A rapid method for loss assessment in stored maize and dried cassava

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A RAPID METHOD FOR LOSS ASSESSMENT IN STORED MAIZE AND DRIED CASSAVA

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Abstract

This paper describes a new method for the rapid assessment of losses in stored maize cobs and dried cassava chips (*cossettes*): the use of visual damage scales. The scales can be calibrated against conventional weight loss assessment techniques to permit the estimation of percentage weight losses in stores.

The scales were first developed for a survey of Larger Grain Borer beetle (*Prostephanus truncatus* (Horn)) damage in farm stores in central Togo. They were constructed by sorting infested maize and cassava by eye into different damage classes (four classes for maize cobs and five for cassava chips). In the survey, each sampled cob or chip was scored for damage on the appropriate visual scale, using reference photos to ensure consistency.

Advantages of the method include: it is quick and easy to use, increasing the number of stores which can be sampled; data loss or fabrication is reduced; anomalous results can be checked on the spot; and it increases farmer participation in the survey work.

Methods of data analysis are discussed in detail. The raw (ranked) data can be analysed by chi-square tests, rank correlation and ordinal logistic regression. Alternatively, if the scales are used to estimate weight losses, this permits the use of more powerful techniques such as analysis of variance.

The scales have potential for many types of survey work, especially rapid appraisal. One of the most interesting applications could be to estimate parameters such as loss in market value and loss of final food product (rather than whole grain), but more work is needed to devise appropriate ways of calibrating the scales for this purpose.

Keywords: loss assessment, maize, dried cassava chips, on-farm storage, post-harvest, Togo

Introduction

Data on stored food losses is needed for several reasons: these include evaluating the impact of new factors (e.g. new varieties) and estimating the potential benefits from new storage technologies. Although a number of methods exist for the assessment of losses in stored grain (see Harris and Lindblad, 1978; FAO, 1983; Boxall, 1986; Reed, 1986; Pantenius, 1988a; Irshad and Javed, 1991; Ratnadass and Fleurat-Lessard, 1991), most of these are relatively slow and demand specially-trained field and laboratory staff, and a number of authors (see for example FAO-PFL, 1990) have called for the development of simpler methods which are suitable for use in rapid rural appraisal and participatory rural appraisal.

This paper describes a rapid loss assessment method which was developed in response to the needs of a specific farm storage survey, and discusses the potential of this method for other types of survey work.

Development of the methodology: the Togo case

The method described in this paper was originally developed for use in a rapid loss assessment survey in farm stores in Central Togo (Compton, 1991; Stabrawa, 1992). The objectives of this survey were threefold: to assess levels of post-harvest loss in maize cobs and dried cassava chips due to insect pests; to evaluate the relative importance of the Larger Grain Borer or LGB (*Prostephanus truncatus* (Horn), Coleoptera: Bostrichidae), a post-harvest pest new to Central Togo; and to identify those aspects of production and storage practice (such as particular varieties and store types) which were associated with lower storage losses.

Methodological needs and constraints

Interest in developing a new methodology arose because none of the existing loss assessment methods appeared suitable for the needs of the survey. The practical constraints were as follows:

(a) Time and facilities were limited. Thus, in order to survey a reasonable number of farms, a quick evaluation method was needed which could be carried out in the field with few staff, avoiding the need to take samples back to a laboratory for analysis. Most existing methods are too time-consuming for field use (or require so many field staff that the farmer may feel 'overwhelmed' and uncomfortable).

(b) No data was available on the condition of the commodities prior to storage, as the survey was limited to two mid-season visits to stores. Thus, a method was needed which did not require baseline data. This made several standard methods, for example the '1000-grain' and 'standard volume-weight' methods (see Boxall, 1986) as well as the 'sample weight method' (Pantenius, 1988a,1988b) and the weigh-in, weigh-out method (Reed, 1986) unsuitable.

(c) This brief survey could only provide a mid-season 'snapshot' of losses - and any figure obtained would only be valid for a small portion of the food store, because most stores in the survey area are closed structures (similar to large pots or baskets) and it is normally only possible to sample the surface layer of the commodity. This was originally another reason for favouring a rapid method of appraisal rather than a detailed method, as it was felt that the latter would give a spurious impression of accuracy. (The problems of taking and interpreting sequential samples in farm storage can be considerable, but will not be discussed in this paper as they are similar whatever the method of loss measurement used; see e.g. Boxall, 1986 and Dick, 1988 for further information on this subject.)

(d) In the case of maize, the nature of the damage caused by the Larger Grain Borer is such that many standard loss assessment measures developed for other pests (for example, the standard 'count and weigh' method and the 'converted percentage damage method') tend to underestimate true losses (Pantenius, 1988 a,b).

The proposal: a visual scale of damage

For the above reasons, we were interested in the concept of a *visual scale of damage* for use in rapid field surveys. Visual scales are used routinely for assessing loss and damage due to pests and diseases in many field crops (see e.g. Chiappara, 1971; Ciba-Geigy, 1981). They are known to have the following advantages: (a) the human eye can synthesize complex information and make an immediate assessment of damage which is fairly accurate (Miller, 1991); (b) visual scales are easy to learn, and if they are well-designed, results from different evaluators will be very similar. However, visual scales have not often been used in post-harvest damage assessment, although a type of visual scale has been used to aid grain graders in some countries (see for example Republic of Zambia, undated; United Republic of Tanzania, undated).

