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

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Increasing agricultural production is one aspect of fulfilling food demand and the efficient use of food materials produced and saving them as much as possible is another aspect.

Delivering food to the consumers by saving produced commodities from loss in fields, transport, storage, retailing, processing etc. without straining our fields, water and environment seems much better option.

After production, agricultural produce undergoes series of post-harvest unit operations, handling stages and storage before they reach to the consumers.

Each operation and handling stage results into some losses.

These post-harvest losses result into decrease in food availability.

A grain saved is considered as a grain produced.

Therefore, it becomes inevitable to identify the operations and channels where losses are considerable.
Improvement in technology in future for these operations and channels will lead towards more availability of produce.

The farmer can save his valuable produce and get more price 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.

A large number of studies on methodological aspects, assessing post-harvest losses and identifying farm operations and channels affecting these losses 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.
In 1972-1973, the Directorate of Marketing and Inspections (DMI), Department of Agriculture, Government of India, has conducted a large-scale sample survey for estimation of marketable surplus and post-harvest losses of food grains.

Another study was conducted again by DMI in 1996-1997 and completed in 2002 covering paddy, wheat, sorghum, bajra, maize, barley, ragi, pigeon pea, chickpea, black gram, green gram and lentil.

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.

The manual was prepared with an aim to study the extent of post-harvest losses of cereals based on actual observations in the field.
Review of Literature

- This manual provides detailed methodology for data collection on losses in different operations and channels.
- However, the manual was applicable for estimation of losses of food grains only.
- Eyo (1997) conducted 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) conducted a study on post-production losses of milk in rural areas of Rohtak district of Haryana State, India.
- Bathla *et al.* (2005) conducted a pilot level sample survey to develop methodology for estimation of harvest and post-harvest losses of milk, meat, poultry meat, egg, inland fish and marine fish.
Review of Literature

- 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) conducted a study during 2003-04 in Karnataka for estimating post-harvest loss in maize at different stages at farm level.
- Hodges et al. (2011) compiled the data of estimated post-harvest loss and computed the financial value of weight losses for sixteen countries in East and Southern Africa (developing countries) for the decade 2001-2010.
- A study by Food and Agriculture Organization of the United Nations (FAO) in 2011 suggested that out of total loss, potentially more than 40% is lost during post harvest handling and processing in developing countries, while more than 40% is lost at retail and consumer levels in industrialized countries.
- Jha et al. (2015) conducted a nationwide survey in 2013-2014 to assess the harvest and post-harvest losses of major crops and commodities in India.
Motivation

- The literature reviewed on estimation of harvest and post-harvest loss revealed 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, there is a need to assess the harvest and post harvest losses of these crops and commodities covering large areas, following standard statistical methodologies at national level to help researchers, policy makers and planners for making future strategic framework to curtail harvest and post harvest losses and make more food materials available to feed masses.

- In view of the above, 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.
Definition of loss

- Reduction in weight of usable portion available for human consumption (reduction in weight due to drying/moisture loss was not included)

- The losses such as quality loss, food value loss, loss of goodwill or reputation, seed vigor loss etc. are not quantitative in nature and hence were not considered in this study.
Methodology for Estimation of Post Harvest Losses

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Crops/commodities covered (45)

Cereals: Paddy, Wheat, Maize, Bajra, Jowar (05)
Pulses: Pigeonpea, Chickpea, Black gram, Green gram (04)
Oilseeds: Mustard, Cottonseed, Soybean, Safflower, Sunflower, Groundnut (06)
Fruits: Apple, Banana, Citrus, Grapes, Guava, Mango, Papaya, Sapota (08)
Vegetables: Cabbage, Cauliflower, Green pea, Mushroom, Onion, Potato, Tomato, Tapioca (08)
Cash Crops: Arecanut, Black pepper, Cashew, Chilli, Coconut, Coriander, Sugarcane, Turmeric (08)
Other Commodities: Egg, Inland fish, Marine fish, Meat, Poultry meat, Milk (06)
Farm operations and channels covered

1. Harvesting
2. Collection
3. Threshing
4. Grading/sorting
5. Winnowing/cleaning
6. Drying
7. Packaging
8. Transportation
9. Storage at farm/household level
10. Storage at godown/warehouse/cold store level
11. Storage at wholesaler level
12. Storage at retailer level
13. Storage at processing unit level
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.
Agroclimatic Zones of India
Sampling design proposed for selection of sample and proposed sample size

