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Promising interventions for inclusion in investments to reduce postharvest losses of key food crops in sub-Saharan Africa and South Asia

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About the report

This report*, Promising interventions for inclusion in investments to reduce postharvest losses of key food crops in sub-Saharan Africa and South Asia*, draws out key actionable insights from two companion reports that review the academic literature on postharvest losses in these regions and assess the current landscape of postharvest loss reduction actors and interventions in a selection of African countries. The authors of this report are Tanya Stathers (Natural Resources Institute (NRI), University of Greenwich) and Deirdre Holcroft (Holcroft Postharvest Consulting). The authors bear sole responsibility for the content of this report, and any errors and omissions are the authors' sole responsibility. Please direct any comments or queries to the corresponding author, Tanya Stathers, at t.e.stathers@greenwich.ac.uk.

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About the Research Commissioning Centre

The Foreign, Commonwealth and Development Office (FCDO) Research Commissioning Centre (RCC) has been established to commission and manage research to enhance development and foreign policy impact. Led by the International Initiative for Impact Evaluation (3ie), the University of Birmingham, and an unmatched consortium of UK and global research partners, the RCC aims to commission different types of high-quality research in FCDO's key priority areas.

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How to use this document

Postharvest (PH) systems include a number of different activity stages, which vary by crop, by location, and are done over different time periods by different actors with varying resource situations and intended end-uses. At each of these activity stages (e.g., harvesting, transporting, drying, threshing, packaging, storage, marketing) losses can happen due to a range of different and possibly interacting causes (Fig. 1). This complexity is not a reason for inaction, instead recognising and understanding and working with it is an opportunity for supporting and targeting relevant, acceptable and effective investments to reduce postharvest losses (PHL), to help maximise the value and impact of investments.

The diversity of postharvest activities and systems means there is no simple answer for reducing postharvest losses (PHLs) in all these different crops. But, a number of interventions that reduce losses during specific PH activity stages for some of the key food crops have been studied and information on their technical efficacy exists although there is very limited information about any of the social, economic or environmental outcomes of these interventions, and the outcomes may differ by situation.

Figure 1. Grain postharvest activity stages and typical loss causing factors at each stage

This document presents findings of promising PHL reduction interventions which evidence collected during a recent update of a systematic scoping review (SSR) of crop postharvest loss reduction interventions in sub-Saharan Africa (SSA) and South Asia (Stathers et al., 2024a; Stathers et al., 2020) suggests can usefully form part of an informed strategy for reducing PHLs. The review covered 22 key food crops[1] of importance in the domestic food systems of the focal 57 low and middle income countries in SSA and South Asia. The review screened and synthesised the available PHL reduction research findings for each of these food crops from the 1970s to January 2024. In this document we also highlight some issues of relevance to these interventions and their focal PH contexts building on the experiences and perceptions of knowledgeable PH key informants in four SSA countries gathered during a recent consultation study on PHL reduction interventions (see Stathers et al., 2024b).

[1] [Cereals]: maize, rice, sorghum, wheat; [Legumes]: beans, cowpeas, pigeon peas, chickpeas, groundnuts; [Root and Tuber]: cassava, potato, sweetpotato, yam; [Fruit]: plantain, banana, mango, papaya, citrus (all citrus fruits including orange, lemon, lime and mandarin); [Vegetable]: cabbage, onion, tomato, leafy vegetable.

Interventions to reduce PHLs can take many different forms. For example, training, access to finance, policy and regulation, farmer organisation, changes to handling practices as well as tangible technologies/ equipment/ tools. These different types of intervention can also be bundled together. The SSR categorised the PHL reduction interventions by these types, and by the PH activity stage which they target. Technology/ equipment/ tool type interventions dominate the evidence-base followed by handling practice changes, but little, if any, evidence on the other intervention types was found.

This document is structured to enable the reader to quickly gain an understanding of the promising PHL reduction interventions for the different crop groups (cereals, legumes, root and tubers, fruits and vegetables) and their different activity stages (e.g., loss reduction during harvesting, or threshing, or storage etc.). Using the SSR findings, the **most 'promising interventions'**, which the evidence has shown to be **technically effective at reducing losses** are presented in **bold** text for each named crop and activity stage. The information on the technical efficacy[2] is then followed by any details of social, economic and environmental outcomes identified during the SSR or consultation, but such information is limited. This document's information expands on the summary table presented in the SSR highlighting effective PHL reduction interventions alongside the critical gaps in the evidence (see Appendix 1), and the list of policy and investment recommendations (see Appendix 2).

The updated SSR indicated the continuing need for study and systematic assessment of interventions across the entire value chain (as on-farm storage interventions for cereals, particularly maize dominate the current evidence-base), over multiple seasons and sites, and targeting stakeholders beyond farmers, if goals such as the Malabo Declaration's aim to reduce PHLs by 50% are to be achieved. The lack of studies on the impact of training, access to finance, infrastructure, policy and market interventions on PHL reduction highlights the need for evidence on interventions beyond technologies or handling practice changes. Additionally, more studies are needed connecting the impact of PHL reductions to social, economic and environmental outcomes. The SSR report provides further details on the interventions and outcomes. While a small body of further information may exist on social, economic or environmental outcomes of some of the interventions identified as promising through the SSR, a separate study of that was beyond the scope of this assignment which builds on the screening of >16,000 studies and detailed review of 457 crop PHL reduction studies, although the findings of a few interesting studies beyond the SSR evidence-base are discussed[3]. Existing information suggests factors influencing the uptake of PHL reduction interventions include cost, local availability, access, ease of use and reuse, quality, cultural acceptability, life-span, one-time subsidies, scale, awareness and demonstrations, use by neighbours, literacy, supportive policies and regulations, labour requirements and availability, and training alongside technical efficacy.

Despite the lack of information on social, economic, environmental outcomes of most of the technically effective interventions, they are still 'promising interventions' which could be included in a basket of options to be integrated into projects in which multi-stakeholder groups prioritise learning topics. Together these stakeholders can test and monitor different interventions to see how they compare to, complement or improve what is already being done by different actors, such as farmers and traders, to reduce losses. Decisions often must be made using incomplete information, but that is not a reason for inaction. By embedding collective learning processes into programme and project delivery, stakeholders can together evaluate and share their learning on these 'promising interventions' and in so doing broaden and deepen the knowledge about them, helping improve programme delivery.

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[2] PHLs are multidimensional and can be measured in different ways, both quantitatively (physical loss) and qualitatively (for example, increased damage, decay, breakage, contamination with toxins, reduced seed viability and deterioration in the nutrient content or economic value of a product) (World Bank et al., 2011; FAO, 2019).

[3] The SSR exclusion criteria excluded any studies which did not show evidence of actual loss reduction; therefore, studies which have looked at the social, economic or environmental outcomes of PHL reduction without also evidencing the loss reduction itself were excluded in the SSR.

Promising interventions for reducing crop postharvest losses

Cereals

Most of evidence for cereal PHL reduction interventions is focused on the technical efficacy of different farmer-level storage loss reduction technologies for maize. The SSR's maize PHL reduction evidence-base contains information on a few interventions to reduce losses during harvesting, drying, threshing/shelling, and sorting as well as storage and these are described in the following paragraphs.

Maize

Harvesting and field drying

Maize should be harvested at the recommended maturity stage[4]. Several studies have shown harvesting later increases grain weight loss and damage during storage (Borgemeister et al., 1998; Jonsson et al., 1987) and can increase aflatoxin concentration in the grain (Kaaya et al., 2005). Harvesting early has been seen to lead to higher incidence of mouldy, diseased or discoloured grains (Borgemeister et al., 1998).

However, a study in Ghana, found leaving the cobs to dry on standing plants in the field, as opposed to heaping them in a pile led to reduced grain weight loss and lower aflatoxin concentrations (Manu et al., 2019) (see SSR Table 5).

Heavy workloads, labour shortages, unpredictable rains and other factors can impact on timely completion of various agricultural activities, including harvesting. Loss assessment studies in Burkina Faso and DRC, found women's workloads in particular affected harvest timing (FAO, 2019a & b).

Drying

Protect maize grain from direct contact with bare ground during sun-drying, by using clean plastic sheets or tarpaulins or mats or drying floors or driers. Studies in Uganda, Tanzania and Ghana found higher weight loss and aflatoxin concentrations or odds ratios in maize grain dried directly on the bare ground as compared to when it is protected from having direct contact with the soil through drying it on plastic sheets/mats/tarpaulins or using raised drying racks (Kamala et al., 2016; Kaaya & Kyamuhangire, 2010; Mwebaze & Mugisha, 2011; Bosomtwe et al., 2019) (see SSR Table 4).

Drying maize grain in a thin as opposed to a thick layer – whether drying using sun-drying, protected solar bubble driers or solar cabinets – led to lower weight loss and less reduction in germination during subsequent storage in an Ethiopian study (Asemu et al., 2020). Although studies of different grain driers exist they tend to focus on the drying efficiency of the equipment as opposed to on the comparative levels of loss occurring between different equipment or methods. Recent work in Malawi highlighted that despite training leading to increased knowledge of proper drying methods, the space limitations at farmers' homesteads and fear of theft if drying were done in the field meant that these methods were not then adequately practiced (Anitha et al., 2019).

[4] The maize crop is mature when the plant has become straw coloured (light brown), the grain hard, and some of the plants droop downwards. Cob maturity in maize can also be tested by checking for the black layer that forms at the base of grains (where they connect to the cob). The layer can be seen by removing grains from the cob and scraping the base with a fingernail (Hodges and Stathers, 2012).

Threshing/ Shelling

For maize threshing interventions, *varying results* were obtained from different studies with some showing higher breakage rates of grains when machine as opposed to manual or stick beating threshing methods were used, and others lower breakage rates (SSR Table 5). Factors such as the type of machine, the flow rates and other settings, labour, variety and grain moisture content may also influence grain breakage rates. It should be noted that recent work by Hoffman et al. (2021) found a link between higher percentages of broken kernels and aflatoxin concentrations.

Mechanised shellers can save time and labour (e.g., one mechanises sheller achieved a throughput of 690 kg/hour versus 68.5 kg/hour from one person's manual shelling (Mutungi et al., 2022b)). Freed up time can be transferred to (other) income-generating or care activities. In many situations women and children do most of the manual shelling of maize. One study in Tanzania found women were hesitant to touch shelling machines, but that this could be overcome if training on use of the machines was done in women only groups by a female agricultural engineering extensionist (Mutungi et al., 2022b). There are ongoing debates around the un/employment dimensions of increasing mechanisation in rural areas of low-income countries, and a need for more evidence. An Ethiopia study emphasised the influence of unimodal or bimodal rainfall on the benefit cost ratio (BCR) of threshers, highlighting that in double cropping locations the BCR of a multi-crop thresher increased above 1[5] (Getachew et al., 2022). The price and efficiency of different machines means BCRs vary between them. A willingness-to-pay study in Tanzania found **80% of farmers would potentially adopt mechanised shelling if it was available as a rental service**, no gender difference for this aspect was found (Mutungi et al., 2022b).

