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Developing cost-effective statistical methods for measuring post-harvest losses in developing countries

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ABSTRACT

In line with the current policy debate on agriculture and rural development, the improvement of methods for estimating post-harvest losses was identified by FAO member countries as a priority research topic to be included in the Research Programme of the FAO Global Strategy to Improve Agriculture and Rural Statistics (GS). The objective of this research is to develop cost-effective statistical methods for measuring post-harvest losses.

Keywords: post-harvest losses, statistical methods, cost-effective.

PAPER

1. Introduction and background

Historically, loss assessment studies have been associated with loss reduction/prevention programmes. The Seventh Session of the United Nations General Assembly, meeting in 1975, set the goal of 50% reduction of post-harvest losses by 1985.

In 1976, FAO formulated a Special Action Programme that identified three major constraints on post-harvest loss prevention in the developing countries. They were as follow:

1. lack of information about the amplitude of the losses, the nature of the losses, their causes and the most effective techniques for reducing or preventing them;
2. lack of infrastructure for implementing loss prevention measures;
3. lack of investment in food loss prevention.

These events highlighted the need to develop standard and suitable terminology and methodology for the measurement of losses.

The manual "Postharvest grain loss assessment methods. A manual of methods for the evaluation of postharvest losses" was then developed by Kenton L. Harris and Carl J. Lindblad published in 1978.

Some methods and techniques compiled by Harris and Lindblad (quite accurate and detailed) were first reviewed by R. A. Boxall in the period 1980-1986, in an attempt to simplify them.

During that same period, FAO also published a manual "assessment and collection of data on post-harvest food-grain losses", manual intended to serve as a guide to the statistical methodology for assessing and collecting data on post-harvest food-grain losses, using objective measurements coupled with statistical survey sampling techniques.

During the period 1990-2000 researchers improved on the previous methods and kept on more and more using the rapid methods (visual scales, standard chart for instance, described above). J.A.F. Compton and J. Sherington, for instance, devised rapid assessment methods for stored maize cobs where weight losses were due to insect pests. From 2000 onward, additional methodological improvements have been brought about by the APHLIS team project and other researchers by making the rapid methods work with more modern sampling-based field surveys to provide the data necessary for loss estimations.

Most of the time, loss prevention and reduction efforts are undertaken within only part of the post-harvest system. Basically this is done by identifying the most obvious and serious grain loss points in a country's post-harvest food system and concentrate the loss prevention and reduction efforts on those points. Methodologies for measuring post-harvest losses, aim at providing outcomes that allow the determination of priorities for loss prevention and reduction efforts.

Assessments may be made by surveys (traditional or improved), or by experimental design studies (field studies, trials), and more recently by using econometric modelling (special cases of machine learning algorithms).

Because of the need to obtain reliable estimates of loss, FAO and other organizations conducted literature reviews in the seventies to map the extent of available quantitative information on post-harvest losses in cereals. A number of examples of very high estimates of unsubstantiated losses were found, most of it due to the ambiguity of the terminology used by their authors. Quoted figures of the type "39% for grain losses in Sub-Saharan Africa, or 45% for pearl millet losses in Namibia" may not provide an objective view of the real situation. In certain situations, figures provided for certain stages of a stated post-harvest chain have simply been totalled, leading to over-estimates. Boxall, in 1986 gave an illustration along the following example:

Table 1 - How post-harvest losses may be over-estimated (Boxall, 1986)

Chain level	% loss	Weight loss (kg)	Balance (kg)
Start	----	----	1,000.00
Harvesting	15	150.00	850.00
Threshing	10	85.00	765.00
Drying	5	38.25	726.75
Transport	5	36.34	690.41
Storage	10	69.04	621.37
Processing	10	62.14	559.23
	-----	--------	
	55%	440.77	

If it is wrongly assumed that each loss figure is a percentage of the initial weight of product, over-estimation will ensure. In fact, here, each loss figure is a percentage of the amount remaining in the preceding level of the chain. Hence, the total loss 55%, a simple addition of the losses at different levels, is an obvious over-estimate. The proper loss is shown on the weights in the right-most two columns, namely 440.77 kg loss from the potential 1,000 kg or 44.077%.