**Strata**

- Ultimate Unit of Sampling
  - FSU
    - FSU
    - SSU
      - Sub districts (Blocks/Mandals/Taluks) (2)
        - (2 x 120 = 240)
      - (2 x 120 = 240)
    - (12 x 120 = 2400)
  - Agro-climatic Zones (14)
    - (The Island Region Excluded)
  - Districts (120)
    - (2 x 120 = 240)
  - Villages
    - (5 x 2 x 120 = 1200)
  - Farmers
    - By Enquiry
      - (10 x 5 x 2 x 120 = 12000)
    - By Observation
      - (2 x 5 x 2 x 120 = 2400)
Selected districts (120)
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 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 sub districts were selected randomly from every selected district.

Five villages were randomly selected from each selected sub district.
Methods of data collection

- Data collection by enquiry
  - Five (5) questionnaires were developed for data collection by enquiry.
  - Questionnaire 1 & 3 – complete enumeration of selected villages and market channels

- Data collection by observation
  - Altogether 18 questionnaires were developed for data collection by observation.
  - These questionnaires were grouped into two categories:
    1. Data collection by observation in farm operations (group of questionnaire number 5, total 12 questionnaires)
    2. Data collection by observation during storage at farm and market channels (group of questionnaire 6, total 6 questionnaires).

- Periodicity of data collection
- During storage – once in every month for one year for durables and once/twice a week for perishables
Data Collection by Observation

- **Field crops and vegetables:**
  A plot of 5mx5m for plains or 2mx10m for hilly regions for assessing the loss

- **Fruits:**
  4 fruit bearing trees in an orchard
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 observation 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 2013-2014.
- 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 procedures for estimation at various levels have been described under different subheads as under:

1- Estimation of loss in farm operations
2- Estimation of Loss during Storage
3- Procedure for Estimation of Total Loss of Crop/Commodity at National Level.

Estimation of loss in farm operations

Estimation of losses was carried out at district level for enquiry and observation 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.

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).
Proposed Estimation Procedure

- 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 observation 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:

\[
\hat{Y}_i = \frac{B_i}{b_i} \sum_{b = 1}^{b_i} \frac{V_{ib}}{v_{ib}} \sum_{v = 1}^{v_{ib}} \frac{F_{ibv}}{f_{ibv}} \sum_{f = 1}^{f_{ibv}} Y_{ibvf}
\]

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 number of blocks selected in \( i \)th district
Proposed Estimation Procedure

\( F_{ibv} \) is total number of farmers growing a particular crop/commodity in \( v \)th selected village of \( b \)th selected block of \( i \)th district.

\( f_{ibv} \) is number of selected farmers growing a crop/commodity in \( v \)th selected village of \( b \)th selected block of \( i \)th district.

\( Y_{ibvf} \) is quantity handled for a farm operation of a crop/commodity by the \( f \)th selected farmer in \( v \)th selected village of \( b \)th selected block of \( i \)th district (by enquiry).

- An estimate of quantity of a crop/commodity loss in the same farm operation in \( i \)th district is given by

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

where

\( \delta_{ibvf} \) is quantity of a crop/commodity loss at a particular farm operation by the \( f \)th selected farmer in \( v \)th selected village of \( b \)th selected block of \( i \)th district (by enquiry).
Proposed Estimation Procedure

- An estimate of loss (%) obtained by enquiry for the crop/commodity in $i^{th}$ district is given by
  \[ \hat{L}_i = \frac{\hat{\delta}_i}{\hat{Y}_i} \times 100 \]
  \[ (3) \]

