Session 6 : Grain Quality and Food Safety

Responding to the current food crisis: better grain quality for postharvest loss reduction in Sub-Saharan Africa

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Abstract

The current food crisis, which began in 2006/2007, has highlighted the need to increase the availability of cereal grain to consumers in Sub-Saharan Africa and elsewhere in the developing world. The previous international food crisis, of the 1970s, prompted participants at the 2nd IWCSPP (in Ibadan, Nigeria) to form a new body, the 'Group for Assistance on Systems relating to Grain After harvest' (GASGA). GASGA co-ordinated donor support for grain loss reduction projects, as a resource efficient means of increasing food availability without wasting further crop production resources (land, water, labour, and agricultural inputs). Efforts were concentrated on introducing technical innovations for smallholder farmers and the development of better loss assessment technologies. The current food crisis presents similar challenges but this time whole value chain approaches to loss reduction are being emphasised. Smallholders are encouraged to invest more effort and skills in postharvest handling and storage to maintain the high quality of their cereals. It is intended that they will reap the rewards of supplying better quality grain to higher value markets in addition to health and nutritional benefits. Loss estimation is now backed up by the African Postharvest Losses Information System (APHLIS) and efforts to reduce mycotoxin contamination have been relaunched. Unlike the 1970s, there is no clearly defined body to co-ordinate grain postharvest development. However, initiatives are emerging that could be linked to a bottom up 'Community of Practice' to provide a dynamic and supportive forum that could lead the international effort on loss reduction.

Keywords: postharvest losses, quality losses, loss reduction, value chains, Community of Practice

1. Introduction

The international community is now getting to grips with the food crisis initiated in 2006/2007. The crisis was characterised by a two-fold increase in global food prices that sparked food riots in 14 African countries (Berazneva et al., 2011). It has some similarities to the global food crisis of the 1970s when cereal prices world-wide rose as much as four-fold (OECD, 2008). Now, as then, the international community is under pressure to increase food availability. In the 1970s, grain postharvest loss reduction was prioritized as a means of increasing food availability since it does not require the increases in land, water, labour and agricultural inputs that accompany attempts to increase production (Harris and Lindblad, 1978; Greeley, 1982). The loss reduction strategy was supported by a 'Community of Practice', called the Group for Assistance for Systems relating to Grain After harvest (GASGA). GASGA was formed in 1978 during the 2nd International Working Conference on Stored-Product Entomology (predecessor of IWCSPP) and eventually, in the late 1990s, had its remit extended to a wide range of food crops and was consequently renamed the Global Postharvest Forum (P*h*Action).

Following the 1970s food price hike, food prices began to fall in real terms and continued to do so well in to the 2000s (Wright and Bohenreith, 2009). This price trend undermined loss reduction efforts since the financial returns gradually became less favourable. As a result, loss reduction initiatives, such as the Prevention of Food Losses programme implemented by the UN Food and Agriculture Organisation (FAO), came to an end, and by the early 2000s P*h*Action fell into abeyance. In the wake of the 2006/2007 food crisis the international community has again recognized that postharvest loss reduction of cereal grains offers more efficient use of resources than simple reliance on increased production (Hodges et al., 2010a; World Bank, 2011).

This paper summarises the current thinking for cereal grain on losses of quality and quantity, loss assessment, and loss reduction, particularly in Sub-Saharan Africa (SSA). It considers approaches that will facilitate better loss reduction projects for smallholder farmers and suggests some future developments. These include the restoration of a Community of Practice that this time would be more closely linked to the intended beneficiaries (i.e. be bottom up in nature) and mediated by modern information and communication technologies.

2. What is being lost

Grain postharvest losses (PHLs) may be both the physical losses (weight and quality) and also the loss of opportunity that results from producers being unable to access markets, or only lower value markets, due to sub-standard grain quality. During harvesting, handling, processing and transport, grain may be scattered or crushed. Grain is also subject to biodeterioration. PHLs due to biodeterioration may start as the crop reaches physiological maturity, i.e. when grain moisture contents reach 20-30% and the crop is close to harvest. It is at this stage, while the crop is still standing in the field, that storage pests may make their first attack and when unseasonal rains can dampen the crop resulting in some mould growth. In SSA, nearly all small-scale farmers rely on sun drying to ensure that their crop is sufficiently dry for storage. Consequently, if weather conditions are too cloudy, humid or even wet then the crop will not be dried sufficiently and losses will be high. More unstable weather conditions due to climate change, leading to damper or cloudier conditions, may therefore increase PHLs (Stathers et al., 2013). However, successful drying alone is not a remedy against all PHLs since insects, rodents and birds may attack well dried grain in the field before harvest and/or invade drying cribs or stores after harvest. In addition, poor handling methods can lead to grain scattering and an inferior product contaminated with foreign matter that has broken grains that are susceptible to more rapid deterioration than whole grains. Finally, poor store hygiene measures can lead to the perpetuation of storage problems from one season to the next.

2.1. Losses of weight

Grain weight loss is defined as a reduction in dry weight. It is the standard measure of grain loss, allowing convenient quantification of the national impact of losses and comparisons across sites and years (De Lima, 1979). In SSA, the typical weight losses for each link in the postharvest chain of cereal grains compute to a cumulative loss from production that ranges from 10-23% (Fig. 1).

There is a possibility that there may be greater absolute PHLs when there are bumper harvests. This may happen through shortage of labour to care for the grain or lack of incentive to provide such care, since larger harvests are associated with a sharper fall in market prices. This price fall may result in a slower flow in the market leading to longer storage periods for grain. In this situation there may be an increase in loss due to insect attack both by the normal pest complex and, in the case of maize grain, the Larger Grain Borer or LGB (*Prostephanus truncatus*); a pest introduced into Africa from Central America in the late 1970s that is associated with a doubling of storage losses (Hodges, 1983, 1986). However, the impact of bumper harvests on losses has not been measured and overall the effect is likely to be small compared with the losses resulting from unfavourable climate at harvest. Certainly, in exceptional years African farmers can supplement fixed stores with grain sacks; in many locations, especially in East and Southern Africa, subsistence farmers now prefer sack storage to traditional structures (Hodges and Stathers, 2013).

