of the ACZs might not be covered for some crops because either the crop area was too less to get samples or the crop was not found in the selected villages and districts. The estimates of losses in major agro-climatic zone level indicated wide variability in different regions of the country. The crop-wise losses in different farm operations and storage along market chain are shown in Tables 2-7.

(i) *Losses in Bajra*

The survey covered seven ACZs to estimate the losses in bajra. The highest losses of 8.01 per cent were observed in Zone 13 (i.e., Gujarat plains and hills region) followed by 5.68 per cent in the Zone 14 (i.e. Western dry region of Rajasthan) (Table 1). The overall total loss was found least (2.81 per cent) in the western region of Uttar Pradesh (Zone 5, i.e., Upper Gangetic plain region). Harvesting of bajra was done manually in all the zones and the loss during harvest ranged between 0.13 to 3.04 per cent. Manual threshing – grains are separated by beating the earheads with sticks; animal threshing – by trampling the earheads under bullock feet, and tyre threshing– under the tractor *tyres* on the harvested produce were found to be more prevalent in all the ACZs except Zone 14, where mechanical threshing was also practiced. Threshing losses ranged from 0.91 to 3.16 per cent (Table 1). The losses during threshing in Zone 14 was to the tune of 2.49 per cent. In this zone wheat

threshers were being used for threshing of bajra, which was not suitable for threshing bajra. Use of improved threshing machine 'Vivek millet thresher-cum-pearler' will significantly reduce (threshing 2-3 per cent and dehulling 10-12 per cent) losses of finger millet and baryan yard millet, respectively, and gain economic benefits over conventional practices (Dixit *et al*., 2011). Hence, suitable thresher for bajra need to be designed and developed. Further, the average land holdings in the Zone 14 are high (Appendix II*)* and therefore the farmers may afford mechanical threshers, which was not practically feasible in other zones where land holdings are 1-2 ha. The losses in other farm operations were less than 0.76 per cent in all the zones. Bajra is a rain-fed crop and the losses in farm operations were more than 4 per cent in the regions where irrigated areas were less than 50 per cent (Appendix II). Threshing, harvesting and winnowing were the major contributors for the losses in farm operations of bajra in all ACZs.

The total loss during storage of bajra varied from 0.27 per cent (Zone 5) to 0.97 per cent (Zone 10, i.e., Northern regions of Tamil Nadu and Karnataka). The farm-level storage losses were the highest contributors with loss of 0.81 per cent in Zone 10 (Table 1). The storage losses were higher in southern India because of high humidity conditions, which attracted insect infestation. Further, the farmers stored bajra in traditional storage structures without any fumigation and other pest protection measures, which resulted into higher loss. The farmers store about 39 per cent of the total produce followed by 36 per cent by the wholesalers and therefore the contribution in storage losses of these two market chains was high. Only a few wholesalers adopted proper storage practices. It was noticed that storage losses increased during monsoon season. The insect infestation was the main reason for loss during storage of bajra in market chains in all the zones. Hence, proper storage and protection protocols need to be developed and disseminated among the various stakeholders involved in bajra marketing chains.

(ii) *Losses in Maize*

This survey covered five major agro-climatic zones in which maize is cultivated. The highest overall losses of 6.89 per cent were found in Zone 8 (Northern region of Rajasthan and Southern region of MP), followed by 4.97 per cent in Zone 10(Southern plateau and hills region*)* (Table 2). Overall, the least loss of 2.0 per cent was in the Zone 7 (tribal region of India) and the higher loss of 3.10 per cent in Bihar and Eastern UP (Zone 4). Bihar is the major producer of maize in our country and high losses may be due to lower penetration of post-harvest technology and poor infrastructure facilities. Harvesting of maize was done manually in all the zones. The loss during harvest was negligible in Zones 4 and 7 because maize cobs were manually harvested first and then plant residue was harvested. The loss during harvest in Zones 8, 9 and 10 were nearly 2 per cent because the maize plant were harvested and heaped in the field for drying and birds caused more damage. Manual

TABLE 1. EXTENT OF HARVEST AND POST-HARVEST LOSSES IN FARM OPERATIONS AND STORAGE OF BAJRA IN DIFFERENT AGRO-CLIMATIC ZONES OF INDIA

	Farm operations								Contribution to post-harvest losses in storage along market Chain						
Agro-climatic Zone	Harvest	Collection	Threshing	Winnowing	Drying	Packaging	Transport	Total loss in farm operation	Farm	*Godown*	Wholesaler	Retailer	Processing unit	Total loss in storage	Overall total loss
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
ACZ 5	0.13	0.27	1.37	0.28	0.00	0.42	0.07	2.54	0.16	-	0.04 (0.05)	0.06	-	0.27	2.81
	(0.59)	(0.00)	(0.15)	(0.11)	(0.00)	(0.03)	(0.04)	(0.28)	(0.13)			(0.05)		(0.13)	(0.18)
ACZ 8	0.93	0.35	1.88	0.12	0.17	0.11	0.15	3.70	0.31	0.01	0.16	0.02	-	0.50	4.20
	(0.10)	(0.14)	(0.23)	(0.01)	(0.15)	(0.04)	(0.04)	(0.14)	(0.00)	(0.01)	(0.08)	(0.01)		(0.03)	(0.11)
ACZ 9	0.99	0.00	2.85	0.31	0.00	0.00	0.00	4.14	0.21	0.03	0.40	0.22	-	0.85	4.99
	(0.14)	(0.00)	(0.38)	(0.16)	(0.00)	(0.00)	(0.00)	(0.18)	(0.03)	(0.02)	(0.15)	(0.12)		(0.11)	(0.13)
ACZ 10	1.25	0.37	1.38	0.21	0.31	0.35	0.22	4.08	0.81	0.02	-	0.12	0.01	0.97	5.04
	(0.45)	(0.51)	(0.49)	(0.1)	(0.03)	(0.03)	(0.02)	(0.35)	(0.00)	(0.01)		(0.05)	(0.00)	(0.03)	(0.27)
ACZ 12	2.22	0.11	0.91	0.76	0.11	0.54	0.31	4.96	0.61	-	-	-	-	0.61	5.57
	(0.00)	(0.00)	(0.00)	(0.0	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					(0.00)	(0.00)
ACZ 13	3.04	0.71	3.16	0.07	0.00	0.19	0.37	7.54	0.22	0.03	0.12	0.11	-	0.48	8.01
	(0.64)	(0.63)	(0.30)	(0.12)	(0.00)	(0.08)	(0.36)	(0.39)	(0.17)	(0.03)	(0.08)	(0.02)		(0.12)	(0.32)
ACZ 14	1.17	0.65	2.49	0.26	0.27	0.18	0.12	5.15	0.33	-	0.15	-	0.05	0.52	5.68
	(0.78)	(0.58)	(0.43)	(0.04)	(0.33)	(0.20)	(0.08)	(0.45)	(0.00)		(0.05)		(0.03)	(0.01)	(0.34)