Over-estimation can also happen during farm level storage loss studies, when grains are being withdrawn at certain intervals during the storage period. In that case it is not enough to record only one loss figure at one point in time during the season and use it as an indication of the overall loss for the year.

2. Types of loss assessment studies

General baseline surveys

These are for preliminary examination of specific problem points and are conducted first to expose the most serious grain loss points. They may or may not be randomized, and may include elements of purposive sampling. Properly conducted, they allow the post-harvest system to be better understood, and the causes of losses to be revealed. At the same time they are conducted, additional relevant available data from other sources like administrative records (rainfall, temperature, etc.) should be collected. These surveys always preceding the main loss assessment survey, should also try to provide initial rough expected values for losses.

Probability sample surveys

They are used for the main loss assessment exercise, with the aim is to obtain statistically reliable quantitative data at different administrative and agro-ecological units (village, regional, national, etc.). Procedures like random sampling (simple, stratified, clustered) with possibly sampling stages, are used. In cases where the primary sampling units differ widely in size, sampling with probability proportional to size can be used. These operations are of course quite expensive and require specially trained personnel. Probability sample surveys (both traditional and modern) are best suited for value chain processes like harvesting, threshing, drying, and processing. They tend to be less suitable for estimating losses during the storage stages of the value chain, where processes of biological degradation occur.

Experimental designs – Field trials

These are also used for loss assessment studies; moreover they can handle loss comparisons between traditional and improved practices. Storage simulation trials can be conducted at research stations with a high degree of control over the conditions of the experiment; alternative post-harvest production practices can be evaluated for their effect on the level of losses, and multivariate analysis is performed using regression models.

Appiah F, Guisse R, and Dartey P.K.A 2009/2010, have used this technique in a study of post-harvest losses of rice from harvesting to milling in Ghana (Ejisu Juabeng District) to provide basic important information regarding the losses.

Multivariate Linear Regression Fitting

Strictly speaking, this is more of an estimation technique than a type of study; data are collected from surveys and administrative records to create a database that is then used to estimate model parameters. At different stages of the food loss value chain, some of the factors causing quantitative and qualitative losses are inter-related. For example at the storage stage, variables like storage structure, moisture content, temperature, relative humidity, insects, mites, rodents, micro-organisms attacks, respiration, and other biological processes (independent variables), all act together at the same place to impact loss variables (dependent variables). Hence, regression equations can easily be fitted to quantify the relationships between dependent and independent variables. The big advantage of doing this is the ability to predict losses in advance so that planners and decision makers can take appropriate measures as early as possible in their decision cycles.

Some of these techniques have been used with some success in studying the factors affecting post-harvest losses in rice and wheat at farm level in India. See H. Basavaraja, S.B. Mahajanashetti and Naveen C. Udagatti. 2007. AbdollahTaherzadeh, Seyed Saeid Hojjat. 2013 also used a regression model in Iran for the study of Post-Harvest Losses of Wheat in North Western Iran, combining post-harvest loss survey data and administrative records data.

3. General Principles of loss assessment studies

In the literature, measurement techniques and methodologies are most often presented at each of the main stages of the food loss chain. For food grain losses to be assessed at any of those stages, statisticians have developed a number of techniques, based on the following principles:

1. definition of the population for which loss estimates are to be produced;
2. construction of a proper sampling frame;
3. design of proper sampling procedure and measurement technique;
4. design of the field work organization, data collection tools, data processing and analysis tools;
5. production and publication of standard errors of the estimated variables to evaluate the quality of the information thus obtained;
6. breakdown the loss estimation at various stages into at least three levels: (a) losses at farm level; (b) losses at the level of the intermediaries (grain merchants, etc.); (c) losses at the level of government agencies (warehouses, etc).

Once the sampling issues have been sorted, the data collection techniques as briefly described below are then implemented, and appropriate estimation procedures devised to obtain average loss figures for the desired level (region, national, etc.).