Harvesting/field drying	4-8%
Transport to homestead	2-4%
Drying	1-2%
Threshing/shelling	1-3%
Winnowing	1-3%
Farm storage	2-5%
Transport to market	1-2%
Market storage	2-4%
Cumulative loss from production	10-23%

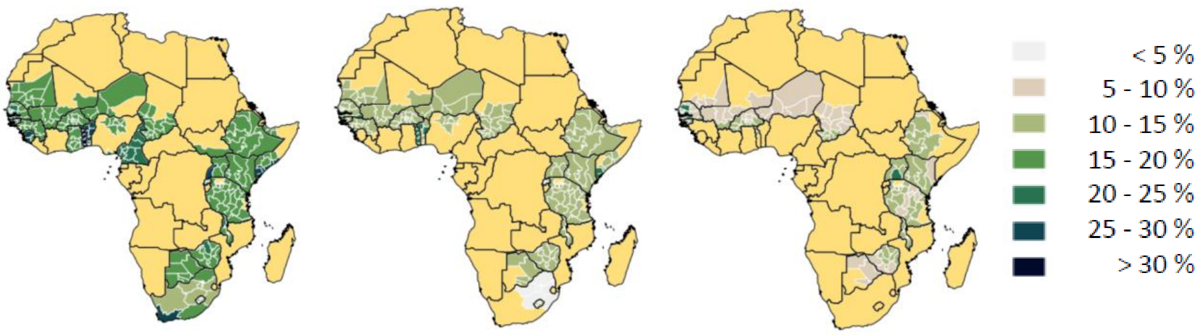
Figure 1 Links in the postharvest chain for cereal grains in Sub-Saharan Africa, showing typical weight loss ranges and the amount of cumulative weight loss from production (Hodges and Stathers, 2013).

Since 2009, African Postharvest Losses Information System, or APHLIS for short (http://www.aphlis.net), has supplied weight loss data for the cereals of SSA (Hodges et al., 2010b). The system was established by a) collecting and then screening all the loss data available but discarding those where the collection method was inadequate or not described (Fig. 2), b) identifying the seasonal factors that are predictive of losses, and c) constructing an algorithm that estimates a cumulative loss from production based on historical loss data and those seasonal factors that affect the magnitude of losses.

The loss estimates are presented as maps as well as tables (Fig. 3). APHLIS estimates are not intended to be ‘statistics’ but rather give an understanding of the scale of postharvest losses using the best available data and a ‘transparent’ method of calculation. Estimates are assigned by primary administative unit (province) and may be aggregated to country or to region. Provinces are usually large geographical units and may include several agro-climatic zones, consequently the loss figures are generalisations, i.e. may be at variance from those experienced in particular situations. APHLIS recognises this limitation and offers a downloadable PHL Calculator that enables practitioniers to change the default estimates to those that are specific to the situation of interest and to obtain loss estimates at a chosen geographical scale. The downloadable PHL Calculator may also be used with hypothetical data in order to model ‘what if’ scenarios.

	No. loss estimates		
	Measured	Q'aire	Discarded
Harvesting/field drying	8	15	14
Transport to homestead	2	13	0
Drying	0	2	0
Threshing/shelling	4	14	3
Winnowing	1	4	2
Farm storage	31	13	28
Transport to market	0	2	0
Market storage	0	3	0

Figure 2 The number of postharvest loss estimates from the scientific literature used by the APHLIS loss calculator or discarded after quality screening. Estimates are either 'measured' or opinions expressed in 'questionnaire' surveys.



Regional PHL by cereal [% of total annual production]											
Cereal	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Wheat	5.6	5.5	13	9.9	12.8	12.6	15.1	14	13.1	12.9	15.2
Maize	16.8	17.3	17.1	17.9	18.9	20	17.7	18.8	17.8	18	17.6
Rice	11.8	11.8	11.6	11.8	11.8	12.1	12	12.6	12.1	13.6	12.2
Sorghum	12.3	11.8	12	12.3	12.3	13	12.5	12.6	12.4	12.4	12.3
Barley	9.8	4.5	9.4	9.4	9.4	9.5	10.9	10.1	9.7	9.7	10.5
Rye	-	-	-	-	-	-	-	-	-	-	-
Oats	-	-	2.1	2.1	2	2.1	2.1	2.1	2.1	2.1	2.1
Millets	9.5	9.9	9.8	10	10.2	10.7	10.1	9.9	10.4	10.1	10.4
Fonio	11.7	11.7	11.7	11.7	11.7	12	12.4	12.2	11.7	11.8	11.7
Teff	11.7	11.7	12.5	12.5	12.1	12.5	12.5	12.5	12.5	12.4	12.5

Figure 3 Cereal % weight losses in Sub-Saharan Africa 2012 estimated by APHLIS presented as maps and tables (http://www.aphlis.net).

APHLIS allows users to see the broad spread of cereal losses across the continent as well as the likely variation of losses between the provinces of a country and between crops. Delving more deeply into APHLIS, users can find the losses associated with each link in the postharvest chain. This allows them to consider priority targets for loss reduction in terms of both geographical location and link in the chain. This is further supported by expressing loss estimates not only as % weight loss but also as loss density (Fig. 4). This highlights locations where the absolute losses (tonnes) are especially severe and so potentially where the greatest returns from investment in weight loss reduction might be achieved.