TABLE 2. EXTENT OF HARVEST AND POST-HARVEST LOSSES IN FARM OPERATIONS AND STORAGE OF MAIZE IN DIFFERENT AGRO-CLIMATIC ZONES OF INDIA

	Farm operations								Contribution to post-harvest losses in storage along market Chain						
Agro-climatic Zone	Harvest	Collection	Threshing	Winnowing	Drying	Packaging	Transport	Total loss in farm operation	Farm	*Godown*	Wholesaler	Retailer	Processing unit	Total loss in storage	Overall total loss
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
ACZ 4	0.07	0.00	1.65	0.84	0.13	0.01	0.01	2.71	0.15	-	0.14	0.08	0.02	0.39	3.10
	(0.04)	(0.07)	(0.35)	(1.05)	(0.38)	(0.04)	(0.03)	(0.42)	(0.03)		(0.25)	(0.06	(0.01)	(0.04)	(0.32)
ACZ 7	0.00	0.59	0.94	0.01	0.05	0.10	0.03	1.73	0.28	-	-	-	-	0.28	2.00
	(0.27)	(0.17)	(0.20)	(0.15)	(0.03)	(0.08)	(0.07)	(0.18)	(0.44)					(0.44)	(0.33)
ACZ 8	2.02	0.87	1.89	0.67	0.45	0.28	0.20	6.37	0.21	0.03	0.20	0.08	-	0.52	6.89
	(0.46)	(0.23)	(0.68)	(0.20)	(0.10)	(0.06)	(0.03)	(0.34)	(0.11)	(0.02)	(0.16)	(0.06)		(0.11)	(0.27)
ACZ 9	1.90	0.52	0.75	0.01	0.03	0.14	0.07	3.42	-	-	-	-	-	0.00	3.42
	(0.56)	(0.17)	(0.15)	(0.08)	(0.05)	(0.08)	(0.18)	(0.26)							(0.26)
ACZ 10	1.83	0.31	0.87	0.28	0.14	0.18	0.18	3.80	0.41	0.05	0.56	-	0.15	1.17	4.97
	(0.24)	(0.14)	(0.24)	(0.08)	(0.05)	(0.07)	(0.15)	(0.17)	(0.04)	(0.03)	0.15)		(0.07)	(0.07)	(0.15)

threshing of maize was done in Zones 4 and 7, whereas maize threshers were also used in Zones 8, 9 and 10. The loss during threshing ranged from 0.75 to 1.89 per cent (Table 2). The losses in other farm operations, such as drying, packaging and transportation were less. Threshing, harvesting and winnowing were major contributors for the losses in all ACZs. Mechanised operations were lacking in all the zones. Manual threshing and winnowing of maize is a tedious job. The machine 'Maize dehusker-sheller' of capacity 800 kg unhusked cobs for dehusking and shelling has been developed and commercialised by All India Coordinated Research Project on Post-Harvest Engineering and Technology (AICRP on PHET), MPUA&T Udaipur Centre. The machine has 99 per cent dehusking efficiency and shelling efficiency of 97-98 per cent in a single pass without any broken (Dixit *et al*., 2015, p. 83). This machine needs to be popularised in maize growing areas to reduce the loss at farm level operations.

The total loss during storage of maize varied from 0.28 per cent (Zone 7) to 1.17 per cent (Zone 10) (Table 2). The farm and wholesaler levels storage were major contributors in storage losses in all the zones. The storage losses were higher in southern India because of high humidity. The maize mainly used in poultry feed production because of poor storability of whole maize flour. However, the degermed maize flour has better keeping qualities and has a great demand in the market. Maize degermer (capacity: 20 kg/h, developed at PAU Ludhiana) – technically efficient and economically viable for production of germ and degermed flour (Sharma *et al.*, 2017), need to be promoted in maize growing areas. The storage in *godown*s was bare minimum. Insect infestation was the main reason for loss during storage in all the zones.

(iii) *Losses in Sorghum*

A total of five agro-climatic zones of the central and southern parts of India were covered in this study to estimate the losses in sorghum. The highest overall total losses of 7.45 per cent were found in Zone 9 and minimum loss of 3.76 per cent in Zone 12 (Table 3). Harvesting was done manually in all the zones. The loss during harvest ranged from 0.73 per cent to 2.39 per cent. Threshing method of bajra and sorghum were similar in all the zones. Threshing losses ranged from 0.66 per cent (Zone 12) to 3.31 per cent (Zone 8). The losses in other farm operations such as drying, packaging and transport were less. Sorghum was also grown as a rain-fed crop in all the Zones and therefore the total losses in farm operations were more than 4 per cent (Table 3). Threshing, harvesting and winnowing were the major contributors to the losses in farm operations. AICRP on PHET, ICAR-CIAE Bhopal centre has developed pedal-cum-power operated grain cleaner with a provision of screens adjustment according to grain to be cleaned. This machine has an efficiency of 99 per cent and capacity of 330-800 kg/h depending upon the type of crop and

TABLE 3. EXTENT OF HARVEST AND POST-HARVEST LOSSES IN FARM OPERATIONS AND STORAGE OF SORGHUM IN DIFFERENT AGRO-CLIMATIC ZONES OF INDIA.