As a general observation, during harvesting, in-field drying, stacking, transport, threshing, drying and cleaning, all losses caused by biological agents, should be adjusted to a dry-weight basis. Other losses are usually expressed in terms of weight of material at 14-percent moisture content (Boxall R.A. 1986). It has been found (Boxall R.A. 1986), that it was more convenient to work on the basis of the dry weight of grain which can then be simply calculated from the formula:

$$Dry\ wt.of\ grain = wt.of\ grain * \frac{(100 - m.c.of\ grain)}{100}$$

$m.c.$ is moisture content

To also be able to compare with other-loss assessment figures, losses can be expressed as percentages (rather than adjusted weights) with a clear statement of the basis of the presentation (the denominator of the percentage). Losses in harvesting, in-field drying, and stacking operations, are expressed as percentage of yield, with yield defined as obtained yield (maximum quantity of clean grain less the losses being assessed. For threshing and cleaning, losses are expressed as a percentage of the grain input to the operation. It should also be noted that farmers' practices in time of harvesting (and rainfall), duration of in-field drying, and stacking, have a marked effect on the level of losses.

4. Data collection and measurement in loss assessment studies

Building a suitable sampling frame is normally the very first stage when planning a main loss assessment survey. First and ultimate sampling units will vary depending on the level/stage of the post harvest process where losses are being measured. Lists of all these units should be prepared to allow proper selection of sampling units.

At the *harvesting level* of the chain, villages (or their groupings) are commonly the primary sampling units (PSU); holders are the secondary sampling units (SSU), and fields the ultimate (tertiary) sampling units.

PSUs may be clustered prior to sampling. Simple or stratified random sampling may be used to select the holders; for each chosen holder, a simple random sample of subplots within fields can then be selected.

For *threshing, cleaning, drying, transportation, and processing*, villages are PSUs and holders the secondary units.

For these levels, additional sampling stages will be necessary; for instance selecting a random sample of produce (maize cobs, etc.) to be threshed and observed for lost or damaged grain.

For *storage*, villages are PSUs, holders are the SSUs, and the storage units (if there are more than one) within the holding are the ultimate sampling units.

The villages (PSUs) may be selected via simple random sampling, stratified random sampling, or may be sampled with probability proportional to size. FAO has produced a number of useful guidelines and manuals on these procedures, to be consulted by the interested readers.

Grain losses at farm level

Losses during harvesting

Strictly speaking, these are post-production rather than post-harvest losses. In fact, they were not considered by Harris and Lindblad in 1978.

Ideally, this stage of the value chain should benefit from a linkage with an annual production survey that has a crop-cutting component. The crop cutting plot is selected at random within the field before harvesting by the holder. The crop inside a crop-cutting plot (usually 10 meters x 5 meters, or 5 meters x meters depending on the type of crop) is harvested according to the usual farmer practices and the yield is weighted and recorded. After the harvested produce is removed from the plot, all grains shed or missed are then carefully picked up for estimating harvest loss.

If a stratified two-stage random sampling design has been used with village as PSU and holder as SSU, *estimates of production and loss* per hectare can be produced as follows (assessment and collection of data on post-harvest food grain losses, FAO Rome 1980):

p_{ij} is production per hectare for holder j in village i

a_{ij} is the area under the crop for holder j in village i

A_i is the area under the crop for village i

l_{ij} is loss per hectare for holder j in village i

m is the number of sampled holders

n is the number of sampled villages for the given stratum

$$\mathrm{P_i} = \frac{\sum_{j=1}^{j=m} a_{ij} p_{ij}}{\sum_{j=1}^{j=m} a_{ij}}$$ is the estimate of production for village i

$$\mathrm{P} = \frac{\sum_{i=1}^{i=n} A_i P_i}{\sum_{i=1}^{i=n} A_i}$$ is the estimate of production per hectare for the given stratum

$$\mathrm{L_i} = \frac{\sum_{j=1}^{j=m} a_{ij} l_{ij}}{\sum_{j=1}^{j=m} a_{ij}}$$ is the estimate of loss for village i

$$\mathrm{L} = \frac{\sum_{i=1}^{i=n} A_i L_i}{\sum_{i=1}^{i=n} A_i}$$ is the estimate of loss per hectare for the given stratum

Hence the percentage loss in this harvesting stage is given by

$$\mathrm{PCL} = \frac{\mathrm{L}}{\mathrm{P}}$$

Estimates of variances for P and L can easily be derived as well as for their ratio PCL.