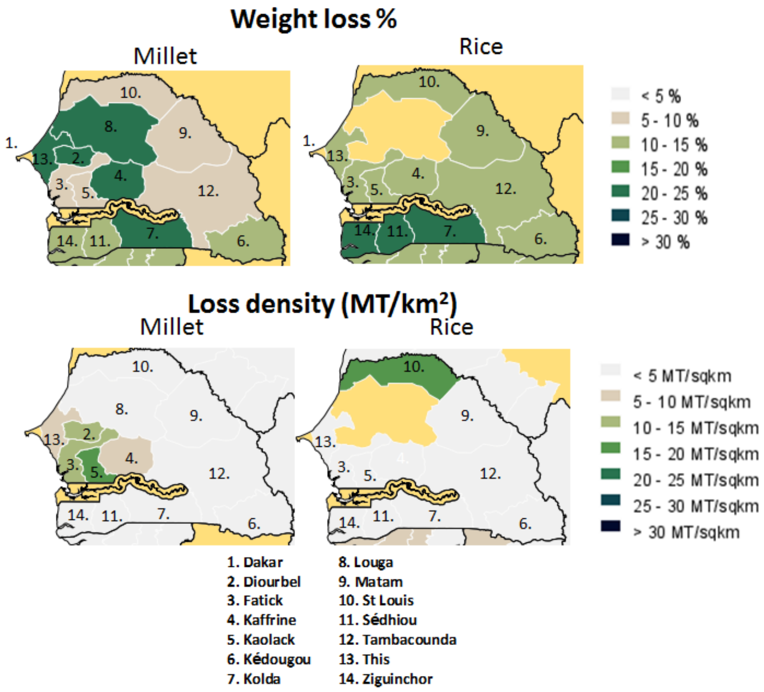


Figure 4 A comparison between the % weight loss maps of millet and rice in Senegal with the corresponding loss density maps that express weight loss as tonnes per km^2.

2.2. Losses of quality

A loss of grain quality may be easy to measure, i.e. a reduction from grade 1 to grade 2 determined by the parameters of a grading system, but to express this in a way that demonstrates the impact on the producer usually requires the calculation of a financial loss; a difficult job because the relationship between quality and value is complex. This may be because markets are insufficiently quality conscious to distinguish between different grades, or grade 1 soon after harvest may actually sell for a lower price than grade 2 six months after harvest when grain is scarce. Consequently, most previous loss estimation has focused on weight loss. Nevertheless, quality losses probably have a more significant economic impact than weight losses and may also impact on food safety and nutrition. In an example from Zambia, cash cost estimates of losses showed that on average quality losses had twice the value of weight losses (Table 1).

Table 1 The cost of losses during maize storage at two locations in Zambia, in Zambian Kwacha (Kw 1.2 = US$1) (Adams and Harman, 1977).

	Direct				Indirect* (insecticides)
	Total direct + indirect costs	**Total direct costs**	**Weight**	**Quality**	
Chivuna	68.93	54.98	20.22	34.76	13.95
Chalimbana	26.12	21.47	3.51	17.96	4.65
Total	95.05	76.45	23.73	52.72	18.6
Mean all farmers	11.88	9.56	2.97	6.59	2.33

*Indirect losses are costs involved in the prevention of losses, in this case the application of storage insecticides

Where specific quality grades are not enforced there would in theory be a continuous relationship between price and quality (if there are grades enforced then there are price steps i.e. price and quality do not have a continuous relationship). It has been assumed that loss in value is equal to the weight of grain lost multiplied by the price of undamaged grain. However, when looking in more detail this appears not always to be the case, especially as in informal markets grain is often sold by volume and not by weight. In cases where weight losses reached up to about 5% due to insect damage, loss in maize value may be negligible because the volume of the grain is effectively the same as that of undamaged maize and the price is unaffected by low levels of damage (Compton, 2002). The effects of quality deterioration, in this case insect damage, on the price of maize have been studied in an informal market in Ghana (Compton et al., 1998). Panels of experienced maize traders suggested prices for pre-prepared maize samples showing different degrees of insect damage. The relative price of damaged maize was quite consistent across the markets studied. At harvest a 1% increase in damaged grains decreased price on average by 1%, but later more damage was tolerated as maize became scarcer (Table 2).

Table 2 The relationship between market availability and the effect of insect damage on market price (Compton et al., 1998).

Availability of maize on the market	Maize given top price (% damaged grains)	Price of highly damaged maize (>90% damaged)
Plentiful (soon after harvest)	0-5%	Unlikely to sell
Moderate (mid-season)	0-5%	Unlikely to sell
Scarce (lean season)	0-7%	25% of top price
Very scarce (bad years)	0-10%	30% of top price

When planning projects to promote new approaches to loss reduction, it is clearly important to have a good understanding of their profitability to smallholders who market grain, as this is a major factor for the adoption of some new practices or technologies. The starting point for determining this profitability is to place a financial value on the losses in weight and quality combined. This is problematic but a start has been made on this in relation to grain storage, where the benefits of smallholders of adopting hermetic grain bags under various market conditions and financial scenarios are considered (Jones et al., 2014).

An important category of quality loss is contamination of grain with mycotoxins; these are the toxic metabolites of fungi growing on grain. There are many different mycotoxins that could contaminate grain; their range and status in African produce has been reviewed by Wagacha and Muthomi (2008). The mycotoxins receiving most attention are aflatoxins produced by some strains of the fungal species *Aspergillus flavus* and *Aspergillus parasiticus* under certain physical conditions. Aflatoxins are cumulative poisons that can induce cancer in susceptible animals, and aflatoxin B_1 is the most potent liver carcinogens known. Following the 1970s food crisis there was an increasing interest in mycotoxins and a growth in methods of measurement. However, although mycotoxin projects offered new approaches to measurement and increasing information on contamination rates the unpredictable nature of their presence in multi-layered value chains based on huge numbers of individual producers made prevention problematic. Consequently, mycotoxin projects fell out of favour with development donors during the 1990s along with postharvest loss reduction projects. However, the latest food crisis has been rekindled interest culminating in the launch in 2011 of the Partnership for Aflatoxin Control in Africa project (PACA, http://www.aflatoxinpartnership.org). This is now co-ordinating mycotoxin reduction both before and after harvest.