	Farm operations								Contribution to post-harvest losses in storage along market Chain						
Agro-climatic Zone	Harvest	Collection	Threshing	Winnowing	Drying	Packaging	Transport	Total loss in farm operation	Farm	*Godown*	Wholesaler	Retailer	Processing unit	Total loss in storage	Overall total loss
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
ACZ 8	1.69	0.01	3.31	0.14	0.00	0.23	0.00	5.39	0.09	0.03	0.04	-	-	0.16	5.55
	(1.05)	(0.00)	(0.68)	(0.30)	(0.00)	(0.24)	(0.00)	(0.52)	(0.01)	(0.01)	(0.02)			(0.01)	(0.35)
ACZ 9	0.73	0.54	2.52	0.59	0.01	0.35	0.07	4.81	0.36	0.17	1.99	0.11	0.01	2.64	7.45
	(0.21)	(0.09)	0.21)	(0.13)	(0.04)	(0.13)	(0.03)	(0.15)	(0.10)	(0.02)	(0.16)	(0.05)	(0.00)	(0.10)	(0.12)
ACZ 10	2.20	0.27	1.01	0.42	0.18	0.24	0.18	4.51	0.33	0.03	0.36	0.19	0.03	0.93	5.44
	(0.47)	(0.05)	(0.27)	(0.24)	(0.06)	(0.09)	(0.05)	(0.26)	(0.05)	(0.05)	(0.32)	(0.06)	(0.01)	(0.14)	(0.23)
ACZ 11	2.39	0.00	1.12	0.82	0.22	0.14	0.00	4.70	0.07	-	0.91	-	-	0.98	5.67
	(0.24)	(0.00)	(0.74)	(0.09)	(0.10)	(0.18)	(0.00)	(0.34)	(0.03)		(0.14)			(0.04)	(0.29)
ACZ 12	1.63	0.00	0.66	0.19	0.36	0.41	0.17	3.41	0.34	-	-	-	-	0.34	3.76
	(0.03)	(0.00)	(0.01)	0.01)	(0.02)	(0.03)	(0.00)	(0.02)	(0.01)					(0.01)	(0.01)

grain size (Dixit *et al*., 2015, p-63). Such machines need to be popularised for wider adoption

The total loss during storage of sorghum varied from 0.16 per cent (Zone 8) to 2.64 per cent (Zone 9). The storage loss was the highest at wholesaler's level in all the zones followed by storage at the farm level. The losses in other market points were very less. The insect infestation was the main reason for loss during storage in sorghum in all the zones.

(iv) *Losses in Paddy*

This survey covered in ten major paddy producing ACZs of India. The overall loss of paddy was highest (7.26 per cent) in Zone 3 (Lower Gangetic plain region i.e. West Bengal) followed by 6.30 per cent in Zone 10 and 6.04 per cent in Zone 2 (Table 4). These zones are least mechanised with small land holdings and therefore the operations were usually delayed. The least loss in farm operations of 2.99 per cent was in zone 6 where 19.8 per cent farmers own combine harvesters *(Appendix-II)* and harvesting was done by combine harvesters indicating the role of mechanisation in reducing the losses. Further, zones 3, 4 and 5 are flood-prone regions of India and harvesting operation is usually delayed, which resulted in higher shattering loss during harvesting. Zone 6 receives no or little rain at the time of harvest and hence timely harvesting with combine harvester is possible. Further, the average land holdings in Zone 6 are high and therefore combine harvesting becomes easy. In the threshing operation, the loss varied between 0.73 to 2.45 per cent (Table 4). The threshing loss with more than 2 per cent value was observed in Zone 3 and 4. Manual threshing by beating resulted in higher losses as some grains are carried away with straw.

The total loss during storage of paddy varied between 0.12-2.55 per cent. The loss during storage at farmer's level was least in Zone 6 where farmers stored paddy for seed purposes only. The storage loss at farmer's level was highest (1.35 per cent) in Zone 7 where rice is the staple food and stored for their own consumption. The losses during storage of paddy in *godown* were very less because the duration of storage was limited to 3-6 months only. Wholesaler level storage losses were less than 0.5 per cent in all the zones (Table 4). The paddy was rarely stored at the retailer level and therefore the losses were bare minimum.

(v) *Losses in Wheat*

This survey covered all the eleven agro-climatic zones of India in which wheat is produced. The overall total loss of wheat was the highest (7.04 per cent) in Zone 13 and more than 6 per cent loss was observed in Zones 1, 2, 3, 7, 8, and 13 (Table 5). The total loss in farm operations was more than 5 per cent in Zone 1, 2, 3, 8 and 13. The Zone 1 and 2 are Himalayan regions and hence very less farmers use power

TABLE 4. EXTENT OF HARVEST AND POST-HARVEST LOSSES IN FARM OPERATIONS AND STORAGE OF PADDY IN DIFFERENT AGRO-CLIMATIC ZONES OF INDIA