Sorting

Sorting of grains before storage and consumption is important practice for reducing insect and fungi at the start of storage, and for removal of grains which may have a higher risk of containing mycotoxins. Consumers in Kenya were found to generally prefer maize that they have grown themselves, this was due to perceptions of superior drying or storage practices and more careful sorting, as well as the absence of chemical additives (Hoffman & Gatobu, 2014; Hoffman et al., 2021). Discoloured or mouldy grains are most likely to be sorted out. However, recent work showed maize with no broken kernels contained roughly half the level of aflatoxin as maize in which over 10% of kernels were damaged (Hoffman et al., 2021). Raising consumers awareness that maize with significant breakage in the outer layer of the grain is likely to be contaminated with aflatoxin could help reduce aflatoxin exposure. Given the higher breakage rate reported in some studies when maize grains are mechanically versus manually shelled (e.g., 31.4% vs. 10.5% (Geremew et al., 2023)), and the expected increase in use of mechanised threshing in many locations, greater awareness about the associated increased aflatoxin risks with broken grains is needed. However, work in Malawi found there was limited willingness to discard grade outs even after learning about their negative impacts, this was due to the portion of grade outs accounting for 10-20% of their profits (Anitha et al., 2019).

Storage

The SSR found 90 studies focused on maize storage interventions, 85 of which were from SSA and five were from South Asia (India (4) and Nepal (1)). These studies predominantly focused on a range of interventions for managing storage insect pests. Promising maize storage loss reduction interventions which had been studied at least twice and kept median % weight loss below 2% during 6 months of

[5] A BCR above 1 suggests that the intervention should bring financial benefits, a BCR of 1 suggest the beneits equal the costs

storage and /or kept median grain insect damage[6] below 10% were the **admixture of diatomaceous earth with grain prior to storage in woven polypropylene (PP) bags, hermetic bags and cocoons alone or in combination with other treatments or handling practices, grain stored untreated in plastic drums or metal silos, grain admixed with vegetable oils** (see SSR Figs. 5a&b).

Fumigation alone and when used in combination with botanicals, hermetic bags, synthetic chemicals or inert dust also kept grain weight loss below 2% during six months storage. However, fumigation[7] should never be done within 100 m of human habitation and should only be carried out by trained and certified pest control operators and is therefore not suitable for smallholders who often store their grain within their households and who are not trained and certified operators.

One of the most commonly used grain storage protection methods in the focal geographies is the admixture of synthetic chemical pesticide dusts (or sometimes liquid emulsifiable concentrates (ECs)) with grain. Many of the studies in the SSR had assessed the efficacy of synthetic chemicals, and median weight loss for a 6-month storage duration was 2.8% but ranged from 0% to 44.0%, and median % grain damage was 11.0% but ranged widely from 0% to 100%. Various synthetic chemicals had been studied, including pyrethroids, organophosphates, neonicotinoids and combinations of them. These products are marketed under trade names such as Actellic Super dust, Actellic Gold dust, Betallic Super EC, Chikwapuro, Malathion, Stocal Super dust, Shumba Super dust, Rambo. For any use of synthetic chemicals grain protectants, the product needs to be registered for use in the focal country and the specific use recommendations on the product's label should be followed (e.g., dosage rate, application method) to optimise efficacy and to reduce risks to human and environmental health. During interviews with PH key informants in July 2024, the importance of **training on safe use of pesticides** was repeatedly mentioned, this should be an integral part of all PH training curriculum.

Differences in the types, efficacy, stability and application rates of synthetic chemicals and other protectants, the susceptibility of varieties, the environmental conditions, the time between harvest and store loading, the level of insect infestation at start of storage etc., account for some of the variability recorded in efficacy within interventions. Recently studied promising interventions also included a woven polypropylene (PP) bag with a hermetic liner with a synthetic pesticide incorporated into the liner, a hermetic liner inside a PP bag which has synthetic pesticide incorporated into its fabric. One Kenyan study showed that just changing the method and/or tool that farmers used to apply/admix their synthetic chemical grain protectant so that the protectant was more thoroughly mixed with the grain could significantly reduce grain damage during maize storage in Kenya (Mutambuki et al., 2010).

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[6] Note there is a relationship between insect grain damage and weight loss during storage as that reported on was due to insect pest attack of the grain during storage. For maize, when 20% of grains show damage by insects this typically equates to ~5% weight loss (Holst et al., 2000), as only part of the weight of each damaged grain has been removed due to insect feeding or boring.

[7] Fumigation is a hazardous procedure, a toxic gas is used and this is a serious hazard for human health if exposure occurs, therefore fumigation must only be done by a licensed fumigator. Fumigation typically involves placing a gas-tight sheet over a stack of bags filled with grain in a store. Solid tablets of aluminium phosphide are placed on trays under the wooden pallets at the bottom of the stack. On contact with air the tablets release a poisonous gas, phosphine, that will kill the insects and can also kill humans (Hodges and Stathers, 2012). Fumigation should never be done when the enclosure is not sufficiently gas-tight, nor within 100 m of human habitation, nor if there is a danger of liquid water coming into direct contact with the metal phosphide tablets, nor if the temperature is below 15 °C, nor when it is very windy, nor if the stored commodity is flour or in fully sealed bags, nor when copper will be exposed to the gas. Effective fumigation requires the gas to be retained with the grain at the correct dosage and for the correct length of time. If either the dosage or the length of exposure are insufficient then some insect pests will survive the treatment (see section 5.14.3 in the training manual by Hodges and Stathers (2012) for further details on fumigation).

A recent study in Ethiopia found adding a hermetic liner into a traditional granary filled with cobs[8] also kept grain damage below 10% during 6 months storage (Tola et al., 2020). While early work in Kenya found that for cob storage, selecting cobs with tightly closed as opposed to open or loose husks reduced subsequent insect damage during storage (Giles & Ashman, 1971), a later study in Benin found the tightness of the husk made no difference to subsequent weight loss during storage unless the cobs with good husk cover were also fumigated prior to storage (Borgemeister et al., 1994). Where practical, adding the hermetic liner to the store or treating the cobs with grain protectants may also help protect them from insects during storage.

Grain stored untreated without a protectant in bags that were not hermetic or grain stored in store rooms, warehouses or traditional or improved granaries typically suffered high median levels of grain damage (9.8-100%) during a six-month storage period, although variability was high between studies.

A comparison of the percentage points reduction in weight loss and damaged grains in maize stored in each tested intervention versus in farmers' traditional storage practices or in untreated stored grain was also done during the SSR (see SSR Fig 6a&b). In addition to the previously mentioned interventions, other interventions which were seen to be effective compared to leaving grain untreated or farmers' traditional practices included, admixture with sand/ashes/dust and bag or plastic drum storage, use of nitrogen gas in a large metal silo, release of the predatory biocontrol agent *Teretriosoma nigrescens* in cob stores against the larger grain borer *Prostephanus truncatus*, use of diatomaceous earth plus the microbial (Spinosad), mass trapping using pheromone traps.

Limited study of the importance of store hygiene has occurred although it is a key aspect in all PH curriculum to help reduce pests and particularly the carryover of pests between stocks from different harvests. The only study on store hygiene in the SSR was in Kenya and found farmers' who received a higher store hygiene score had significantly lower maize storage losses (Makinya et al., 2021).

There is less evidence on effect of storage interventions in protecting grain against rodent as opposed to insect pests. Since 2019, one maize study found a nine percentage point reduction in the likelihood of rodent damage in hermetic bags versus in jute sacks plus fumigant treatment (Shukla et al., 2023). However, during exploration of farmers' store hygiene practices in Kenya, Makinya et al. (2021) remark on the many rodent damaged hermetic bags they encountered. Perforation of hermetic bags by rodents as well as insects is reported in some on-farm maize storage trials (e.g., Mlambo et al., 2017; Singano et al., 2019). An earlier Tanzanian study (Mdangi et al., 2013) showed that sealing of traditional granaries could reduce rodent consumption of stored maize grain, and closing sacks (as opposed to leaving them open) and then protecting them using a metal mesh as proofing could eliminate it.

Four of the studies included in the SSR since 2019, reported on the effect of interventions on mycotoxins. Three of the studies (Opuku et al., 2023; Worku et al., 2022; Nyarko et al., 2021) had not fumigated the maize grain prior to set up, and found lower aflatoxin levels in grain stored in hermetic bags as opposed to in PP bags plus synthetic chemicals, or untreated in either PP bags or metal silos following six months of storage for two of the studies, and 12 months for the other study. A similar effect was seen for the mycotoxin fumonisin. Work from Nigeria showed that poor storage hygiene and no monitoring led to higher weight loss and a slight increase in aflatoxin concentration (Otitodun et al., 2018). Studies of the effect of bundling multiple interventions together on mycotoxin contamination in maize grain found training combined with use of plastic drying sheets were the most important aspects for aflatoxins although for storage, protection from insect and rodent damage is needed.

It should be noted that although the focus of most of the maize storage protection research to date has been on farm-level storage and farmers, some of the technically effective interventions (e.g., admixture

[8] Cob storage is the form farmers' in that area of Ethiopia prefer

with synthetic chemicals or diatomaceous earth, storage in hermetic facilities) are also applicable for use by traders depending on their scale of operations, and their facilities.

The reported cost of different types of sacks with and without addition of a synthetic chemical to treat 100 kg of grain were typically <1 USD in studies since 2019. While hermetic bags ranged in cost from USD 1.20 to USD 2.50, varying by location, brand, and exchange rates. A local hermetic bag version using a fertiliser bag with a low-density polyethylene liner cost just USD 0.40. A 20-t capacity hermetically sealed cocoon cost USD 4,000, while a 1,000kg-capacity hermetic bag cost USD 190.

Study of social, economic or environmental outcomes of PHL reduction interventions for maize or other crops is rarely undertaken. However, *there is a clear link between access to improved storage interventions, reduction in storage losses, extended periods of sufficient food stocks and reduced food insecurity*. In Uganda, provision of one hermetic bag per household led to maize being available for consumption for an extra 3 weeks (Omotilewa et al., 2018). Household-level metal silo use in Kenya led to the period of household food insecurity starting 7-10 weeks later (Gitonga et al., 2013, 2015). Self-reported severe food insecurity reduced by 20.4% among Tanzanian households given five hermetic bags and three rounds of standardised PH training (Brander et al., 2021). Household food insecurity score reduced by 30.9% among Tanzanian households given PH training and enough hermetic bags to store 60% of their maize harvest, PH training alone reduced it by 10.8% (Chegere et al., 2020). An Indian study found hermetic bag use had no effect on dietary diversity, although sugar and dairy consumption increased (Shukla et al. 2023). However, hermetic bag storage of maize extended the duration of storage by 25%, increased the share of the harvest being stored, increased the sales price received by 13%, and the likelihood of a household making grain market sales by 30% (Shukla et al. 2023).

Avoided or improved use of pesticides can have health, environmental and economic benefits. Less use of and expenditure on pesticides was reported for households using hermetic bags or metal silos (Gitonga et al., 2013; Omotilewa et al., 2018). The lifespan, recycling, repair and reusability of hermetic bags – which can be damaged by insects, rodents, chickens and poor handling – all influence the environmental and economic outcomes of hermetic bag use and deserve attention. While grain is sometimes stored in reused containers such as bags and drums it is important to ensure that these have not previously stored chemicals or other potentially toxic materials.