Knowing where and when aflatoxins are formed in grain is an important contribution to limiting contamination. The growing crop in the field can become infected with *Aspergillus* spp. if subject to drought stress as this reduces plants' defences against mould growth. Consequently, grain may be contaminated with aflatoxin before it is even harvested. Moulds may also grow on moist grain that has been left exposed by the attack of field pests and/or has come into contact with the soil which is a source of mould spores (and moisture). During postharvest handling if moist grain is not dried quickly and thoroughly it is in danger of mould infection and toxin formation. To prevent the production of aflatoxin after harvest requires avoiding the following: harvest when the weather prevents good drying; delays in harvesting (Kaaya et al., 2005; Golob, 2007; Hell et al., 2010); or, the storage of the harvested crop in the field in stooks or stacks (Waliyar et al., 2002). If mould damage and toxin formation has been avoided prior to storage then grain maintained at a safe moisture content should remain free of aflatoxin. The main danger is then water entry into store due to leakage. In large scale storage there is also a danger of hot spots occurring in the grain due to insect infestation, this results in high temperature and moisture which presents a danger, but these conditions appear not to have been reported from small bulks of grain stored by smallholders or in sack storage. If aflatoxin concentrations do rise during smallholder storage then the use of hermetic stores could benefit smallholders as they prevent moisture uptake. However, justification for grain storage in hermetic storage based on the notion that there is "….. rapid growth of post-harvest aflatoxin levels when stored for prolonged periods in conditions of high temperature and relative humidities above 65% …" (Villiers, 2014) seems improbable in view of the known physical limits to both the growth of *A. flavus* and *A. parasiticus* and the production of aflatoxin. For germination and growth, *A. flavus* requires a minimum water activity (a_w) of about 0.82 (Sauer and Burroughs, 1980; Sauer, 1987; Gibson et al., 1994; Pitt and Miscamble, 1995; International Commission on Microbiological Specifications for Food, 1996). For cereals at typical tropical temperatures (20 - 30°C) this would equate to a grain moisture content of about 18% but may be as low as 17.5% in some cereal grain varieties.

The same minimum applies to toxin formation which is not maximal until temperatures are in the range of 16 to 31°C and a_w 0.95-0.99. For *A. parasiticus* the situation appears to be similar, growth and germination require a minimum of a_w 0.83 and for toxin formation 0.87 a_w (Pitt and Miscamble, 1995). It is clear that if cereal grain is maintained at a maximum not exceeding 14% moisture content (i.e. the moisture content in equilibrium with a_w 0.7$_)$, considered to be the safe moisture content for cereals stored in bags in the topics, then aflatoxin formation is excluded. Nevertheless there have been surveys suggesting that aflatoxin concentrations rise during grain storage by smallholders (Hell et al., 2000) and traders (Kaaya and Kyamuhangire, 2006), which suggests that the grain is being stored at moisture contents in excess of 17%. However, surveys are confronted with inevitable sampling challenges that result from the very uneven distribution of aflatoxin contamination within the grain mass, where exceptional sampling protocols are required (EU Regulation, 2006). Further detailed investigation is needed, which includes the tracking of grain moisture, to demonstrate whether or not significant increases in aflatoxin contamination do occur as a result of the conditions experienced during smallholder storage, and distinct from catastrophic failures allowing water entry.

3. The assessment of losses

The assessment of losses is potentially an expensive and time consuming process. The broad brush approach taken by APHLIS offers loss estimates at a geographical scale that would be impractical to achieve by multiple measurements on the ground. However, the continued collection of loss estimates is required, especially in relation to the impact of loss reduction activities and for updating the figures used by the APHLIS PHL Calculator; for reasons of economy these two objectives should be pursued simultaneously.

In the 1970s several techniques were developed for assessing postharvest grain losses which are detailed in Harris and Lindblad (1978) and reviewed in Boxall (1986). They mostly concern grain storage losses and the proposed techniques, although relatively accurate, are very time consuming. They involve taking samples, returning them to a laboratory and then analysing them. From the 1990s onwards, researchers shifted from purely lab-based techniques to rapid methods (called visual scales) that could be implemented on site and done with the participation of grain owners (Compton et al., 1995, 1999). Furthermore, any grain samples extracted remained with their owners. These rapid methods can be linked to questionnaire surveys and designed so that these two methods are complementary. For advice about the use of visual scales, a manual can be downloaded from APHLIS website (http://www.aphlis.net). Although loss assessment methods for storage losses are well developed, those for other links in the postharvest chain require further attention.

It is unlikely that a survey to make actual measurements of losses would be implemented without a simultaneous questionnaire survey to put the loss measurements into a household/farming context. However, it is not infrequent that loss surveys have relied solely on the use of questionnaires with no actual loss measurement undertaken. Indeed some APHLIS loss data originate from questionnaire surveys (Fig. 2) simply because the overall losses data set would be too small without them. During a questionnaire survey it should never be assumed that the answers given by individuals are accurate because the respondent 1) may have no real knowledge of what the losses are, 2) may only be able to respond in relative terms i.e. put losses in relation to other hardships of life, or 3) may give responses just to please the questioner or gain some other advantage. In order to overcome some of these problems the approach taken should involve some degree of ‘triangulation’ (Pretty et al., 1995) but best of all losses should be assessed using rapid techniques together with a questionnaire survey so that farmers’ perceptions are compared with some actual loss measurement. Farmers’ perceptions are valuable in their own right but it has often been found that farmers put postharvest losses low on their priorities. This should not be taken as a sign that these losses either do not exist or are unimportant, which appears to be the case in a recent postharvest questionnaire survey (Kaminski and Christiaensen, 2014). For example farmers often don’t seem to connect the loss of grain early in the season with their need to purchase grain on the market at a later stage before the new harvest. Nor do they tend to appreciate the potential better livelihoods that could be obtained by producing better quality grain; this is understandable because they are one removed from this opportunity since it requires the development of group marketing and access to a market outlet that values better quality grain.