	Farm operations								Contribution to post-harvest losses in storage along market Chain						
Agro-climatic Zone (1)	Harvest (2)	Collection (3)	Threshing (4)	Winnowing (5)	Drying (6)	Packaging (7)	Transport (8)	Total loss in farm operation (9)	Farm (10)	*Godown* (11)	Wholesaler (12)	Retailer (13)	Processing unit (14)	Total loss in storage (15)	Overall total loss (16)
ACZ 2	2.69	-	1.01	1.48	0.18	0.00	0.08	5.44	0.47	0.13	-	-	-	0.60	6.04
	(3.55)		(0.88)	(2.23)	(0.03)	(0.01)	(0.13)	(1.84)	(0.04)	(0.00)				(0.04)	(1.45)
ACZ 3	2.15	0.67	2.40	1.56	0.03	0.07	0.01	6.91	0.21	-	0.12	0.02	-	0.35	7.26
	(0.33)	(0.09)	(0.35)	(0.21)	(0.06)	(0.10)	(0.02)	(0.22)	(0.10)		(0.12)	(0.01)		(0.10)	(0.20)
ACZ 4	1.59	0.30	2.45	0.21	0.02	0.06	0.06	4.69	0.19	-	0.04	0.00	0.34 (0.21	0.57	5.26
	(0.36)	(0.15)	(0.75)	(0.20)	(0.03)	(0.02)	(0.05)	(0.31)	(0.14)		(0.04)	(0.00)		(0.13)	(0.23)
ACZ 5	1.48	0.50	1.30	0.44	0.17	0.19	0.07	4.15	0.19	-	0.02	0.01	-	0.22	4.37
	(0.03)	(0.04)	(0.12)	(0.05)	(0.10)	(0.02)	(0.01)	(0.06)	(0.13)		(0.02)	(0.00)		(0.12)	(0.10)
ACZ 6	2.59	0.02	-	0.33	-	0.02	0.02	2.99	0.12	-	-	0.00	0.12	0.12	3.11
	(0.30)	(0.00)		(0.09)		(0.02)	(0.01)	(0.16)	(0.02)			(0.05)	(0.03)	(0.03)	(0.15)
ACZ 7	1.11	0.41	1.28	0.22	0.10	0.08	0.22	3.41	1.35	0.25	0.47	0.04	0.43 (0.03	2.55	5.96
	(0.71)	(0.40)	(0.40)	(0.42)	(0.21)	(0.03)	(0.08)	(0.41)	(0.12)	(0.01)	(0.05)	(0.01)		(0.12)	(0.29)
ACZ 9	1.39	0.43	1.02	0.48	0.01	0.25	0.02	3.60	0.03	0.00	0.31	0.02	0.00	0.36	3.96
	(0.12)	(0.14)	(0.18)	(0.10)	(0.01)	(0.08)	(0.01)	(0.11)	(0.21)	(0.10)	(0.24)	(.01)	(0.00)	(0.19)	(0.15)
ACZ 10	3.00	0.49	0.73	0.12	0.11	0.19	0.15	4.81	0.91	0.01	0.54	0.03	-	1.50	6.30
	(0.79)	(0.15)	(0.27)	(0.08)	(0.06)	(0.12)	(0.15)	(0.38)	(0.23)	(0.01)	(0.05)	(0.02		(0.20)	(0.34)
ACZ 11	2.43	0.36	1.00	0.30	0.15	0.04	0.03	4.30	0.25	0.07	0.13	0.05	0.04	0.53	4.83
	(0.43)	(0.19)	(0.13)	(0.08)	(0.15)	(0.03)	(0.03)	(0.22)	(0.25)	(0.01)	(0.01)	(0.00)	(0.01)	(0.21	(0.22)
ACZ 12	2.14	0.57	1.18	0.37	0.09	0.13	0.12	4.61	0.20 (0	0.02	0.08	0.01	-	0.31	4.92
	(0.16)	(0.12)	(0.25)	(0.12)	(0.03)	(0.02)	(0.04)	(0.14)	.09)	(0.00)	(0.02)	(0.01)		(0.08)	(0.13)

threshers and combine harvesters (Appendix II). Mechanisation was very low in Zone 2, 3, 8 and 13, particularly for wheat. The least loss in farm operations (2.99 per cent) was in Zone 6 where harvesting is done by combine harvesters. It again highlights the role of mechanisation in reducing the losses. In threshing operation, the loss was more than 1.5 per cent in all zones except Zone 6 and 9 (Table 5). Harvesting, collection, threshing and winnowing contributed mainly to the losses in farm operations in all the agro-climatic zones.

Table 5 depicts that the total loss during storage of wheat varied from 0.07 per cent (Zone 3) to 2.64 per cent (Zone 7). The loss during storage at farm level was more than 0.5 per cent in the ACZs where wheat is the staple food of the population and storage duration was more. The higher losses during storage at farm level were due to insect infestation. The losses during storage of wheat in other market points were very less. This situation is due to the adoption of appropriate wheat storage structure and protocols for control of insect infestation.

In maybe inferred that the overall losses of cereals were higher in ACZs 2, 3, 7, 8, 10 and 13 (West Bengal, North East, Tribal regions, Central plateau and Hills region, Southern plateau and hills regions, and Gujarat). Threshing, harvesting, and winnowing were contributing more towards total losses in farm operations. Untimely heavy rain, small land holdings, use of inappropriate machines, less mechanization and improper storage at farmer's level were the major factors responsible for higher losses. According to Kudos *et al*. (2016) wheat stored in *godown* (FCI and CWC), experienced weight gain after three months of storage in Transgangetic plain region (0.72 per cent) followed by Western plateau and hill region (0.41 per cent) and Central plateau and hill region (0.31 per cent) in FCI and CWC godown. This was due to the fact that wheat stacks absorbed moisture. However, the Upper gangetic plain region (Dhamora depot) underwent a loss of 0.07 per cent.

Summing up, mechanisation of farms helped in reducing losses in farm operations, particularly for wheat and paddy. Besides, the poor infrastructure facilities such as bulk storage systems for sorghum, bajra and maize in major producing regions and non-availability of community storages in the ACZs added to the losses during storage of cereals. Use of proven post-harvest technologies and practices at the farm level should be popularised on a large scale. Custom hiring centers for harvest and threshing machines, and procurement by the Government agencies with good storage management in the major producing regions of bajra, maize and sorghum may reduce the losses.

Extent of losses in different operations and storage at the National level

The estimates of losses at the national level are reported in Table 6. The estimated overall losses of cereals at the national level were 5.23 per cent (bajra), 4.65 per cent (maize), 5.99 per cent (sorghum), 5.53 per cent (paddy), and 4.93 per cent (wheat) during 2012-14 (Table 6). The corresponding figures of losses in the

TABLE 5. EXTENT OF HARVEST AND POST-HARVEST LOSSES IN FARM OPERATIONS AND STORAGE OF WHEAT IN DIFFERENT AGRO-CLIMATIC ZONES OF INDIA

