[1]Food Loss Index for India for inclusion of the SDG indicator 12.3.1 in the National Indicator Framework of India

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Abstract

In India, the Ministry of Statistics and Programme Implementation (MoSPI), Government of India (GoI) has the responsibility of developing a National Indicator Framework (NIF) for monitoring Sustainable Development Goals (SDGs) at the national level. Indian Council of Agricultural Research (ICAR)-Indian Agricultural Statistics Research Institute (IASRI) in collaboration with ICAR-Central Institute of Post Harvest Engineering & Technology (CIPHET), has developed a sampling methodology for the estimation of harvest and post-harvest losses of major crops and commodities in India and this methodology was adopted in the previous three national-level surveys conducted during 2005-2007, 2012-2014 and 2020-2022 for estimating percentage loss of 45, 45 and 54 crops and commodities respectively.

Additionally, recognizing the need of separate methodology for grains, horticultural crops, livestock and fish by the countries, Food and Agriculture Organization of the United Nations (FAO), Rome signed a Letter of Agreement with ICAR-IASRI to develop guidelines to meet the growing demand from countries for methodological guidance and technical assistance. Accordingly, three separate methodologies i.e. sampling methodology for estimation of harvest and post-harvest losses of (i) horticultural crops, (ii) livestock and (iii) fish have been developed. The developed sampling methodology for estimation of harvest and post-harvest losses of (i) fruits and vegetables was field tested in Mexico and (ii) meat and milk was field tested in Zambia. In addition, technical guidance was provided to the officials of government of Nepal and Thailand for field testing of the developed methodologies for food loss measurement in tomato and milk in Nepal, and mungbean and banana in Thailand. The developed methodologies provide crop and commodity-wise reliable estimates of losses at district/sub-district level which in turn will be helpful in conducting national level surveys for the respective crops and commodities. The estimates of percentage loss along with their percentage coefficient of variation (%CV) obtained for these four countries have been compared with the estimates of these crops and commodities obtained under the study conducted in India.

Also, since India is the only country that has carried out three nation-wide sample surveys on food losses along the entire supply chain, the Food Loss Index (FLI) i.e. SDG Indicator 12.3.1, has been compiled following the methodology developed by the FAO and methodology for year-wise estimation of food loss developed by ICAR-IASRI, based on the data obtained from these three national-level post-harvest losses (PHL) surveys conducted using the methodology developed by ICAR-IASRI in collaboration with ICAR-CIPHET. Some alternative variants of FLI for India under two different categories; (i) Country FLI with 2005 as base year and (ii) FLI for India with 2015 as

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base year for SDG monitoring and international comparison, have been compiled. Under FLI for India with 2015 as base year for SDG monitoring, the following has been carried out:

i) Calculation of FLI for India for international monitoring of SDG considering 2015 as base year based on loss estimates with harvest loss
ii) Calculation of FLI for India for international monitoring of SDG considering 2015 as base year based on loss estimates without harvest loss.

It is evident under this study that the Food Loss Percentage (FLP) for India has decreased from 4.72% to 3.68% using internationally agreed commodity basket recommended by FAO and from 5.35% to 4.30% using all 45 commodities during 2005-2022 considering 2005 as the base year inferring that there is a gain of 1.04% and 1.05% decrease respectively in food losses for India over the period of 2005-2022. It can also be seen that FLI for India has decreased from 100.00 to 77.90 using internationally agreed commodity basket recommended by FAO and from 100.00 to 80.39 using all 45 commodities during 2005-2022 considering 2005 as the base year and using step-wise year-wise decrement procedure. Report on FLI for India for including SDG indicator 12.3.1 in National Indicator Framework (NIF) of India was accepted by FAO, Rome. Consequently, MoSPI, GoI has approved inclusion of FLI in NIF of India. Therefore, SDG 12.3.1a "Food Loss Index" is included in the NIF 2025 of India by the GoI for its global reporting and finally FLI for India i.e. SDG 12.3.1a has been officially reported to FAO by GoI.

Key Words: Food losses; food security; food loss measurement; food loss index; sampling; sampling methodology; SDG 12.3.1; SDG monitoring; SDG progress.

1. Introduction

One of the key programmatic areas of Food and Agriculture Organization of the United Nations (FAO) is the measurement of country progress towards achieving Sustainable Development Goals (SDGs). The objective of the SDG 12 is to 'Ensure sustainable consumption and production patterns', with the more specific Target 12.3 which aims, "by 2030, to halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses." Many studies on methodological aspects were 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.