Tremendous difficulties are associated with the usage of crop-cutting techniques to assess yields in normal annual agriculture production surveys as conducted in developing countries. Therefore the use of these techniques for loss assessment should be carefully evaluated for the situation at hand. In fact, there is still no best single ideal method for crop-cutting.

Losses during stacking/stooking

In the literature, it has been suggested to measure these losses when the operation is being carried out normally by ensuring the stacks or stooks are built on a plastic sheet or tarpaulin to collect all scattered grains when the bundles are later removed. This approach might be a problem if the labourers perceive the situation as a not 'normal' situation and hence try to handle the bundles (carefully or roughly) differently from the usual situation.

Sometimes, loss of quality may occur for newly harvested grain stacked for threshing during a wet season. Grain may become mould or discoloured, when exposed to humidity for relatively long period. In case of severe deterioration of grain leading to grain rejection as unfit for human consumption, then reduction of quality may be expressed on a quantitative basis. In case the grain is not rejected, some sort of estimate of the reduction in quality can be provided by contrasting the condition of a carefully processed sample of grain from a stack/stook at threshing time with that of a sample drawn at time of stacking/stooking.

If grain remains stacked or stooked for many months, this can be regarded as a means of storage during which losses to rodents, birds, insects and microorganisms may occur. Hence, the standard techniques for estimating losses due to insects during storage can still be applied, though it might be difficult to estimate losses due to birds and rodents. Using the standard technique, grain samples are collected at stacking time and also before threshing; they are then carefully threshed and analysed for insect loss. There was no substantial account in the literature of such technique being used.

Losses during threshing/shelling

Data on grain loss at this stage of the chain will be collected from a sample of produce from the sampled holders.

Losses during threshing may occur following (i) incomplete threshing (grain remains on the straw) or (ii) damage through the grain or (iii) spillage and scattering during the process.

In case of incomplete threshing, random samples of bundles of harvested crops are threshed by farmers' methods, and the grain obtained weighed and recorded. After that the remaining straw is carefully examined for grain which has escaped the threshing process. Hand-winnowing is done next to bring the two samples to the same quality level. Moisture content measurement is conducted for both samples and weights converted to standard moisture content.

Assessing grain damage during threshing is similar to with any other processing stage. Basically, all processing steps leading to the final products are standardized; then grains are threshed by the farmers' methods and by an optimal method which provides the optimal yield of the undamaged grain.

For losses due to scattering and spillage, there is little guidance in the literature on ways to assess these losses. Some researchers suggested using a large sheet to be spread on the threshing floor to capture all possible scattered grains. This however might be difficult to achieve in practice especially is the area to cover is quite big (grains can be scattered several meters from the point of threshing.

In the case of maize shelling, losses may be due to grains remaining on the cob or damage caused to the grain by the shelling method. The technique for assessing the loss of maize on the cob is similar to assessing threshing losses as shown above. Usually the loss is expressed as a percentage of the total weight of grain; some researchers however, have elected to express it as a percentage of the weight of shelled grain.

There might be an interest in examining grain damage caused by the shelling process, possibly to provide an indication of the efficiency of the shelling instead of an estimate of food loss. In that case shelled grain are grouped as a representative sample of a minimum of 200 grains and examined for damage in order to express the number of damaged grains as a percentage. Then a second sample of cobs is hand-striped and a sample of 200 grains observed as previously to constitute a check of shelling damage.

Estimates of average losses for the given stratum can be computed as follows (assessment and collection of data on post-harvest food grain losses, FAO Rome 1980):

P_i is the estimated grain production for village i

p_{ij} is grain production for holder j in village i

x_{ij} is the percentage loss of any kind for holder j in village i

m is the number of sampled holders

n is the number of sampled villages for the given stratum?

$$X_i = \frac{\sum_{j=1}^{j=m} p_{ij} x_{ij}}{\sum_{j=1}^{j=m} p_{ij}}$$ is the estimate of percentage loss of grain for village i

$$X = \frac{\sum_{i=1}^{i=n} P_i X_i}{\sum_{i=1}^{i=n} P_i}$$ is the estimate of percentage loss of grain for the given stratum

Variances and hence standard errors can also be worked for X.