Constructing the visual scales

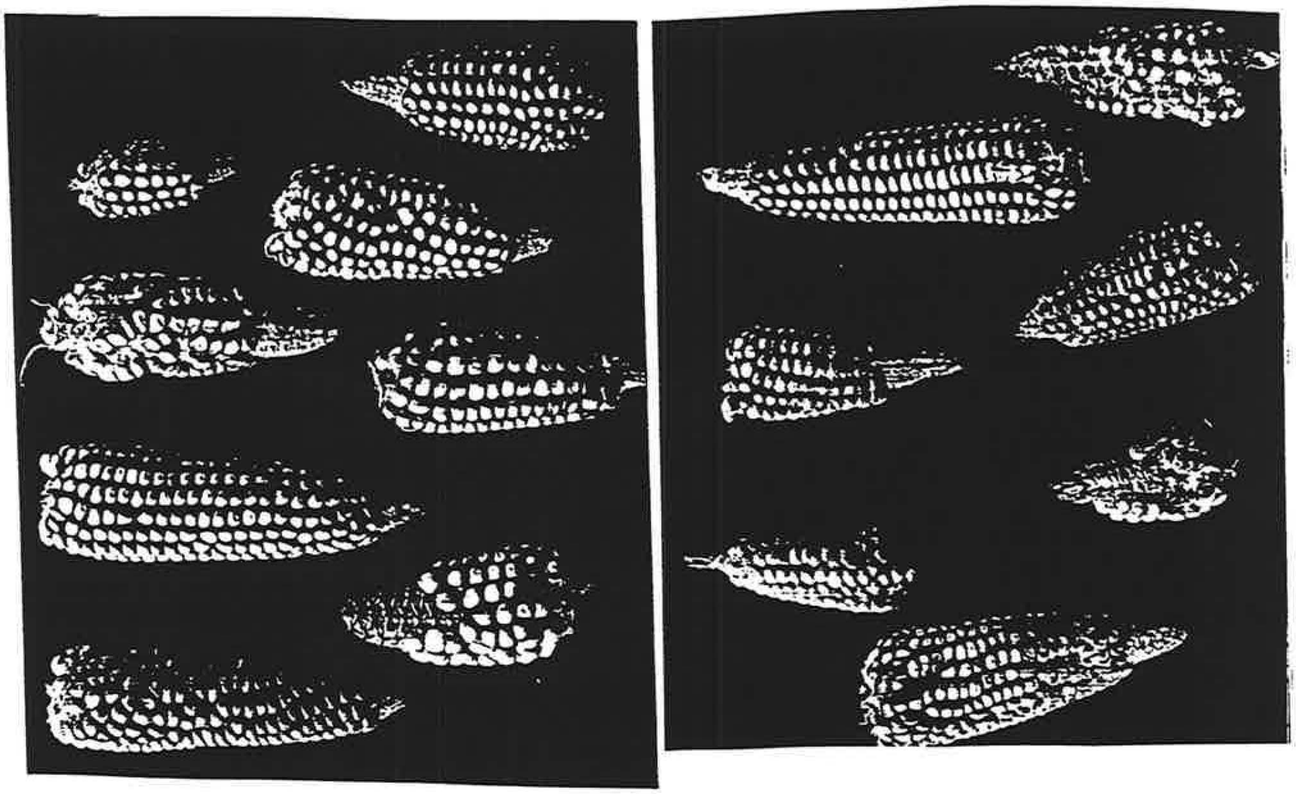
Initial construction and definition of the damage scales was carried out in the Service de Protection des Végétaux, Lomé, Togo (Compton, 1991). A group of nine colleagues formed a working group for this task, with the objective of minimising individual bias.

The working group took a pile of maize (about 100 fumigated cobs), containing cobs which had been previously damaged by a variety of insects (mainly stalkborer larvae, grain weevils (*Sitophilus* sp) and Larger Grain Borer) and with a wide spectrum of damage levels, dehusked each cob and sorted cobs by eye into four different 'damage classes', numbered from 1 [no damage] to 4 [severe damage] (see Figure 1).

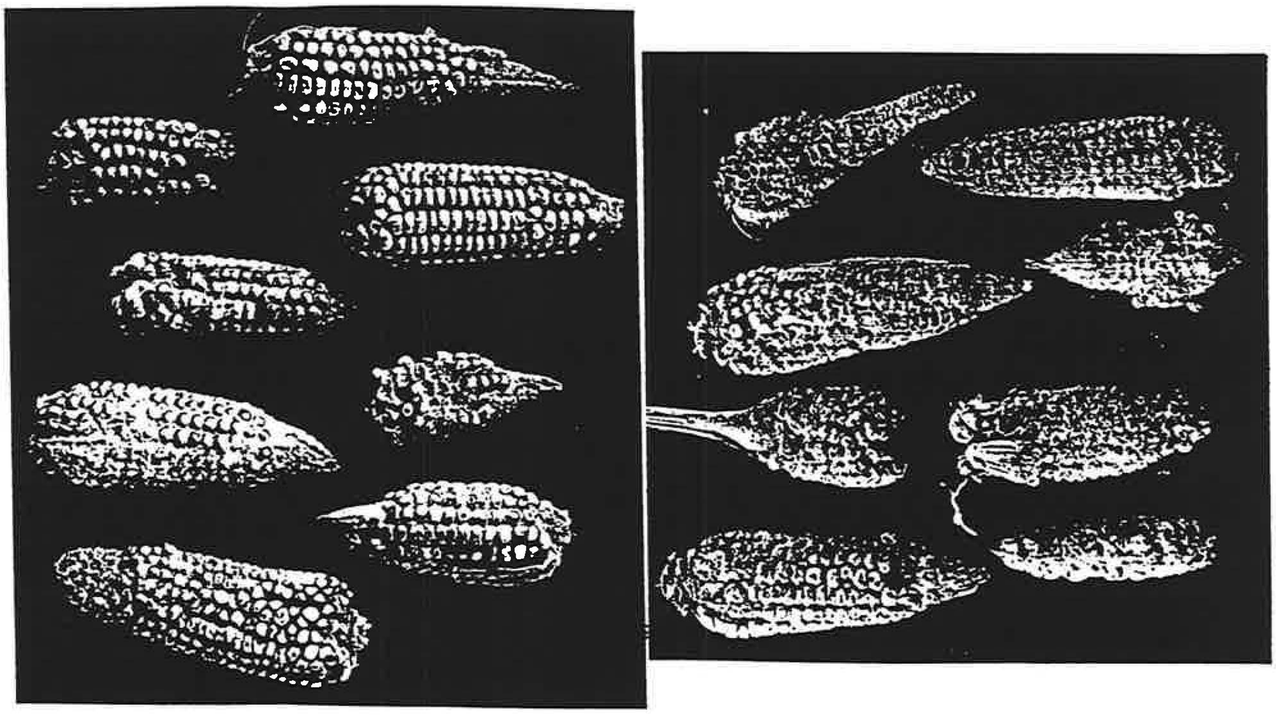
The group initially tried to identify six or seven maize damage classes, but because of difficulty in agreeing the class boundaries, the number of classes had to be reduced to four. This illustrates a general problem with all visual scales, that is: there is a trade-off between the number of classes which can be clearly distinguished by eye and the precision of the range covered by each class. Many visual scales err on the side of being 'too precise', probably because they are devised on paper before anyone actually tries to use them. In this case, we settled for the very limited number of classes on which the whole working group agreed.

Figure 1. Visual damage scale for maize:

(a) Class 1 - undamaged (b) Class 2 - light damage



(c) Class 3 - medium-high damage (d) Class 4 - severe damage



A similar method was used to prepare a damage scale for cassava chips (pieces of dried, peeled roots up to about 40 cm long; also known as *cossettes*) which had been damaged by boring beetles: mainly *Dinoderus* sp and Larger Grain Borer. Five damage classes were distinguished (Figure 2)*. Table 1 (taken from Compton, 1991) shows the average hole density for a sample of chips taken from each damage class after preparing the scale. The main distinction between Classes 1,2 and 3 is the range of hole densities visible. Chips in all three of these classes have a surface which is superficially intact. Class 4 chips have areas where the surface structure has been destroyed, making it difficult to evaluate the exact number of holes. In class 5, little of the outside remains intact, and much of the chip has crumbled into dust.