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. 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. 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.

Nanda *et al.* (2012) and Jha *et al.* (2015) conducted nationwide surveys during 2005-2007 and 2012-2014 respectively to assess the harvest and post-harvest losses of major crops and commodities in India. The integrated sampling methodology developed for estimation of quantitative harvest and post-harvest losses of major crops and commodities for these national level surveys has been discussed in Ahmad *et al.* (2021) which provides reliable estimates of quantitative harvest and post-harvest losses of 45 crops and commodities in India in various operations and storages in different channels at agro-climatic zone level and national level.

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 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). NABCONS (2022) conducted a study to determine post-harvest losses of agri produces in India involving a national level surveys during 2020-2022 covering 54 crops and commodities in various operations and channels at district, state, agro-climatic zone and national level.

Sampling methodology for estimation of harvest and post-harvest losses of (i) fruits and vegetables was field tested in Mexico and (ii) meat and milk was field tested in Zambia. FAO (2020a) discussed in detail the findings from the field test on estimating harvest and post-harvest losses of fruits and vegetables in Mexico in 2018 in collaboration with ICAR-IASRI and National Institute of Statistics and Geography (INEGI), Mexico. Field testing of the guidelines on estimating harvest and post-harvest losses of meat and milk was carried out in Zambia in 2018 in collaboration with ICAR-IASRI and Central Statistical Office of Zambia (CSO) and is discussed in detail in FAO (2020b). In addition, technical guidance was provided by ICAR-IASRI to the officials of government of Nepal and Thailand for field testing of the developed methodologies for food loss measurement in tomato & milk in Nepal and mungbean & banana in Thailand in 2019.

Therefore, in this paper, the sampling methodologies developed for food loss measurement of horticultural crops, livestock and fish have been discussed and the estimates of percentage loss along with their %CV obtained for the above four field testing countries have been compared with the estimates of these crops and commodities obtained during the study conducted in India. Also, since India is the only country that has carried out three nation-wide sample surveys on food losses along the entire supply chain, the Food Loss Index i.e. SDG Indicator 12.3.1, has been compiled based on the data obtained from the above mentioned three national-level PHL surveys.

2. Proposed sampling design 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 of horticultural crops (fruits and vegetables) is as follows:

Sampling design and sample size for on-farm post-harvest loss assessment in case of fruits

In order to estimate the on-farm losses in fruits, stratified multistage sampling has been proposed for selection of samples treating different agro-climatic zones of a country as strata, districts in each stratum as primary stage units (PSUs), sub-districts as secondary stage units (SSUs), villages/ Enumeration Areas (EAs) as third stage units (TSUs), orchards as fourth stage units and bearing trees as ultimate stage units (USUs). Within the stratum, at all stages, sampling units are selected by Simple Random Sampling Without Replacement (SRSWOR) i.e. equal probability sampling scheme using proportional allocation.

Sampling design and sample size for on-farm post-harvest loss assessment in case of vegetables

In order to estimate the on-farm losses in vegetables, stratified multistage sampling has been proposed for selection of samples treating different agro-climatic zones of a country as strata, districts in each stratum as primary stage units (PSUs), sub-districts as secondary stage units (SSUs), villages/Enumeration Areas (EAs) as third stage units (TSUs), vegetable growers as fourth stage units, parcels as fifth stage units and plots within the selected parcel as ultimate stage units (USUs). Within the stratum, at all stages, sampling units are selected by SRSWOR i.e. equal probability sampling scheme using proportional allocation. The plots of specified size 5m x 5m within the selected parcels are selected using Crop Cutting Experiments (CCE) technique.

For both fruits and vegetables survey, within each stratum, 10% districts are to be selected by SRSWOR following proportional allocation. From each selected district, two sub-districts, from

each selected sub-district, five villages/enumeration areas and from each selected village/ enumeration area, five orchards/ten vegetable growers are to be selected randomly using SRSWOR.