- Estimate of variance of $\hat{L}_i$ after ignoring higher order terms is given by
  \[ \hat{V}(\hat{L}_i) = \left( \frac{\hat{\delta}_i}{\hat{Y}_i} \times 100 \right)^2 \left( \frac{\hat{V}(\hat{\delta}_i)}{\left( \hat{\delta}_i \right)^2} + \frac{\hat{V}(\hat{Y}_i)}{\left( \hat{Y}_i \right)^2} \right) \]
  \[ (4) \]

where estimate of variance of $\hat{\delta}_i$ and $\hat{Y}_i$ is given by
  \[ \hat{V}(\hat{X}_i) = \frac{1}{b_i (b_i-1)} \sum_{b=1}^{b_i} \left( \hat{X}_{ib} - \hat{X}_i \right)^2 \]
  \[ (5) \]
Proposed Estimation Procedure

\[
\hat{X}_{ib} = \frac{V_{ib}}{v_{ib}} \sum_{v=1}^{v_{ib}} \frac{F_{ibv}}{f_{ibv}} \sum_{f=1}^{f_{ibv}} x_{ibvf}
\]

\[
\hat{X}_i = \frac{1}{b_i} \sum_{b=1}^{b_i} \hat{X}_{ib}
\]

- where \( \hat{X}_i \) is the mean of variable (quantity handled or quantity lost) for \( i^{th} \) district and \( \hat{X}_{ib} \) is estimate of quantity handled/lost for \( b^{th} \) block in \( i^{th} \) district.

- Estimation procedure for data collected by actual observation: Similarly, an estimate of quantity of a crop/commodity handled for a particular farm operation in \( i^{th} \) district in a manner similar to that of the data collected by enquiry is given by

\[
\hat{Y}_{i}' = \frac{B_i}{b_i} \sum_{b=1}^{b_i} \frac{V_{ib}}{v_{ib}} \sum_{v=1}^{v_{ib}} \frac{F_{ibv}}{f_{ibv}} \sum_{f=1}^{f_{ibv}} y'_{ibvf}
\]
Proposed Estimation Procedure

Similarly, an estimate of quantity of a crop/commodity lost in the same farm operation in \( i \)th district is given by

\[
\hat{\delta}'_i = \frac{B_i}{b_i} \sum_{b=1}^{b_i} \sum_{v=1}^{v_i} \frac{V_{ib}}{f_{ibv}} \sum_{f=1}^{f_{ibv}} \delta'_{ibvf}
\]  

(7)

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

\[
\hat{L}'_i = \frac{\hat{\delta}'_i}{Y'_i} \times 100
\]  

(8)

Estimate of variance of \( \hat{L}'_i \) after ignoring higher order terms is given by

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

(9)
Proposed Estimation Procedure

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

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

(10)

where $X$ is a variable for quantity handled / quantity lost in ith district as expressed below:

$$\hat{X}_{ib}' = \sum_{v=1}^{v_{ib}} \sum_{f=1}^{f_{ibv}} x_{ibvf}'$$

$$\hat{X}_i' = \frac{1}{b_i} \sum_{b=1}^{b_i} \hat{X}_{ib}$$
Proposed Estimation Procedure

- **Pooling of enquiry and observation 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 observation using weighted estimator given by

\[
\hat{L}_i^{(c)} = \frac{\hat{S}_i' \hat{L}_i + \hat{S}_i \hat{L}_i'}{\left(\hat{S}_i' \hat{S}_i + \hat{S}_i \hat{S}_i'\right)}
\]

(11)

where \(\hat{S}_i'\) is estimate of standard error of percentage loss in a farm operation of i\(^{th}\) district obtained by observation 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 ith district is given by

\[
\hat{S}_i = \sqrt{\frac{\hat{S}_i^2 + \hat{S}_i'^2}{\hat{S}_i' \hat{S}_i + S_i'^2}}
\]

(12)
Proposed Estimation Procedure

Estimation of Loss at Agro-Climatic Zone Level

- An estimate of percentage loss of a crop/commodity handled in a farm operation at agro-climatic zone level for data collected by enquiry is given by

\[ \hat{L}_z = \sum_{i=1}^{d} \frac{\hat{P}_{iz} \times \hat{L}_{iz}}{\sum_{i=1}^{d} \hat{P}_{iz}} \]  

(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.
Proposed Estimation Procedure

- An estimate of percentage loss of a crop/commodity handled in a farm operation at agro-climatic zone level for data collected by observation is given by

\[
\hat{L}_z' = \frac{\sum_{i=1}^{d} \hat{P}_{iz} \times \hat{L}_{iz}'}{\sum_{i=1}^{d} \hat{P}_{iz}}
\]  

(14)
Proposed Estimation Procedure

- Estimate of standard error of percentage loss for data collected by enquiry/observation is given by

\[
\hat{S}_z = \sqrt{\sum_{i=1}^{d} P_{iz}^2 \hat{\text{V}}(\hat{L}_{iz})} \cdot \left( \sum_{i=1}^{d} P_{iz} \right)^{-2} \tag{15}
\]

where

\( \hat{S}_z \) is the estimate of standard error of percentage loss for data collected by enquiry/observation in \( z^{th} \) Agro-climatic zone using the respective variance expression given in equations 4 and 9 respectively.