Hermetic bags provide many benefits for maize storage given their efficacy and their removal of the need to admix pesticides with food grains. Concerns regards them include, the nascent stage of the supply and distribution chain in many of the focal countries making it difficult currently to access hermetic bags in many areas, their cost and the risk of them being punctured by insects, chickens, rodents or poor handling. It should also be noted that as with all products, the efficacy may differ between the different brands of hermetic bags.

Several studies focused on the economics of maize grain storage technologies that reduce losses, several of them calculating the positive benefit cost ratios (BCR) for different interventions (e.g., hermetic bags, admixture with synthetic chemicals, metal silos, traditional granaries; a 20t hermetic cocoon (Gitonga et al., 2013 [Kenya]; Ndegwa et al., 2016 [Kenya]; Chigoverah et al., 2018 [Zimbabwe]; Gbenou et al., 2021 [Benin]; Kalsa et al., 2020 [Ethiopia]; Chegere et al., 2022 [Tanzania]; Shukla et al., 2023 [India]). However, these were influenced by a number of factors including the selling price of the maize, the duration of storage, the volume of grain stored, the lifespan, reusability and repair of storage interventions, and the import tariffs. More detailed descriptions of the economic outcomes are provided in the SSR section 3.7.2.

Study of the effect of introducing a quality sensitive market buyer alongside extension training into villages in Uganda saw farmers with access to a high-quality market receive USD 2.40 or 11% more per bag of maize (Bold et al., 2022). The price and the productivity increase saw farmers in the treatment group earn on average USD 63 or 36% more per season than farmers in the control group.

Beyond the SSR evidence-base there are a few other studies exploring the gender dimensions of storage. Hermetic storage bag use reduced perceived stress and increased coping by pregnant women in small-scale farming households (Eichenauer et al., 2023). A study of metal silos suggested men benefit more than women from the introduction of metal silos, that ownership of the grain storage facilities switch from women to men, and women's rights to negotiate over and use the stored grain then diminish (Farnworth et al., 2021). It is important that socio-economic and environmental outcomes are monitored alongside technical efficacy.

Combinations of multiple focal activity stages and interventions

A handful of studies have shown that **training on and use of improved PH practices combined with access to technologies** can reduce losses. For example, when the effect of different combinations of training, plastic sheet for drying, grain dryer use and hermetic bag use on aflatoxin contamination of maize were studied in Kenya. **Training on aflatoxin management and the use of drying sheets** to protect grain from direct contact with the ground played the largest role in reducing aflatoxin contamination by over 50% (Pretari et al., 2019). Similar findings were reported from work in Senegal by Leavens et al. (2021) and Bauchet et al. (2021). **Training on PH and/or aflatoxin management** has been found to reduce perceived loss levels during studies in Tanzania and Malawi (Chegere et al., 2020; Vandercasteelen & Christiaensen, 2022; Anitha et al., 2019). One of these studies found **bundling the provision of a hermetic bag with the PH training** further reduced perceived levels of loss.

In Kenya, the effect of combining farmer training on aflatoxin management with full price or subsidised access to PH technologies was studied, the use of plastic drying sheets (which cost USD 5 per farmer) led to 79% lower aflatoxin concentration which Pretari et al. (2019) suggest makes this a simple and relatively low-cost technology. They calculate the training costs at USD 1.70 per farmer and suggest USD 6.70 per farmer (which covers the drying sheet plus training) is cost effective compared to other methods such as Aflasafe KE01 which cost USD 8.40 per farmer without including training on timely and correct product application. Other costings of farmer trainings range from USD 50 per farmer for PH training including suite of interventions in Gambia (Turner et al., 2005; Wu & Khlangwiset, 2010); USD 1.01 per ppb reduction of aflatoxin in a study with 2000 farmers in Senegal (Leavens et al., 2021; Bauchet et al., 2021).

When farmers in Tanzania followed **a set of improved PH practices (harvest timing, off-ground drying, threshing, winnowing, air-tight storage)** as opposed to their ordinary practices, grain weight loss and damage during storage were reduced, but % mouldy grains remained similar (Mutungi et al., 2022a; 2019). During interviews with PH key informants in 2024, the importance of **training on safe use of pesticides** was repeatedly mentioned, this should be an integral part of all PH training curriculum.

One study's findings suggested when women as opposed to just their husbands also attended PH training bundled with the provision of a tarpaulin and a hygrometer it led to a greater impact on reduced aflatoxin concentrations (Leavens et al, 2021).

When the quantity of food saved by different combinations of grain PHL reduction interventions was converted into the equivalent area of agricultural land that could be saved (Mutungi et al. 2022b). The authors' suggest the collapsible grain dryer (CDC) they tested could save 5-6% of the agricultural land area used, the mechanised sheller 6-8%, hermetic storage 8-17%. They calculate combining the collapsible grain dryer and mechanised sheller would save 8-11%, the hermetic storage and mechanised sheller 19-28%, and by combining all three interventions 21-32% of the agricultural land area could be saved.

Rice, Sorghum and Wheat

The SSR's evidence-base for PHL reduction of rice, sorghum and wheat is dominated by interventions for loss reduction during farm-level storage, with just a few studies examining interventions during harvesting and threshing.

Harvesting

Rice

Harvesting rice at the recommended time resulted in lower reaping losses, scattering losses and non-separation from straw weight losses (0-1.2%) and fewer broken grains during milling (8.5-10.0%) than either earlier or later harvesting (11–30.0% (early); 3.4-11% (late) weight loss and 14.9-5% (early); 15.2-35.7% (late) broken grains) in studies from Pakistan (Bhatti et al., 1983) and India (Sajwan et al., 1993).

Mechanised rice harvesting and **improved harvest and handling practices** were found to usually lead to lower actual or perceived weight losses, or lower numbers of uncut plants left in the field compared to the use of simple harvesting tools such as sickles. The cost and design of harvesting machines varies by location, prices reported in the SSR data set ranged from USD 1,750 to USD 36,000. Indian farmers viewed the pros of sickle use as it being cheaper, easy to operate, did not vibrate, not gender specific, easily available and easy to replace, light weight and compact in size, but they reported that the sickle was less-productive, laborious and time consuming to use and can cause injuries. The evidence in the rice harvesting studies came from Sri Lanka (Mahrouf & Rafeek, 2003), India (Basavarajappa et al., 2013; Mishra & Satapathy 2021), Bangladesh (Alam et al., 2016, Nath et al., 2022), Ghana (Guisse, 2010; Appiah et al., 2011) and Nigeria (Castelein et al., 2022).

Mechanising of rice harvesting was calculated by Castelein et al. (2022) to reduce losses and avoid GHG emissions compared to manual harvesting (for example, 0.9% losses reported with mechanised harvesting were lower than the 9.6% with manual harvesting). Castelein et al. (2022) suggest that if all the rice farmers in Nigeria (3.2 million ha of rice is farmed in Nigeria) harvested mechanically this would avoid 5.4 million tonnes of CO_2eq.

Wheat

One study from India of mechanised combine harvesting of wheat reported that perceived loss was much lower than when harvesting with a sickle (6.3% versus 21.3%) (Hussain et al., 2019).

Clearly loss levels associated with mechanised harvesting will vary based on the particular machine and the settings used, the crop type and the variety, harvest timing and conditions and the experience of the operator etc. Many of these factors also influence manual harvesting loss levels. Various service provision and/or farmer group ownership models for reapers/harvesters have been tried as they are relatively expensive investments (see Castelein et al., 2022). The likely outcomes from increased mechanisation of smallholder farming systems are a topic of debate, and key issues are summarised at end of the rice threshing section below.

Threshing/ Shelling

Rice

Early work in Bangladesh comparing different rice threshing practices (e.g., hand beating, bullock treading and pedal thresher) found the lowest threshing weight losses (0.6%) occurred when short straw rice was **hand beaten followed by bullock treading** (Greeley, 1980). When the same treatment was applied to long straw rice, losses were 1.5%, and when bullock treading of broadcast rice stems was done losses of 2.5% occurred. Use of a pedal thresher with short or long straw rice resulted in 1.8% and 3.5% losses, respectively. **Placing harvested rice stems in a sack and beating them** led to lower losses than threshing it over a wooden *bambam* box or metal drum (0.9-4.0% versus 5.3-7.0%, Appiah et al., 2011 or 6.8% versus 9.0-10.7%, Sanneh, 2015) in Ghana. However, it is much quicker for farmers to thresh rice using the *bambam* box or drum method than placing it in a sack and beating it.

Contrasting loss reduction results exist for mechanised versus manual threshing studies. In DRC, losses were lower with manual (11.3%) as opposed to mechanised rice threshing (22.2%) (FAO, 2019b). While in Sri Lanka (Prasanna et al., 2004) a study found the amount of rice lost per hectare (ha) if a combined thresher or a small thresher were used was perceived to be lower than with the commonly used tractor treading or buffalo treading methods. Additionally, the rice produced from either of these mechanised threshers also received higher sales prices due to its higher quality, e.g., free of stones. The study's authors calculated that adoption of a small thresher or a combined thresher, would increase farmers profit margins by USD 75/ha or USD 107/ha, respectively.

A recent study in Nigeria (Castelein et al., 2022) calculated higher losses (~7%) if rice was threshed using stick beating as opposed to a **mechanised thresher** (~1% loss). Although mechanised threshing is more expensive than manual threshing (the rental cost of the thresher equals the total labour costs of manual threshing), the researchers' reported that the improved threshing efficiency and reduced losses increases the total yield sufficiently to make this intervention worthwhile. Switching to mechanised threshing was found to increase farmers' profit by USD 75/ha. The mechanical thresher cost USD 875, and has an expected life span of 5 years, (possibly 8 with good maintenance). Castelein et al. (2022) calculate that if the cost of buying the equipment can be spread over three harvests or more, then buying becomes the more cost-effective option. The mechanical thresher in their study can harvest 1 ha per day, and 30 ha per season so 15 farmers with 2 ha of rice each could share the equipment.

Suggested challenges include the capacity of farmer cooperatives to procure, maintain and store the mechanised thresher and the ability of individual farmers to co-invest and cover the upfront cost of buying equipment. Castelein et al. (2022) report that the labour-saving aspect of mechanised threshing freed up women's time during the busy harvest period. However, in general questions around the relationship between mechanisation and socioeconomic development (including rural (un)employment and gender disparities) and environmental impacts in SSA exist (see Daum & Birner, 2020; World Bank et al., 2011). Issues around the lack of service providers, lack of training of operators, poor quality of the machinery, suitability of imported machinery are also important (Castelein et al., 2022; Appiah et al., 2011; FAO, 2018)

Sorghum

Relatively low losses were recorded for both manual and tractor threshing (0.7% vs 0.6%) of sorghum during a load tracking loss assessment (FAO, 2019a)

Storage

Rice

The SSR's evidence-base on rice storage interventions is composed of studies from Sri Lanka, Mozambique, India, Ghana, Burkina Faso and Niger. The evidence shows storage of untreated paddy rice in **hermetic bags or cocoons, plastic drums and metal bins** were effective in keeping grain weight loss below 2% and / or grain damage below 6% during 6 months storage (see SSR Fig. 7a&b) (e.g., Donahaye et al., 1991; Guenha et al., 2014; Covele et al., 2020). Fumigation of rice followed by storage in bags or metal silos, and fumigation plus use of a pesticide incorporated bag also kept weight loss low, however fumigation should only be done by a trained certified pest control operator and is not recommended for smallholder farmer use (see footnote on fumigation in maize storage section). One study from across Ghana, Burkina Faso and Niger (Baoua et al., 2016) found that even when paddy rice was stored untreated in woven polypropylene (PP) bags or an improved granary it suffered less than 6%

insect grain damage during a 6-month storage period. Although other studies found untreated paddy rice stored in jute or another unspecified type of sack, or in storerooms or traditional granaries, or even when treated with synthetic chemicals experienced higher grain damage levels of above 13% during a 6-month storage period. Damage levels will vary by situation due to numerous factors such as different insect species, mixtures and population density, varieties, the form the crop is stored in (husked, dehusked, shelled, unshelled etc.), environmental conditions, management practices including hygiene etc. Within the SSR cereal storage evidence-base, most studies had focused on managing insect damage with very few studies focusing on or attempting to assess rodent damage. One recent Sri Lankan study that did, found wrapping the typically-used polyethylene bags of rice in two layers of fish netting helped reduce rodent attack during storage (Htwe et al., 2021). They hypothesise it would be cost-effective unless rodent populations were much higher than during their study. Other common rodent protection methods include storing grain in sealed metal or plastic drums.