In case of fruits survey, for selection of five orchards, a list of households growing fruit crops in the season is to be prepared using a designed questionnaire and the number for each fruit crop is given separately. An orchard is to be considered as an orchard for selection purpose, if minimum 12 fruit bearing trees of particular crop are planted in a cluster by systematic manner on a single piece of land managed by singly or jointly. Total five orchards are to be selected if only one fruit crop is planted in the village/Enumeration area. If more than one fruit crops are planted in the village/Enumeration area, three orchards of major fruit crop (more number of orchards) and two of minor crop (orchards at second place as per number) are to be selected randomly. Loss during plucking/ harvesting is to be recorded from all 5 selected orchardists by inquiry. For recording data through actual measurement, 2 orchards are to be selected out of 5 selected orchards by SRSWOR and two fruit bearing trees out of total number of bearing tress in each selected orchard are to be selected using SRSWOR. A list of bearing trees within the selected orchard is to be prepared for selection of bearing trees out of total number of bearing trees.

In case of vegetables survey, for selection of ten vegetable growers, a list of households growing vegetables in the season is to be prepared using a designed questionnaire. Further, it is to be arranged in decreasing order as per area of vegetable crops planted or expected to be planted/sown in the current survey period which needs to be sub-stratified into two categories. The first and second category may have equal number of vegetable growers, if total number of vegetable growers in the village/enumeration area is even number. In case total number of vegetable growers is odd, then the first category will have one additional vegetable grower (i.e. if total is 20 then 10 in first and 10 in second category or if total is 21 then 11 in first and 10 in second category). Random samples of 6 vegetable growers are to be selected from the first category and four from the second category. In case, the number of vegetable growers is less than the number suggested in each category, all vegetable growers are to be selected. In case, it is less in either of the categories, then rest of the vegetable growers are to be selected from another category. Loss during harvesting/plucking is to be recorded from selected vegetable growers by inquiry and from four vegetable growers out of ten vegetable growers by actual measurement. From each selected grower, one major vegetable crop needs to be identified based on area of each crop for recording actual measurement through CCE. It is suggested to record picking on the day of visit in case of multiple picking crops and observe the loss in operation.

The sampling design proposed here for loss assessment in case of fruits and vegetable crops may be similar to the sampling design recommended for estimation of area and production of horticultural crops especially fruits and vegetables (if conducted) in a country. If the sampling design proposed here for loss assessment is not similar to the standard procedures used by countries for their own existing independent horticultural surveys, this loss assessment survey may be clubbed with their agricultural or farm surveys in which the sampling design used is generally stratified multi-stage random sampling with a focus on the elements of interest for loss assessment.

Sampling design and sample size for off-farm post-harvest loss assessment in case of fruits and vegetables

It is proposed to adopt stratified multistage sampling treating agro-climatic zones as strata, districts in each stratum as primary stage units (PSUs), wholesale and retail markets (second stage units i.e. SSUs)/ cold storages/processing units as ultimate stage units (USUs). Similarly, in each of the selected wholesale and retail markets, wholesalers and retailers are third stage units (TSUs) or ultimate stage units (USUs). If markets/ cold storages/processing units are not available in the selected district, they may be selected from nearby district or even outside the stratum which is the closest. Within the stratum, at all stages, sampling units are to be selected by SRSWOR i.e. equal

probability sampling scheme using proportional allocation. A portion/ part of the selected markets is completely enumerated for preparation of sampling frame of wholesalers and retailers. Within each stratum, 10% districts are to be selected by SRSWOR following proportional allocation. 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 are to be selected randomly from the list of the respondents prepared after complete enumeration of units for each channel of each selected district. The data by enquiry as well as by actual measurement is to be collected from all selected respondents.

Similarly, separate sampling designs have been proposed for selection of respondents in order to collect the data for assessment of harvest and post-harvest losses of livestock (meat and milk) and fish (Ahmad *et al.* (2019b, 2019c)).

3. Proposed estimation procedure for estimation of quantitative harvest and post-harvest losses at various levels

Estimation procedures have been developed as per the proposed sampling designs 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.

For estimating the losses at agro-climatic zone level, weightage is to be assigned based on the production of the specific crop/commodity in all the sampled districts, to be obtained separately from the state/official report. Similarly, post-harvest losses at the national level are to be 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 for horticultural crops (fruits and vegetables)

