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Sampling Methodology for Estimation of Harvest and Post-harvest Losses of Major Crops and Commodities

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SUMMARY

In developing countries, efficient use of food materials produced and saving them as much as possible is one of the ways of achieving the target of ensuring availability of food to the masses. In order to make strategies for reducing the losses, knowledge of extent of losses and their reasons is essential. Based on the literature reviewed on estimation of harvest and post-harvest losses, it has been observed that most of the studies did not follow standard statistical methods and thus may not reflect the accurate scenario of extent of losses at national level. Therefore, an appropriate sampling methodology for estimation of quantitative harvest and post-harvest losses of major crops and commodities has been developed. Estimates of percentage loss along with percentage standard error of the estimates at agro-climatic zone level and national level have been obtained using this developed methodology. This methodology provides reliable estimates of quantitative harvest and post-harvest losses of 45 crops and commodities in India through an integrated national level survey conducted during 2012-2014. The developed methodology generates reliable estimates of losses in various operations and storages in different channels.

Keywords: Harvest loss, Post-harvest loss, Sampling design, Estimation procedure, Survey, Sampling methodology, Operations, Channels, Percentage loss, Percentage standard error.

1. INTRODUCTION

One aspect of fulfilling food demand is to increase the agricultural production whereas the efficient use of food materials produced and saving them as much as possible is another aspect. Saving produced commodities from loss in fields, transport, storage, retailing, processing *etc*. without straining our fields, water and environment and delivering food to the consumers seems much better option. Agricultural produce undergoes series of post-harvest unit operations after production such as handling stages and storage before they reach to the consumers. Each operation and handling stage results into some losses and these post-harvest losses result into decrease in food availability.

A grain saved is considered as a grain produced. Therefore, it is desirable to identify the operations and channels where losses are considerable. Technological improvement for these operations and channels in future will lead towards more availability of produce and hence farmers can save their valuable produce and get more prices in the market. The reduction in losses in different channels will help in providing the quality produce for the consumers and hence all stakeholders including farmers, marketing persons and consumers will be benefited. Reduction in post-harvest losses will also be helpful in ensuring food security of the country.

Many studies on methodological aspects have been carried out for assessing post-harvest losses and identifying farm operations and channels affecting these losses and the results of these studies are published in various journals and reports. However, most of these studies deal with laboratory scale experiments and are limited to one or more crops/commodities, or specific locations.

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A large-scale sample survey was conducted in 1972-1973 for estimation of marketable surplus and post-harvest losses of food grains by Directorate of Marketing and Inspections (1978), Department of Agriculture, Government of India.

FAO (1977) prepared a report of the action-oriented field workshop for prevention of post-harvest rice losses held at Alor Setar, Kedah, Malaysia, in cooperation with the Government of Malaysia. FAO (1980) prepared a manual on "Assessment and Collection of Data on Post Harvest Food Grain Losses" for the benefit of developing and underdeveloped countries.

Eyo (1997) carried out an assessment of the quantifiable post-harvest losses using questionnaires at fisher folk, fish processors and fish traders operating within the Kainji Lake basin, Nigeria. Ngoan (1997) dealt with a brief account of the current status of post-harvest fisheries technology in Vietnam, detailing the various infrastructures available for fish processing and storage for export. Khatri *et al.* (1998) piloted a study on post-production losses of milk in rural areas of Rohtak district of Haryana State, India. Bathla *et al.* (2005) piloted a sample survey to develop methodology for estimation of harvest and post-harvest losses of milk, meat, poultry meat, egg, inland fish and marine fish. Kumar *et al.* (2006) conducted survey in two districts of Karnataka, India to assess the post-harvest losses in onion and potato. Basappa *et al.* (2007) carried out a study during 2003-04 in Karnataka for estimating post-harvest loss in maize at different stages at farm level. Jeeva *et al.* (2006, 2007) estimated harvest and post-harvest losses in inland fisheries and Srinath *et al.* (2007, 2008) estimated harvest and post-harvest losses in marine fisheries.