Representative cobs and cassava chips from each damage class, including examples of the highest and lowest damage in each class, were photographed for use as a reference standard. The process of preparing and photographing the scales took about half a day.

The possibility of trying to construct separate scales for damage caused by different types of pests was discussed, but rejected. In the case of cassava, it is virtually impossible to distinguish between the damage caused by different borers. In the case of maize, the degree of interaction between different pests (Dick, 1988) makes an additive approach to damage assessment impracticable. The scales we finally chose, therefore, provide a measure of all physical damage including that caused by different insect and rodent species and also mechanical damage (although in our survey work mechanical damage was negligible). The scales do not, however, measure mould damage; in our survey work this was registered separately.

Field use of the scales

The scales were used in the Togo survey to score the damage in maize cobs and cassava chips sampled from farmers' stores. Full details of sampling methods and other data collection techniques can be found in Compton (1991) and Stabrawa (1991).

Twenty cobs or cassava chips were randomly sampled from the accessible surface of each store. (Sampling problems in farm storage can be considerable - see Boxall (1986) - but will not be discussed here.) A separate data sheet was filled in for each store, registering (among other data) the damage class for each cob or chip.

Sampling and assessment of each store took about half an hour. The damage assessment was carried out by two people while a third interviewed the farmer. The three-person team visited one village a day, covering on average five farmers per village and two stores (one hour) per farmer.

The speed of using the scales made it possible for all measurements to be completed before leaving the farm. This had the following spin-off benefits: (a) unexpected results could be quickly checked and corrected - or investigated - on the spot and (b) the assessment provided a useful focus for discussion with the farming family and other bystanders, generating useful ideas and incidentally freeing the interviewee (who was kept a few metres away) to answer questions

* Not presented. Similar in format to figure 1.

Table 1. **Average density of insect holes for classes in the cassava visual damage scale** (Compton, 1991)

Damage class	Number of holes/cm^2 Average	Range(min-max)
1	0 (a)	(a)
2	1	0.1-2.3
3	4	2.4-7.1
4	7	4.1-9.1
5	(b)	

Notes: (a) Class 1 (undamaged) was not available for measurement; holes are zero by definition
(b) Class 5 was too severely damaged to obtain a realistic hole count

Table 2. **Example of presentation of raw visual scale data.** (part of maize data from Compton 1991)

Data presentation is not easy because it is not possible to calculate an overall average damage figure for each store (unless the scales are calibrated for weight loss).

Store code*	No. of cobs (out of 20) at damage level: I	II	III	IV
251	12	8	0	0
261	11	8	1	0
262	11	8	1	0
311	5	14	1	0
321	12	8	0	0
331	0	9	11	0
341	4	16	0	0
343	18	2	0	0
351	6	13	1	0
411	8	12	0	0
421	10	10	0	0
431	9	10	1	0
432	14	6	0	0
451	14	6	0	0
511	6	13	1	0
521	9	11	0	0
531	0	20	0	0
541	1	16	3	0
551	4	14	1	1
553	6	14	0	0
612	6	14	0	0
621	4	3	13	0
631	1	5	1	13
652	5	9	6	0

* Note: The store code is composed of: village code (first digit); farm code (second digit); and farmer's store (third digit).

without interference.

Interpretation of the results

The main aim of the following discussion is to give other research workers examples of different ways in which the scale data can be used and analysed. There are two main ways of interpreting the results: firstly, analysis can be performed on the original (ranked) data to investigate the relationship between damage levels and other survey variables (such as insect numbers or store type). Secondly, the original data can be used to estimate weight loss (and potentially other parameters), by calibrating the scales.

Analysis based on the original, ranked data

Strictly speaking, the damage scale provides only *ranked* (ordered, categorical) data. It is not possible to calculate an average loss figure for each store and data presentation is thus rather awkward (see Table 2).

Nevertheless, the use of ranked data is perfectly adequate for many purposes (see Table 3), and a number of techniques are available for data analysis. Typically, the aim of statistical analysis will be to examine the relationship between damage and one or more suspected explanatory variables. The choice of statistical technique depends on the nature of the explanatory variable, as follows.

First, the effect on damage of *qualitative factors* (such as store type and crop variety) can be investigated by cross-tabulation, in conjunction with chi-square tests of association or log-linear modelling. Table 4 shows an example from the Togo survey, looking at the relationship between store type and level of damage in stored maize. To construct the contingency table, the damage scores were first converted into *proportions*. That is: for a sample of 20 cobs of which 10 cobs were ranked in Class I, 4 in Classes II and III and 2 in Class IV, the corresponding proportions in each class would be 0.5, 0.2, 0.2 and 0.1. Next, the proportions in each class were totalled for the stores corresponding to each store-type. In this particular example there was no significant relationship found, although inspection of the contingency table (average proportions are given in *italics*) gives the impression that damage was slightly higher in open platform stores.

The effect of *quantitative variables* (such as length of time in store, or insect numbers) can be studied by means of rank correlation or ordinal logistic regression. In rank correlation, stores are ranked by overall damage, using a weighted assessment of the damage scores for the samples drawn from each. This weighted assessment may be difficult to achieve, however, and rank correlation also suffers from the disadvantage that it is difficult to separate out the effect of different factors. Thus, no example is given here. The technique of *ordinal logistic regression* (see for example McCullagh, 1980) is more flexible and informative, but is also more technically demanding. In the Togo survey, a multiple ordinal logistic regression model was used to investigate the relationship between damage levels in maize and numbers of the two main pest species: the Larger Grain Borer and *Sitophilus* sp., following the 'Ordinal-Logistic' procedure in GENSTAT (Payne *et al.*, 1991). The fitted regression coefficients were 0.148

Table 3. POTENTIAL FOR THE USE OF VISUAL SCALES FOR VARIOUS TYPES OF LOSS SURVEY

Objective of loss assessment	Data needs	Requirements for methods	Visual scale suitable or not?
To justify setting up projects for loss reduction in a particular country (e.g. international programmes)	Value of losses (approx.)	Large scale, so easy to use by enumerators. Low-cost, quick.	Yes, with calibration for value losses
To identify areas, farm types or commodities for prioritizing R&D work (e.g. Min of Ag.)	Relative scale of losses	Large scale. Low cost, quick. Relative ranking normally enough.	Yes.
To estimate food production and requirements (e.g. for food aid)	Quantity or percent of lost *food*	Large scale. Low cost. Quick.	Yes, with calibration for food loss
To estimate impact of new factor (e.g. Larger Grain Borer)	Value loss or farmer opinion of losses	Normally large-scale. Large sample size preferred to minimize background variation.	Yes, together with farmer interviews.
To look for factors which might affect losses (e.g. store-type)	Relative scale of losses	Relative ranking probably enough. Large sample size preferred to minimize background variation.	Yes.
To aid farmers etc. to take management decisions on stored grain	Value of loss as perceived by stockholder	Case studies needed to explore perceptions of loss	Could be used to extrapolate case study results by calibrating against perceived values of different scale classes (see text).
Cost/benefit analysis for proposed inputs such as metal bins, insecticides, varieties. (assessment of benefits of reducing losses)	Value of loss as perceived by stockholder	As above.	As above.
To help estimate local food production and consumption (e.g. household food security studies)	Quantity of lost *food*	Case studies of consumption patterns needed.	As above.