Estimation of losses is to be carried out at district level for enquiry and actual measurement data separately before agro-climatic zone level. Thereafter, both data are to be 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/plucking, collection, sorting/grading, packaging and transportation). Each operation is performed separately and hence the losses are also different. Therefore, the estimation procedures for 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 percentage loss (% loss) of a fruit/vegetable obtained by enquiry in ith district is given by $\hat{L}_i = \frac{\hat{\delta}_i}{\hat{Y}_i} \times 100$ (3.1)

where, $\hat{\delta}_i = \frac{B_i}{b_i} \sum_{b=1}^{b_i} \frac{U_{ib}}{u_{ib}} \sum_{u=1}^{u_{ib}} \frac{F_{ibu}}{f_{ibu}} \sum_{f=1}^{f_{ibu}} \delta_{ibuf}$ is an estimate of quantity of a fruit/vegetable lost in a particular farm operation in ith district, $\hat{Y}_i = \frac{B_i}{b_i} \sum_{b=1}^{b_i} \frac{U_{ib}}{u_{ib}} \sum_{u=1}^{u_{ib}} \frac{F_{ibu}}{f_{ibu}} \sum_{f=1}^{f_{ibu}} y_{ibuf}$ is an estimate of quantity of a fruit/vegetable handled for the same farm operation in ith district,

B_i is total number of sub-districts in i[th] district,

b_i is number of sub-districts selected in i[th] district,

U_{ib} is total number of EAs/villages in b[th] selected sub-district of i[th] district,

u_{ib} is number of selected EAs/villages in b[th] selected sub-district of i[th] district,

F_{ibu} is total number of orchards/vegetable growers of a particular fruit/vegetable in u[th] selected EA/village of b[th] selected sub-district of i[th] district,

f_{ibu} is number of selected orchards/vegetable growers of a particular fruit/vegetable in u[th] selected EA/village of b[th] selected sub-district of i[th] district,

δ_{ibuf} is quantity of fruit/vegetable lost at a particular farm operation in the f[th] selected orchard/by vegetable grower in u[th] selected EA/village of b[th] selected sub-district of i[th] district (by enquiry),

y_{ibuf} is quantity of fruit/vegetable handled for a farm operation of a particular fruit in the f[th] selected orchard/by vegetable grower in u[th] selected EA/village of b[th] selected sub-district of i[th] district (by enquiry).

An approximate estimate of variance of $\hat{L}_i$ after ignoring higher order terms is given by

$$\hat{V}\left(\hat{L}_i\right)=\left[\frac{\hat{\delta}_i}{\hat{Y}_i}\times 100\right]^2\left[\frac{\hat{V}\left(\hat{\delta}_i\right)}{\left(\hat{\delta}_i\right)^2}+\frac{\hat{V}\left(\hat{Y}_i\right)}{\left(\hat{Y}_i\right)^2}-2\frac{\hat{Cov}\left(\hat{\delta}_i,\hat{Y}_i\right)}{\left(\hat{\delta}_i\hat{Y}_i\right)}\right]. \tag{3.2}$$

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

$$\hat{V}\left(\hat{X}_i\right)=B_i^2\left(\frac{1}{b_i}-\frac{1}{B_i}\right)\frac{1}{b_i-1}\sum_{b=1}^{b_i}\left(\hat{X}_{ib}-\hat{\bar{X}}_i\right)^2, \tag{3.3}$$

where,

$\hat{X}_{ib}=\frac{U_{ib}}{u_{ib}}\sum_{u=1}^{u_{ib}}\frac{F_{ibu}}{f_{ibu}}\sum_{f=1}^{f_{ibu}}x_{ibuf}$ is estimate of quantity handled/lost for b[th] sub-district in i[th] district and

$\hat{\bar{X}}_i=\frac{1}{b_i}\sum_{b=1}^{b_i}\hat{X}_{ib}$ is the mean of variable (quantity handled or quantity lost) for i[th] district and

the estimate of covariance of $\hat{\delta}_i$ and $\hat{Y}_i$ is given by

$$\hat{Cov}\left(\hat{\delta}_i,\hat{Y}_i\right)=B_i^2\left(\frac{1}{b_i}-\frac{1}{B_i}\right)\frac{1}{b_i-1}\sum_{b=1}^{b_i}\left(\hat{\delta}_{ib}-\hat{\bar{\delta}}_i\right)\left(\hat{Y}_{ib}-\hat{\bar{Y}}_i\right). \tag{3.4}$$

Estimation procedure for data collected by actual measurement:

An estimate of percentage loss (% loss) of the fruit/vegetable crop obtained by actual measurement in i[th] district is given by

$$\hat{L}_i'=\frac{\hat{\delta}_i'}{\hat{Y}_i'}\times 100 \tag{3.5}$$

where, in case of fruits,

$\hat{\delta}_i^{'} = \frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{U_{ib}}{u_{ib}}\sum_{u=1}^{u_{ib}}\frac{F_{ibu}}{f_{ibu}}\sum_{f=1}^{f_{ibu}}\frac{M_{ibuf}}{m_{ibuf}}\sum_{m=1}^{m_{ibuf}}\delta_{ibufm}^{'}$ is an estimate of quantity of a fruit lost in a particular farm operation in i[th] district,

$\hat{Y}_i^{'} = \frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{U_{ib}}{u_{ib}}\sum_{u=1}^{u_{ib}}\frac{F_{ibu}}{f_{ibu}}\sum_{f=1}^{f_{ibu}}\frac{M_{ibuf}}{m_{ibuf}}\sum_{m=1}^{m_{ibuf}}y_{ibuf}^{'}$ is an estimate of quantity of a fruit handled for the same farm operation in i[th] district, and in case of vegetables,

$\hat{\delta}_i^{'} = \frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{U_{ib}}{u_{ib}}\sum_{u=1}^{u_{ib}}\frac{F_{ibu}}{f_{ibu}}\sum_{f=1}^{f_{ibu}}\delta_{ibuf}^{'}$ is an estimate of quantity of a vegetable lost in a particular farm operation in i[th] district by actual measurement through CCE,

$\hat{Y}_i^{'} = \frac{B_i}{b_i}\sum_{b=1}^{b_i}\frac{U_{ib}}{u_{ib}}\sum_{u=1}^{u_{ib}}\frac{F_{ibu}}{f_{ibu}}\sum_{f=1}^{f_{ibu}}y_{ibuf}^{'}$ is an estimate of quantity of a vegetable handled for the same farm operation in i[th] district by actual measurement through CCE,

M_{ibuf} is total number of bearing trees in f[th] orchard of a fruit in u[th] selected EA/village of b[th] selected sub-district of i[th] district,

m_{ibuf} is number of selected bearing trees in f[th] orchard of a fruit in u[th] selected EA/village of b[th] selected sub-district of i[th] district,

$\delta_{ibufm}^{'}$ is quantity of a fruit lost at a particular farm operation for the m[th] selected bearing tree in the f[th] selected orchard in u[th] selected EA/village of b[th] selected sub-district of i[th] district (by actual measurement),

$y_{ibufm}^{'}$ is quantity handled at the farm operation of a particular fruit for the m[th] selected bearing tree in the f[th] selected orchard in u[th] selected EA/village of b[th] selected sub-district of i[th] district (by actual measurement).

$\delta_{ibuf}^{'}$ is quantity of a vegetable lost at a particular farm operation in the CCE plot of the f[th] selected vegetable grower in u[th] selected EA/village of b[th] selected sub-district of i[th] district (by actual measurement),

$y_{ibuf}^{'}$ is quantity handled at the same farm operation of a particular vegetable crop in the CCE plot of the f[th] selected vegetable grower in u[th] selected EA/village of b[th] selected sub-district of i[th] district (by actual measurement).

An approximate estimate of variance of $\hat{L}_i^{'}$ is to be obtained using similar to Eqns. (3.2), (3.3) and (3.4) considering

$$\hat{X}_{ib} = \frac{U_{ib}}{u_{ib}}\sum_{u=1}^{u_{ib}}\frac{F_{ibu}}{f_{ibu}}\sum_{f=1}^{f_{ibu}}\frac{M_{ibuf}}{m_{ibuf}}\sum_{m=1}^{m_{ibuf}}x_{ibufm} \quad \text{and} \quad \hat{\bar{X}}_i = \frac{1}{b_i}\sum_{b=1}^{b_i}\hat{X}_{ib} \text{ (in case of fruits)} \tag{3.6}$$

$$\text{and } \hat{X}_{ib} = \frac{U_{ib}}{u_{ib}}\sum_{u=1}^{u_{ib}}\frac{F_{ibu}}{f_{ibu}}\sum_{f=1}^{f_{ibu}}x_{ibuf} \quad \text{and} \quad \hat{\bar{X}}_i = \frac{1}{b_i}\sum_{b=1}^{b_i}\hat{X}_{ib} \text{ (in case of vegetables)} \tag{3.7}$$

where $\hat{\bar{X}}_i$ is the mean of variable (quantity handled (y') or quantity lost (δ')) for i[th] district and $\hat{X}_{ib}$ is the estimate of quantity handled/lost at a farm operation by actual measurement for b[th] sub-district in i[th] district.