Hodges *et al.* (2011) compiled the data of estimated post-harvest losses and computed the financial value of weight losses for sixteen countries in East and Southern Africa (developing countries) for the decade 2001-2010. Jha *et al.* (2015) conducted a nationwide survey in 2012-2014 to assess the harvest and post-harvest losses of major crops and commodities in India. Global Strategy to Improve Agricultural and Rural Statistics (2018) developed guidelines on the measurement of harvest and post-harvest losses for food grains (cereals and pulses). English *et al.* (2018) discussed the pilot testing of the food loss index in India. Vishwakarama *et al.* (2019) estimated harvest and post-harvest losses of major pulses in India. Assessment of harvest and post-harvest losses of cereals and effect of mechanization in different agro-climatic zones of India was done by Vishwakarama *et al.* (2020). Ahmad *et al.* (2020) discussed in detail the findings from the field test on estimating harvest and post-harvest losses of fruits and vegetables in Mexico in collaboration with FAO, Rome and INEGI, Mexico. Field testing of the guidelines on estimating harvest and post-harvest losses of meat and milk was done in Zambia by Ahmad *et al.* (2020) in collaboration with FAO, Rome and CSO, Zambia.

The literature reviewed on estimation of harvest and post-harvest losses revealed that most of the studies did not follow sound statistical methodology and hence may not provide the accurate scenario of extent of losses at national level. In view of this, there is a need to assess the harvest and post-harvest losses of major crops and commodities, following standard statistical methodologies at national level to help researchers, policy makers and planners for making future strategies to reduce harvest and post-harvest losses and make more food materials available to feed masses.

Therefore, a suitable sampling methodology for estimation of quantitative harvest and post-harvest losses of major crops and commodities has been developed. The developed methodology provides estimates of percentage loss along with percentage standard error of the estimates at agro-climatic zone level and national level.

2. SAMPLING DESIGN PROPOSED FOR SELECTION OF SAMPLE AND PROPOSED SAMPLE SIZE

The sampling design proposed for selection of respondents in order to collect the data for assessment of harvest and post-harvest losses is stratified multistage sampling treating agro-climatic zones as strata, districts in each stratum as first stage units, sub-districts as second stage units, villages as third stage units and farmers as fourth stage units. The operations considered for assessment of losses are harvesting, collection, threshing, grading/sorting, winnowing/cleaning, drying, packaging, transportation, and storage depending upon the commodity. All operations except storage are grouped under 'farm operations'. Storage is further sub-divided into farm level, godown/cold storage, wholesalers, retailers and processing unit levels.

India is divided into 15 agro-climatic zones. The island region was not included in the survey as the total contribution in Indian agricultural production from this zone is negligible. Remaining 14 zones were treated as strata. The crops for different agro-climatic zones were allotted according to the production of crops/commodities in that zone. A total of 120 districts were selected randomly from 14 agro-climatic zones (20% of the total districts in each agro-climatic zone, excluding the urban districts where cultivation is not done). Allocation of 120 districts in different agro-climatic zone was done according to proportion of area cultivated in the previous year under major crops.

Two blocks were selected from every selected district by simple random sampling without replacement (SRSWOR). Then five villages were selected from each selected block by SRSWOR. A random sample of ten farmers was drawn from each selected village for data collection by enquiry at farm level and two farmers from the list of 10 selected ones for data collection by actual measurement. Same sample of farmers (as taken for data collection at farm level) was taken for data collection by enquiry and actual measurement at storage at producer level.

For assessment of loss at storage at market level, two units of each channel such as wholesaler, retailer, godown, and processing unit for each crop/commodity were selected randomly from the list of the respondents prepared after complete enumeration of units for each channel of each selected district. In case a particular channel was not available in the selected district then nearby districts for data collection by enquiry/actual measurement were considered. The data by enquiry as well as by actual measurement was collected from all selected respondents.

3. PROPOSED ESTIMATION PROCEDURE FOR ESTIMATION OF QUANTITATIVE HARVEST AND POST-HARVEST LOSSES OF MAJOR CROPS AND COMMODITIES AT VARIOUS LEVELS

Estimation procedure has been developed as per the proposed sampling design for different channels/ operations. The estimates are the pooled estimates of percentage loss from the data collected by enquiry and actual measurement computed separately and then pooled using an optimum pooling technique.

Using this estimation procedure, reliable estimates of quantitative harvest and post-harvest losses of 45 crops and commodities in India have been obtained through an integrated national level survey conducted during 2012-2014. For estimating the losses at agro-climatic zone level, weightage was assigned based on the production of the specific crop/commodity in all the sampled districts, obtained separately from the state report. Similarly, post-harvest losses at the national level were estimated by assigning weightage on the basis of the production of a specific crop/commodity in all the agro-climatic zones. The procedure for estimation at various levels has been described under different subheads as under:

3.1 Estimation of loss in farm operations

Estimation of losses was carried out at district level for enquiry and actual measurement data separately before agro-climatic zone level. Thereafter, both data were merged to obtain final estimates of loss at agro-climatic zone and national level.