\( \hat{L}_{iz} \) is the estimate of percentage loss for data collected by enquiry/observation 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. 11 and 12 respectively.
Proposed Estimation Procedure

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 observation) at agro-climatic zone level. The estimate of percentage loss of cth crop/commodity at national level \( \hat{L}_N^{(c)} \) was obtained using weighted estimator given by

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

(16)

where

- \( \hat{P}_{iN} \) is the production of crop/commodity in ith agro-climatic zone and
- \( \hat{L}_{iN} \) is the estimate of loss (%) of crop/commodity after pooling the enquiry and observation data of ith agro-climatic zone.
Proposed Estimation Procedure

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

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

Estimation of Loss during Storage

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

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 ith district during total enquiry period is given by
Proposed Estimation Procedure

\[ \hat{P}_i = B_i \sum_{b=1}^{b_i} \sum_{v=1}^{v_{ib}} \sum_{f=1}^{f_{ibv}} \sum_{t=1}^{T} \left( \sum_{f_{ibv}} P_{ibvf} \right) \]  

where

- \( P_{ibvf} \) 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 \( i^{th} \) district during total enquiry period is given by

\[ \hat{\zeta}_i = B_i \sum_{b=1}^{b_i} \sum_{v=1}^{v_{ib}} \sum_{f=1}^{f_{ibv}} \sum_{t=1}^{T} \left( \sum_{f_{ibv}} \zeta_{ibvf} \right) \]  

where \( \zeta_{ibvf} \) is the quantity loss of crop/commodity 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).
Proposed Estimation Procedure

- **Estimate of farm level storage loss (%) of crop/commodity by enquiry in ith district is given by**
  \[
  \hat{L}_i = \frac{\xi_i}{p_i} \times 100
  \]  
  (20)

  Estimate of variance of \( \hat{L}_i \) was obtained using eqn. 4.

- **Estimation procedure for data collected by observation:** Estimate of farm level storage loss (%) of crop/commodity by observation in ith district is given by
  \[
  \hat{L}_i' = \frac{B_i}{b_i} \sum_{b=1}^{b_i} \sum_{v=1}^{v_i} \sum_{f=1}^{f_{iv}} \left( \sum_{t=1}^{T} d_{ibvft} \right) \times 100
  \]  
  (21)

  where

  \( d_{ibvft} \) is the weight/number of crop/commodity damaged in the sample drawn at the time of \( t^{th} \) visit to \( f^{th} \) selected farmer in \( v^{th} \) selected village of \( b^{th} \) selected block of \( i^{th} \) district (by observation), \( u_{ibvft} \) is the weight/number of crop/commodity undamaged.
Proposed Estimation Procedure

in the sample drawn at the time of the th visit to the th selected farmer in the th selected village of the th selected block of the th district (by observation).

- Approximate estimate of variance of the above estimator is given by

\[
\hat{V}\left(\hat{L}_i\right) = \left(\hat{L}_i\right)^2 \left\{ \left(\hat{S}_i'\left(\hat{d}_i\right)\right)^2 + \left(\hat{S}_i'\left(\hat{TG}_i\right)\right)^2 \right\} \left[ \frac{B_i}{b_i} \sum_{ib=1}^{ibv} \sum_{ibv=1}^{ibvf} \sum_{t=1}^{T} d_{ibvt} \right]^2
\]

- Estimate of variance is obtained as

\[
\hat{V}\left(\hat{X}_i\right) = \frac{1}{b_i(b_i-1)} \sum_{b_i=1}^{ib} \left(\hat{X}_{ib} - \hat{X}_i\right)^2
\]

where

\[
\hat{X}_{ib} = \sum_{v=1}^{vib} \sum_{f=1}^{f_{ibv}} \sum_{t=1}^{T} x_{ibvt} \quad \text{and} \quad \hat{X}_i = \frac{1}{b_i} \sum_{b=1}^{b_i} \hat{X}_{ib}
\]

where \( X \) is the variable \( d_i \) or \( TG_i \)