Pooling of enquiry and actual measurement based estimators at district level:

In order to estimate the % loss during farm operations at district level for different fruits/ vegetable crops, the estimate of percentage loss of fruit/vegetable in the ith district is to be obtained by pooling estimate of percentage loss by enquiry and actual measurement using weighted estimator given by

$$\hat{L}_{iw} = \frac{\hat{s}_i^2 \hat{L}_i' + \hat{s}_i'^2 \hat{L}_i}{\left(\hat{s}_i'^2 + \hat{s}_i^2\right)} \tag{3.8}$$

where, $\hat{L}_i'$ and $\hat{s}_i'$ are estimate of % loss and its standard error during a farm operation in ith district obtained by actual measurement and $\hat{L}_i$ and $\hat{s}_i$ are estimate of % loss and its standard error during a farm operation in ith district obtained by enquiry.

Estimate of standard error of pooled estimate of percentage loss in a farm operation of ith district is given by

$$\hat{S}_{iw} = \sqrt{\frac{\hat{s}_i'^2 \hat{s}_i^2}{\hat{s}_i'^2 + \hat{s}_i^2}} \tag{3.9}$$

Estimation of loss at strata (agro-climatic zone) level

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

$$\hat{L}_z^* = \left(\sum_{i=1}^{d} \hat{P}_{iz} \times \hat{L}_{iz}^*\right) \Big/ \sum_{i=1}^{d} \hat{P}_{iz} \tag{3.10}$$

where $\hat{P}_{iz}$ is the estimate of production of the fruit/vegetable crop for the ith district falling in zth agro-climatic zone in the agricultural year for which the percentage loss is being estimated and $\hat{L}_{iz}^*$ is the estimate of percentage loss (% loss) obtained by enquiry ($\hat{L}_i$)/ actual measurement ($\hat{L}_i'$) for the fruit/vegetable in the ith district of zth agro-climatic zone. Thus, the percentage loss at agro-climatic zone level is to be 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

$$\hat{S}_z^* = \sqrt{\left(\sum_{i=1}^{d} \hat{P}_{iz}^2 \times \hat{V}\left(\hat{L}_{iz}^*\right)\right) \Big/ \left(\sum_{i=1}^{d} \hat{P}_{iz}\right)^2} \tag{3.11}$$

where $\hat{\mathrm{V}}\left(\hat{L}_{iz}^*\right)$ is the estimate of variance of percentage loss for data collected by enquiry/ actual measurement in the ith district of zth agro-climatic zone using equations (3.2), (3.3), (3.4), (3.6) and (3.7). The estimate of loss (%) and its standard error for data collected by enquiry and actual measurement at agro-climatic zone level is to be obtained using pooled estimator similar to equations (3.8) and (3.9) respectively.

Estimation of loss in farm operations at National level

Estimation of losses at national level in different farm operations is to be obtained from pooled estimates of % loss (enquiry and actual measurement) at agro-climatic zone level. Estimate of

percentage loss of a fruit/vegetable crop at national level is to be obtained using weighted estimator as given by

$$\hat{L}_N = \frac{\sum_{z=1}^{Z} \hat{P}_z \times \hat{L}_{zw}}{\sum_{z=1}^{Z} \hat{P}_z} \tag{3.12}$$

where, $\hat{P}_z$ is the estimate of production of the fruit/vegetable crop in z^{th} agro-climatic zone and $\hat{L}_{zw}$ is the pooled weighted estimate of % loss using the enquiry and actual measurement data for the fruit/vegetable crop of z^{th} agro-climatic zone.

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

$$\hat{S}_N = \sqrt{\left(\sum_{z=1}^{Z} \hat{P}_z^2 \times \hat{V}\left(\hat{L}_{zw}\right) \right) \Big/ \left(\sum_{z=1}^{Z} \hat{P}_z \right)^2} \tag{3.13}$$

where, $\hat{V}\left(\hat{L}_{zw}\right)$ is the estimate of variance of loss (%) for the pooled weighted estimate $\hat{L}_{zw}$ using data collected by enquiry and actual measurement at strata level in z^{th} agro-climatic zone level.

3.2 Estimation of farm level storage loss and loss in storage and marketing channels

In order to estimate farm level storage loss and loss in storage and marketing channels from the data collected by enquiry and actual measurement, district-wise estimates are to be obtained separately and then pooled through an optimum pooling technique and agro-climatic zone and national level estimates are to be obtained following the estimation procedure given in (Ahmad *et al.* (2019b, 2019c)).