Table 4. **Example showing the use of contingency tables for analysis of visual scale data: relationship between store type and damage in stored maize (data from Compton 1991)**

Store type	Total proportion in each damage class (see text for details of calculation)						
	Class						Total stores
	I	#	II	#	III/IV*	#	
Closed mud bin	3.5	*(0.5)*	3.4	*(0.5)*	0.15	*(0.02)*	7
Open platform	14.9	*(0.4)*	20.2	*(0.5)*	5.9	*(0.15)*	41
Total	18.4		23.6		6.1		48

Chi-squared = 0.97 on 2 degrees of freedom ($p = 0.62$). In this example, there is no statistically significant evidence for an association between store type and damage.

Notes: * Classes II and IV were amalgamated due to paucity of data for the mud bin.

The average proportion in each class (= total proportion / total store numbers) is shown *(in parentheses)* to aid data interpretation, but the chi-squared test uses the total proportions.

Table 5. **Summary results of calibration of visual damage scale for maize** (Compton, 1991)

Characteristics of each class (on a per cob basis)

Damage class [a]	Mean weight loss	Range of weight loss (%)	Mean % destroyed grains	Mean % damaged grains	Mean no. grains
I	0 %				
II	8.9%	0.4 - 20	3	18	179
III	26.3%	13 - 43	10	56	195
IV	62.3%	40 - 100	47	46	165

Notes: (a) A weakness of this particular calibration was that Class I was not measured, but defined as zero loss. It is recommended that Class I is carefully checked for damage in future calibrations.

(SE = 0.06) for LGB and 0.091 (SE = 0.08) for *Sitophilus*. (These coefficients give a rather complex measure of the relationship between insect numbers and damage: they are interpreted as the natural logarithms of the amount by which the ratio of odds of higher to lower damage increases following an increase of 1 in the average number of LGB (or *Sitophilus* sp.) per cob.) The statistical significance of the regression coefficients is measured by calculating the ratio of each coefficient to its standard error (see Payne *et al*, 1991); in this example, only LGB made a significant contribution to the model. The analysis thus indicates that the introduced Larger Grain Borer was more damaging than the indigenous *Sitophilus* species. (This shows, incidentally, that it is not necessary to have separate visual scales for the damage caused by different agents in order to draw conclusions as to which is more damaging.)

Using the scales to estimate weight losses

We considered that the value of the damage scales would be enhanced if they could be used to estimate weight losses. For this purpose, we 'calibrated' each scale against standard weight loss assessment measures (details are given below). The main objective of the calibration was to determine the mean weight loss for each damage class in the scale for both maize and cassava. The calibration also produced other descriptive statistics which improved our understanding of the scales.

The mean weight loss figures obtained from the calibration were then used to calculate mean weight loss for each surveyed store, as described below.

Calibration of the maize scale

The batch of maize cobs which was used to develop the original damage scale was also used in the calibration. Ten cobs were chosen from each damage class (more would have been desirable, but poor handling had led to grains falling off many cobs and these could not be used). Weight loss was measured for each cob separately, using a modified version of the 'count and weigh' technique.

Modified 'count and weigh' technique: Each cob was carefully shelled, grain by grain. Note was taken of the numbers and weights of grain in the following categories:

- Destroyed grains: i.e. those which had been wholly eaten, or so nearly so that they could not be shelled without crumbling entirely into dust. These are easily distinguished by eye from 'missing grains' which have been knocked off in handling.;

- Damaged grains (those which were visibly damaged or holed, but could be shelled without completely losing their identity);

- Undamaged grains. (Grains with invisible internal infestation were included in this category.)

From these, a standard 'count and weigh' calculation was performed to assess percent weight loss for each cob separately. The calculation of weight loss was carried out using the following formula (see Boxall, 1986):

$$\% \text{ Weight loss} = 100 * \frac{(W_u N_d - W_d N_u)}{W_u N_t}$$

where

N_t = Total number of grains (= number destroyed + number damaged + number undamaged grains)

W_d = Weight of damaged grains (excluding weight of dust from destroyed grains, which was negligible)

W_u = Weight of undamaged grains

N_u = Number of undamaged grains

N_d = Number of damaged grains (including destroyed grains).

The results of the calibration are shown in Table 5. The mean percent weight loss was about 9% for cobs in class II; 26% for cobs in class III, and 62% for cobs in class IV. Table 5 also shows additional data collected to characterize each damage class, including the mean number of damaged and destroyed grains per cob (expressed as a percentage of total grain numbers per cob). There was no obvious difference between the average sizes of the cobs in each class, as expressed by mean total grain numbers per cob.

The calibration had the following weaknesses which should be rectified in any future attempt to use visual scales:

(a) Insufficient material was available for the calibration. In future work, it is recommended that 50 cobs or cassava chips per class should be used. (This recommendation is based on estimates of the sampling error: see the Statistical Appendix.)

(b) Class I was not calibrated; it was assumed to have zero losses, which is possibly untrue even if internal infestation is ignored (some holes are not visible without shelling). For this reason, and to pre-empt possible criticism, it is recommended that Class I be included in future calibrations. However, recent calibration work with the maize scale in Kenya (G. Farrell, personal communication) showed a mean of only 0.02% weight loss in 50 cobs calibrated in Class I, so an estimate of zero losses is unlikely to cause serious errors.

(c) There was no chance to verify the calibration with other maize varieties and different pest complexes, but it is likely that these factors will affect the relationship between visible damage and weight loss. Thus, it is provisionally recommended that a separate calibration be carried out for each study.

(d) In this calibration, a modified count and weigh technique was used for the reasons described. However, the count and weigh technique, although widely used, has itself been the subject of some criticism (see for example Boxall, 1986; Reed, 1986), especially when applied to maize, in which grain size is normally quite variable. (Critics claim among other things that where pests preferentially attack larger grains, the count and weigh technique tends to underestimate losses.) There is also a chance that, where LGB is involved, the modified count and weigh method will underestimate weight loss at very high damage levels by undercounting the number of destroyed grains (Pantenius, 1988a), but this is less likely to happen during calibration than when using count and weigh as a field method, because there is more time to make a sensible assessment. The important point here is that any use of the scales to estimate weight losses is subject not only to the limitations of the scales themselves, but also to the limitations of the technique used in the calibration. Ideally, the scales should be calibrated against a 'weigh-in, weigh-out' method (Reed, 1986) as described below for cassava.