4. Moving to better quality grain and more efficient value chains for loss reduction

Central to any effort to reduce losses is the adoption of better postharvest practice. This is key for both smallholders who are deficit producers, and focused on improving household food security, and smallholders who are surplus producers, and focused on making better livelihoods from grain sales. Improvements include the diligent application of existing approaches to postharvest handling (e.g. ensuring basic hygiene, monitoring, storage practices, etc.) and the introduction of new technologies (better grain driers, shellers, stores etc.). Most deficit producers lack commercial opportunities and may need direct subsidy before they can adopt improved postharvest methods to reduce losses and improve their food security. For those seeking commercial opportunities, these can be facilitated by the adoption of new marketing arrangements such as collective marketing or new financial institutions. The latter include inventory credit or warehouse receipts systems (CTA & EAGC, 2013). These give access to the credit needed by smallholders that enables them to adopt the better practices and technologies required to produce grain that can enter better value markets.

For surplus producers, the process leading to adoption of better technology requires preconditions such as a market that offers sufficient reward for better quality grain; transport infrastructure giving reliable linkage to a market; and, the knowledge and skills to produce good quality grain in a commercial context. Farmers often find that it is not worthwhile investing in the production of good quality grain because the financial rewards are insufficient. Such an investment is not necessarily confined to the costs of better technology but also requires a change in farmers’ priorities and in a willingness to take risks. Critically, a suitable incentive is needed to encourage postharvest loss reduction and the financial benefits may have to be several multiples of the financial costs before behaviour will change.

It is not only surplus-producing farmers who would benefit from the production of good quality grain. Others working in the grain trade, the traders, transporters etc., also benefit because a successful, quality conscious grain trade offers much increased grain flows in national and regional markets, leading to better business and better nutrition for all. Currently, in some countries it is common for traders to purchase poor quality grain from farmers at a low price. This poor quality grain may then be placed on the market directly and, if it is not consumed quickly, weight losses may be high due to biodeterioration (Scenario 1 in Fig. 4) and in any case opportunity losses are inevitably high (Hodges and Stathers, 2013). If traders are keen to exploit higher value markets then they may instead condition grain (clean and dry it) so that it conforms to grade requirements (Scenario 2, Fig. 4). But the process of conditioning involves substantial grain losses and costs. The result is less grain on the market and at a higher price. Alternatively, farmers could use better postharvest handling techniques that retain grain quality so that subsequent conditioning is not needed (Scenario 3, Fig. 4). In that case, consumers benefit as they do not have to pay the costs of the losses inherent in this process and as the losses are lower there will be more grain on the market that will result in prices rising less steeply. This highlights the need for a value-chain approach and appropriate incentives to help farmers sell better quality grain for higher prices.

		Farmer	Trader
Scenario 1	PHHS	Basic	Basic
	Grain Quality	**Poor**	
	Losses	**High due to marketing low quality grain**	
Scenario 2	PHHS	Basic	Grain conditioning
	Grain Quality	**Poor**	**Good**
	Losses	**High due to conditioning operations**	
Scenario 3	PHHS	Improved	Basic/ improved
	Grain Quality	**Good**	
	Losses	**Low since quality is achieved at the start**	

Figure 4 Three scenarios in which differing postharvest handling and storage (PHHS) procedures by smallholder farmers and by traders result in different outcomes for grain quality and grain losses (adapted from Hodges and Stathers, 2013).

Consistent financial rewards to farmers for the production of better quality grain are only likely to be offered in the context of a formal market with clearly defined and enforced quality standards. In SSA most grain moves in informal markets. However, the need for formal markets is well recognised and at least in East Africa, the East African Grains Council (EAGC) and its development partners are seeking to raise standards and pay a premium for better quality.

The principle that a quality conscious market offers the incentive needed to reduce PHLs by creating a shift from scenarios 1 or 2 to scenario 3 (Fig. 4) is demonstrated by the UN World Food Programme's Purchase for Progress pilot programme (P4P). This programme buys grain at a clearly specified quality from groups of local producers for distribution as food aid, meeting the needs of food aid beneficiaries and at the same time helping to stimulate good quality local grain markets (WFP, 2009). The Producer Groups are treated according to their state of development and WFP has adjusted procurement modalities accordingly so that they can fulfil grain tenders. The Groups are also provided with training on business and postharvest handling and storage (PHHS). The PHHS aspects of this process have been given a boost by the development of a 'Training Manual for Improving Grain Postharvest Handling and Storage' (Hodges and Stathers, 2012), in both English and French, for use by WFP training staff and partners. The Manual gives clear guidelines and instructions on how to retain grain quality throughout the supply chain and is illustrated throughout with simple, clear cartoons that express some of the many basic messages.

A real life example demonstrating the complexity of circumstances is the case of the Iganga Farmers' Group in Uganda (Hodges et al., 2013). Previously, they could not shell their maize cobs soon after harvest as they had more important tasks, including land preparation for another crop. When there was time, they shelled their maize by beating the cobs with sticks, a long and tedious process resulting in plenty of broken grain. They then lacked time to sort the grain to meet the quality requirements of a local warehouse receipts system. But then a new opportunity appeared when a motorised thresher was offered for hire. Using this machine they could shell their maize quickly and directly after harvest, giving a number of important advantages. As the machine was more efficient than hand-shelling there were fewer broken grains; with less delay quality decline was minimised, and now they had time to sort their grain to ensure good quality. In this new scenario they moved their maize very quickly to the warehouse and received a warehouse receipt. With the receipt they borrowed money from the bank to finance the inputs required for planting the next crop. At the warehouse the Manager noted that the grain from this Group was now of much better quality, so he didn't have to reject any and buyers of this warehouse receipt paid a premium price.