3.1.1 Estimation of loss at district level

After maturity of crop, usually complete produce passes through a series of farm operations (harvesting, collection, sorting/grading, threshing, winnowing, drying, packaging and transportation). Each operation is performed separately and hence the losses are also different. Therefore, the estimation procedures of farm operations and storage channels are different and have to be computed separately both for data obtained by enquiry and actual measurement methods.

Estimation procedure for data collected by enquiry: An estimate of quantity of a crop/commodity handled for a particular farm operation in i^{th} district is given by

$$\hat{Y}_i = \frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}} y_{ibvf} \qquad (3.1)$$

where

B_i is total number of blocks in i^{th} district

b_i is number of blocks selected in i^{th} district

V_{ib} is total number of villages in b^{th} selected block of i^{th} district

v_{ib} is number of selected villages in b^{th} selected block of i^{th} district

F_{ibv} is total number of farmers growing a particular crop/commodity in vth selected village of bth selected block of ith district

f_{ibv} is number of selected farmers growing a crop/commodity in vth selected village of bth selected block of ith district

y_{ibvf} is quantity handled for a farm operation of a crop/commodity by the fth selected farmer in vth selected village of bth selected block of ith district (by enquiry)

An estimate of quantity of a crop/commodity lost in the same farm operation in ith district is given by

$$\hat{\delta}_i = \frac{B_i}{b_i}\sum_{i=1}^{b_i}\frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}}\delta_{ibvf} \tag{3.2}$$

where δ_{ibvf} is quantity of a crop/commodity lost at a particular farm operation by the fth selected farmer in vth selected village of bth selected block of ith district (by enquiry).

An estimate of loss (%) obtained by enquiry for the crop/commodity in ith district is given by

$$\hat{L}_i = \frac{\hat{\delta}_i}{\hat{Y}_i}\times 100 \tag{3.3}$$

Estimate of variance of $\widehat{L_i}$ after ignoring higher order terms is given by

$$\hat{V}\left(\hat{L}_i\right) = \left(\frac{\hat{\delta}_i}{\hat{Y}_i}\times 100\right)^2\left(\frac{\hat{V}\left(\hat{\delta}_i\right)}{\left(\hat{\delta}_i\right)^2} + \frac{\hat{V}\left(\hat{Y}_i\right)}{\left(\hat{Y}_i\right)^2}\right) \tag{3.4}$$

where estimate of variance of $\hat{\delta}_i$ and $\hat{Y}_i$ is given by

$$\hat{V}\left(\hat{X}_i\right) = \frac{1}{b_i(b_i-1)}\sum_{b=1}^{b_i}\left(\hat{X}_{ib}-\hat{\bar{X}}_i\right)^2 \tag{3.5}$$

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

where $\hat{\bar{X}}_i$ is the mean of variable (quantity handled or quantity lost) for ithdistrict and $\hat{X}_{ib}$ is estimate of quantity handled/lost for bth block in ithdistrict.

Estimation procedure for data collected by actual measurement: Similarly, an estimate of quantity of a crop/commodity handled for a particular farm operation in ith district in a manner similar to that of the data collected by enquiry is given by

$$\widehat{Y}_i' = \frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}}y'_{ibvf} \tag{3.6}$$

Similarly, an estimate of quantity of a crop/commodity lost in the same farm operation in ith district is given by

$$\hat{\delta}_i' = \frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}}\delta'_{ibvf} \tag{3.7}$$

and an estimate of percentage loss for the district is given by

$$\widehat{L}_i' = \frac{\hat{\delta}_i'}{\hat{Y}_i'}\times 100 \tag{3.8}$$

Estimate of variance of $\widehat{L_i}'$ after ignoring higher order terms is given by

$$\hat{V}\left(\hat{L}_i'\right) = \left(\frac{\hat{\delta}_i'}{\hat{Y}_i'}\times 100\right)^2\left(\frac{\hat{V}\left(\hat{\delta}_i'\right)}{\left(\hat{\delta}_i'\right)^2} + \frac{\hat{V}\left(\hat{Y}_i'\right)}{\left(\hat{Y}_i'\right)^2}\right) \tag{3.9}$$

where estimate of variance of $\hat{\delta}_i'$ and $\hat{Y}_i'$ is given by

$$\hat{V}\left(\hat{X}_i'\right) = \frac{1}{b_i(b_i-1)}\sum_{b=1}^{b_i}\left(\hat{X}'_{ib}-\hat{\bar{X}}'_i\right)^2 \tag{3.10}$$

$$\hat{X}'_{ib} = \frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}}x'_{ibvf}\ ,\ \hat{\bar{X}}'_i = \frac{1}{b_i}\sum_{b=1}^{b_i}\hat{X}'_{ib}$$

where $\hat{\bar{X}}'_i$ is the mean of variable (quantity handled or quantity lost) for ith district and $\hat{X}'_{ib}$ is estimate of quantity handled/lost for bth block in ith district.