Sorghum

The SSR's evidence-base of sorghum storage interventions studies were from Eritrea, Ethiopia, Sudan, Kenya, Tanzania, Zimbabwe, Burkina Faso and Mali. Storage of untreated sorghum grain in **hermetic bags, metal silos or improved underground pits**, or when **admixed with wood ash and then stored in a traditional granary** kept grain weight loss below 2% during six months of storage (Ratnadass et al., 1992; Shazali et al., 1998; Waongo et al., 2019; Mubayiwa et al., 2021). When sorghum grain was fumigated, treated with synthetic chemicals, and then stored in bags; or **admixed with wood ash, synthetic chemicals or DE and stored in bags or a traditional granary**; or stored **untreated in hermetic bags** or an improved granary less than 10% damage occurred (see SSR Fig 7b) (Ratnadass et al., 1992; Shazali et al., 1998; Haile, 2006; Stathers et al., 2008; Waongo et al., 2019; Mubayiwa et al., 2021). Untreated sorghum grain stored in bags or storerooms, or in traditional granaries with or without botanical preparations, or admixed with synthetic chemicals, or in a PP bag with pesticide incorporated into its fabric sustained between 14.1% and 45.4% damage during 6 months storage (see SSR Fig 7b). The sorghum weight loss recorded without storage protection methods, was 3.5–7.7%. (see SSR Fig. 7a). The climate resilience of small grains (such as millets and sorghum) vs. maize or other staple food crops during production and postharvest stages needs to be given greater attention.

Reduced incidence of aflatoxin contamination >20 ppb was found in grain samples from those farmers who had received **training on aflatoxin and PH management** in Malawi (Anitha et al., 2019).

Wheat

The SSR's evidence-base of wheat storage interventions studies come from India, Pakistan, Nepal, Bangladesh, Afghanistan and Ethiopia. Storage of untreated wheat grain in **hermetic bags**, or **admixture of botanicals or synthetic chemicals or filter cake and some industrial by-products**[9] with wheat grain followed by storage in bags, the use of **improved granaries** or sealing the untreated grain in **metal silos or drums or concrete bins**, and fumigation and use of synthetic chemical dust or spray treatments kept weight loss below 2% and/or grain damage below 5% during six months storage (e.g. Kalsa et al., 2019; 2020; Melese et al., 2022;). Fumigants, such as metal phosphides, should not be used within 100m of human habitation and should only be applied by trained certified operators, they should not be recommended for grain stored at household level by smallholder farmers. Researchers often use fumigants to enable them to set up trials with grain batches containing no live insects, however this differs from farmers' usual situations.

[9] e.g., by-products from soap factory (Triplex powder), aluminium sulphate factory, industrial filter cake.

Legumes

From the updated SSR's evidence-set, 81% of the interventions that had been studied for reducing PHLs of the focal legume crops (bean, cowpea, chickpea, pigeon pea and groundnut), were focused on reducing losses during their storage, and particularly of cowpea which accounted for 47.8% of legume PH interventions studied. Therefore, the evidence-base is currently very limited for legume PHL reduction during the non-storage activity stages, e.g., harvesting, drying, sorting and no-evidence was found on legume PHL reduction interventions during transport or threshing/ shelling. A few interesting studies focused on combinations of intervention types. A summary of **promising interventions** for reducing legume PHLs follows.

Harvesting and drying

Groundnut

Use of an **A-shaped drying frame**, a **raised drying rack** or the **Mandela cock** (a circular stack) drying methods resulted in lower incidence of % mouldy kernels (<10.1% vs. 27.8%) and aflatoxin B1 (<1.1 vs. 4.8 ppb) in Malawi (Dambolachepa et al., 2019) than when the freshly harvested groundnut plants were sun-dried directly on the ground. Plants harvested at 90 days after sowing as opposed to 80 or 100 days also had lower aflatoxin levels. Harvesting groundnuts in the rain and slow drying, as opposed to **rapid drying**, increased fungal incidence on pods from 19.4–24.5% to 32.5–38.9% (Palanisami et al., 1990; India).

In Pakistan's Punjab Province, a tractor-mounted groundnut pod collector was trialled at different speeds and in soils of different moisture contents to address the need for time-consuming and costly manual picking up of groundnut pods left behind in the soil during harvesting – a period when labour availability can be low (Nasir et al., 2022). A speed of 1.5-2 km/hour left the lowest percentage (6.7%) of pods behind in the soil. This mechanisation reportedly reduced the time and cost taken to collect left-behind pods by manual pod collection by 60.9% and 31.6%, respectively.

Sorting

Groundnut

Careful sorting, off-ground drying and storage of groundnuts in Guinea led to a reduction in aflatoxin B1 content (from 55 ppb to 17 ppb), although still beyond the safe limits of most standards (Turner et al., 2005). **Training women in manually sorting and removing mouldy groundnuts** in Gambia, resulted in the removal of 1.9% of the weight of groundnuts and led to an average aflatoxin B1 concentration of 0.28 ppb in the remaining groundnuts, versus the baseline samples of groundnuts which had an average aflatoxin B1 content of 112.5 ppb and a median level of 0.49 ppb (Xu et al., 2017).

Although farmers' understanding of aflatoxin risks increased following training in Malawi, they were found to still consume and sell the grains they had graded out as the grade outs accounted for 10 to 20% of their expected profit (Anitha et al., 2019). Practice of the better drying methods they learnt about also did not occur, due to space limitations at their homesteads and fear of theft if drying was done in the field.

Storage

Most of the evidence-base from research on legume storage loss reduction interventions is from grain protection methods that do not involve the use of synthetic chemical protectants. This included interventions, such as cowpea storage in hermetic bags or following admixture with botanicals (plant materials), diatomaceous earths (DE's) or ashes (see SSR Fig. 8a&b). **Hermetic bags** have been shown to be effective in keeping median weight loss <2% and/or grain damage <20% in cowpeas, groundnuts and beans and chickpea and were more effective than traditionally-used practices or untreated controls within the same studies (see SSR Fig. 9a&b and for example Bakoye et al., 2020; Ngwenyama et al., 2020; Baoua et al., 2018; Mutungi et al., 2020; Berhe et al., 2023; Baributsa et al., 2017). This remained the case when **re-used hermetic bags** were studied for cowpeas. Briefly opening and then reclosing hermetic bags to withdraw grain each week during the storage period also did not affect their efficacy (Baoua et al., 2012; 2013) (see SSR Fig. 8b). Other interventions that kept the grain damage levels at least 20 percentage points lower than in untreated control grain during 4.5 months of storage included **admixture with synthetic chemicals**[10] (e.g., Actellic Super dust at 0.05% w/w [pirimiphos-methyl 1.6% and permethrin 0.3%] (Stathers et al., 2002), Actellic Gold dust at 0.05% w/w [pirimiphos-methyl 1.6% and thiamethoxam 0.036%] (Ngwenyama et al., 2020), **diatomaceous earths (DE's)** (e.g., Protect-it at 0.05-0.2% w/w, Dryacide at 0.1-0.2% w/w (Stathers et al., 2002; 2008), or **botanicals** (e.g., *Azadirachta indica* seed powder, *Chenopodium ambrosioides, Lipia javanica, Combretum imberbe* (Paul et al., 2009; Chikukura et al., 2011)) with cowpeas or beans before storing them in sacks (see Fig. 9b). Untreated cowpea grains **stored in clay pots, or in sealed plastic drums** as opposed to sacks suffered lower storage insect losses, but the evidence suggests hermetic bags or other admixed protectants are more effective. Some studies used toxic fumigant gases (e.g., aluminium phosphide), often in addition to other protectants which adds cost, fumigation can be effective if properly done but is illegal for non-certified operators to use and should never occur within 100m of human habitation. When cowpeas or beans were stored in jute or woven polypropylene (PP) bags with no protectant for a standardised 4.5-month storage duration, grain damage ranged from 25.2% to 100%, and weight loss ranged from 4.5% to 32.3% (see Fig. 8a&b).

Limited data on mycotoxin levels in different legume storage interventions was found. Chickpea stored for 6 months in hermetic bags (PICS and SGB brands) in Ethiopia had 8.1-8.3 ppb aflatoxin and 0.3 ppm fumonisin. While that stored untreated in metal silos had 12 ppb and 0.4 ppm, and in either jute or PP bags 13-14 ppb and 0.6-0.7 ppm, respectively (Alemayehu et al., 2020). Germination of chickpea remained high (86-89%) in the hermetic bags, was 82% in the metal silo, and 44-46% in the jute and PP bags. Hermetic bag storage of cowpea or groundnut also kept germination higher than when the grain was stored untreated in PP bags (Bakoye et al., 2020; Baributsa et al., 2017).

Simple handling practice changes, such as **weekly sieving** (for at least 5 minutes for a 5 week period) **or weekly sunning on a mat (for at least 6 hours) of dried beans during storage** in Uganda, kept storage insect damaged grains at 3.6 to 4.1%, compared with 37.7% which occurred in stored untreated control grain (Nahdy & Agona, 1992). One early study in Nigeria illustrated the protective effect of **storing dried cowpeas unshelled** (Caswell, 1975). A similar effect was seen in Niger when untreated shelled groundnut in PP bags suffered 19.0% weight loss during 4.5 months storage versus 5.5% in unshelled groundnut (Baributsa et al., 2017). When stored in hermetic bags, weight loss was 0.14% for the shelled and 0% for the unshelled.

Many factors affect the choice and use of PHL reduction interventions. In Burkina Faso, women explained that their heavy workloads impact on the timely completion of PH activities and use of good practices, and despite their responsibility for many agricultural activities they had limited control over the management of food stocks and use of income from sales (FAO, 2019a). Beyond the SSR data set a few studies exist on gendered uptake of hermetic bags for legume storage. For example, a survey in 2010 of almost 3,000 randomly selected rural women in Niger, Burkina Faso and Nigeria found 46% of them had used hermetic PICS bags for cowpea storage and that women stored 50% of their cowpea in

[10]Synthetic chemical grain protectant products are required to be registered and approved for use in the target country, recommended application rates and methods for each specific product should be followed. Different brands/ products/ plant materials will perform differently and context-specific application rates may need determining.