Losses during cleaning/winnowing

Losses occur because part of the edible grain passes into the chaff. For the estimation, a sample of grain in a single batch is taken and the quantity of chaff and grain obtained in the operation are recorded.

Lost grain isolated from a sample of chaff has to be grossed up to give the total quantity. Percentage is calculated on the basis of grain obtained by normal cleaning. In the case where two or more samples were taken, they will be averaged to get the percentage loss in the winnowing process. Stratum and regional levels of percentages are then computed from holder percentage level using the same technique as in threshing/shelling stage

Losses during drying

To estimate losses at this stage, it is required to know the quantity of grain initially spread out for drying, along with its moisture content (reduction in weight resulting from loss of moisture is not counted as loss), and also the quantity of dried grain collected (with its moisture content) by the farmer after drying. Methods for determining moisture content are many and therefore care should be exercised to ensure methods are uniform in any given region.

For estimating losses at this stage, a stratified two-stage random sampling design is assumed. The difference between initial quantity of grain spread out for drying, and the quantity of grain collected after drying is divided by the initial quantity of grain spread out to obtain the percentage loss. For getting the obtained percentage at stratum and regional levels, the formulae used for the threshing/ shelling stage apply.

Losses during storage

Storage losses are investigated at different levels of farmer, trade, and government distribution agency. Hence, the losses will be estimated differently. Again, in countries where crop-cutting surveys are being conducted annually, a sample of farmers can easily be obtained from the annual production survey; otherwise, multistage stratified sampling of farmers can be used, as already described. Loss data may be collected at different frequent intervals, depending on the prevailing period and mode of storage.

Loss in weight during storage (due to insects and moulds, rodents, and birds at farm and village level) must always be related to the quantity in store at the time of assessment. A number of methods have been devised for assessing losses during storage; most original methods are found in the manual of methods compiled by Kenton L. Harris and Carl J. Lindblad; these methods were then reviewed by Boxall et al. in the eighties and later on also by Compton A. J. and other researchers (in the nineties) to make them more "rapid"(hence also less reliable); for the purpose of illustration, the original methods (compiled by Kenton L. Harris and Carl J. Lindblad) are quickly reviewed here. The reference section of this report contains the essentials of the other methods; in addition, new methods are also being devised by researchers in other countries around the world.

As reported in the manual of Harris and Lindblad, J.M. Adams and G.G.M. Schulten (1978), suggested three methods of determining losses in grains due to insects, and microorganisms.

Losses due to insects

Determination of the weight of a measured volume of grain: in this **Standard Volume/Weight method (SVM)**, also known as **Volumetric/Bulk density**, dry weight of a standard volume of grain is measured by a standard method at the beginning of the storage period and is compared with the dry weight of the same volume of grain after a certain storage period (depending on farmers practices in the study region - 6 to 9 months – in some African countries). The dry weight of a standard volume of grain depends on moisture content and variety. This is probably the most reliable method of loss determination. A variation of the technique exists when baseline samples cannot be obtained (Boxall R.A.1986). The modified standard volume/weight method uses an artificial baseline prepared by selecting undamaged samples from the grain present in the store at the time of loss determination. The loss is then the difference in weight (expressed as a percentage) between the undamaged and the damaged sample. Moisture content being approximately the same, there is no need for conversion for moisture.

The Count and Weight or Gravimetric method: The count and weight method provides an estimate of loss where a baseline cannot be determined at the beginning of the storage period and requires only minimal equipment. The method, which is applied to a single sample, requires the computation of (a) the proportion by weight of grains damaged by insects, and

(b) the percentage of damaged grains. Damaged and undamaged grains in a sample of 100-1000 grains are counted and weighted. The weight of the sample is compared with the weight it would have registered in the absence of damage. The base equation (FAO. 1985 "Prevention of post-harvest food losses") reads as follows:

$$\% \, weight \, loss = \frac{[UaN - (U + D)] * 100}{UaN}$$

With U = weight of undamaged fraction in sample
N = total number of grains in sample
Ua = average weight of one undamaged kernel
D = weight of damaged fraction in sample