Pooling of enquiry and actual measurement based estimators: In order to estimate the loss during farm operations at district level for different crops/commodities, the estimate of percentage loss of cth crop/commodity in ith district was obtained by pooling estimate of percentage loss by enquiry and actual measurement using weighted estimator given by

$$\hat{L}_i^{(c)} = \frac{\hat{s}_i'^2\hat{L}_i + \hat{s}_i^2\hat{L}_i'}{\left(\hat{s}_i'^2+\hat{s}_i^2\right)} \tag{3.11}$$

where $\hat{s}_i'$ is estimate of standard error of percentage loss in a farm operation of ith district obtained by actual measurement and $\hat{s}_i$ is estimate of standard error

of percentage loss in a farm operation of i[th] district obtained by enquiry.

Estimate of standard error of pooled estimate of percentage loss in a farm operation of i[th] district is given by

$$\hat{S}_i = \sqrt{\frac{\hat{s}_i^2 \hat{s}_i'^2}{\hat{s}_i^2 + \hat{s}_i'^2}} \tag{3.12}$$

3.1.2 Estimation of loss at agro-climatic zone level

Estimates of percentage loss of a crop/commodity handled in a farm operation at agro-climatic zone level for data collected by enquiry and actual measurement are given by

$$\hat{L}_z = \frac{\sum_{i=1}^{d} \hat{P}_{iz} \times \hat{L}_{iz}}{\sum_{i=1}^{d} \hat{P}_{iz}}, \quad \hat{L}'_z = \frac{\sum_{i=1}^{d} \hat{P}_{iz} \times \hat{L}_{iz}'}{\sum_{i=1}^{d} \hat{P}_{iz}} \text{ respectively.} \tag{3.13}$$

where $\hat{P}_{iz}$ is the production of crop/commodity for the i[th] district falling in z[th] zone in the agricultural year for which the percentage loss is being estimated. Thus, the percentage loss at agro-climatic zone level is estimated as a weighted average of production of the selected districts.

Estimate of standard error of percentage loss for data collected by enquiry / actual measurement is given by

$$\hat{S}_z = \sqrt{\frac{\sum_{i=1}^{d} P_{iz}^2 \hat{V}(\hat{L}_{iz}^*)}{\left(\sum_{i=1}^{d} P_{iz}\right)^2}}, \tag{3.14}$$

where $\hat{S}_z$ is the estimate of standard error of percentage loss for data collected by enquiry/actual measurement in z[th] agro-climatic zone using the respective variance expression given in equations 3.4 and 3.9 respectively. L_{iz}^* is the estimate of percentage loss for data collected by enquiry/actual measurement in the i[th] district falling in z[th] agro-climatic zone.

The estimate of loss (%) and its standard error for data collected by enquiry and observation at agro-climatic zone level was obtained using pooled estimator similar to eqns. (3.11) and (3.12) respectively.

3.1.3 Estimation of loss in farm operations at national level

Estimation of losses at national level in different farm operations was obtained from pooled estimates of loss (enquiry and actual measurement) at agro-climatic zone level. Estimate of percentage loss of c[th]crop/ commodity at national level ($\hat{L}_N^{(c)}$) was obtained using weighted estimator given by

$$\hat{L}_N^{(c)} = \frac{\sum_{i=1}^{a} \hat{P}_{iN} \times \hat{L}_{iN}}{\sum_{i=1}^{a} \hat{P}_{iN}} \tag{3.15}$$

where $\hat{P}_{iN}$ is the production of crop/commodity in i[th] agro-climatic zone and $\hat{L}_{iN}$ is the estimate of loss (%) of crop/commodity after pooling the enquiry and actual measurement data of i[th] agro-climatic zone.

Estimate of standard error of estimate of percentage loss at national level is given by

$$\hat{S}_N = \sqrt{\frac{\sum_{i=1}^{a} \hat{P}_{iN}^2 \hat{V}(\hat{L}_{iN})}{\left(\sum_{i=1}^{a} \hat{P}_{iN}\right)^2}} \tag{3.16}$$

3.2 Estimation of loss during storage

In order to estimate percentage loss from the data collected by enquiry and actual measurement, district-wise estimates were obtained separately and then pooled through an optimum pooling technique.