PICS bags and that their net cash flow was USD 10.81/100kg bag or USD 39.27 per respondent, and living in a village where PICS bag demonstrations had occurred was the main factor influencing their use (Ibro et al., 2014). A cowpea storage competition for women in a Sourou province in Burkina Faso, involving training and demonstrations through women's groups, and prizes based on the duration of storage, quantity stored and quality of the stored cowpea resulted in more cowpea being stored in PICS bags both for sale and home consumption, but found poor distribution networks limited access to PICS bags (Baributsa et al., 2013).

Very limited analysis of the cost benefits of legume loss reduction was found in the SSR data set. One study which calculated the net present value (NPV) for different cowpea storage interventions in Ghana, found hermetic PICS bag use was the most viable with a USD 901 NPV, while plastic drum use had a USD 787 NPV and jute bag use a USD 771 NPV (Sugri et al., 2021). Another study calculated the value of the saved chickpea grain in different storage treatments (Dubey et al., 2022). Hermetic bags ranged in cost from USD 1.20 to USD 2.50. A local hermetic bag version using a fertiliser bag with a low-density polyethylene (LDPE) liner as opposed to a high-density one was costed at USD 0.40 but it is not safe to keep grain in contact with residues of chemical fertilisers. Different types of sacks with and without a synthetic chemical to treat 100 kgs of grain ranged from USD 0.15 to USD 2.00, but prices will vary by location and product. In studies outside the SSR dataset, the willingness-to-pay (WTP) for hermetic bags has been explored (e.g., Channa et al., 2019; Schwab & Yu, 2022; Shukla et al., 2022), findings showed an increase in the WTP for the technology if credit is made available, or after gaining experience of using the hermetic bag for a year. In Tanzania, an organisation offering farmers access to credit views hermetic bag storage of collateralised grain as lowering their risk, as if the grain needed to be repossessed it would still be good quality (Channa et al., 2022). They have switched to offering farmers credit collateralised with 200kg of common beans stored in hermetic bags, as they view intervention in bean market prices as less likely.

Hermetic bags provide many benefits for legume storage given their efficacy and their removal of the need to admix pesticides with food grains. Concerns regards them include the nascent stage of the supply and distribution chain in many of the focal countries making it difficult currently to access hermetic bags in many areas, their cost and the risk of them being punctured by insects, chickens, rodents or poor handling. It should also be noted that as with all products, the efficacy may differ between the different brands of hermetic bags.

No environmental outcomes had been measured, a few authors commented on the use of hermetic bags leading to reduction in use of synthetic chemical pesticides, others discussed the need for prolonging the lifespan of and recycling of the plastic hermetic bags. Hermetic bags are not yet always easily locally available to farmers in many of the focal countries and the higher price of the hermetic bags versus PP bags can also be a constraint.

Combinations of interventions and training interventions

Recent work in Tanzania (Mutungi et al., 2022a) showed that in comparison to farmers' ordinary practices the **use of a combination of improved PH handling practices (e.g., harvest timing, off-ground drying, threshing, winnowing, air-tight storage)** reduced weight loss in beans from 14.5% to 4.5% and damage from 29.7% to 6.5%. A study in Malawi found **training on aflatoxin and PH management** resulted in a reduced percentage of groundnut samples with >20 ppb aflatoxin in the stocks of those farmers who had received training (Anitha et al., 2019). **Training women in sorting and removing mouldy groundnuts** in Gambia, led to an average aflatoxin B1 concentration of 0.28 ppb in the remaining groundnuts, compared to the baseline samples which had an average of 112.5 ppb and a median level of 0.49 ppb (Xu et al., 2017).

Roots and tubers

The PHL reduction interventions studied for the root and tuber crops have mainly been different storage structures or containers, storage protectants, and packaging. Potato has received more research attention than yam, sweetpotato and cassava. Overall, roots and tubers have received much less PHL reduction focused consideration than cereals. The main loss metrics studied for root and tuber crop interventions were % loss, decay, damage and sprouting. Further details are available in the SSR 3.5.3.

Harvesting

Sweetpotato

Harvesting sweetpotato later (6-9 months after planting) reduced loss in quantity compared to earlier harvests (4-5 months after planting), but no data on decay levels was presented (Smit, 1997).

Cassava

Harvesting from moist less compacted soil reduced root damage by up to 23.0% compared to harvesting cassava from dry compacted soil (Ayemou-Allou et al., 2008).

Transport

Potato

Only one study on infrastructure was found and it showed a reduction in quantity loss of potato from 17.9% when transported on poor roads to 15.3% on improved roads in Ethiopia (Kuyu et al., 2019).

Storage

Potato

Storage structures that were cooler than ambient conditions resulted in lower quantity loss, decay, and sprouting (see SSR Table 10) (e.g., Verma et al., 1974; Mehta et al., 1991; Kumar et al., 1995; 1999; Khan et al., 1995; Cheong et al., 1999; Das et al., 2000; Patel et al., 2001; Jaiswal et al., 2002; Khan et al., 2006; Venugopal et al., 2017). **Cold-rooms** were the most effective storage structures, followed by **evaporatively cooled structures** and **pits or trenches**. **Storing harvested potato in heaps in the shade** as opposed to in the sun reduced average quantitative losses by up to 14 % and decay by up to 4.9% (Paul & Ezekiel, 2003).

Storage protectants included pesticides, growth regulators (particularly anti-sprouting compounds), botanicals/essential oils, heat treatments and radiation. Using **growth regulators** reduced sprouting in potatoes compared to no protectant (Mehta et al., 2011; Mehta & Singh, 2015) (see SSR Table 9).

Access to information on ware potato, potato harvest and PH handling, and potato storage was lower in female than male-headed households in Uganda, as was storage of potato (Wauters et al., 2022).

Yam

Storing yams in structures with forced air ventilation or in pits as opposed to in traditional structures at ambient conditions keeps quantity loss, decay and sprouting lower (e.g., Mozie, 1982;1996; Ezeike, 1985; Nwankiti et al., 1988; Osunde & Orhevba, 2009). **Selecting only undamaged yams for long term storage** durations of 6 months resulted in less quantity loss and no decay. While yams with slight or severe wounds had higher quantity losses and 80.0% and 100.0% decay, respectively (Mozie, 1982).

Cassava

Soaking cassava chunks/chips in water before sun-drying or smoke-drying them resulted in 23.9% weight loss during a six-month storage period versus 96.4% weight loss for unsoaked chunks/chips (Tata-Hangy et al., 1997).

Fruits

Harvesting and handling

In India, the **improved mango harvesting tool** (IIHR[11] harvester – a pole with a net and cutting blade) led to more mango fruit being harvested per hour, 354/h versus 290/h and 250/h for the local harvesting tool or manual plucking, respectively – and it also caused less damage to the fruit (Aparna et al., 2020). The IIHR harvester saved ~USD 28/ha/day vs. manual plucking as less labour was required per ha, and it reduced the drudgery index score[12] (43%), compared to the local harvester (65%) or manual plucking (72 %). Earlier studies found use of **improved mango harvesting tools** ranging in cost from ~USD 2-5.5 led to savings of 27-45%, while use of a local harvesting stick with a cutter led to 18% savings in India (Srinivasappa et al., 2015, Savita et al., 2010).

Handling practice changes affected both quantity and quality losses in mango. Traditional handling practices were associated with a quantity loss of 27.9% and 68.3% decay, while **improved handling conditions (i.e., more selective picking, leaving a stalk or pedicel, removing latex before packing),** had an average quantity loss of 9.8%, 22.5% decay, and extended the shelf life by 1.5 days (Herath et al., 2021; Rahman et al., 2019; Rahman et al., 2018; Mazhar et al., 2011). While manual plucking of mango fruits or tree shaking harvesting methods resulted in 28.5% decay, the use of improved mango harvesting tools resulted in between 0 and 18.5% decay.

Precooling

Precooling, (i.e., rapidly removing the field heat from fruit before placing in storage) was evaluated on mango and banana. In mango, it reduced quantity loss by about 10% when compared to no precooling (Kapse & Katrodia, 1997; Puttaraju & Reddy, 1997; Singh et al., 2003; Doshi et al., 2010). Hydrocooling of mango (i.e., precooling with cold water) reduced decay by 42.9% (Kapse & Katrodia, 1997; Puttaraju & Reddy, 1997).

Packaging

Cardboard/fibreboard cartons (CFB) are superior to wooden boxes for packaging the focal fruits, especially in terms of decay incidence. The **use of liners** (whether plastic, paper, or natural products) in the boxes, cartons or baskets reduces quantity loss. Citrus packed in cartons had an average quantity loss of 12.6%, when a liner was added average quantity loss reduced to 8.1%, but decay increased by 1.2% (e.g., Singh et al., 1988; Ladaniya & Mahalle, 2004). Plastic liners can increase condensation which favours decay. Use of cardboard cartons (CFB), plastic crates or wooden boxes increased profit for mango, but not sufficiently for banana to justify the use of CFB in Bangladesh so **plastic crates** were recommended for banana (Roy, 2005).

Transport

No data on the scale of losses during mango transport was found. But one study discussed the need to airfreight some varieties of export mango due to their shorter shelf-life, while others can be shipped (Abu et al., 2020).

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[11] Indian Institute of Horticultural Research (IIHR)

[12] Drudgery index score of ≥70 = maximum drudgery, between 50-70 = moderate drudgery, ≤50 = minimum drudgery

Storage

Cool storage structures providing conditions colder than ambient storage resulted in less quantity loss and decay, more marketable fruit, and longer shelf life. When the effect of structures, that resulted in ambient conditions, evaporative cooled structures, or cold-rooms (including CoolBots which are insulated rooms cooled with a modification to an air conditioner) were compared across all four focal fruit crops (see SSR Table 13), average quantity loss decreased from 21.4% under ambient conditions to 8.4% and 6.5% for evaporatively cooled structures and cold-rooms, respectively. Fruit decay was reduced by 17.5% in bananas, and 6% in mango when stored in **cold-rooms** versus ambient structures. Shelf life increased by 9.9 days in banana and 12.0 days in mango when stored in cold-rooms versus ambient structures (e.g., (banana) Deka et al., 2006; Doshi et al., 2010; Gomez et al., 2023, (mango) Pujari et al., 2016; Abu et al., 2020). It increased by 24.4 days in citrus and 7.4 days in papaya when stored in **evaporatively cooled structures** versus ambient structures. The percent of papaya fruit that were considered 'not marketable' decreased by 45.5% in evaporatively cooled versus ambient structures (Azene et al., 2014). Evaporatively cooled structures reduced fruit decay in citrus by 5.9% (Bharwaj & Sen, 2003; Goswami et al., 2008; Ishaque et al., 2021), and in mango (Eyese et al., 2022). Use of shade netting reduced quantity loss in mango (Msogoya et al., 2011), and use of cellar stores reduced quantity loss and decay in citrus (Subedi et al., 1995).