Calibration of the cassava scale

Calibration of the visual scale for cassava was more difficult than for maize because there is no well-established loss assessment method for dried cassava chips. Initially, an attempt was made to measure the density of chips in different damage classes, as density has been shown to be closely correlated with weight loss (Wright, 1990). However, it was difficult to measure the volume of chips at higher levels of damage (badly damaged cassava is porous to water, which made volume measurement by displacement inaccurate) and the data was of poor quality (Compton, 1991).

Data from a long-term loss assessment study in Togo (Wright, 1991) was later used to calibrate the cassava scale against weight loss. In this study, cassava chips were marked at the beginning of the season before being placed in farmers stores. At regular intervals, the chips were removed and their weight was recorded (correcting for moisture content) along with their damage class on the visual scale. The summarized results are shown in Table 6. The mean percent weight loss was about 16% for chips in class II; 29% for chips in class III; 42% for chips in class IV; and 50% for chips in Class V.

Calculating mean weight losses

Having carried out the relevant calibration the visual scale data can be used to estimate the mean weight loss *of the sample taken from each store*. (This is not the same thing as the *mean weight loss in the store*, for reasons outside the scope of this paper but discussed at length by other authors, for example Boxall, 1986.)

~~This estimate is made as shown in the example in Figure 3.~~ First, each damage class is assigned an *imputed loss* which is equal to the mean value of percent weight loss calculated in the calibration. For each store, the number recorded in each damage class is then multiplied by the imputed loss for that class to calculate a weighted mean weight loss for the store. Averaging over the sample of (in our case) 20 cobs or cassava chips provides some safeguard against the approximation involved in substituting imputed values for ordered categorical scores.

(It might be questioned whether the use of a single standard imputed loss per damage class is valid, since the distribution of weight loss values within each class in the sample is likely to vary between

Table 6. **Calibration of cassava visual damage scale against measured weight loss** (Wright 1991)

Variable	Damage level II	III	IV	V
Sample size	50	110	66	4
Mean (%)	15.8	29.3	42.0	49.7
Minimum (%)	5.2	12.2	23.9	44.5
Maximum (%)	29.7	51.9	70.7	55.0

Table 7. **Standard errors of cassava weight loss estimates for cassava chips, showing the effect of increased sample sizes (based on data from Wright 1991).**

Estimated mean weight loss	Baseline standard error *	Estimated standard errors following increased sampling as follows #: Tripling chips sampled/store (to 60)	Doubling surveyed stores (to 50)	Increasing stores in calibration by 50% (to 18)
10%	±2.8 % @	±2.8 %	±2.8 %	±2.4 %
20%	±1.4 %	±1.3 %	±1.2 %	±1.2 %
30%	±1.9 %	±1.9 %	±1.8 %	±1.65 %

Notes:

* Standard error for a group of 25 stores, 20 cassava chips sampled per store, based on a calibration graph constructed using 12 stores.
# See the Statistical Appendix for details of the calculations.
@ All standard errors are in units of % weight loss.

stores. In recognition of this fact, a more sophisticated weight loss calculation based on weighted imputed scores was compared with the simplified approach outlined above. As the results were very similar, it is recommended that the simplified calculation is used.)

How accurate is the estimate thus obtained? Insufficient data was available to answer this question for maize but some data is available for cassava. Figure 4 shows, for 12 cassava stores, the relationship between the weight loss estimated from the scale data and the 'true' dry weight loss measured figure using a weigh-in, weigh-out method (data from Wright, 1991). The fitted regression line or 'calibration line' approximates to linear over the available data range (about 5-35% 'true' weight loss) and can be defined by the equation:

$$\text{Measured weight loss} = -13.8 + 1.61(\text{Estimated weight loss})$$

$$(r^2 = 0.86)$$

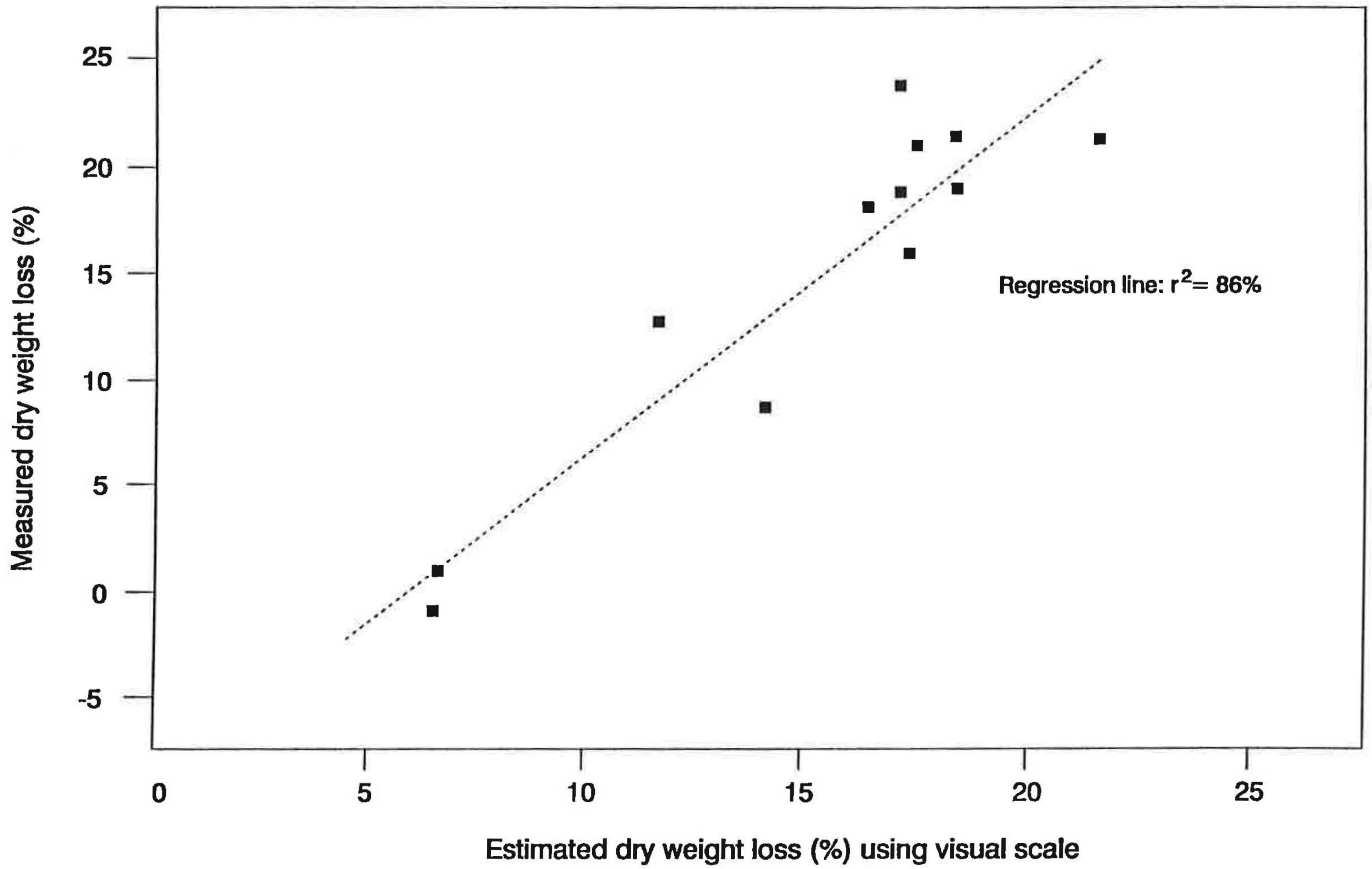
This data supports the idea that the scales can be used to estimate weight loss with a reasonable degree of precision over this range. However, it also implies that that it will be necessary to construct calibration graphs of this type in all future work, as it is likely that the correspondence between estimated and 'true' weight losses will not be exact.