3.2.1 Estimation of farm level storage loss at district level

Estimation procedure for data collected by enquiry: An estimate of total quantity of crop/ commodity withdrawn from the store by the selected farmers of the i[th]district during total enquiry period is given by

$$\hat{P}_i = \frac{B_i}{b_i} \sum_{b=1}^{b_i} \frac{V_{ib}}{v_{ib}} \sum_{v=1}^{v_{ib}} \frac{F_{ibv}}{f_{ibv}} \sum_{f=1}^{f_{ibv}} \left(\sum_{t=1}^{T} p_{ibvft} \right) \tag{3.17}$$

where p_{ibvft} is the quantity of crop/commodity withdrawn from the storage between previous and t[th] visit to f[th] selected farmer in v[th] selected village of b[th]selected block of i[th] district (by enquiry).

An estimate of total quantity loss of crop/ commodity of the selected farmers of the ithdistrict during total enquiry period is given by

$$\hat{\xi}_i = \frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}}\left(\sum_{t=1}^{T}\zeta_{ibvft}\right) \quad (3.18)$$

where ζ_{ibvft} is the quantity loss of crop/commodity between previous and tth visit to fth selected farmer in vth selected village of bth selected block of ith district (by enquiry).

Estimate of farm level storage loss (%) of crop/ commodity by enquiry in ith district is given by

$$\hat{L}_i = \frac{\hat{\xi}_i}{\hat{P}_i}\times 100 \quad (3.19)$$

Estimate of variance of $\hat{L}_i$ was obtained using eqn. (3.4).

Estimation procedure for data collected by actual measurement: Estimate of farm level storage loss (%) of crop/commodity by actual measurement in ith district is given by

$$\hat{L}_i' = \frac{\hat{d}_i}{\hat{TG}_i}\times 100 = \frac{\frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}}\left(\sum_{t=1}^{T}d_{ibvft}\right)}{\frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}}\left(\sum_{t=1}^{T}d_{ibvft}+\sum_{t=1}^{T}u_{ibvft}\right)}\times 100 \quad (3.20)$$

where d_{ibvft} is the weight/number of crops/ commodities damaged in the sample drawn at the time of tth visit to fth selected farmer in vth selected village of bth selected block of ith district (by actual measurement), u_{ibvft} is the weight/number of crops/ commodities undamaged in the sample drawn at the time of tth visit to fth selected farmer in vth selected village of bth selected block of ith district (by actual measurement).

Approximate estimate of variance of the above estimator is given by

$$\hat{V}\left(\hat{L}_i'\right) = \left(\hat{L}_i'\right)^2\left\{\frac{\left(\hat{S}_i'\left(\hat{d}_i\right)\right)^2}{\left(\hat{d}_i\right)^2}+\frac{\left(\hat{S}_i'\left(\hat{TG}_i\right)\right)^2}{\left(\hat{TG}_i\right)^2}\right\} \quad (3.21)$$

Estimate of variance of d_i and TG_i is obtained as

$$\hat{V}\left(\hat{X}_i\right) = \frac{1}{b_i\left(b_i-1\right)}\sum_{b_i=1}^{b_i}\left(\hat{X}_{ib}-\hat{\bar{X}}_i\right)^2 \quad (3.22)$$

where $\hat{X}_{ib} = \frac{V_{ib}}{v_{ib}}\sum_{v=1}^{v_{ib}}\frac{F_{ibv}}{f_{ibv}}\sum_{f=1}^{f_{ibv}}\sum_{t=1}^{T}x_{ibvft}$ and $\hat{\bar{X}}_i = \frac{1}{b_i}\sum_{b=1}^{b_i}\hat{X}_{ib}$

where X is the variable d_i or TG_i.

Pooled estimate of the estimates of loss (%) for data collected by enquiry and actual measurement was obtained using eqns. (3.11) and (3.12).

3.2.2 Estimation of loss in storage and marketing channels (Wholesaler, Retailer, Godown and Processing unit) at district level

Data for this purpose was collected from respondents of different marketing channels selected using stratified two stage random sampling as described in section 2. The estimate of loss (%) for different crops/commodity and its estimate of variance for data collected by enquiry were estimated using eqns. (3.17), (3.18), (3.19) and (3.4).