	Farm operations								Contribution to post-harvest losses in storage along market Chain						
Agro-climatic Zone	Harvest	Collection	Threshing	Winnowing	Drying	Packaging	Transport	Total loss in farm operation	Farm	*Godown*	Wholesaler	Retailer	Processing unit	Total loss in storage	Overall total loss
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
ACZ 1	2.00	0.70	2.54	0.12	0.47	0.03	0.00	5.86	0.19	0.00	0.02	0.01	0.02	0.24	6.10
	(0.23)	(0.14)	(0.29	(0.29)	(0.30)	(0.03)	(0.00)	(0.22)	(0.03)	(0.00)	(0.00)	(0.01)	(0.01)	(0.03)	(0.15)
ACZ 2	0.31	0.96	2.61	0.85	0.30	0.19	0.05	5.27	0.70	0.11	0.26	0.03	0.05	1.15	6.42
	(0.86)	(0.24)	(0.19)	(0.12)	(0.15)	(0.11)	(0.03)	(0.39)	(0.26)	(0.06)	(0.07)	(0.01)	(0.01)	(0.24)	(0.35)
ACZ 3	2.14	0.58	2.78	0.57	0.00	0.00	0.00	6.08	-	-	0.04	0.03	-	0.07	6.14
	(0.31)	(0.10)	(0.07)	(0.19)	(0.00)	(0.00)	(0.00)	0.15)			(0.03)	(0.01)		(0.02)	(0.14)
ACZ 4	0.19	0.36	2.44	0.35	0.00	0.07	0.07	3.48	0.20	-	0.00	-	0.01	0.21	3.69
	(0.34)	(0.34)	(0.78)	(0.51)	(0.00)	(0.06)	(0.05)	(0.40)	(0.18)		(0.00)		(0.01)	(0.17)	(0.26)
ACZ 5	0.55	0.59	2.04	0.35	0.12	0.14	0.07	3.86	0.22	-	0.03	0.02	0.12	0.39	4.25
	(0.61)	(0.27)	(0.44)	(0.08)	(0.00)	(0.11)	(0.06	(0.35)	(0.14)		(0.02)	(0.01)	(0.10)	(0.14)	(0.23)
ACZ 6	2.36	0.03	0.32	0.25	-	0.02	0.02	2.99	0.88	0.00	0.00	-	0.08	0.96	3.95
	(0.26)	(0.00)	(0.01)	(0.08)		(0.00)	(0.00)	(0.14)	(0.13)	(0.02)	(0.00)		(0.03)	(0.12)	(0.13)
ACZ 7	1.09	0.49	1.80	0.11	0.15	0.07	0.04	3.75	2.17	0.00	0.19	0.07	0.21 (0.01)	2.64	6.39
	(0.41)	(0.06)	(0.21)	(0.06)	(0.08)	(0.03)	(0.01)	(0.21)	(0.12)	(0.01)	(0.02)	(0.01)		(0.11)	(0.15)
ACZ 8	1.48	1.48	1.78	0.83	0.06	0.20	0.21	6.03	0.43	-	0.10	-	-	0.53	6.56
	(0.22)	(0.16)	(0.19)	(0.14)	(0.02)	(0.03)	(0.03)	(0.14)	(0.01)		(0.03)			(0.01)	(0.11)
ACZ 9	1.73	0.36	0.42	0.33	0.00	0.03	0.08	2.96	0.31	0.00	0.07	0.02	-	0.40	3.36
	(0.69)	(0.11)	(0.08)	(0.10)	(0.00)	(0.03)	(0.03)	(0.31	(0.01)	(0.00)	(0.04)	(0.03)		(0.02)	(0.23)
ACZ 10	1.02	0.55	1.86	0.37	0.15	0.33	0.23	4.52	0.14	-	-	-	-	0.14	4.66
	(0.29)	(0.22)	(0.33)	(0.22)	(0.03)	(0.14)	(0.13)	(0.24)	(0.11)					(0.11)	(0.23)
ACZ 13	2.35	0.64	2.37	0.06	0.00	0.24	0.02	5.68	0.18	0.08	0.37	0.02	0.71	1.36	7.04
	(0.45)	(0.15)	(0.44)	(0.04)	(0.00)	(0.02)	(0.02)	(0.26)	(0.01)	(0.01)	(0.23)	(0.01)	(0.22)	(0.06)	(0.20)

TABLE 6. HARVEST AND POST-HARVEST LOSSES OF CEREALS AT NATIONAL LEVEL IN 2013-14

Crop	Farm operations							Total loss in farm operation	Contribution to post-harvest losses in storage along market Chain					Total loss in storage	Overall total loss
	Harvest	Collection	Threshing	Winnowing	Drying	Packaging	Transport		Farm	*Godown*	Wholesaler	Retailer	Processing unit		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Bajra	1.15	0.43	2.15	0.19	0.16	0.20	0.15	4.43	0.38	0.02	0.21	0.12	0.06	0.79	5.23
	(0.54)	(0.42)	(0.32)	(0.09)	(0.22)	(0.12)	(0.16)	(0.33)	(0.09)	(0.01)	(0.12)	(0.03)	(0.03)	(0.09)	(0.24)
Maize	1.42	0.42	1.20	0.40	0.18	0.16	0.13	3.90	0.21	0.04	0.30	0.12	0.08	0.75	4.65
	(0.31*)	(0.16)	(0.40)	(0.65)	(0.24)	(0.06)	(0.09)	(0.33*)	(0.20)	(0.03)	(0.17)	(0.07)	(0.06)	(0.20#)	(0.29*)
Sorghum	1.47	0.33	2.04	0.47	0.08	0.28	0.09	4.78	0.24	0.08	0.73	0.15	0.02	1.21	5.99
	(0.48)	(0.06)	(0.38)	(0.20)	(0.05)	(0.14)	(0.03)	(0.28*)	(0.09)	(0.01*)	(0.18)	(0.05*)	(0.01)	(0.10)	(0.20*)
Paddy	2.08	0.37	1.44	0.50	0.10	0.08	0.09	4.67	0.39	0.07	0.21	0.02	0.16	0.86	5.53
	(0.79*)	(0.29)	(0.39)	(0.50)	(0.15)	(0.04)	(0.06)	(0.44)	(0.15)	(0.03)	(0.07)	(0.01)	(0.04#)	(0.14)	(0.34)
Wheat	1.43	0.56	1.43	0.40	0.07	0.10	0.08	4.07	0.53	0.03	0.10	0.02	0.17	0.86	4.93
	(0.47)	(0.22)	(0.41)	(0.19)	(0.09)	(0.07)	(0.04)	(0.29)	(0.14)	(0.02)	(0.07)	(0.01)	(0.04#)	(0.13)	(0.20#)

*Figures in parenthesis shows the percentage standard error of estimate; *Estimated loss is significantly higher ($p \leq 0.05$) in comparison to estimated loss in 2005-07; # Estimated loss is significantly lower ($p \leq 0.05$) in comparison to estimated loss in 2005-07.*

year 2005-07 in the previous study conducted by Nanda *et al*. (2012) were 4.8 per cent (bajra), 4.1 per cent (maize), 3.9 per cent (sorghum), 5.2 per cent (paddy), and 6.0 per cent (wheat). It may be observed that the overall losses have increased considerably for bajra, maize, sorghum, and paddy whereas it decreased significantly for wheat. More losses during harvest and threshing of cereals (except wheat) contributed to such increases in losses. In 2005-07 survey, the manual harvesting and threshing of cereals was practiced mainly in bajra and sorghum, but subsequently during 2012-14, it was found that the threshing of these crops was done with high capacity wheat in bajra and sorghum growing regions. Thus, the use of improper machines might have led to higher losses. Further, the untimely rain in harvest season also resulted in higher losses in harvesting. The long duration storage losses in market points decreased to some extent in the cereals during 2012-14 in comparison to 2005-07.