What are the likely standard errors on weight loss estimates obtained from the scale data, and how can errors be minimised? The same cassava data was used to estimate standard errors on the data. The detailed calculations are given in the Statistical Appendix. The most important conclusions were as follows:

(a) Standard errors are between 4 and 5% (weight loss) for the estimated weight loss in one store. This standard error will diminish in proportion to the number of stores surveyed: for example, an estimate of mean losses in a region based on a sample of 50 stores would have a standard error between 2.5 and 3.5%. This is comparable with the precision in weight loss estimates produced by other methods (Reed, 1986).

(b) If resources are limited, errors can best be minimised by increasing the number of stores in the calibration and/or by surveying more stores, rather than increasing sampling within each store. This can best be appreciated by reference to Table 7, which shows the way that standard errors are likely to change if sampling is increased. The table first shows estimated standard errors for sample sizes close to those actually used in the Togo surveys: that is, 25 stores, with 20 cassava chips being sampled per store and with a calibration graph constructed from 12 stores. Standard errors are then estimated for three hypothetical cases: (a) increasing the number of stores in the calibration by 50% to 18, (b) tripling the within-store sample to 60 and (c) doubling the number of surveyed stores to 50 (these three increases would involve roughly similar amounts of time and effort). It can be seen that none of these increases in sampling has a very large impact on standard errors, but some reduction in errors is possible by better calibration and increased store numbers. Even tripling the number of chips sampled per store hardly reduces standard errors at all.

Figure 4. Calibration graph for weight loss in stored cassava chips (n=12 stores; data points = mean of 20 chip samples)



These conclusions should give some guidance for future surveys using similar scales. However, it should be cautioned that the data set from which these calculations were made is itself rather small and the conclusions should be verified by more detailed work in future.

Using estimated weight losses in survey data analysis

Having transformed the visual data to estimated weight losses as described above, parametric statistical analysis can then be used to relate the estimated weight loss in each store to other variables. For example, in the Togo work, transformed scale data were used to investigate which of the two common primary pest species (the Larger Grain Borer and *Sitophilus* sp.) was associated with higher weight losses in stored maize. This was done by regressing estimated percentage weight loss on insect numbers, as shown in Figure 5. Earlier, we presented analysis of the same data using an ordinal logistic regression model for the untransformed rank data. The conclusions are similar whichever approach is used. However, the quantitative interpretation of results is made easier in the case of regression analysis on the transformed data. It is also somewhat easier to fit models to the transformed data and check their validity.

Use of the scales to estimate loss in value and other parameters

One of the most interesting potential uses of the scales is to estimate parameters such as loss in market value or food value of the commodity. For many purposes (see Table 3), these parameters are of greater interest than simple weight loss. For example, an estimate of the value of the stored commodity is required in order to assess the potential economic benefits of new storage technologies.

Insofar as market value is related to the appearance of the commodity, it should be possible to devise and calibrate visual scales to give a rough estimate of value. In most areas, farmers and traders use an informal visual grading system, and their involvement should be sought to develop a scale which reflects their own perceptions of commodity value. Similarly, it may be possible to relate other parameters (e.g. yield of edible flour) to a visual scale.

In this context, the approach needed for maize is likely to differ slightly from that needed for cassava. Dried cassava chips are normally sold in the same form in which they are stored, so that it would theoretically be possible for a trader to value each chip in the store. Thus, it is comparatively easy to use a visual scale to put a relative value on losses.

In contrast, maize stored on the cob is nearly always shelled before it is sold. Thus, in valuing stored maize it is important to understand how the farming family selects cobs and grains for sale and consumption. In Togo, we made a start on this area of work by asking the women of one farming family to take samples of cobs from each of the four damage classes (I-IV) on the maize scale, and to shell and select them as they would normally do. This particular family produced (by means of winnowing, hand selection and flotation) three grades of shelled maize: high-quality grains used for preparation of flour or for sale; medium quality grains with a high proportion of brokens, used to prepare morning gruel; and poor-quality brokens used

Figure 5. Example of regression analysis using the transformed scale data: relationship between insect numbers and estimated weight loss in stored maize. (data from Stabrawa 1991)

We investigated the relationship between damage and numbers of the two main primary pests, Larger Grain Borer (N_{LGB}) and *Sitophilus* sp. (N_{Sito}). The estimated percent weight loss was first regressed separately on each of N_{LGB} and N_{Sito}, and then on both explanatory variables together in a multiple regression analysis. All regressions were fitted using weighted least squares, the weights being necessary because the dependent variable (% loss) in the regression is a percentage variable and extreme percentages typically exhibit lower variation than intermediate percentages.

The results of the single species regressions were as follows:

% loss = 6.06 + 1.17 (N_{LGB}) (r^2 = 70.4%; SE of slope = 0.13)

% loss = 6.45 + 0.61 (N_{Sito}) (r^2 = 13.6%; SE of slope = 0.26)

while the fitted multiple regression model was:

% loss = 5.45 + 1.11(N_{LGB}) + 0.38(N_{Sito})

(r^2 = 75.3%; SE of slope = 0.14 (N_{LGB}) + 0.12 (N_{Sito}).

Both species variables play a statistically significant role in the explanation of variation in percentage loss estimates between stores. However, the fitted regression coefficients suggest that each adult LGB is associated with two to three times as much damage as each adult Sitophilus. The analysis thus suggests that both primary species are damaging but that the introduced LGB is much more damaging than the indigenous *Sitophilus* sp.