Similarly, separate estimation procedures have been developed as per the proposed sampling designs for assessment of harvest and post-harvest losses of livestock (meat and milk) and fish for different channels/operations (Ahmad *et al.* (2019b, 2019c)).

4. Field testing in four different countries

The developed sampling methodology for estimation of harvest and post-harvest losses of fruits and vegetables was field tested in Mexico in 2018 in collaboration with FAO, Rome and INEGI, Mexico. The developed sampling methodology for estimation of harvest and post-harvest losses of meat and milk was field tested in Zambia in 2018 in collaboration with FAO, Rome and CSO, Zambia. Also, technical guidance was provided by ICAR-IASRI to the officials of Govt. of Nepal and Thailand for field testing of the developed methodologies for food loss measurement in tomato and milk in Nepal and mungbean and banana in Thailand in 2019 in collaboration with FAO Regional Office for Asia and the Pacific (FAORAP), Bangkok.

5. Food Loss Index (FLI) for India based on previous three national level surveys

The Food Loss Index (FLI) focuses on food losses that occur from production to the retail level. It measures the changes in percentage losses for a basket of 10 main commodities by country in comparison with a base period. The FLI contributes to measure progress towards SDG Target 12.3. India is the only country in the world which has conducted three national level surveys on harvest and post-harvest losses at the interval of 6-7 years for estimating percentage loss of 45, 45 and 54 crops and commodities respectively along the entire supply chain. The FLI for India has been computed following the methodology developed by FAO to compute FLI based on three national level post-harvest losses (PHL) surveys conducted during 2005-2007, 2012-2014 and 2020–2022 for 45, 45 and 54 crops and commodities respectively. The calculation of the Food Loss Percentage

(FLP) and FLI were designed by FAO to be a simple tool to monitor food losses from production to retail under the SDG Indicator 12.3.1. Although the calculation is simple, the greatest amount of effort is for countries in conducting PHL survey either as an independent survey or with the existing national level surveys for collecting the data for estimation of loss percentages for the key commodities following the guidelines developed by FAO. The FLI for India based on the three surveys is shown in Figure 1.

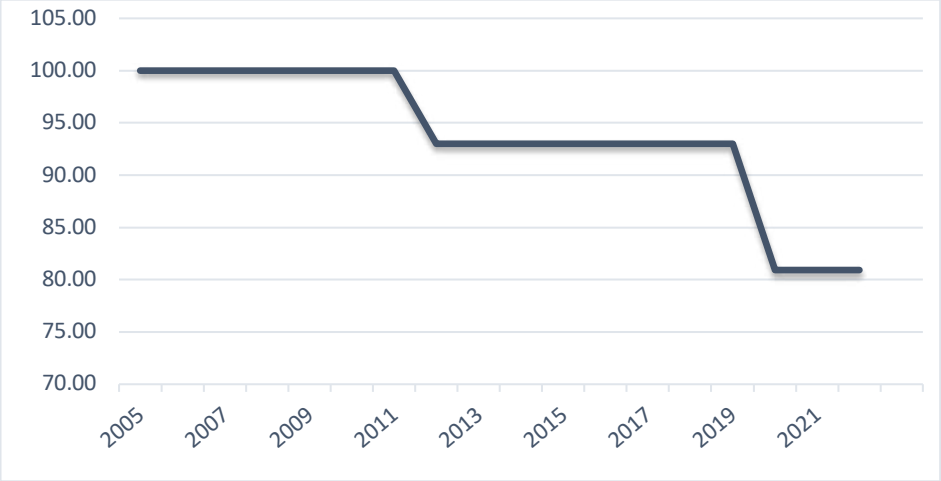

Figure 1. The Food Loss Index (FLI) for India 2005-2022

6. Results and discussion

The sampling methodology developed for estimation of harvest and post-harvest losses of (i) fruits and vegetables was field tested in Mexico and (ii) meat and milk was field tested in Zambia. Field testing of the developed methodologies was also carried out for food loss measurement in (i) tomato and milk in Nepal and (ii) mungbean and banana in Thailand. The estimates of percentage loss of these field tested crops and commodities along with their %CV were obtained for these four countries and have been compared with the national level estimates of percentage loss of these crops obtained during the study conducted during 2012-15 in India which are given in Table 1.