Economic analysis of the storage of citrus fruits at ambient versus lower temperatures in an evaporatively cooled zero energy cool chamber (ZECC) in Bangladesh for 35 days, gave an economic return of USD 693 and was perceived to be more environmentally friendly (Ishaque et al., 2022). Compared to a conventional refrigeration system, the lower upfront and running costs of a ZECC, make it more economical. In Nigeria, the cost of constructing a ZECC with storing capacity for 250 kg of tomato was USD 1,200 (Odeyemi et al., 2022). From the available data in the SSR, the cost of evaporative cooling structures ranged from USD 600 to USD2,000. Prices will be dependent on the capacity, materials and location. The update SSR found more testing of cold-rooms as opposed to evaporatively cooled structures. However, more substantial studies including cost-benefit and socio-economic analyses of building cold storage versus renting cold storage would be beneficial to address the gaps in knowledge and evaluate investment and operational costs.

Waxes or coating agents are designed to decrease water loss (quantity loss), reduce decay and increase the proportion of marketable stored fruit. When banana, mango and citrus fruits treated with wax or coatings - with or without other storage protectants (e.g., fungicides, botanical products or growth regulators) - were compared to untreated control fruits, quantity loss and decay were consistently lower, and shelf life was longer (e.g., (banana) Elbagoury et al., 2022; Ali et al., 2022, (mango) Shah & Hashmi, 2020; Shah et al., 2021; Prasad et al., 2022; Fatima et al., 2022; Ali et al., 2022a; Ali et al., 2022b; Silue et al., 2022, (citrus) Rashid et al., 2018; Nasrin et al., 2018; Gupta et al., 2021). The vitamin C content of citrus and mango was higher following storage in fruit that had been treated with waxes or coatings agents (e.g., Rashid et al., 2020; Nasrin et al., 2018; Prasad et al., 2022). However, these studies were conducted on-station. **No large-scale pilot studies of the use of waxes or coating agents under real-world conditions were reported in the evidence-base.** These products are also being tested by large scale private companies, particularly on citrus and tomato, but limited information on that is shared. Waxes may be more difficult to adapt by small-scale producers. Most produce is washed to improve appearance and remove dirt and latex before being waxed or coated. However, experience in commercial conditions has demonstrated that this washing can increase the risk of spreading decay organisms, e.g., fungal spores, and human pathogens, e.g., *E. coli* bacteria (Zagory, 2013). Wash water sanitisers can prevent cross-contamination, but cannot completely clean produce (defined at a log five reduction in microbial load) (Zagory, 2013; Gombas et al., 2017). A positive BCR was calculated for treatment of citrus fruits with a wax coating in India, leading to a profit of INR 448 for 1000 fruits versus INR 300 for untreated fruit (Zade et al., 2005).

Vegetables

More study of PHL reduction interventions has occurred for tomato and onion than for leafy vegetables or cabbage. These were mainly storage structures, storage protectants and packaging.

Harvesting and handling practice changes

Tomato

Harvesting less mature tomatoes reduced quantity loss by 20 %. Tomatoes harvested at turning stage were firmer and less damaged during handling, transportation and marketing and their price increased from USD0.25/kg to USD0.5/kg in Rwanda (Odeyemi et al., 2022). This led to a relative profit of USD 170 for each 1000 kg load.

Onion

Harvesting later, curing, and improved handling practices on average reduced quantity loss in onions by 20%, 18%, and 12.4%, respectively (Warade et al., 1997; Sharma et al., 2007; Kiura et al., 2021).

Cabbage

Harvesting later reduced quantity loss in cabbage by 3.6 % (Champa et al., 2007).

Packaging and transport

Tomato

Returnable plastic crates reduced tomato losses from 30% to 10% in Rwanda with an increased relative profit of USD 9, and from 40% to 5% in Nigeria with a relative profit of USD 76 (Odeyemi et al., 2022). Ten re-uses of the crates will pay for them in Rwanda and five re-uses in Nigeria. However, straightforward logistics for return of the crates to the farmers is needed to avoid problems. Long-distance transporters in Nigeria, questioned the occupation of truck space with empty returnable plastic crates on return trips, that could otherwise be used for transporting merchandise (Sibomana et al., 2022). Overall, the SSR found use of plastic crates reduced average quantity loss to 12.6 %, compared to 28.3% when packaged in baskets (Dari et al., 2018; Plaisier et al., 2019; Odeyemi et al., 2022). Quantity loss totalled 48.2 % in wooden boxes.

Improved roads resulted in slightly lower quantity loss (4.3%) of tomatoes than poorer roads. Quantity loss was higher where a greater length of the road was bumpy (Tadesse et al., 2022).

Storage

Evaporative cooling, or mechanically cooled cold-rooms (including CoolBots), led to reductions in quantity loss, decay and sprouting across the four focal vegetable crops compared to when the crops were stored at ambient conditions (see SSR Table 15).

Tomato

Storage of tomatoes in **cold-rooms** resulted on average in much lower average quantity loss (5.9%) and % decay (23.3%) rates compared to those in ambient structures (18.7% and 46.3%, respectively) (Saran et al., 2013; Nkolisa et al., 2018; Sibanda et al., 2019; Majubwa et al., 2021; Orovwode et al., 2022).

Evaporatively cooled structures (including pots) also resulted in reduced average % quantity loss and decay rates (7.7% and 29.6%, respectively) (Garg et al., 1997; Mishra et al., 2009; Getinet et al., 2011; Goswami et al., 2008; Woldemariam et al., 2014; Nkolisa et al., 2018; Odeyemi et al., 2022). Compared to a conventional refrigeration system, the lower upfront and running costs of an evaporatively cooled zero energy cool chamber (ZECC) make it more economical.

In Nigeria, the cost of constructing a ZECC with storing capacity for 250 kg of tomato was USD 1,200 (Odeyemi et al., 2022). When compared with the current practice of immediate sales of harvested produce with a 30% loss, use of the ZECC reduced loss to 5%. This loss reduction provided a relative profit of USD 55 per 1,000 kg of tomato in comparison to the traditional practice of handling and temporary storage of the fruit at ambient temperature. Odeyemi et al. (2022) calculated that 22 uses would pay for the ZECC and plastic crates with subsequent earnings of USD 209/ 1000kg vs. USD 154 for current practice.

Onion

Storage of onions in **cold-rooms** versus ambient structures reduced quantity loss by 30 percentage points (Singh & Singh, 1973; Babarinsa et al., 2002; Dabhi et al., 2008; Nabi et al., 2013; Bhasker et al., 2020).

Use of fungicides resulted in reduced quantity and quality losses in onion (Randhawa et al., 1985; Mesta & Kukanur, 2013). **Irradiation** reduced quantity loss but increased decay from 40 % (a single specific control) to 55 % (Matin et al., 1992; Tripathi et al., 2011; Sharma et al., 2020).

Cabbage

Storage of cabbage in **cold-rooms** versus ambient structures reduced quantity loss by 25 percentage points (Saran et al., 2013).

Leafy vegetables

Storage of leafy vegetables in **cold-rooms** versus ambient structures reduced quantity loss by 35.5 percentage points and storage in evaporatively cooled rooms reduced quantity loss by 40.9 percentage points (Dari et al., 2015; Mahangade et al., 2020).

References

Abu, M., Olympio, N.S., Darko, J.O. (2020). Effects of different storage temperature conditions on ripening quality and shelf life of mango (Mangifera indica) fruits in Ghana. *Journal of Horticulture and Postharvest Research*, 3, 245-255.

Appiah, F., Guisse, R., Dartey, P.K.A. (2011). Post harvest losses of rice from harvesting to milling in Ghana. *Journal of Stored Products and Postharvest Research*, 2, 64–71. http://www. academicjournals.org/jsppr/PDF/pdf2011/Apr/Appiah et al.pdf.

Alam, M.A., Hossen, M.A., Islam, A.K.M.S., Alam, M.M. (2018). Performance evaluation of power-operated reapers for harvesting rice at farmers' field. *Journal of the Bangladesh Agricultural University* 16, 144-150 (2018).

Alemayehu, S., Abay, F., Ayimut, K. M., Assefa, D., Chala, A., Mahroof, R., ... & Subramanyam, B. (2020). Evaluating different hermetic storage technologies to arrest mold growth, prevent mycotoxin accumulation and preserve germination quality of stored chickpea in Ethiopia. *Journal of Stored Products Research*, *85*, 101526.

Ali, S., Ullah, M.A., Nawaz, A., Naz, S., Shah, A.A., Gohari, G., Razavi, F., Khaliq, K., Razzaq, K. (2022). Carboxymethyl cellulose coating regulates cell wall polysaccharides disassembly and delays ripening of harvested banana fruit. *Postharvest Biology and Technology*, 191, 111978.

Ali, S., Anjum, M.A., Khan, A.S., Nawaz, A., Ejaz, S., Khaliq, G., Iqbal, S., Ullah, S., Ur Rehman, R.N., Ali, M.M., Saleem, M.S. (2022a). Carboxymethyl cellulose coating delays ripening of harvested mango fruits by regulating softening enzymes activities. *Food Chemistry*, 380, 131804.

Ali, S., Zahid, N., Nawaz, A., Naz, S., Ejaz, S., Ullah, S., Siddiq, B. (2022b). Tragacanth gum coating suppresses the disassembly of cell wall polysaccharides and delays softening of harvested mango (Mangifera indica L.) fruit. *International Journal of Biological Macromolecules*, 222, 521-532.

Anitha, S., Tsusaka, T. W., Njoroge, S. M., Kumwenda, N., Kachulu, L., Maruwo, J., Machinjiri, N., Botha, R., Msere, H.W., Masumba, J., Tavares, A., Heinrich, G.M., Siambi, M., Okori, P. (2019). Knowledge, attitude and practice of Malawian farmers on pre-and post-harvest crop management to mitigate aflatoxin contamination in groundnut, maize and sorghum—implication for behavioral change. *Toxins*, *11*(12), 716.

Aparna, P., Babu, G.P., Chaithanya, B.H. (2020). Assessment of IIHR mango harvester for drudgery reduction over conventional practice. *Asian Journal of Home Science* 15, 273-275 (2020).

Appiah, F., Guisse, R., Dartey, P.K.A. (2011). Post harvest losses of rice from harvesting to milling in Ghana. *Journal of Stored Products and Postharvest Research,* 2, 64-71.

Asemu, A. M., Habtu, N. G., Subramanyam, B., Delele, M. A., Kalsa, K. K., Alavi, S. (2020). Effects of grain drying methods on postharvest insect infestation and physicochemical characteristics of maize grain. *Journal of Food Process Engineering*, *43*(7), e13423.

Ayemou-Allou, A.S., Tschannen, A., Allou, D., Assa, A. (2008). Influence of three soil physical parameters on the harvesting of cassava (*Manihot esculenta* Crantz) in central Cote d'Ivoire. *Journal of Applied Biosciences,* 9, 416-423.

Azene, M., Workneh, T.S., Woldetsadik, K. (2014). Effect of packaging materials and storage environment on postharvest quality of papaya fruit. *Journal of Food Science and Technology (Mysore)*, 51, 1041-1055.

Babarinsa, F.A., Okanlawon, S.O., Ibrahim, M.H. (2002). A modified crib for ambient temperature storage of onions. *Tropical Science,* 42, 17-19.

Bakoye, O. N., Ibrahim, B., Seyni, H., Amadou, L., Murdock, L. L., Baributsa, D. (2020). Comparative study of cowpea storage technologies in the Sahel region of Niger. *Insects*, *11*(10), 689.