A number of qualifications must be made to this conclusion. First, the analysis does not necessarily imply a causal effect: damage could be caused by another factor closely associated with adult insect numbers, such as larvae. Second, the regression coefficients can only safely be applied to the particular time and place that the survey was conducted, and over the range of infestation levels encountered. Third, the interpretation of the relative losses attributable to LGB and *Sitophilus* was simplified in this example because the survey data exhibited no significant correlation between LGB and Sitophilus numbers. If the two had been strongly correlated it would have been more difficult to apportion blame between the species.

for animal feed. As expected, the cobs in different damage classes varied dramatically in value, from class I (composed entirely of high-grade maize grain) to class IV (composed largely of poor-quality animal feed); however, our data is not presented here due to laboratory errors.

It can be seen that this type of data could be used as the basis for calibrating the visual scale to estimate food and monetary value. For example, if it were possible to estimate or impute monetary values for different grades of shelled maize and brokens, we could in theory take a sample from a store, score the damage classes of the cobs, and - on the basis of a 'calibration' such as that just described - immediately estimate a monetary value for the sample taken. This is clearly a major improvement over previous methods of valuing losses: these typically involve calculating a rather precise estimate of weight loss and then relying on some fairly crude assumptions (for example, that all the weight lost was high-quality maize) to estimate a value loss. However, much more work is needed both to extend the analysis within a particular household (for example: How should animal feed be valued? Does the family's quality classification of maize change as supplies run down?) - see McHugh, 1990 - and to see how applicable the data would be to other farming households.

In sum, what the visual scales potentially offer is a simple means of extrapolating case study results to a larger sample size. A number of assumptions and simplifications would be necessary for this extrapolation, but this is also true of other methods of estimating quality-related losses for large survey populations. We have now set up a research project on 'appropriate methods for loss assessment' to investigate this area further.

Discussion

Advantages of the scales

The visual scales have the following advantages:

1. They are *easy to use*, and *easy to train others to use*. No previous knowledge (e.g. of grain technology) is required.

2. They are *quick to use*: in Togo, sampling and scoring took about one half-hour per farm store (20 cobs or cassava chips). Two field workers were involved in this case, but the assessment could have been done (perhaps a bit more slowly) by one.

3. Because the scales are quick to use, *increased sampling* (e.g. of villages, farms, stores or cobs within stores) is possible, thus *reducing sampling error*. Slower methods of assessment normally mean that sampling must be reduced, as survey resources are limited.

4. Speed of use also *reduces the likelihood of data fabrication* by field staff. Bored workers have been known to make up results (Poate and Daplyn, 1991), especially in large surveys where many enumerators are involved, but using the scales is nearly as quick as inventing data!

5. Results are obtained on the spot. It is *not necessary to transport samples to the lab, risking loss or damage* to them in the process. The probability of other associated errors - including measurement errors in the lab and copying errors - is also reduced.

6. Similarly, *anomalous results can be double-checked on the spot* before leaving the store, rather than being an unexplained mystery in the lab.

7. Farmers and other bystanders can see and understand the scales, and scoring is quick enough so that their interest is maintained throughout. Thus, the use of the scales is *highly participatory*, stimulating discussion and generating information and opinions. In Togo, farmers were interested in the photos of the scales which we carried, and made use of them to help illustrate their own points - for example, about the level damage had reached last season.

8. Use of the scales is non-destructive: *after scoring, the cobs or cassava chips can be handed back to the farmer intact.* Thus, researchers can avoid the problem of how to compensate farmers for any samples removed (this often poses difficulties with other loss assessment techniques).

9. Experience to date indicates that the *consistency of results* obtained by the scales is reasonably good, provided that field workers make use of the reference photos.

10. The scales can potentially *produce a variety of data for different survey needs.* The ranked data produced by the scales can be used directly for many purposes, or the scales can be calibrated and used to estimate weight loss. There is potential to use the scales to estimate other parameters of interest, for example food loss and loss in value, although the calibration necessary for this is still the subject of research.

11. An analysis of our survey data has shown the *standard errors on estimated weight losses to be surprisingly low*, and comparable with those obtained using other loss assessment methods.

Problems and priorities for future work

A number of difficulties and doubts remain about the use of the scales, which need to be addressed by further research. These include:

1. *Consistency of results.* Although experience to date has given good consistency of ranking between one field worker and another, this needs to be formally confirmed by research.

In the field, the *constant* use of reference photos is very important to maintain consistency of judgement. "In the absence of objective standards, people make judgements based on a comparison of the geometric mean of the previous stimuli. Thus, if a batch of good-quality items are presented, the inspector will be more sensitive to slight defects" (Miller, 1991). In the case of the scales, this means that if a particular store has very low damage compared with the majority, field workers are likely to overestimate the damage by 'sliding the scales downwards' in their minds. There is indirect evidence to show that this problem has already occurred in one case where field staff did not use the photos.

2. *Validity of calibrations.* There is doubt as to whether a calibration carried out on a particular sample of maize or cassava will be valid for maize and cassava throughout the survey area. For example, it is not known how different varieties and different pest complexes affect the relationship between visible damage and weight loss, although recent calibration work with the maize scale in Kenya has produced very similar weight loss figures to the Togo work (G. Farrell, personal communication). More research is needed to clarify the importance of these factors. This is crucial if the scales are to be used over a wide and/or variable area, or if the calibration made in one area or season is to be used in another.

3. *Validity of approximations used in the analysis.* As explained above, a number of assumptions and approximations have been used in estimating weight losses and in the analysis. More work is needed to see if these approximations hold good for a wide variety of uses of the scales.

4. *Modifying the number of classes in the scales.* As explained in the methods section, the scales developed in Togo are composed of very few classes, because it was felt this would help field staff score more consistently. However, there may be a case for dividing the scales into more and finer divisions, especially if they are to be used by one person or a small group which has had a chance to 'get their eye in' and distinguish small differences more easily. For example, 7-point scales are commonly used in food testing (Land and Shepherd, 1984). Work is needed to evaluate the way the precision and accuracy of the results is affected by the number of classes in each scale.

5. *Development of similar visual scales for other commodities.* The work described in this paper was carried out on commodities which are stored as large, discrete entities which can be sampled: that is, chips and cobs. It is not known if similar scales could be used for loss assessment work in loose grain. As mentioned in the introduction, visual scales already exist for grading of loose grain in a number of countries. However, these have never - so far as we know - been calibrated and used to estimate weight loss and other types of loss, as suggested here. Work is needed to investigate this possibility.

Potential for using the scales in other surveys

The main points to consider when choosing a methodology for any survey work (Casley and Lury, 1981; Poate and Daplyn, 1992) are: (1) *what type and quality of data is needed* and what methodologies produce this type of data? (2) *what are the practical constraints* (time, seasonality, personnel, laboratory facilities) on choice of method? . Nowadays, with the increasing interest in a participatory approach to research and development work (see for example Farrington and Martin, 1988), a third question is often added to these two: (3) *Which methodologies fit best into a participatory approach* to data collection? (Participatory methods are likely to increase data quality as well as increasing survey respondents' interest and involvement in the survey outcome.)