With this formula, the percentage weight loss has to be adjusted to 14-percent mcwb, or moisture content should be stated. Percentage weight loss can also be computed using a formula that does not require the value of the mean weight of undamaged grain. This method has some sources of error, which may give negative weight-loss figures at low infestation levels. Other variations of the formula have been reported as follows: (Harris & Lindblad)

$$\% \text{ weight loss} = \frac{(UNd) - (DNu)}{U(Nd + Nu)} * 100$$

Where U = weight of undamaged grain,
Nu = number of undamaged grains,
D = weight of damaged grains,
Nd = number of damaged grains.

This formula does not require knowing the value of the mean weight of undamaged grain.

There is a variation of this traditional count and weigh method, in case maize grain kernels are destroyed or lost, as opposed to damaged by pests. In those cases, the traditional count and weigh method, grossly underestimates the losses. The modified count and weigh method was proposed by J.A.F. Compton in 1998 for assessing losses due to insect pests in stored maize cobs. In essence, the method is applied by counting the destroyed grains in each cob and applying an adjusted calculation through an 8-step process. After performing the 8 steps, the formula as given by Compton is as follows:

$$\text{Percentage weight loss} = 100 \times \frac{TND(W_d + W_u)W_u + FW(N_d W_u - N_u W_d)}{TND(W_d + W_u)W_u + FW(N_d + N_u)W_u}$$

Where TND = total number of destroyed and missing grains,
FW = the final weight after the 8-step process,
Nd = number damaged grains in subsample,
Wd = weight damaged grains in subsample,
Wu = weight undamaged grains in subsample.

This method is an improvement on the traditional one when maize grain kernels are destroyed or lost during storage.

The Converted Percentage Damage Method relies on the determination of the percentage insect-damaged grain in a sample and its conversion to a weight loss using a predetermined factor; it is a method suitable only for insect damage that provides a useful estimate for quick appraisal of losses. Although the method is liable to the same sources of error as the modified standard volume/weight method and the count and weighs method, it has apparently given good results in practice. Hence, it is recommended to use it rather than guessing when these two earlier mentioned methods cannot be used. Boxall R.A. suggests that once the relationship between percentage damage has been established by laboratory experiment, a conversion factor could be calculated and subsequently used to determine the weight losses in other samples of the same type of grain. Adams and Schulten (1978) recommended that the percentage damage/weight loss relationship be established from the count and weight method. This obviously, is the reason why this method is subject to the same sources of errors as the count and weight method. The conversion factor is calculated from the formula by using the figures from the count and weigh technique:

Most of these techniques that were compiled by Harris and Lindblad involved collecting grain samples from the farmers and sending them to distant laboratories for further analysis and returning them afterwards; this back and forth movement of grain samples created of lot of delays for getting the results of the surveys. Hence the attempt by J.A.F. Compton and other researchers to devise rapid and improved methods, avoiding sending sampling grains to the lab. Instead, they devised visual scales (maize cobs) and standard charts (maize grains) to be used directly in the field during enumeration. Using visual impression, the enumerator is able to match the farmers' sample cobs with various classes of infested cob portrayed in the pictures handed over to them. The percentage weight loss assigned to the picture with corresponding appearance can later be entered as the weight loss for the cob. The enumerator can then sum up the number of cobs assigned to each class; the percentage weight loss for the maize stored in cob form is determined by using the following formula (J.A.F. Compton, A. Sherington 1998).

$$Vissloss = \frac{aN_1 + bN_2 + cN_3 + ...+ nN_i}{N_T}$$

Where

$Vissloss$ = weight loss estimated using the visual scale

a to n = damage coefficients for each class

N_1 to N_i = Number of cobs in each class

N_T = Total number of cobs in sample

In order to estimate the weight loss for maize stored in grain form, the enumerator uses a standard chart. The enumerator randomly selects separate samples of say 100 grains each from the farmers' maize. The enumerator then places the grains in a litre plate to physically count the damaged grain. The process is repeated for the samples and an average number of damaged grains per 100 grains is established. The number of damaged grains is read off against a predetermined regression chart to find the percentage weight loss.