For smallholder farmers, both now and since the 1960s, the most frequent option for the improvement of postharvest handling has been to adopt improved grain stores. The current emphasis is on fully sealed stores, particularly metal silos and drums as well as plastic bags and drums. They all offer an opportunity to kill insect pests without recourse to the admixture of insecticidal dusts. This is possible because either they are airtight, so that the atmosphere around the grain becomes low in oxygen and high in carbon dioxide resulting in the death of any infesting insects, or the grain can be fumigated and following the death of the insects the stores are sufficiently insect-proof to prevent reinfestation. These sealed stores have an additional advantage in that they prevent any uptake of moisture. Similar stores were available in the 1970s. For example, hermetic plastic grain bags (Fig. 5a,b) for cowpea storage were being extended by Ahmadu Bello University in 1972. They resemble the current triple bagging (PICS bags) and GrainPro Super bags, except that they included a cotton bag-liner. This prevented any adults that might emerge from cowpeas from penetrating the plastic bag. Likewise in Swaziland, metal silos of about 1 tonne capacity became popular in the 1970s and by the 1990s about 30,000 were in use despite the absence of any concerted extension programme (Fig. 5c). These metal silos are similar in design to those introduced into Central America by the PostCosecha project of the Swiss Agency for Development and Cooperation.

a. **b.** **c.**

Figure 5 a.,b. Hermetic cowpea storage plastic bags with a cotton liner (Ahmadu Bello University, 1972), c. Metal silos used to store grain in Swaziland in the 1970s and later.

Although the more modern versions of sealed stores are probably more effective than their 1970s counterparts, the principle difference has been the more sophisticated measures used to facilitate smallholder adoption of the modern stores. In Central America, very high adoption rates were achieved by a social-marketing approach that was inclusive of product, price, distribution and promotion (Coulter et al., 1995; Coulter and Schneider, 2004). By 2008 the project had recorded the transfer of 586,000, although government subsidy supported the adoption of a considerable proportion of these (Bokusheva, 2012). PICS bags have also been the subject of local manufacture, the development of carefully managed supply chains, and farmer motivation through media and village awareness activities (Baributsa et al., 2010).

Although sealed stores are the focus of current attention, the range of options for farmers is wider than this and selection at least in part addresses the quantities of grain to be stored and the anticipated storage period (Fig. 6). Other practical considerations are the costs and availability of the various store types, security from theft, physical space, life span of the technology and cultural preferences. When planning loss reduction projects that involve improvements in storage these factors must all be taken into account. To be successful, projects need to offer a range of storage option appropriate to the needs of smallholders or other users. When offered at no cost, or low cost, most storage methods are accepted by households, even if they are not perceived as suitable, then stores may be abandoned or pressed into other uses, e.g. rain water tanks (Fig. 7).

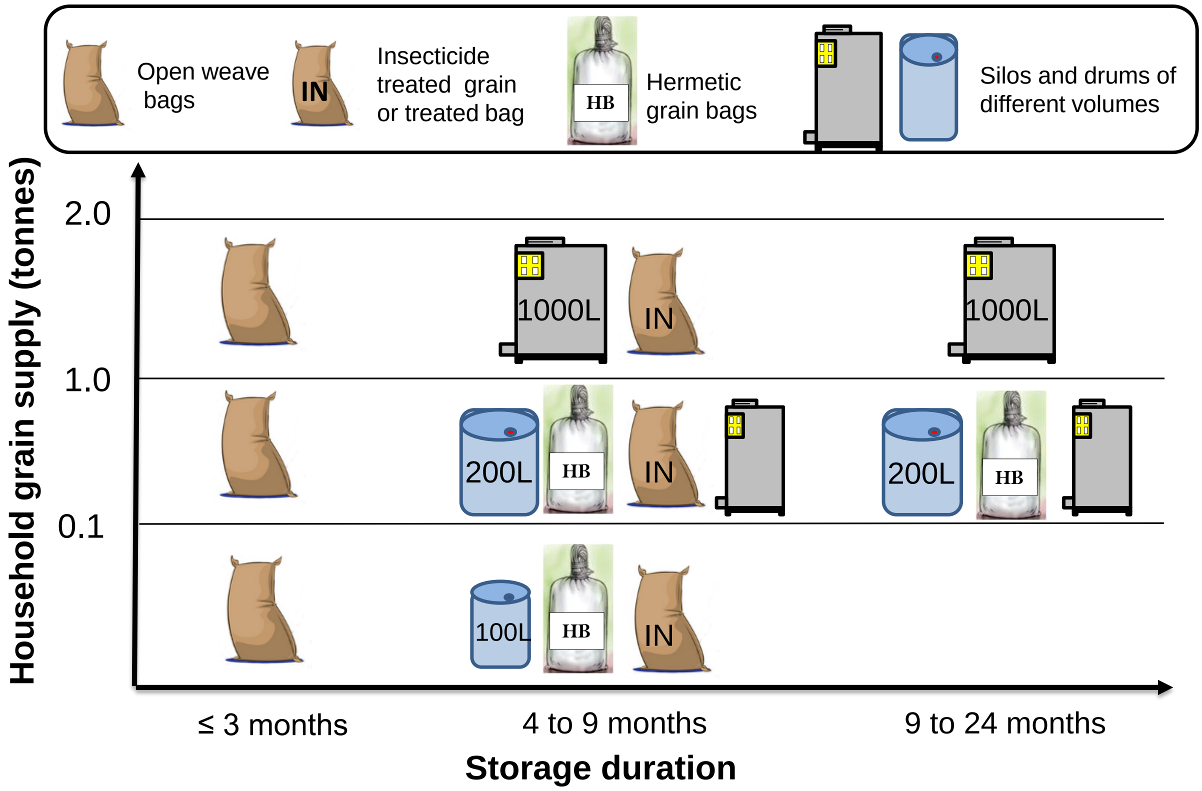


Figure 6 Maintaining good grain quality – choice of a store type for smallholder farmers based on the amounts of grain to be stored and the length of the storage period. (Hodges, unpublished)