Baoua, I.B., Margam, V., Amadou, L., Murdock, L.L. (2012). Performance of triple bagging hermetic technology for postharvest storage of cowpea grain in Niger. *Journal of Stored Products Research* 51, 81-85 (2012).

Baoua, I.B., Amadou, L., Murdock, L.L. (2013). Triple bagging for cowpea storage in rural Niger: questions farmers ask. *Journal of Stored Products Research,* 52, 86-92.

Baoua, I.B., Amadou, L., Bakoye, O., Baributsa, D., Murdock, L.L. (2016). Triple bagging hermetic technology for post-harvest preservation of paddy rice *Oryza sativa* L. in the Sahel of West Africa. *Journal of Stored Products Research,* 68, 73-79.

Baoua, I.B., Bakoye, O., Amadou, L., Murdock, L.L., Baributsa, D. (2018).Performance of PICS bags under extreme conditions in the Sahel zone of Niger. *Journal of Stored Products Research,* 76, 96-101.

Baributsa, D., Dabiré, C., Sawadogo, K., Lowenberg-DeBoer, J. (2013). Increasing women's participation in cowpea storage activities: The case of Burkina Faso. *Journal of Agricultural Extension and Rural Development*, 5(10), 232-239.

Baributsa, D., Baoua, I.B., Bakoye, O.N., Amadou, L., Murdock, L.L. (2017). PICS bags safely store unshelled and shelled groundnuts in Niger. *Journal of Stored Products Research* 72, 54-58.

Bauchet J, Prieto S, Ricker-Gilbert J. (2021). Improved Drying and Storage Practices that Reduce Aflatoxins in Stored Maize: Experimental Evidence from Smallholders in Senegal. *American Journal of Agricultural Economics* 103, 296-316.

Basavarajappa, D.N., Chinnappa, B., Sannathimmappa, H.G. (2013). Farm machinery: the economics of paddy harvesting. *International Journal of Agricultural Engineering* 6, 240-243.

Berhe, M., Subramanyam, B., Demissie, G., Chichaybelu, M., Abera, F. A., Mahroof, R., Harvey, J. (2023). Impact of storage technologies and duration on insect pest population, post-harvest losses, and seed quality of stored chickpea in Ethiopia. *Pest Management Science*, *80*(2), 518-532.

Bhardwaj, R.L., Sen, N.L. (2003). Zero energy cool-chamber storage of Mandarin (Citrus reticulata Blanco) cv. 'Nagpur Santra'. *Journal of Food Science and Technology (Mysore)*, 40, 669-672.

Bhasker, P., Gupta, P.K., Rayte, B.P., Ambare, T.P. (2020). Modern NHRDF onion storage structure under sub-tropical conditions *Vegetable Science* 47, 261-265.

Bhatti, I.M., Khuhro, G.A., Baloch, M.H. (1983). Influence of time of harvest on yield and milling quality of rice. *Sind Journal of Agricultural Research* 3, 30-35.

Bold, T., Ghisolfi, S., Nsonzi, F., Svensson, J. (2022). Market Access and Quality Upgrading: Evidence from Four Field Experiments *American Economic Review* 112, 2518-2552.

Borgemeister, C., Adda, C., Djomamou, B., Degbey, P., Agbaka, A., Djossou, F., Meikle, W.G., Markham, R.H. (1994). The effect of maize cob selection and the impact of field infestation on stored maize losses by the larger grain borer (*Prostephanus truncatus* (Horn) Col., Bostrichidae) and associated storage pests. Proceedings of the 6th International Working Conference on Stored-Product Protection, 906-909.

Borgemeister, C., Adda, C., Setamou, M., Hell, K., Djomamou, B., Markham, R.H., Cardwell, K.F. (1998). Timing of harvest in maize: effects on post harvest losses due to insects and fungi in central Benin, with particular reference to (*Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *Agriculture, Ecosystems and Environment* 69, 233-242.

Bosomtwe, A., Danso, J.K., Osekre, E.A., Opit, G.P., Mbata, G.N., Armstrong, P.R., Arthur, F.H., Campbell, J.F., Manu, N., McNeill, S.G., Akowuah, J.O. (2019). Effectiveness of the solar biomass hybrid dryer for drying and disinfestation of maize. *Journal of Stored Products Research,* 83, 66-72.

Brander, M., Bernauer, T., Huss, M. (2021). Improved on-farm storage reduces seasonal food insecurity of smallholder farmer households–Evidence from a randomized control trial in Tanzania. *Food Policy*, *98*, 101891.

Castelein, R.B., Broeze, J.J., Kok, M.M., Axmann, H.H., Guo, X.X., Soethoudt, J.H. (2022). Mechanization in rice farming reduces greenhouse gas emissions, food losses, and constitutes a positive business case for smallholder farmers–Results from a controlled experiment in Nigeria. *Cleaner Engineering and Technology*, *8*, 100487.

Caswell, G.H. (1975). The development and extension of nonchemical control techniques for stored cowpeas in Nigeria. Proceedings of the First International Working Conference on Stored-Product Entomology, Savannah, Georgia, USA, October 7-11, 1974, 63-67.

Champa, W.A.H., Palipane, K.B., Weerakkody, W.A.P., Fernando, M.D. (2007). Maturity indices for harvesting of cabbage (Brassica oleraceae L.) variety green coronet. *Tropical Agricultural Research*, 19, 254-264.

Channa, H., Chen, A.Z., Pina, P., Ricker-Gilbert, J., Stein, D. (2019). What drives smallholder farmers' willingness to pay for a new farm technology? Evidence from an experimental auction in Kenya. *Food policy*, *85*, 64-71.

Chegere, M.J., Lokina, R., Mwakaje, A.G. (2020). The impact of hermetic storage bag supply and training on food security in Tanzania. *Food Security,* 12, 1299-1316.

Chegere, M. J., Eggert, H., Söderbom, M. (2022). The effects of storage technology and training on postharvest losses, practices, and sales: evidence from small-scale farms in Tanzania. *Economic Development and Cultural Change*, *70*(2), 729-761.

Cheong, J.K.C.W.Y., Govinden, N. (1999). Quality of potato during storage at three temperatures. Proceedings of the Third Annual Meeting of Agricultural Scientists, Reduit, Mauritius, 17-18 November 1998, 175-179.

Chigoverah, A.A., Mvumi, B.M., Muchechemera, C., Dator, J.V. (2018). Are GrainPro Cocoons™ an effective alternative to conventional phosphine fumigation in large-scale control of stored-maize insect pests? *Journal of Pest Science* 91, 1393-1406.

Chikukura, L., Mvumi, B.M., Chikonzo, R., Chenzara, C. (2011). Evaluation of selected indigenous pesticidal plant powders against stored maize and cowpeas insect pests. 10th African Crop Science Conference Proceedings, Maputo, Mozambique, 10-13 October 2011 10, 189-192.

Covele, G., Gulube, A., Tivana, L., Ribeiro-Barros, A.I., Carvalho, M.O., Ndayiragije, A., Nguenha, R. (2020). Effectiveness of hermetic containers in controlling paddy rice (Oryza sativa L.) storage insect pests. *Journal of Stored Products Research*, 89, 101710.

Dabhi, M.N., Patel, N.C., Dhamsaniya, N.K. (2008). Effect of storage conditions on the quality characteristics of onion. *Journal of Food Science and Technology (Mysore),* 45, 376-377.

Dambolachepa, H.B., Muthomi, J.W., Mutitu, E.W., Njoroge, S.M. (2019). Effects of postharvest handling practices on quality of groundnuts and aflatoxin contamination. *Novel Research in Microbiology Journal*, *3*(3), 396-414.

Dari, L., Nenguwo, N., Afari-Sefa, V. (2018). Evaluation of packaging liners in wooden and plastic crates for handling tomatoes. *Journal of Postharvest Technology,* 6, 36-40.

Dari, L., Owusu-Ansah, P., Nenguwo, N., Afari-Sefa, V. (2015). Comparative study of the performance of kiln-fired brick and mud block zero energy cool chambers in the Northern Region of Ghana. *International Journal of Tropical Agriculture,* 33, 2037-2041.

Das, M., Ezekiel, R., Verma, V.S. (2000). Comparative evaluation of on-farm storage losses of two potato cultivars in Bihar. *Journal of the Indian Potato Association*, 27, 83-86.

Daum, T., Birner, R. (2020). Agricultural mechanization in Africa: myths, realities and an emerging research agenda. Global Food Security, 26, 100393. https://doi.org/ 10.1016/j.gfs.2020.100393.

Deka, B.C., Choudhury, S., Bhattacharyya, A., Begum, K.H., Neog, M. (2006). Postharvest treatments for shelf life extension of banana under different storage environments. *Acta Horticulturae*, 712, 841-849.

Donahaye, E., Navarro, S., Ziv, A., Blauschild, Y., Weerasinghe, D. (1991). Storage of paddy in hermetically sealed plastic liners in Sri Lanka. *Tropical Science,* 31, 109-121.

Doshi, J.S., Sutar, R.F. (2010). Studies on pre-cooling and storage of banana for extension of shelf life. *Journal of Agricultural Engineering (New Delhi)*, 47, 14-19.

Dubey, A., Mani, I., Nebapure, S. M., Sharma, P. K., Parray, R. A., Rudra, S. G., ... Singh, M. K. (2022). Effectiveness of bio-insecticide incorporated storage bag for safe storage of legumes. *The Indian Journal of Agricultural Sciences*, *92*(7), 897-901.

Eichenauer, H., Huss, M., Brander, M., Bernauer, T., Ehlert, U. (2023). Effects of improved on-farm crop storage on perceived stress and perceived coping in pregnant women—Evidence from a cluster-randomized controlled trial in Kenya. *Plos one*, *18*(7), e0288446.

Elbagoury, M.M., Turoop, L., Runo, S., Sila, D.N., Madivoli, E.S. (2022). Postharvest treatments of banana (Musa acuminata cv. 'Grand Nain', AAA) during cold and ripening temperatures with chitosan and chitosan nanoparticles to alleviate chilling injury and maintain antioxidant activity. *Horticulture, Environment and Biotechnology*, 63, 677-699.

Eyese, W.W., Badebo, E.D., Tessema, M.L. (2022). Effect of harvesting stage and storage condition on post-harvest quality and sensory acceptability of mango fruit in Gamo Zone, Southern Ethiopia. *International Journal of Agricultural Research, Innovation and Technology (IJARIT),* 12, 82-87.

Ezeike, G.O.I. (1985). Experimental analysis of yam (D. spp.) tuber stability in tropical storages. *Transactions of the American Society of Agricultural Engineers,* 28, 1641-1645.

FAO (2018). Food loss analysis: causes and solutions. www.fao.org

FAO (2019). The State of Food and Agriculture 2019: Moving Forward on Food Loss and Waste Reduction http://www.fao.org/3/ca6030en/ca6030en.pdf

FAO, WFP, IFAD. (2019a). Food loss analysis: causes and solutions – Case studies on sorghum, maize and cowpea in Burkina Faso. 242 pp. Rome.

FAO, WFP and IFAD. (2019b). Food loss analysis: causes and solutions - Case studies on maize and rice in the Democratic Republic of Congo. 192pp. Rome.

Farnworth, C.R., Badstule, L.B., de Groote, H., Gitonga, Z. (2021). Do metal grain silos benefit women in Kenya, Malawi, Zambia and Zimbabwe? *Journal of Stored Products Research*, *93*, 101734.