The total loss in farm operations of cereals ranged from 3.90 per cent (maize) to 4.78 per cent (sorghum). Threshing followed by harvesting and winnowing were the main contributors. Higher losses of cereals at harvest level were observed in West Bengal, Assam, Coastal, Central and Tribal regions of India due to manual harvesting. Some of these losses are avoidable to a certain extent with better technological interventions.

The actual losses incurred in the storage of the cereals in the market chain at the national level are presented in Table 7. Storage losses in sorghum were quite high in most of the market points. The farm-level storage losses were generally higher for the cereals. The farmers usually stored cereals for their own consumption mainly in temporary structures without curative measures, leading to higher losses due to insect infestation. Further, the storage losses were noteworthy in all the market points indicating the need for proper storage facilities and infrastructure along the market chain.

TABLE 7. EXTENT OF LOSSES DURING STORAGE OF PRODUCE ALONG MARKET POINTS AT NATIONAL LEVEL

		Actual estimated losses in market chain during storage (per cent)				
S. No.	Crop	Farm	*Godown*	Wholesaler	Retailer	Processing unit
(1)	(2)	(3)	*(4)*	(5)	(6)	(7)
1)	Bajra	0.97 (12.30)	0.53 (27.72)	0.58 (28.25)	1.09 (14.56)	0.71 (21.87)
2)	Maize	0.90 (49.87)	0.46 (32.71)	0.79 (23.81)	0.81 (29.00)	0.56 (33.83)
3)	Sorghum	1.05 (18.83)	1.57 (9.59)	1.22 (12.53)	1.36 (18.16)	1.04 (26.31)
4)	Paddy	1.18 (19.33)	1.05 (24.44)	1.38 (16.92)	0.87 (17.79)	0.39 (12.28)
5)	Wheat	1.40 (13.09)	0.28 (28.25)	0.57 (34.34)	0.48 (25.01)	0.62 (11.68)

Figures in parenthesis shows the percentage standard error of estimates

The storage losses have reduced in comparison to reported values for 2005-07 by Nanda *et al*. (2012). Wholesale and retail market level storage losses of cereals, except sorghum, were reduced to some extent in comparison with losses during 2005-07. The storage losses in processing units decreased considerably. The storage capacity of Food Corporation of India has increased considerably in the past 10 years

and some private companies also started storage of wheat in the silos. Further, the rural godown scheme of the Government of India has also created additional storage facilities at the village level.

Extent of Monetary Losses in Cereals

At the national level, the monetary value of harvest and post-harvest loses of cereals, as estimated in this study, was to the tune of Rs. 20698 crore at the average annual price of 2014 and production of selected cereals in 2012-13 (Table 8). The highest monetary losses were accounted for by paddy, contributing to 49.98 per cent of total monetary loss in cereals, followed by wheat (38.08 per cent) (Table 8). These two crops contributed around 88 per cent monetary loss because of higher production as well as higher market prices of these crops than other cereals. The focus should be on entrepreneurship development programmes (EDPs) on various farm operations, such as harvesting, threshing, storage and marketing practices. EDPs were found effective towards encouraging and motivating potential entrepreneurs, besides reduction of losses (Dixit *et al*., 2016). Agro Processing Centre (APC) and custom hiring centre need be promoted in the production catchments and location-specific model and type of machinery are required to be analysed to further reduce the losses of cereals and to capture the economic and social benefits (Dixit *et al.,* 2011; Kumar *et al*., 2016).

TABLE 8. MONETARY VALUE OF HARVEST AND POST-HARVEST LOSSES OF CEREALS IN INDIA

S. No.	Crop	Production (million tonnes) 2012-13	Average Wholesale Price at 2014 (Rs./tonne)	Overall total loss (per cent)	Monetary value of loss (Rs. crore)
(1)	(2)	(3)	(4)	(5)	(6)
1)	Bajra	8.74	12666	5.23	579 (2.80)
2)	Maize	22.23	12662	4.65	1309 (6.32)
3)	Sorghum	5.28	18456	5.99	584 (2.82)
4)	Paddy	104.40	17918	5.53	10344 (49.98)
5)	Wheat	92.46	17309	4.93	7882 (38.08)
	Total				20698 (100)

Source: Computed by authors, Figures in parentheses indicate percentage of the total.

IV

CONCLUSIONS

Overall the quantitative harvest and post-harvest losses of cereals at the national level ranged between 4.65 per cent in maize to 5.99 per cent in sorghum. The losses during harvesting, threshing, winnowing, and storage at farm and wholesaler levels were quite high. The estimated output worth of Rs.20698 crore per annum was lost mainly due to inappropriate harvesting and poor post-harvest management of cereals. The use of improper threshers, delayed harvesting, and improper storage practices were probably the reasons for losses in the selected cereals. Harvesting and threshing

practices should be standardised for bajra, maize and sorghum. Further, refinements in the existing machine are needed to reduce the losses. Mechanisation of harvest and post-harvest farm operations has displayed a substantial reduction of losses in cereals, particularly in paddy and wheat. The less mechanised regions spread in West Bengal, Bihar, North-East States, Chhattisgarh, Jharkhand, Tribal regions of Orissa, Madhya Pradesh and Maharashtra need due attention. Efficient infrastructure facilities are required in these regions at each level to further reduce the losses.

Physical and monetary losses could be avoided to certain extent by technology interventions (development and adoption of improved threshing and harvesting machinery), improving storage infrastructure, skill development and entrepreneurship development programme for proper use of machinery and threshing operations, awareness to the farmers, traders, and processors about scientific storage along with the appropriate policies of scientific bulk storages, and custom hiring of machines.