- Pooled estimate of the estimates of loss % for data collected by enquiry and observation was obtained using eqns. 11 and 12
Proposed Estimation Procedure

**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 multistage random sampling.
- The estimate of loss % for different crops/commodity and its estimate of variance for data collected by enquiry were estimated using eqns. 18, 19 and 20.
- Estimation procedure for data collected by actual observation: Estimation of loss(%) during storage in ith district for data collected by actual observation is given by

\[
\hat{L}_i = \frac{\sum_{b=1}^{b_i} \sum_{t=1}^{T} d_{ibt}}{\left( \sum_{b=1}^{b_i} \sum_{t=1}^{T} d_{ibt} + \sum_{ib=1}^{ib} \sum_{t=1}^{T} u_{ibt} \right)} \times 100
\]  

(24)

where

- \(d_{ibt}\) is the weight/number of crop/commodity damaged in the sample drawn at the time of \(t^{th}\) visit to \(b^{th}\) respondent (Godown/wholesaler/retailer/processing unit) of \(i^{th}\) district (by observation),
- \(u_{ibt}\) is the weight/number of crop/commodity undamaged in the sample drawn at the time of \(t^{th}\) visit to \(b^{th}\) respondent (Godown/wholesaler/retailer/processing unit) of \(i^{th}\) district (by observation).
• Approximate estimate of variance of estimate of percentage loss during storage in \( i^{th} \) district is given by

\[
\hat{V}\left(\hat{L}_i\right) = \left(\hat{L}_i\right)^2 \left(\frac{\left(\hat{S}_i'(d_i)\right)^2}{\sum_{b=1}^{b_i} \sum_{t=1}^{T} d_{ibt}}\right)^2 + \left(\frac{\left(\hat{S}_i'(TG_i)\right)^2}{\sum_{b=1}^{b_i} \sum_{t=1}^{T} TG_{ibt}}\right)^2 \right)
\]  \tag{25}

The estimate of variance of \( d_i \) and \( TG_i \) was obtained as given by eqn. 21. Again, merging of estimates of loss % from data collected through enquiry and observation was carried out using eqns. 11 and 12 in order to get the pooled estimates of percentage loss.
Proposed Estimation Procedure

- 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 ($\hat{L}_{zs}$) separately for enquiry and observation data is given by

\[
\hat{L}_{zs} = \frac{\sum_{i=1}^{d} (\hat{L}_{iz})}{d}
\]  

(26)
Proposed Estimation Procedure

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

\[ \hat{S}_z = \sqrt{\frac{\sum_{i=1}^{d} \hat{V}(\hat{L}_{iz})}{d^2}} \]  

(27)

• Estimate of loss (%) and its standard error for pooled data collected by enquiry and observation at agro-climatic zone level were obtained using estimator similar to eqns. 11 and 12.
Proposed Estimation Procedure

- **Estimation of storage loss in different channels at national level:**
  
  - Estimate of percentage loss of cth crop/commodity during storage in a channel at national level by pooling data of loss (%) at agro-climatic zone level is given by
    \[
    \hat{L}_{SN}^{(c)} = \frac{\sum_{i=1}^{a} \hat{L}_{iS}}{a}
    \]  
    (28)
  
  - Estimate of standard error of estimate of storage loss (%) for each crop/commodity is given by
    \[
    \hat{S}_{SN} = \sqrt{\frac{\sum_{i=1}^{a} \hat{V} \left( \hat{L}_{iS} \right)}{a^2}}
    \]  
    (29)
Proposed Estimation Procedure

Procedure for Estimation of Total Loss of Crop/ Commodity 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 channels during storage.
- Since, the total produce is handled in each of the farm operations, the total loss of a crop/ livestock produce 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

\[
\hat{L}_{TS} = \frac{\hat{L}_F \times \hat{R}_F + \hat{L}_G \times \hat{R}_G + \hat{L}_W \times \hat{R}_W + \hat{L}_R \times \hat{R}_R + \hat{L}_P \times \hat{R}_P}{100}
\]  (30)
Proposed Estimation Procedure