Estimation procedure for data collected by actual measurement: Estimate of loss (%) during storage in ith district for data collected by actual measurement is given by

$$\hat{L}_i' = \frac{\hat{d}_i}{\hat{TG}_i}\times 100 = \frac{\frac{B_i}{b_i}\sum_{b=1}^{b_i}\sum_{t=1}^{T}d_{ibt}}{\left(\frac{B_i}{b_i}\sum_{b=1}^{b_i}\sum_{t=1}^{T}d_{ibt}+\frac{B_i}{b_i}\sum_{b=1}^{b_i}\sum_{t=1}^{T}u_{ibt}\right)}\times 100 \quad (3.23)$$

where d_{ibt} is the weight/number of crops/ commodities damaged in the sample drawn at the time of tth visit to bth respondent (godown/wholesaler/retailer/ processing unit) of ith district (by actual measurement), u_{ibt} is the weight/number of crops/commodities undamaged in the sample drawn at the time of tth visit to bth respondent (godown/wholesaler/ retailer/processing unit) of ith district (by actual measurement).

Approximate estimate of variance of estimate of percentage loss during storage in ith district is given by

$$\hat{V}\left(\hat{L}_i'\right) = \left(\hat{L}_i'\right)^2\left\{\frac{\left(\hat{S}_i'\left(\hat{d}_i\right)\right)^2}{\left(\hat{d}_i\right)^2}+\frac{\left(\hat{S}_i'\left(\hat{TG}_i\right)\right)^2}{\left(\hat{TG}_i\right)^2}\right\} \quad (3.24)$$

The estimate of variance of d_i and TG_i was obtained as given by eqn. (3.22). Again, merging of estimates of loss (%) from data collected by enquiry and actual measurement was carried out using eqns. (3.11) and (3.12) in order to get the pooled estimate of percentage loss.

3.2.3 Estimation of storage loss in different channels at agro-climatic zone level

After production of crop, the produce is distributed in different channels where it is stored or used for further processing and consumption. Production therefore may not be used as weights. The estimate of loss (%) of a crop/commodity, therefore, during storage in a channel at agro-climatic zone level ($\hat{L}z_s$) separately for enquiry and actual measurement data is given by

$$\hat{L}z_s = \frac{\sum_{i=1}^{d}(\hat{L}_{iz})}{d} \tag{3.25}$$

Estimate of standard error of estimate of storage loss (%) for data collected by enquiry/actual measurement is given by

$$\hat{S}_z = \sqrt{\frac{\sum_{i=1}^{d}\hat{V}\left(\hat{L}_{iz}\right)}{d^2}} \tag{3.26}$$

Estimate of loss (%) and its standard error for pooled data collected by enquiry and actual measurement at agro-climatic zone level were obtained using estimator similar to eqns. (3.11) and (3.12).

3.2.4 Estimation of storage loss in different channels at national level

Estimate of percentage loss of c^{th} crop/commodity during storage in a channel at national level by pooling data of loss (%) at agro-climatic zone level is given by

$$\hat{L}_{SN}^{(c)} = \frac{\sum_{i=1}^{a}\hat{L}_{iS}}{a} \tag{3.27}$$

Estimate of standard error of estimate of storage loss (%) for each crop/commodity is given by

$$\hat{S}_{SN} = \sqrt{\frac{\sum_{i=1}^{a}\hat{V}\left(\hat{L}_{iS}\right)}{a^2}} \tag{3.28}$$

3.3 Estimation of total loss of crop/commodities at national level

In order to estimate the overall total loss of a crop/commodity during storage, it is essential to know the quantity of crop/commodity retention/handling in each operation and channel during storage. Since, the total produce is handled in each of the farm operations, the total loss of a crop/commodity in all farm operations was taken as arithmetic sum of losses in individual operations.

Estimate of total percentage loss of a crop/commodity during storage in different channels is given by

$$\hat{L}_{TS} = \frac{\hat{L}_F \times \hat{R}_F + \hat{L}_G \times \hat{R}_G + \hat{L}_W \times \hat{R}_W + \hat{L}_R \times \hat{R}_R + \hat{L}_P \times \hat{R}_P}{100} \tag{3.29}$$

where $\hat{L}_F$ is estimated loss of crops / commodity during storage at farm,

$\hat{R}_F$ is estimated percent retention of crops / commodity in storage at farm,

$\hat{L}_G$ is estimated loss of crops / commodity during storage at godown,

$\hat{R}_G$ is estimated percent retention of crops / commodity in storage at godown,

$\hat{L}_W$ is estimated loss of crops / commodity during storage at wholesaler level,

$\hat{R}_W$ is estimated percent retention of crops / commodity in storage at wholesaler level,

$\hat{L}_R$ is estimated loss of crops / commodity during storage at retailer level,

$\hat{R}_R$ is estimated percent retention of crops / commodity for storage at retailer level,

$\hat{L}_P$ is estimated loss of crops / commodity during storage at processing unit and

$\hat{R}_P$ is estimated percent retention of crops / commodity for storage at processing unit.