Received October 2019. *Revision accepted October 2020.*

REFERENCES

Ahmad, T.; U.C. Sud, A. Rai, P.M. Sahoo, S.N. Jha and R. K. Vishwakarma (2016), "Sampling methodology for estimation of harvest and post-harvest losses of major crops and commodities", Paper presented at the Global Strategy Training and Outreach Workshop on Agricultural Surveys, FAO Headquarters, Rome, 24-25 October. gsars.org/wp-content/uploads/2016/10/4_PHL_Tauqueer_GSWorkshop-PHL-ICASVII-24-25Oct16.pdf

Ajeigbe, H.A.; S.G. Mohammed, J.O. Adeosun, and D. Ihedioha (2010), "Farmers' Guide to Increased Productivity of Improved Legume-Cereal Cropping Systems in the Savannas of Nigeria", International Institute of Tropical Agriculture, Ibadan, Nigeria.

Aulakh, J. and A. Regmi (2013), "Post-harvest Food Losses Estimation-Development of Consistent Methodology, Proceedings of Workshop on 'Improving Methods for Estimating Post-Harvest Losses", Food and Agriculture Organisation (FAO), Rome.

Basappa, G.; J.B. Deshmanya, and B.L. Patil (2007), "Post-Harvest Losses of Maize Crop in Karnataka-an Economic Analysis", *Karnataka Journal of Agricultural Sciences*, Vol.20, No.1, pp.69-71.

Basavaraja, H.; S.B. Mahajanashetti and N.C. Udagatti (2007), "Economic Analysis of Post-Harvest Losses in Food Grains in India: A Case Study of Karnataka", *Agricultural Economics Research Review*, Vol.20, No.6, pp.117-126.

Basu, D.N. and G.S. Guha (1996), *Agro-Climatic Regional Planning in India, Volume 1: Concept and Applications*, Concept Publishing, New Delhi.

Dixit, A.K., I. Rawat, S. Sharma, S. Mann and R. Kumar (2016), "Entrepreneurship through EDP and Licensing of Post-Harvest Technology: An Impact Assessment", *Indian Journal of Economics and Development*, Vol.12, No.4, pp.679-686.

Dixit, A.K.; S.N. Jha and S.K.A. Kudos (2015), "Four Decades: R&D of All India Coordinated Research Project on Post-Harvest Engineering and Technology", ICAR-Central Institute of Post-Harvest Engineering and Technology, Ludhiana.

Dixit, A.K.; S.K. Nanda, K.P. Singh and S.K.A. Kudos (2011), "Economic Benefits of Vivek Millet Thresher-Cum-Pearler and Agro Processing Centre in Hilly Region of Uttarakhand", *Journal of Hill Agriculture*, Vol.2, No.2, pp.177-183.

Food and Agriculture Organization of the United Nations (FAO) (1977),"Report of the Action Oriented Field Workshop for Prevention of Post-Harvest Rice Losses" held at Alor Setar, Kedah, Malaysia, cooperation with the Government of Malaysia and Food for the Hungry, FAO, Rome.

Food and Agriculture Organization of the United Nations (FAO) (1980), "Assessment and Collection of Data on Post-Harvest Losses". FAO Economic and Social Development Paper No.13, 1980.

Food and Agriculture Organization of the United Nations (FAO) (2011), "Global Food Losses and Food Waste-Extent, Causes and Prevention", Food and Agricultural Organization, Rome.

Government of India (2002), *Report of the Survey of Marketable Surplus and Post-Harvest Losses of Paddy in India (1997-99)*, Directorate of Marketing and Inspection, Department of Agriculture and Co-operation, New Delhi.

Government of India (2015), Agricultural Statistics at a Glance 2015, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, New Delhi.

Government of India (2016), "Estimated Number of Operational Holding in Agricultural Machinery by Size Groups", Agricultural Census Division, Department of Agriculture and Cooperation, Ministry of Agriculture, New Delhi, India. http://agcensus.nic.in.(website visited during 10-30 June 2016).

Hodges, R.J.; J.C. Buzby and B. Bennett (2011), "Postharvest Losses and Waste in Developed and Less Developed Countries: Opportunities to Improve Resource Use". *Journal of Agricultural Science*, Vol.149, pp.37-45.

https://drive.google.com/file/d/0B_n_IfXoFZZ6aUJQQ3FMbUswREk/view.

Jha, S.N.; R.K. Vishwakarma, T. Ahmad, A. Rai, and A.K. Dixit (2015), "Report on Assessment of Quantitative harvest and Post-Harvest Losses of Major Crops and Commodities in India", ICAR-All India Coordinated Research Project on Post-Harvest Technology, ICAR-CIPHET, P.O.-PAU, Ludhiana-141 004.

Kudos S.K.A.; S.K. Jha, A.K. Dixit (2016), "Assessment of Loss during Bulk Storage of Wheat (*Triticum aestivum*) in India", Pp.447–454, in Navarro S., Jayas D.S., Alagusundaram K, (Eds.) (2016), Proceedings of the 10th International Conference on Controlled Atmosphere and Fumigation in Stored Products (CAF2016), CAF Permanent Committee Secretariat, Winnipeg, Canada.

Kumar, R.; A.K. Dixit, A. Kumar and S. Singh (2016), "Agroprocessing Industries in Haryana: Status, Problems and Prospects", *Economic Affairs*, Vol.61, No.4, pp.707-715.

Nanda, S.K.; R.K. Vishwakarma, H.V.L. Bathla, A. Rai, and P. Chandra (2012), "Harvest and Post-Harvest Losses of Major Crops and Livestock Produce in India", All India Coordinated Project on Post-Harvest Technology, (ICAR), Ludhiana.

Narain, P. and R.K. Khosla (1984), "Statistical Methodology for Estimation of Losses of Agricultural Products at Different Stages", *Journal of Indian Society of Agricultural Statistics*, Vol.36, No.2, pp.74.

Nawab Ali (1983), "Storage Losses and Methodology for Its Determination", *Journal of Indian Society of Agricultural Statistics*, Vol.35, No.1, pp.75-76.