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

\( \hat{R}_P \) 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.
Results and discussion

- Survey was conducted for 45 crops and commodities in 120 districts of the country.
- 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 observation.
- 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.
- The final results of crop and commodities-wise losses in different operations at national level along with % CV are reported in the next Table:
## Results and discussion

### Table: Estimates of Harvest and Post-Harvest Losses (%) of Crops and Commodities at National Level with % CV

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Crop/Commodity</th>
<th>Total Loss in Farm operations</th>
<th>Total Loss in storage channels</th>
<th>Overall Total Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Paddy</em></td>
<td>4.67</td>
<td>0.86</td>
<td>5.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.80)</td>
<td>(8.31)</td>
<td>(3.11)</td>
</tr>
<tr>
<td>2</td>
<td><em>Wheat</em></td>
<td>4.07</td>
<td>0.86</td>
<td>4.93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.58)</td>
<td>(7.65)</td>
<td>(2.05)</td>
</tr>
<tr>
<td>3</td>
<td><em>Maize</em></td>
<td>3.90</td>
<td>0.75</td>
<td>4.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.38)</td>
<td>(13.32)</td>
<td>(3.17)</td>
</tr>
<tr>
<td>4</td>
<td><em>Bajra</em></td>
<td>4.43</td>
<td>0.79</td>
<td>5.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.80)</td>
<td>(5.72)</td>
<td>(2.34)</td>
</tr>
<tr>
<td>5</td>
<td><em>Sorghum</em></td>
<td>4.78</td>
<td>1.21</td>
<td>5.99</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.98)</td>
<td>(4.25)</td>
<td>(1.72)</td>
</tr>
<tr>
<td>6</td>
<td><em>Pigeon Pea</em></td>
<td>4.69</td>
<td>1.67</td>
<td>6.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.85)</td>
<td>(3.99)</td>
<td>(2.44)</td>
</tr>
<tr>
<td>7</td>
<td><em>Chick Pea</em></td>
<td>7.23</td>
<td>1.18</td>
<td>8.41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.66)</td>
<td>(4.21)</td>
<td>(1.56)</td>
</tr>
</tbody>
</table>

Figures in parenthesis represent % CV
### Results and discussion

#### Table: Estimates of Harvest and Post-Harvest Losses (%) of Crops and Commodities at National Level with % CV

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Crop/Commodity</th>
<th>Total Loss in Farm operations</th>
<th>Total Loss in storage channels</th>
<th>Overall Total Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Black Gram</td>
<td>5.89</td>
<td>1.18</td>
<td>7.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.57)</td>
<td>(6.57)</td>
<td>(2.80)</td>
</tr>
<tr>
<td>9</td>
<td>Green Gram</td>
<td>5.37</td>
<td>1.24</td>
<td>6.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.45)</td>
<td>(6.08)</td>
<td>(2.72)</td>
</tr>
<tr>
<td>10</td>
<td>Mustard</td>
<td>5.32</td>
<td>0.22</td>
<td>5.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.33)</td>
<td>(12.94)</td>
<td>(2.89)</td>
</tr>
<tr>
<td>11</td>
<td>Cottonseed</td>
<td>2.54</td>
<td>0.54</td>
<td>3.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7.40)</td>
<td>(5.23)</td>
<td>(4.66)</td>
</tr>
<tr>
<td>12</td>
<td>Soybean</td>
<td>8.95</td>
<td>1.00</td>
<td>9.96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.14)</td>
<td>(3.64)</td>
<td>(1.56)</td>
</tr>
<tr>
<td>13</td>
<td>Safflower</td>
<td>2.80</td>
<td>0.34</td>
<td>3.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6.32)</td>
<td>(13.89)</td>
<td>(4.38)</td>
</tr>
<tr>
<td>14</td>
<td>Sunflower</td>
<td>3.65</td>
<td>1.61</td>
<td>5.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.47)</td>
<td>(6.70)</td>
<td>(1.83)</td>
</tr>
<tr>
<td>15</td>
<td>Groundnut</td>
<td>5.09</td>
<td>0.95</td>
<td>6.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.66)</td>
<td>(5.69)</td>
<td>(2.40)</td>
</tr>
</tbody>
</table>
## Results and discussion