The overall total loss of a crop/commodity at national level was calculated adding the total loss in farm operations and total loss during storage in different channels.

4. RESULTS AND DISCUSSION

Survey was conducted for 45 crops and commodities in 120 districts of the country (Jha *et al*., 2015). This survey was carried out to cover one-year crop cycle for all selected crops and commodities. Five questionnaires were developed for data collection by enquiry and 18 questionnaires for data collection by

actual measurement. Data, which was found unfit or could not get verified, was discarded. The remaining data of 107 districts was analyzed and harvest and post-harvest losses of all 45 crops and commodities were estimated at agro-climatic zone and national level using the developed estimation procedures described in section 3. This section presents the final results of crop and commodities-wise losses in different operations at national level and are reported in the Table 1.

It can be observed from the Table 1 that:

- The losses in cereals were estimated to be in the range of 4.65% (Maize) to 5.99% (Sorghum) as discussed by Vishwakarama *et al.* (2020). Harvesting, threshing and storage at farm and wholesaler level contributed more towards losses.
- The total losses in pulses ranged from 6.60% (Green gram) to 8.41% (Chick pea) as discussed by Vishwakarama *et al.* (2019). Harvesting, threshing, storage at farm and processing units were identified as major contributors in total losses. Use of improper threshers, delayed harvesting and improper storage practices were probably the main reasons of losses in pulses.
- Estimated losses of oil seeds ranged from 3.08% (Cottonseed) to 9.96% (Soybean). Harvesting, collection, threshing and storage at wholesale level were the major contributors towards total loss. Delayed harvesting and improper method, improper thresher, and storage practices were identified as main reasons for losses.
- For fruits, the losses ranged from 6.70% (Papaya) to 15.88% (Guava). Harvesting, sorting/grading, transportation, storage at wholesaler and retailer levels were the main operations and channels where losses were found to be high. Considerable losses during storage in market showed the need of multi-crop cold storages. Cold chain is essential to reduce the losses of fruits.
- The losses in vegetables varied from 4.58% (Tapioca) to 12.44% (Tomato) owing to harvesting, sorting/grading, transportation, storage at wholesaler and retailers levels. Glut in the market in the production season led to higher loss in farm operations. Contribution of storage losses in total loss was considerable. Cold chain, multi-commodity cold storages and low cost short

Table 1. Estimates of harvest and post-harvest losses (%) of crops and commodities at national level with % S.E.