With these new technologies the techniques have become faster and less cumbersome; in addition, they clearly demonstrate, once again that the sampling statistician (who might not know about biological laboratory calibration of experiments), has to work very closely with the biometrician and other food loss specialists to make these techniques successful.

The Thousand Grain Mass Method (TGM) is another method (Boxall 1986) that was advocated as capable of determining insect losses, and which can overcome the problems encountered with both the volumetric and the count and weigh method. It is a technique modified from a standard procedure of determining the weight of one thousand grains and is known as the thousand grain mass method (TGM). The multiple TGM technique, a variation of the TGM has also been proposed to take into account the variations in grain size and the difficulties in obtaining representative samples when using the traditional TGM.

The TGM is the mean grain weight multiplied by 1000, corrected to a dry weight; it is calculated by counting and weighing the number of grains in a sample; to avoid possible sources of error and bias, the sample is not adjusted to a specific weight or number of grains; a reference TGM is determined from a sample of grain collected at the beginning of the storage season and compared with subsequent measurement throughout the season. The weight loss in a sample of grains is given by the formula (Boxall, 1986):

$$\frac{Initial\ TGM - Sample\ TGM}{Initial\ TGM} \times 100$$

Dry weight TGM can be derived from the following formula:

$$M_D = \frac{10m(100 - H)}{N}$$

Where M_D = TGM (dry basis)

m = mass (weight) of grains in the sample

N = number of grains in sample

H = moisture content in sample

However, there was no account in the literature of a practical application of these TGM techniques in loss assessment studies.

Losses due to microorganisms (moulds)

Grains infected by microorganisms will lose weight at a rate which varies according to the grain moisture content, temperature, and the amount of physical damage to the grain. There does not seem to be much work done on the quantification of losses due to moulds at the farm level through the literature. The methods used to assess weight losses caused by insects can be used for assessing losses due to microorganisms. The loss in weight caused by microorganisms in a sample of grain can be calculated by a comparison of the damaged (infected) sample with a baseline (undamaged) sample. As in the case of insect losses assessment, the baseline sample should ideally be collected at the time the grain is stored.

Losses due to vertebrate pests (rodents, birds)

There is a lack of data and appropriate studies and techniques to assess losses due to rodents and birds in the literature. There have been proposals that in order to measure loss of grain cobs or heads caused by rodents, an estimate of percentage of grain removed has to be calculated first; second, undamaged cobs or heads of the same size as the damaged ones should be shelled or threshed and the grain weighed; last, the loss is calculated by multiplying the weight by the percentage of grain removed. It is not clear however, how this method should be used.

It has also been proposed in the literature that losses of threshed grain to rodents can be estimated by comparing weights of grain stored and removed, provided allowance is made for other losses, for example, losses due to insects. This can be really challenging with in farm-level studies because of the difficulty of monitoring all grain movements in and out of farmer store (unless the study is conducted in the experimental way under more controlled conditions).

There is no generally accepted methodology for assessing bird losses after harvest, though losses before harvest are known to be serious. The little guidance that exists revolves around estimating losses in the field. At some other stages of the post-harvest system, one can compare weights of grain entering and leaving the stage (correcting by moisture content) in order to estimate losses caused by birds. However, estimating losses caused by birds during storage still remains a difficult task.

Calculating total storage losses

When performing assessments of total storage losses at the farm level, losses calculated from samples should be related to the quantity of grains originally stored and to the pattern of grain consumption.

When grain is being removed at regular intervals during the storage season, total loss due to insects can be gauged by calculating the loss in each quantity of grain removed by comparing samples of grains collected from the removals with a sample of grains collected at the beginning of the season. Boxall (1986) gives the example as illustrated in the following table.

Table 2 - Relationship between weight loss and grain consumption

	Months during which grain is removed					
	1	2	3	4	5	6
Quantity (volume) of grain removed (%)	10	10	15	15	20	30
Weight loss in sample (%)	1	2	3	5	7	10
Weight loss (as percentage of total stored)	0.1	0.2	0.45	0.75	1.4	3.0
Cumulative weight loss (as percentage of total stored)	0.1	0.3	0.75	1.5	2.9	5.9

Ideally quantities of grain stored put into and removed from store should be weighed. In practice, this might be extremely difficult to achieve. Hence some sort of estimation of grain quantities has to be made.