### Table: Estimates of Harvest and Post-Harvest Losses (%) of Crops and Commodities at National Level with % CV

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Crop/Commodity</th>
<th>Total Loss in Farm operations</th>
<th>Total Loss in storage channels</th>
<th>Overall Total Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Apple</td>
<td>9.08 (1.67)</td>
<td>1.31 (4.34)</td>
<td>10.39 (1.18)</td>
</tr>
<tr>
<td>17</td>
<td>Banana</td>
<td>6.04 (2.83)</td>
<td>1.72 (5.03)</td>
<td>7.76 (1.88)</td>
</tr>
<tr>
<td>18</td>
<td>Citrus</td>
<td>7.55 (2.58)</td>
<td>2.14 (2.67)</td>
<td>9.69 (1.53)</td>
</tr>
<tr>
<td>19</td>
<td>Grapes</td>
<td>6.52 (2.05)</td>
<td>2.11 (3.74)</td>
<td>8.63 (1.32)</td>
</tr>
<tr>
<td>20</td>
<td>Guava</td>
<td>11.90 (5.33)</td>
<td>3.98 (7.07)</td>
<td>15.88 (3.58)</td>
</tr>
<tr>
<td>21</td>
<td>Mango</td>
<td>6.92 (3.97)</td>
<td>2.24 (6.33)</td>
<td>9.16 (2.80)</td>
</tr>
<tr>
<td>22</td>
<td>Papaya</td>
<td>4.12 (4.55)</td>
<td>2.58 (2.46)</td>
<td>6.70 (1.96)</td>
</tr>
<tr>
<td>23</td>
<td>Sapota</td>
<td>7.41 (4.61)</td>
<td>2.31 (1.90)</td>
<td>9.73 (2.42)</td>
</tr>
</tbody>
</table>
## Results and discussion

### Table: Estimates of Harvest and Post-Harvest Losses (%) of Crops and Commodities at National Level with % CV

<table>
<thead>
<tr>
<th>S. No.</th>
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<th>Overall Total Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>Cabbage</td>
<td>6.81 (3.16)</td>
<td>2.56 (4.13)</td>
<td>9.37 (1.95)</td>
</tr>
<tr>
<td>25</td>
<td>Cauliflower</td>
<td>7.55 (3.54)</td>
<td>2.00 (5.73)</td>
<td>9.55 (2.43)</td>
</tr>
<tr>
<td>26</td>
<td>Green Pea</td>
<td>5.72 (2.81)</td>
<td>1.73 (6.11)</td>
<td>7.45 (1.91)</td>
</tr>
<tr>
<td>27</td>
<td>Mushroom</td>
<td>7.32 (1.30)</td>
<td>2.19 (33.82)</td>
<td>9.51 (3.49)</td>
</tr>
<tr>
<td>28</td>
<td>Onion</td>
<td>6.05 (3.41)</td>
<td>2.16 (3.97)</td>
<td>8.20 (1.73)</td>
</tr>
<tr>
<td>29</td>
<td>Potato</td>
<td>6.54 (4.91)</td>
<td>0.78 (4.22)</td>
<td>7.32 (3.07)</td>
</tr>
<tr>
<td>30</td>
<td>Tomato</td>
<td>9.41 (2.10)</td>
<td>3.03 (3.95)</td>
<td>12.44 (1.44)</td>
</tr>
<tr>
<td>31</td>
<td>Tapioca</td>
<td>3.22 (3.79)</td>
<td>1.36 (7.42)</td>
<td>4.58 (2.55)</td>
</tr>
</tbody>
</table>
## Results and discussion