Sharma, S.; A.K. Dixit and G.K. Sidhu (2017), "Techno-Economic Evaluation of Maize Degermer Machine", *Journal of Hill Agriculture*, Vol.8, No.1, pp.93-97.

Verma, S.R. (2008), "Status of Farm Mechanization in India", Paper presented in National Seminar on Impact of Agricultural Mechanization on Production, Productivity, Cropping Intensity Income Generation and Employment of Labour, Punjab Agricultural University, Ludhiana.

Vishwakarma, R.K.; S.N. Jha, A.K. Dixit, A. Kaur, A. Rai and T. Ahmed (2019), "Assessment of Harvest and Post-Harvest Losses of Major Pulses in India". *Agricultural Economics Research Review*, Vol.32, No.2, pp.247-258.

APPENDIX I. AGRO CLIMATIC ZONES-WISE SELECTION OF NUMBER OF DISTRICTS AND RESPONDENTS FOR SELECTED CROPS

ACZ No. (1)	Crops (2)	No of districts selected (3)	No. of farmers for farm and post-harvest operations (4)	Number of respondents in market points			
				Godown (5)	Wholesaler (6)	Retailer (7)	Processing unit (8)
1)	Wheat	2	36	4	2	4	2
2)	Wheat	4	81	2	4	2	2
	Paddy	1	113	1	-	-	-
3)	Wheat	3	26	-	6	2	-
	Paddy	4	273	-	8	6	-
4)	Wheat	2	198	-	8	8	2
	Paddy	2	186	-	8	8	2
	Maize	5	345	-	8	8	4
5)	Wheat	5	415	-	20	20	2
	Paddy	4	83	-	16	8	-
	Bajra	3	61	-	8	4	-
6)	Wheat	3	292	8	4	-	12
	Paddy	3	280	4	-	-	12
7)	Wheat	6	253	6	20	20	20
	Paddy	11	1248	8	8	6	20
	Maize	3	105	-	-	-	-
	Bajra	-	-	2	4	8	-
8)	Wheat	3	137	-	8	-	-
	Maize	5	193	4	16	16	-
	Bajra	2	147	4	8	4	-
	Sorghum	2	29	4	6	4	-
9)	Wheat	3	44	2	8	6	-
	Paddy	4	84	8	8	8	2
	Maize	2	99	-	-	-	-
	Bajra	1	4	1	10	6	-
	Sorghum	4	94	7	12	12	4
10)	Wheat	2	28	-	-	-	-
	Paddy	6	146	2	14	6	-
	Maize	6	94	4	10	6	8
	Bajra	3	12	4	8	6	8
	Sorghum	7	84	4	12	6	8
11)	Paddy	12	881	4	16	20	20
	Sorghum	1	25	-	1	-	-
12)	Paddy	6	246	4	6	6	-
	Bajra	1	4	-	-	-	-
	Sorghum	1	4	-	-	-	-
13)	Wheat	5	158	4	6	12	2
	Bajra	1	63	2	4	24	-
14)	Bajra	2	121	-	8	8	-
	Total	140	6692	93	285	254	130

Please note that some of the districts are common (data collected from 107 districts were utilised for analysis).

Agro-climatic Zone Names are as: 1: Western Himalayan region; 2: Eastern Himalayan region; 3: Lower Gangetic plain region; 4: Middle Gangetic plain region; 5: Upper Gangetic plain region; 6: Trans Gangetic plain region; 7: Eastern plateau and hills region; 8: Central plateau and hills region; 9: Western plateau and hills region; 10: Southern plateau and hills region; 11: East coast plains and hills region; 12: West coast plains and ghats region; 13: Gujarat plains and hills region; 14: Western dry region.

APPENDIX II. STATUS OF FARM MECHANIZATION (HARVEST AND POST-HARVEST EQUIPMENT) IN DIFFERENT AGRO-CLIMATIC ZONES OF INDIA (2011-12)

Agro-climatic Zone (1)	Number of farm holdings (2)	Net sown area (ha) (3)	Av. sown area per holding (ha) (4)	Irrigated area (per cent) (5)	Farm holdings possessing harvest and threshing machines (per cent)					
					Tractor (6)	Pedal thresher (7)	Power thresher (8)	Combine harvester (9)	Self-propelled reaper (10)	Total power operated machine (11)
Zone 1	3211297	1864027	0.58	34.35	21.46	4.26	8.93	1.42	0.32	10.67
Zone 2	5304266	5152881	0.97	22.41	15.12	25.87	1.92	0.55	0.61	3.08
Zone 3	5597044	3719777	0.66	66.97	37.72	50.49	12.59	0.73	0.28	13.60
Zone 4	24476708	9887123	0.40	65.97	74.28	2.84	29.26	2.86	0.00	32.11
Zone 5	13412696	9737410	0.73	90.51	72.51	0.89	2.62	0.39	0.07	3.08
Zone 6	2963586	8955853	3.02	90.73	63.95	1.12	23.77	19.83	2.87	46.47
Zone 7	11537735	11346743	0.98	22.19	24.93	8.96	3.98	0.93	0.54	5.44
Zone 8	11429204	18057324	1.58	54.15	52.60	2.22	33.08	3.03	1.51	37.62
Zone 9	14503656	20576836	1.42	25.82	20.55	18.01	7.09	1.42	0.33	8.85
Zone 10	19352867	20019978	1.03	39.35	38.53	4.48	2.15	9.00	2.67	13.82
Zone 11	8576738	6487375	0.76	55.42	51.50	1.76	4.57	6.46	2.53	13.56
Zone 12	10552886	4661152	0.44	31.77	10.37	1.86	0.19	1.20	0.69	2.08
Zone 13	4903573	9581351	1.95	41.93	20.48	1.35	10.26	1.07	0.34	11.66
Zone 14	2266689	9585910	4.23	21.10	83.13	1.29	55.84	4.72	0.21	60.76
Zone 15	20948	15740	0.75	1.14	16.47	0.00	0.00	0.00	0.00	0.00
Total	138109893	139649480	1.01	46.08	44.26	7.52	12.44	3.40	0.91	16.75

Source: Rearranged data on "Estimated number of operational holding in agricultural machinery by size groups" taken from Agricultural Census Division, Department of Agriculture and Cooperation, Ministry of Agriculture and Farmers Welfare, New Delhi, India (2016).