In some studies, volume occupied by the produce in store was measured and transformed into a standard weight using some predetermined factor and quantities of grain removed calculated by reference to standard baskets. Grain removed was first placed in the basket; with prior knowledge of the dimensions of the basket used, the volume and weight of grain removed could be calculated. In other studies researchers had to rely upon the use of traditional/local volume measures to obtain estimates of quantities of grain stored and removed. Once the proper figures of average quantity of grain stored, aggregate loss of grain during the storage period and its break-down by causes of loss (insects, moulds, etc.) are obtained for the holding, stratum and regional estimates of the same indicators can be obtained using the estimation formulae similar to those derived at the threshing/shelling stage.

Losses during transport

Losses in transport at the farm level may occur in (a) transport from field to the threshing floor; (b) from threshing floor to the storage; and (c) from storage to the market, with different modes of transport being used at different stages. Losses are normally estimated as difference of weights between the quantity loaded and the quantity unloaded. When transport operations might take days, samples will be taken at the loading stage and at the unloading stage, and then examined for change in moisture content and qualitative damage during transit. Based on the percentages obtained, percentage losses for any given stratum/region can be derived using the procedure described in the threshing/shelling stage. Estimating percentage losses at the stratum/regional levels (based on percentages obtained at holding level follows the same procedure as indicated in the threshing/shelling stage.

Losses during processing

Traditional hand processing or mechanical processing is used to process grain through de-husking, milling and grinding of grains. At this stage, grain loss is normally expressed as a reduction in quality of finished product, although there may be some physical loss of grain through spillage. In large-scale, commercial mills, grain is usually processed in a continuous operation; grain can also be processed in small batches (hand pounding for instance), using querns or village custom mills. Loss assessment studies at farm level are mostly concerned with the latter mode of processing. In that case, it should be possible to weigh the grain before processing, and after to obtain a measure of physical loss. In addition, a comparison between the products of the process with that of a sample of grain carefully processed in the laboratory will provide an indication of the loss of quality.

Estimating percentage losses at the stratum/regional levels (based on percentages obtained at holding level follows the same procedure as indicated in the threshing/shelling stage.

Losses during packaging

Losses occurring due to defects in the methods of packaging and handling of grains can also be estimated. Data on different types of packaging could be collected for a selected sample of farmers to study the efficiency of alternative methods of packaging. However, within the context of the post-harvest value chain, the losses at this stage do not seem important.

Estimating percentage losses at the stratum/regional levels (based on percentages obtained at holding level follows the same procedure as indicated in the threshing/shelling stage.

Grain losses at intermediary level

In this category, reference is made to government distribution agencies, mills, marketing cooperatives, wholesale and retail traders. At this level, losses are to be estimated at the stage of transport, storage, processing, packing and distribution. For transport, storage and handling by market handlers, a sample of such handlers is to be selected and the required information collected. In the same way, random sample of mills/processing factories, may be chosen and the data collected. The design used for this stage calls for a two-stage stratified random sampling with the market of some sort as the primary sampling unit, and the intermediary as the secondary sampling unit. Then for each sampled intermediary, different kinds of percentage losses are computed and then grossed-up to stratum/regional levels using the same techniques as in the threshing/shelling stage. In the case of mills and similar units, a single stage sampling design will suffice and the estimation will get even simpler.

Grain losses at Government warehouses

These agencies and other public distribution agencies should maintain detailed administrative records of grains received and dispatched. Food technology specialists working in these agencies are expected to collect samples of grains periodically, and record pertinent information, such as moisture content, insect and pest infestation and other causes of damage. Hence these agencies should therefore have readily available comprehensive data on levels of losses and their causes. A number of these surveys have been conducted in various countries around the world mostly in India for food grains (maize, rice, sorghum, wheat, etc.). APHLIS has been very active in Southern and Eastern Africa regions concentrating on the maize crop. Selection of warehouses may be done by a single stage random sampling if they are many or all of them selected if they are only a few. Estimation of average and percentage loss can be worked out as in the case of mills.

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