### Table: Estimates of Harvest and Post-Harvest Losses (%) of Crops and Commodities at National Level with % CV

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<thead>
<tr>
<th>S. No.</th>
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<th>Total Loss in storage channels</th>
<th>Overall Total Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>Arecanut</td>
<td>3.94</td>
<td>0.97</td>
<td>4.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.01)</td>
<td>(7.86)</td>
<td>(2.33)</td>
</tr>
<tr>
<td>33</td>
<td>Black pepper</td>
<td>0.99</td>
<td>0.20</td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5.64)</td>
<td>(17.77)</td>
<td>(4.62)</td>
</tr>
<tr>
<td>34</td>
<td>Cashew</td>
<td>3.82</td>
<td>0.35</td>
<td>4.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(14.99)</td>
<td>(10.08)</td>
<td>(10.26)</td>
</tr>
<tr>
<td>35</td>
<td>Chilli</td>
<td>5.11</td>
<td>1.40</td>
<td>6.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.61)</td>
<td>(5.15)</td>
<td>(2.23)</td>
</tr>
<tr>
<td>36</td>
<td>Coconut</td>
<td>3.45</td>
<td>1.32</td>
<td>4.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.38)</td>
<td>(2.70)</td>
<td>(2.11)</td>
</tr>
<tr>
<td>37</td>
<td>Coriander</td>
<td>5.33</td>
<td>0.55</td>
<td>5.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.00)</td>
<td>(4.63)</td>
<td>(0.80)</td>
</tr>
<tr>
<td>38</td>
<td>Sugarcane</td>
<td>7.29</td>
<td>0.60</td>
<td>7.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.25)</td>
<td>(7.43)</td>
<td>(1.08)</td>
</tr>
<tr>
<td>39</td>
<td>Turmeric</td>
<td>3.60</td>
<td>0.84</td>
<td>4.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.97)</td>
<td>(2.73)</td>
<td>(1.75)</td>
</tr>
</tbody>
</table>
## Results and discussion

### Table: Estimates of Harvest and Post-Harvest Losses (%) of Crops and Commodities at National Level with % CV

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Crop/Commodity</th>
<th>Total Loss in Farm operations</th>
<th>Total Loss in storage channels</th>
<th>Overall Total Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>Egg</td>
<td>4.88</td>
<td>2.31</td>
<td>7.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.68)</td>
<td>(3.00)</td>
<td>(1.05)</td>
</tr>
<tr>
<td>41</td>
<td>Inland Fish</td>
<td>4.18</td>
<td>1.05</td>
<td>5.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.25)</td>
<td>(11.59)</td>
<td>(2.51)</td>
</tr>
<tr>
<td>42</td>
<td>Marine Fish</td>
<td>9.61</td>
<td>0.91</td>
<td>10.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.05)</td>
<td>(9.71)</td>
<td>(0.94)</td>
</tr>
<tr>
<td>43</td>
<td>Meat</td>
<td>1.99</td>
<td>0.72</td>
<td>2.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.91)</td>
<td>(5.22)</td>
<td>(1.89)</td>
</tr>
<tr>
<td>44</td>
<td>Poultry meat</td>
<td>2.74</td>
<td>4.00</td>
<td>6.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(13.37)</td>
<td>(2.05)</td>
<td>(4.21)</td>
</tr>
<tr>
<td>45</td>
<td>Milk</td>
<td>0.71</td>
<td>0.21</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7.98)</td>
<td>(39.22)</td>
<td>(6.33)</td>
</tr>
</tbody>
</table>
It can be observed from the previous Table that

- The losses in cereals were estimated to be in the range of 4.65% (Maize) to 5.99% (Sorghum).
- The total losses in pulses ranged from 6.60% (Green gram) to 8.41% (Chick pea).
- Estimated losses of oil seeds ranged from 3.08% (Cottonseed) to 9.96% (Soybean).
- For fruits, the losses ranged from 6.70% (Papaya) to 15.88% (Guava).
- 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.
- In plantation crops and spices, the losses ranged from 1.18% (Black pepper) to 7.89% (Sugarcane).
Results and discussion

- 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. R&D 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.
Conclusions

- A suitable 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 observation 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 livestock produce in India have been obtained through an integrated national level survey conducted during 2013-2014.
- This study provides reliable estimates of losses in various operations and storages in different channels.
Conclusions

- Harvesting and threshing practices should be standardized and refinements in machines are needed to reduce the loss.
- Appropriate techniques and infrastructure for short-term storages need to be popularized and made available.
- Diverting the excess produce for value addition has potential to reduce the losses and stabilize the prices as well.
- Training, demonstrations, incubation and entrepreneurship development, skill development and appropriate publicity may be helpful in this regard.
- Investment in post-harvest infrastructure and mega Food Park is the need of hour for reduction of losses.
References


References


• Jha, SN, Vishwakarma, RK, Ahmad, T, Rai, A and Dixit, AK (2015). 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, Ludhiana, India


References


Thank You