Table 1. Estimates of Harvest and Post-Harvest Losses (%) with %CV

Sl. No.	Country	Level	Crop / Commodity	Loss in On-farm Operations (%)	Loss in Off-farm Operations (%)	Overall Loss (%)
1	Mexico	Sub-district	Banana	**3.67** (16.81)	**6.91** (28.12)	**10.58** (19.28)
		Sub-district	Broccoli	**28.86** (10.17)	**43.67** (17.72)	**72.53** (11.41)
2	Zambia	District	Milk	**8.92** (17.69)	**4.66** (15.02)	**13.58** (12.34)
		District	Meat	**3.99** (14.74)	**2.63** (4.84)	**6.62** (9.08)
3	Nepal	Ward	Tomato	**2.29**	**13.60**	**15.89**
		Ward	Milk	**0.79**	**4.63**	**5.42**
4	Thailand	Sub-district	Banana	**2.81**	**1.68**	**4.49**
		Sub-district	Mungbean	**7.08**	-	**7.08**
5	India	National	Banana	**6.04** (2.83)	**1.72** (5.03)	**5.99** (1.72)
		National	Cauliflower	**7.55** (3.54)	**2.00** (5.73)	**9.55** (2.43)

		National	Milk	**0.71** (7.98)	**0.21** (9.22)	**0.92** (6.33)
		National	Meat	**1.99** (2.91)	**0.72** (5.22)	**2.71** (1.89)
		National	Tomato	**9.41** (2.10)	**3.03** (3.95)	**12.44** (1.44)
		National	Pigeon Pea	**4.69** (4.85)	**1.67** (3.99)	**6.36** (2.44)

Figures in parenthesis represent % CV

It can be observed from the above table that the results indicate substantial variation in loss levels across countries and commodities. In Mexico, total losses for banana and broccoli at the sub-district level were estimated at 10.58 percent and 72.53 percent, respectively, with acceptable precision levels. In Zambia, district-level losses for milk and meat were estimated at 13.58 percent and 6.62 percent, respectively, exceeding corresponding national-level estimates reported for India. Nepal exhibited relatively high losses in tomato and moderate losses in milk, while Thailand's estimates for banana and mungbean were broadly comparable to Indian national-level figures. The coefficients of variation reported in Table 1 generally fall within acceptable limits for agricultural surveys, indicating that the proposed methodology is capable of producing reliable estimates even in pilot-scale applications. Notably, higher variability was observed for commodities with highly fragmented production systems or pronounced seasonality, underscoring the importance of adequate sample sizes and careful domain specification.

It is evident from this study that the FLP for India has decreased from 4.72% to 3.68% using internationally agreed commodity basket recommended by FAO and from 5.35% to 4.30% using all 45 commodities during 2005-2022 considering 2005 as the base year and using step-wise year-wise decrement procedure inferring that there is a gain of 1.04% and 1.05% decrease respectively in food losses for India over the period of 2005-2022. It can also be seen that FLI for India has decreased from 100.00 to 77.90 using internationally agreed commodity basket recommended by FAO and from 100.00 to 80.39 (Figure 1) using all 45 commodities during 2005- 2022 considering 2005 as the base year. This indicates that India has been undertaking loss reduction strategies even prior to the start of the SDG 12.3.1 monitoring process.

Conclusions

In this study, three separate methodologies i.e. sampling methodology for estimation of harvest and post-harvest losses of (i) horticultural crops, (ii) livestock and (iii) fish have been developed. The developed methodologies were field tested in four different countries namely Mexico, Zambia, Nepal and Thailand and provide crop and commodity-wise reliable estimates of losses at district/ sub-district level which in turn will be helpful in conducting national level surveys for the respective crops and commodities. These methodologies may be used for conducting the field tests and adoption in different countries which may be helpful in generation of quality data and reliable estimates of food loss in different countries.

Also, the Food Loss Index compilation i.e. SDG Indicator 12.3.1, has been compiled on the available India's data based on the previous three national level surveys and it was observed over the period of the three different studies that there were decreases in losses over the previous period for some of the key commodities. Report on FLI for India for including SDG indicator 12.3.1a in National Indicator Framework (NIF) of India was accepted by FAO, Rome. Consequently, MoSPI, GoI has included FLI in NIF 2025 of India and has officially reported FLI i.e. SDG 12.3.1a to FAO.

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