Progress in the introduction of postharvest improvements in general, not just grain stores, appears to have been rather slow and the approach to the identification, screening, testing and roll-out of improvements seems often to have been unsystematic. The Missing Food report (World Bank, 2011) highlighted value-chain approaches to the introduction of innovations that would help farmers sell better quality grain for higher prices. Such approaches imply timely harvesting and shelling, improvements in supply chain coordination so as to better match supply with urban demand, a need to help the farmers to get maximum value added, and to take advantage of seasonal price variations. Farmers often know how to improve the quality of grain they sell, but do not find it worthwhile because they can't earn a premium by doing so. Development projects may seek to address this by focusing more on market intermediaries, i.e. forward-looking local merchants, large-scale traders and farmer organisations (FOs), as channels to convey extension messages and premiums to farmers, rather than just public extension services. It has been suggested (Coulter, J., Pers. Comm.) that improvements to the system should be introduced through a systematic marketing approach called New Product Development (NPD), used widely in business and engineering, that can be adapted to grain systems – where the word "product" is interpreted broadly to include both hardware and soft innovations (i.e. new approaches). The NPD starts with identifying a range of postharvest improvement ideas that meet the needs of different target groups, and requiring more or less household expenditure; these are then screened and tested in terms of performance and socio-economic fit to produce a smaller number to be taken to scale (Fig. 8). The selected improvements will typically be the object of test-marketing exercises in representative geographical areas, sometimes in partnership with manufacturers/artisans, and with full educational and promotional support to the other parties involved (farmers, producer organisations, hardware distributors, stockists etc.), including quality control and monitoring their adoption over time. The advantage of NPD is that it weeds out the less promising ideas in the early stages, and ensures that costly activities like test marketing are only employed with ideas/technologies that have passed earlier tests. It also leads to market segmentation, where different approaches support and empower different household types (re wealth/poverty levels, female headed, post-conflict status etc.), and where more expensive solutions (e.g. the metal silo) are targeted at those who can afford them, or who can access suitable financing.

a) **b)**

Figure 7 Metal silo grain stores modified as water tanks rather than being used for their original purpose, in a) note tap installed in the grain outlet port.

To start this process requires an in-depth analysis of what has been learned and achieved to date, and the potential for new initiatives. This involves desk research and an extensive programme of site visits to interview key personnel, farmers, artisans, merchants, input suppliers and others involved. Knowledge of the environment into which the postharvest improvements are to be introduced is required and is obtained by asking questions such as: Is public policy facilitative or otherwise? Is there sufficient seasonal price variability to make storage worthwhile?; and, What are the rates of return?

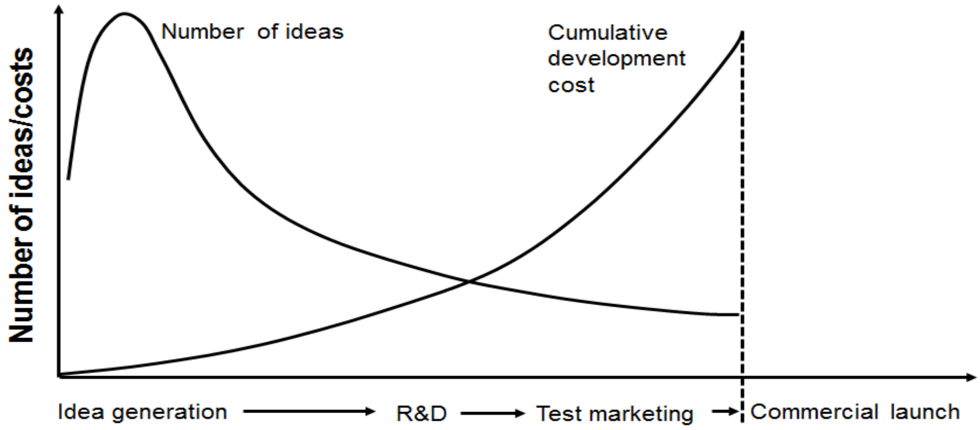


Figure 8 The process of 'New Product Development', a systematic approach to the introduction of postharvest ideas that focuses on market intermediaries, i.e. forward-looking local merchants, large-scale traders and farmer organisations (FOs), as channels to convey extension messages and premiums to farmers.

5. Future directions for loss reduction

Postharvest loss reduction is a complex and multi-faceted activity that would benefit from modern approaches to co-ordinate and inform it, especially information and communication technologies (ICTs). Some suggestions for future development are listed below.

5.1. Creation of a community of practice

The international community currently has no effective means of co-ordinating and promoting the reduction of postharvest grain losses, more so since the demise of P*h*Action (The Global Postharvest Forum). In the wake of the recent food crisis the first move in this direction has been the launch in October 2014 of a 'Community of Practice' website within the frame of FAO's 'SAVE FOOD: Global Initiative on Food Loss and Waste Reduction' project, with the financial support of the Swiss Agency for Development and Co-operation (SDC). This links the activities of various Rome-based UN-organisations and those of SDC. Its objectives are aligned with the outcomes of existing projects on many different types of food and it offers a moderator to facilitate webinars on topics of interest. However, the prize will be to create a bottom-up forum that links those people working at all levels in relevant value chains so that their voices can direct, or at least inform, policy and priorities. In the case of grains this would particularly involve smallholder farmers and their associations and then other value chain actors such as trader, millers, input suppliers and those within government responsible for regulation. Reaching out to these groups would benefit from a degree of personal contact and should be a two-way exchange. The first step to achieve this would be to make active links with other bodies and institutions engaged in postharvest loss reduction. In the case of grains, this would include among others USAID, the ADM Institute for the Reduction of Postharvest Losses, the NRI Postharvest Loss Reduction Centre, and APHLIS. In the case of APHLIS, its network members in developing countries have already started to create their own country-specific web pages that give narratives elaborating on postharvest losses. In the future, these will be expanded to describe national opportunities for loss reduction. However, there are much closer connections to loss reduction that could be made that would enable a 'bottom-up' approach within the Community of Practice. It has been proposed that APHLIS could be connected directly to the intended beneficiaries of loss reduction projects. This could be achieved both when loss reduction approaches are being disseminated and also at the time data on the loss reduction impacts are collected. A novel means of implementing this information flow would be by connecting APHLIS, and potentially other loss reduction initiatives, to the RUN-System (see http://www.erails.net/FARA/erails2/erails2/the-run-system/). This uses ICT to train young professionals (YPs) in Africa to deliver specific services for the collection of certain data or for the dissemination of information upon the request of an actor in the innovation system. On the completion of tasks the YPs receive a voucher that is redeemable for cash. ICT is used to control and monitor the process and to collect data that can be analysed to plot the progress of initiatives, show impact and provide feedback. The system has many additional advantages. These include accomplishing tasks at relatively low cost, using local people to solve local problems, and it offers employment to suitably qualified young people who are otherwise unemployed or under-employed.