At least six methods are already available for loss assessment in maize and two for dried cassava, as well as the visual scales. Tables 8 and 9 summarize the characteristics of these methods, including: the type of data produced and the expected consistency of results, the relative speed of the method, whether baseline data is needed (from undamaged material), whether lab or field equipment is needed, and the potential for farmer participation in assessing losses with the method. It can be seen that the visual scales compare favourably with other methods on many of these points.

Table 3 lists the most common reasons for collecting loss data and for each, suggests whether the visual scales could be a suitable tool. It is anticipated that the scales may be appropriate for many different types of survey work, although they are a particularly attractive tool for rapid, large-scale surveys. As an example, the Collaborative Study of Cassava in Africa (COSCA Phase III) is presently using the cassava scale to assess damage in dried cassava as part of a large-scale survey covering six countries (A. Westby and Z. Bainbridge, pers. comm.).

Some recommendations for using the scales in future surveys follow. Ideally, the survey staff should devise and photograph their own scale prior to beginning the survey, as we did in Togo. Making a new scale ensures that it will be suitable for the varieties and pests in the survey region, and for collecting the right type of data. (For example, if the aim of the study is to estimate loss in market value, it would be worthwhile to enlist the help of farmers and traders to devise an appropriate scale, as discussed above.) Making a new scale may be difficult unless suitably damaged commodities are available, but these could probably be collected during pre-survey field visits. If it is not possible to devise a tailor-made scale, it may be viable to make use of an existing one, such as described in this paper. In either case, it will be necessary to calibrate the scale carefully against the parameters it is wished to estimate.

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Table 8. **COMPARISON OF VISUAL SCALES WITH OTHER METHODS FOR COLLECTING LOSS DATA IN STORED MAIZE COBS**

Method	Type of data produced	Data quality	Relative speed	Baseline needed	Equipment needed	Farmer participation
Weigh-in - weigh-out	% weight loss	Good	Slow	Yes	Yes	Possible
Volumetric (Bulk density)	% weight loss	Moderate	Mod.	Yes	Yes	Difficult
1000-grain mass	% weight loss	Mod.-good	Slow	Yes	Yes	Difficult
Count & Weigh	% weight loss	Moderate	Slow	No	Yes	Difficult
Conversion factor for no. damaged grains	% weight loss *	Moderate	Mod.*	No*	No*	Difficult
Rank % damaged grains (maize cobs)	ranked data; % weight loss*	Moderate	Fast*	No*	No*	Possible
Visual scale of damage	ranked data; % weight loss; * other parameters *	Moderate for weight loss (to be confirmed)	Fast*	No*	No*	Possible

Note: * Calibration necessary to estimate weight loss and other parameters

Table 9. **COMPARISON OF VISUAL SCALES WITH OTHER METHODS FOR COLLECTING LOSS DATA IN DRIED CASSAVA CHIPS (COSSETTES)**

Method	Type of data produced	Data quality	Relative speed	Baseline needed	Equipment needed	Farmer participation
Weigh-in - weigh-out	% weight loss	Good except for high losses	Slow	Yes	Yes	Possible
Volumetric (Bulk density)	% weight loss	Poor	Mod.	Yes	Yes	Difficult
Visual scale of damage	ranked data; % weight loss; * other parameters*	Moderate for weight loss (to be confirmed)	Fast*	No*	No*	Possible

Note: * Calibration necessary to estimate weight loss and other parameters

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STATISTICAL APPENDIX

Assessing the errors in weight losses estimated using the scales

In estimating the weight loss due to pest damage in any store, or sample of stores, it is important to be able to produce not just an estimate, but also a standard error for the estimate, in order to give an impression of the likely error associated with it. There are at least three different components which will contribute towards the overall error:-

(1) The variance of the fitted calibration line (see Fig 4). In the work reported here a sample of 12 stores was used to assess the relationship between estimated weight loss and actual weight loss. If a different sample of 12 stores had been taken then a different result would have been obtained, reflecting the fact that both the intercept and slope of the line are prone to error. The bigger the sample of stores used to fit the calibration, the lower the error ought to be. We may refer to this first component of variance as calibration error.

(2) Even if the true calibration line is known exactly, the weight loss in a given store will vary from the line. The variance of individual stores about the calibration line is clearly visible in Fig 4. We may refer to this second source of variance as store error and denote it by s^2.

(3) The third component of error derives from the fact that the estimated loss for any store is based on a limited sample of cassava chips or maize cobs. In the work reported here the number of chips drawn from each store was set at 20. Independent sets of 20 chips would invariably give slightly different results from one to another. We shall refer to this third component of variance as the sampling error and denote it by s_E^2.

The first two components of error can be estimated from a standard regression analysis, such as that used to fit the calibration line in Fig 4. The sampling error was estimated, using cassava data reported elsewhere in the paper, in the following manner. For each of 40 stores, 20 randomly selected cassava chips were randomly divided into two groups of ten chips. Treating these as two replicates, an independent loss estimate was computed for each and a nested analysis of variance performed for the full set of 80 values so obtained. As a result of this analysis it was possible to estimate the sampling variance for samples of size 10 chips as 7.2 (on 40 degrees of freedom). The estimated sampling variance for a sample of 20 chips can then be reasonably assumed to be half this, or 3.6. It should be noted that this is a pooled estimate, over all loss levels, and may not be a perfect representation of the sampling variance associated with a store at any single loss level.

Having estimated the individual components of error it is necessary to combine them in an overall estimate of error. Unfortunately, the components do not combine in a purely additive way. In particular, the sampling error associated with estimated loss combines in a multiplicative way with the variance of the slope in the fitted calibration line. An approximate formula for the overall variance for prediction of true loss in a single store is given by:-

$$s^2(1+1/n) + B^2 s_E^2 + (x-x)^2 \mathrm{Var}(B)$$

where n is the number of stores comprising the calibration data set, x denotes estimated weight loss and x the mean value of x among the stores comprising the calibration set. The term B is the estimated slope in the calibration line and Var(B) is an estimate of its variance. If an estimate of mean weight loss is required over a set of m stores, then the formula may be rewritten:-

$$s^2((1/m)+(1/n)) + B^2 s_E^2/m + (x-x)^2 \mathrm{Var}(B)$$

The standard error of prediction is simply the square root of these formulae. Table 7 contains estimates of the effect on the standard error of altering the values of m and n and also the number of chips per store which are sampled. It is difficult to be entirely sure of the effect of changing the number of chips per store, but any increase would certainly reduce the value of s_E^2 and therefore the contribution of the $B^2 s_E^2/m$ component. In Table 7 it is assumed that only s_E^2, and not the other sources of error, are affected by changing the number of chips.