S.No.	Crop/ commodity	Total loss in farm operations	Total loss in storage channels	Overall total loss
1	Paddy	4.67 (4.80)	0.86 (8.31)	5.53 (3.11)
2	Wheat	4.07 (3.58)	0.86 (7.65)	4.93 (2.05)
3	Maize	3.90 (4.38)	0.75 (13.32)	4.65 (3.17)
4	Bajra	4.43 (3.80)	0.79 (5.72)	5.23 (2.34)
5	Sorghum	4.78 (2.98)	1.21 (4.25)	5.99 (1.72)
6	Pigeon Pea	4.69 (4.85)	1.67 (3.99)	6.36 (2.44)
7	Chick Pea	7.23 (2.66)	1.18 (4.21)	8.41 (1.56)
8	Black Gram	5.89 (4.57)	1.18 (6.57)	7.07 (2.80)
9	Green Gram	5.37 (4.45)	1.24 (6.08)	6.60 (2.72)
10	Mustard	5.32 (4.33)	0.22 (12.94)	5.54 (2.89)
11	Cottonseed	2.54 (7.40)	0.54 (5.23)	3.08 (4.66)
12	Soybean	8.95 (2.14)	1.00 (3.64)	9.96 (1.56)
13	Safflower	2.80 (6.32)	0.34 (13.89)	3.13 (4.38)
14	Sunflower	3.65 (2.47)	1.61 (6.70)	5.26 (1.83)
15	Groundnut	5.09 (3.66)	0.95 (5.69)	6.03 (2.40)
16	Apple	9.08 (1.67)	1.31 (4.34)	10.39 (1.18)
17	Banana	6.04 (2.83)	1.72 (5.03)	7.76 (1.88)
18	Citrus	7.55 (2.58)	2.14 (2.67)	9.69 (1.53)
19	Grapes	6.52 (2.05)	2.11 (3.74)	8.63 (1.32)
20	Guava	11.90 (5.33)	3.98 (7.07)	15.88 (3.58)
21	Mango	6.92 (3.97)	2.24 (6.33)	9.16 (2.80)
22	Papaya	4.12 (4.55)	2.58 (2.46)	6.70 (1.96)
23	Sapota	7.41 (4.61)	2.31 (1.90)	9.73 (2.42)
24	Cabbage	6.81 (3.16)	2.56 (4.13)	9.37 (1.95)
25	Cauliflower	7.55 (3.54)	2.00 (5.73)	9.55 (2.43)
26	Green Pea	5.72 (2.81)	1.73 (6.11)	7.45 (1.91)
27	Mushroom	7.32 (1.30)	2.19 (33.82)	9.51 (3.49)
28	Onion	6.05 (3.41)	2.16 (3.97)	8.20 (1.73)
29	Potato	6.54 (4.91)	0.78 (4.22)	7.32 (3.07)
30	Tomato	9.41 (2.10)	3.03 (3.95)	12.44 (1.44)
31	Tapioca	3.22 (3.79)	1.36 (7.42)	4.58 (2.55)
32	Arecanut	3.94 (3.01)	0.97 (7.86)	4.91 (2.33)
33	Black pepper	0.99 (5.64)	0.20 (17.77)	1.18 (4.62)
34	Cashew	3.82 (14.99)	0.35 (10.08)	4.17 (10.26)
35	Chilli	5.11 (3.61)	1.40 (5.15)	6.51 (2.23)
36	Coconut	3.45 (3.38)	1.32 (2.70)	4.77 (2.11)
37	Coriander	5.33 (1.00)	0.55 (4.63)	5.87 (0.80)
38	Sugarcane	7.29 (1.25)	0.60 (7.43)	7.89 (1.08)
39	Turmeric	3.60 (2.97)	0.84 (2.73)	4.44 (1.75)
40	Egg	4.88 (1.68)	2.31 (3.00)	7.19 (1.05)
41	Inland Fish	4.18 (3.25)	1.05 (11.59)	5.23 (2.51)
42	Marine Fish	9.61 (1.05)	0.91 (9.71)	10.52 (0.94)
43	Meat	1.99 (2.91)	0.72 (5.22)	2.71 (1.89)
44	Poultry meat	2.74 (13.37)	4.00 (2.05)	6.74 (4.21)
45	Milk	0.71 (7.98)	0.21 (39.22)	0.92 (6.33)

Figures in parenthesis represent % S.E.

duration structures are essential in checking the loss of vegetables.

- In plantation crops and spices, the losses ranged from 1.18% (Black pepper) to 7.89% (Sugarcane). In general, harvesting, threshing, and storage at wholesaler and processing units level contributed more towards losses. Staling loss of sugarcane due to longer period of holding before crushing caused considerable loss and affected juice recovery. Problem of each crop needs to be addressed separately.
- The loss of egg was 7.19% owing to less use of cold storage in market. Mechanization showed positive impact in reducing the loss in egg.
- The loss in inland fish was 5.23% whereas loss of marine fish was 10.52%. Throwing uneconomical fish was the major contributor to the loss. Considerable loss during storage at wholesaler and retailer levels advocates the need of cold chain for fish.
- The loss in goat meat was 2.71% whereas the loss in poultry meat was 6.74%. Considerable loss at wholesaler and retailer levels indicates the need of proper and hygienic meat shops with cold chain/ carcass handling system.
- The loss of milk was observed to be 0.92%. Loss during storage at processing unit needs attention.
- Average range of losses altogether for food grains, oilseeds and fruits and vegetables were found to be 4.65% to 15.88%.
- Improvements in farm operations are essential and need to be addressed immediately. Research and development interventions are needed for controlling losses during harvest, threshing, sorting/ grading and retailer level storages. Infrastructural improvement is required at market level. Location of markets, marketing practices, handling methods and policies need to be looked into for changed scenario of demand and supply pattern.

5. CONCLUSIONS

An appropriate sampling methodology for estimation of quantitative harvest and post-harvest losses of major crops and commodities has been developed. Estimation procedure has been developed as per the proposed sampling design for different channels/operations. The developed methodology provides estimates of percentage loss along with percentage standard error of the estimates at agro-climatic zone level and national level. The estimates are the pooled estimates of percentage loss from the data collected by enquiry and actual measurement computed separately and then pooled through an optimum pooling technique. Using this methodology, reliable estimates of quantitative harvest and post-harvest losses of 45 crops and commodities in India have been obtained through an integrated national level survey conducted during 2012-2014. This study provides reliable estimates of losses in various operations and storages in different channels.

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