5.2. Strengthening the supply of loss data and offering loss predictions

APHLIS is the sole source of broad based metrics on grain weight losses across Sub-Saharan Africa. It relies heavily on ‘seasonal’ data that contribute to loss calculations yet to date advantage has not been taken of automatic weather data collection systems (rainfall, cloud cover, humidity and temperature). Since there is no extensive, high-quality network of weather stations in Africa, exploring the potential of downscaling analytical data sets like the European Centre for Medium-Range Weather Forecasts (ECMWF) re-analysis or high resolution precipitation reconstructions are of interest. These would improve the quality and rate of supply of seasonal data and could possibly be used as the basis for predicting certain postharvest problems, especially those associated with crop drought stress, crop drying, LGB, and climate change. These issues could be highlight with maps and alerts.

The conditions that result in plant drought stress and subsequent formation of aflatoxin on maize and groundnuts are reasonably well known (Chauhan et al., 2008) so that there is an opportunity to use monitoring systems such as ASIS (Agricultural stress index, see http://www.fao.org/giews/earthobservation/asis/index_1.jsp?lang=en) with weather data to model the occurrence of aflatoxin risk due to drought stress. This would be complementary to risk warnings based on the identification of locations where damp weather conditions and harvest times coincide to create grain drying problems. In such locations, grain losses would be elevated and also growth of *A. flavus* may lead to the production of aflatoxins. These outputs could be linked into current projects on mycotoxin reduction such as PACA.

Automatic weather data downloads may be used to predict those years where the LGB is a severe problem. An existing rule-based climate model of its flight behaviour (Hodges et al., 2003) could be used to predict locations likely to be experiencing LGB outbreaks. These predictions can be used to support the seasonal data currently submitted by APHLIS Network members, to advise current projects focusing on smallholder grain storage, and to formulate plans for new loss reduction initiatives.

In addition, the automatic download of weather data can contribution to an understanding of the impacts of climate change. Future climates are likely to become more variable and this implies greater difficulty in planning agricultural activities, including crop drying. Data would be available to show changes over time and the scale of the problem, such as comparison maps between seasons and years. This would contribute to projects dealing with climate change adaption for smallholder farmers.

5.3. Widening the scope of postharvest losses measures to include value loss

Currently the only widely available loss data are cereal weight losses and these are not expressed as value (monetary) losses. If both weight loss and quality losses could be monetized then there would be a common denominator for both types of loss. They could then be summed to express an overall postharvest loss. Thus there remains a considerable opportunity to display the true significance of postharvest losses and assess both their financial and economic impacts.

Suitable methodologies are required to enable the monetization of losses. To make estimations of monetary loss due to weight loss is fairly simple once there is agreement on the price of the lost grain. One approach to this could be to adopt a range of grain prices reflecting different marketing options at a chosen time of year, and then to quote a range of potential monetary loss values. The availability of such price data would be limited, but the conversion of weight loss into monetary loss could be undertaken on a demonstration basis, at least until such data are more readily available. Much more complex would be to ascribe a monetary value to quality changes (as mentioned in Section 2.2). The prize in making significant progress in valuing losses is that it will be possible to improve the efficiency of loss reduction planning, the subject of the next sub-section.

5.4. Offering more help to identify and plan loss reduction actions

Planning loss reduction projects to optimize outcomes and ensure best value from investments is a significant future challenge. Currently very little help is available in this regard. APHLIS weight loss tables display the extent of losses accruing at each link of the postharvest chain. However, this takes no account of quality losses and no financial value is put on these losses. As the grain passes along the postharvest chain the process adds value to it, i.e. grain is more valuable once it is in the farmer’s store than at harvest time due to the time and effort required for postharvest handling operations. Further, with the passage of time after harvest, grain becomes scarcer and so gains value. Consequently, a decision is required as to whether the objective of loss reduction is to maximize grain availability, in which case the target is postharvest link with the greatest weight loss, or to maximize farmer incomes in which case the target is postharvest link contributing the greatest value loss. Furthermore the choice of target and the approach used would depend on a range of factors related to the efficiency and costs of the innovations required to reduce losses, their likely adoption rates by the target population and the amount of investment available. Two loss reduction centres have identified loss reduction planning as an area for development and have made the first step to make assistance available. The ADM Institute offers a ‘Postharvest Investment Tool’ (http://postharvestinstitute.illinois.edu/tools_outreach.html) that estimates the value of postharvest loss based on known practices and expected loss percentages at each link in the postharvest chain, that can combine mixes of different technologies. A rather different tool is offered by the NRI Postharvest Loss Reduction Centre in the form of an ‘app’ (http://postharvest.nri.org/losses-information/analysing-losses) intended as an imaginative way to draw attention to the key factors affecting investment in loss reduction projects. It doesn’t actually make any decisions for the user but shows how financial investment, the efficiency of the loss reduction innovation, and the rate of adoption by a target population all interact and can be optimized for best outcome (Fig. 9).

Figure 9 Portion of a postharvest losses 'app' designed to draw attention to the interaction between investment, adoption rate and the efficiency of postharvest improvements on loss reduction performance. The postharvest link shown is harvesting, other link are also included and when adjusted contribute to an estimation of the change in cumulative loss.

For the future, more complex models could be developed to enter real data and take into account a wider range of factors. This will be a move towards real decision support and at the same time lead to a debate, and in time agreement upon, the factors that must be considered before embarking on a loss reduction project.

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