Fatima, F., Basit, A., Ahmad, A., Shah, S.T., Sajid, M., Aman, F., Mohamed, H.I., Elhakem, A. (2022). Enhancement of the fruit quality and postharvest life expectancy of mango fruit (Mangifera indica L.) applying ecofriendly bio-coatings. *Notulae Botanicae, Horti Agrobotanici, Cluj-Napoca*, 50(4), 12917.

Garg, S., Gupta, A.K., Kumar, A. (1997). Storage of tomatoes in evaporatively cooled chambers. *Journal of Research Punjab Agricultural University,* 34, 320-327.

Gbenou, E.S, Adegbola, Y.P, Hessavi, P.M, Zossou, S.R.C, Biaou, G. (2021). On-farm assessment of maize storage and conservation technologies in the central and northern republic of Benin *Agriculture*, *11*(1), 32.

Geremew, M., Molla, A., Gabbiye, N., Harvey, J., Mahroof, R., Abay, F. (2023). Effects of threshing and storage conditions on post-harvest insect infestation and physical characteristics of maize grain *Journal of Stored Products Research*, *103*, 102131.

Getachew M, Fentahun M, Fikadu C. (2022). Economic analysis of threshing and shelling machine service provision to reduce post-harvest loss in Ethiopia. *African Journal of Food, Agriculture, Nutrition and Development,* 22(6), 20701-20720.

Getinet, H., Workneh, T.S., Woldetsadik, K. (2011). Effect of maturity stages, variety and storage environment on sugar content of tomato stored in multiple pads evaporative cooler. *African Journal of Biotechnology*, 10, 18481-18492.

Giles, P.H., Ashman, F. (1971). A study of pre-harvest infestation of maize by *Sitophilus zeamais* Motsch. (Coleoptera, Curculionidae) in the Kenya highlands. *Journal of Stored Products Research,* 7, 69-83.

Gitonga, Z. M., de Groote, H., Kassie, M. & Tefera, T. (2013). Impact of metal silos on households' maize storage, storage losses and food security: an application of a propensity score matching. *Food Policy,* 43, 44–55.

Gitonga, Z., de Groote, H., Tefera, T. (2015). Metal silo grain storage technology and household food security in Kenya. *Journal of Development and Agricultural Economics* 7, 222-230.

Gombas D, Luo Y, Brennan J, Shergill G, Petran R, Walsh R, Hau H, Khurana K, Zomorodi B, Rosen J, Varley R, Deng K. (2017). Guidelines To Validate Control of Cross-Contamination during Washing of Fresh-Cut Leafy Vegetables. *Journal of Food Protection,* 80(2):312-330. doi: 10.4315/0362-028X.JFP-16-258. PMID: 28221982.

Gomez, S., Paul, A.A., Kiribhaga, S., Josep, M. (2023). Shelf life and quality of banana cultivar nendran as influenced by shrink-wrap packaging and storage temperature. *Plant Science Today*, 10, 152-159

Goswami, S., Borah, A., Baishya, S., Saikia, A., Deka, B.C. (2008). Low cost storage structures for shelf-life extension of horticultural produces. *Journal of Food Science and Technology (Mysore),* 45, 70-74.

Greeley, M. (1980). Rural technology, rural institutions and the rural poorest: the case of rice processing in Bangladesh. The Bangladesh Development Studies 8, 143-159.

Guenha, R., Salvador, B.das V., Rickman, J., Goulao, L.F., Muocha, I.M., Carvalho, M.O. (2014). Hermetic storage with plastic sealing to reduce insect infestation and secure paddy seed quality: a powerful strategy for rice farmers in Mozambique. *Journal of Stored Products Research,* 59, 275-281.

Guisse, R. (2010.) Post Harvest Losses of Rice (Oriza Spp) From Harvesting to Milling: A Case Study in Besease and Nobewam in the Ejisu Juabeng District in the Ashanti Region of Ghana. MSc Thesis, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, 82 pp.

Gupta, M., Rattanpal, V.H.S., Singh, G., Arora, A. (2021). Influence of potassium sorbate with wax coating on post harvest life of Kinnow mandarin under ambient conditions. *Agricultural Research Journal*, 58, 1093-1099.

Haile, A. (2006). On-farm storage studies on sorghum and chickpea in Eritrea. *African Journal of Biotechnology*, 5, 1537-1544.

Herath, M.M., Dissanayake, C.A.K., Wasala, W.M.B., Somakanthan, N., Gunawardane, C.R. (2021). The effect of improved postharvest practices on the postharvest losses and quality of mango fruit in Sri Lanka's supply chain. *Journal of Horticulture and Postharvest Research*, 4, 509-520.

Hodges, R.J., Stathers, T.E. (2012). Training Manual for Improving Grain Postharvest Handling and Storage. WFP, 246pp.

Hoffmann, V., Gatobu, K. M. (2014). Growing their own: Unobservable quality and the value of self-provisioning. *Journal of Development Economics*, *106*, 168-178.

Hoffmann, V., Mutiga, S. K., Harvey, J. W., Nelson, R. J., Milgroom, M. G. (2021). Observability of food safety losses in maize: evidence from Kenya. *Food Policy*, *98*, 101895.

Holst, N., Meikle, W.G., Markham, R.H. (2000). Grain injury models for *Prostephanus truncatus* (Coleoptera: Bostrichidae) and *Sitophilus zeamais* (Coleoptera: Curculionidae) in rural maize stores in West Africa. *Journal of Economic Entomology,* 93, 1338–1346.

Htwe, N.M., Sarathchandra, S.R., Sluydts, V., Nugaliyadde, L., Singleton, G.R., Jacob, J. (2021). Small mammal communities, associated damage to rice and damage prevention in smallholder rice storage facilities in Sri Lanka. *Crop Protection* 145, 105638.

Hussain, M., Singh, P.K., Hussain, N. (2019). Post-Harvest Farm Operation Losses in Wheat-A Case Study of Kathua District. *Indian Journal of Hill Farming*, 32(1).

Ibro, G., Sorgho, M. C., Idris, A. A., Moussa, B., Baributsa, D., Lowenberg-DeBoer, J. (2014). Adoption of cowpea hermetic storage by women in Nigeria, Niger and Burkina Faso. *Journal of Stored Products Research*, *58*, 87-96.

Ishaque, F., Hossain, M. A., Sarker, M. A. R., Rahman, M. J., Moniruzzaman, M., Baidya, J., & Jubayer, M. F. (2022). Performance evaluation of a low-cost evaporative cooling storage structure for citrus fruits in Sylhet region of Bangladesh. *Thai Journal of Agricultural Science*, 54(4), 235-257.

Jaiswal, A.K., Singh, B., Mehta, A., Lal, M. (2022). Post-harvest losses in potatoes from farm to fork. *Potato Research,* 66, 51-66.

Jonsson, L.O., Kashweka, K. (1987). Relationship between drying, harvesting and storage losses, production and consumption of maize for a rural household in Zambia. Proceedings of FAO-SIDA Seminar on Increased Food Production through Lowcost Food Crops Technology. 2-17 March 1987. Harare, Zimbabwe, 475-482.

Kaaya, A. N., Kyamuhangire, W. (2010). Drying maize using biomass-heated natural convection dryer improves grain quality during storage. *Journal of Applied Sciences*, *11*, 967-974.

Kaaya, A.N., Warren, H.L., Kyamanywa, S., Kyamuhangire, W. (2005). The effect of delayed harvest on moisture content, insect damage, moulds and aflatoxin contamination of maize in Mayuge district of Uganda. *Journal of the Science of Food and Agriculture,* 85, 2595-2599.

Kalsa, K.K., Subramanyam, B., Demissie, G., Mahroof, R., Worku, A., Gabbiye, N. (2019). Evaluation of postharvest preservation strategies for stored wheat seed in Ethiopia. *Journal of Stored Products Research*, 81, 53-61.

Kalsa, K. K., Subramanyam, B., Demisse, G., Worku, A., Workneh, S., & Gabbiye, N. (2020). On-farm performance and assessment of farmers' perceptions of hermetic bags for farm-stored wheat and maize in northwestern Ethiopia. In *Advances of Science and Technology: 7th EAI International Conference, ICAST 2019, Bahir Dar, Ethiopia, August 2–4, 2019, Proceedings 7* (pp. 98-109). Springer International Publishing.

Kamala, A., Kimanya, M., Haesaert, G., Tiisekwa, B., Madege, R., Degraeve, S., Cyprian, C., De Meulenaer, B. (2016). Local post-harvest practices associated with aflatoxin and fumonisin contamination of maize in three agro ecological zones of Tanzania. *Food Additives and Contaminants A*, 33, 551-559.

Kapse, B.M., Katrodia, J.S. (1997). Studies on hydrocooling in Kesar mango (Mangifera indica L.). *Acta Horticulturae*, 455, 707-717.

Khan, D.I., Jan, H.U., Khan, N.I., Muhammad, A., Sajid, M. (2006). Potato seed tubers storage under high altitude conditions of Kaghan valley. *Sarhad Journal of Agriculture*, 22, 41-43.

Khan, D.I., Zaman, M.K., Hussain, S., Lughmani, A.M., Jan, H., Iqbal, M. (1995). Seed potatoes storage under high hill conditions of upper Kaghan valley. Research and development of potato production in Pakistan. Proceedings of the National Seminar held at NARC, Islamabad, Pakistan, 23-25 April, 1995, 102-108.

Kiura, I.N., Gichimu, B.M., Rotich, F. (2021). Proximate and nutritional composition of stored bulb onions as affected by harvest and postharvest treatments. *International Journal of Agronomy*, 2021(1), 5532349.

Kumar, D., Kaul, H.N., Singh, S.V. (1995). Keeping quality in advanced potato selections during non-refrigerated storage. *Journal of the Indian Potato Association,* 22, 105-108.

Kumar, S., Gupta, A.K. (1999). Studies on non-refrigerated storage of potatoes. *Journal of Research Punjab Agricultural University,* 36, 242-251.

Kuyu, C.G., Tola, Y.T., Abdi, G.C. (2019). Study on post-harvest quantitative and qualitative losses of potato tubers from two different road access districts of Jimma zone, South West Ethiopia. *Heliyon,* 5, e02272.

Ladaniya, M.S., Mahalle, B. (2004). Evaluation of containers, cushioning material and liners for packaging of 'Nagpur' mandarin. *South Indian Horticulture*, 52, 45-52.

Leavens, L., Bauchet, J., Ricker-Gilbert, J. (2021). After the project is over: measuring longer-term impacts of a food safety intervention in Senegal. *World Development*, *141*, 105414.

Mahangade, P.S., Mani, I., Beaudry, R., Muller, N., Chopra, S. (2020). Using amaranth as a model plant for evaluating imperfect storages: assessment of solar-refrigerated and evaporatively-cooled structures in India. *HortScience,* 55, 1759-1765.

Mahrouf, A.R.M., Rafeek, M.I.M. (2003). Mechanization of paddy harvesting: the economic perspective. *Annals of the Sri Lanka Department of Agriculture* 5, 161-172.

Majubwa, R.O., Msogoya, T.J., Mtui, H.D., Shango, A.J. (2022). Coolbot Coldroom technology enhance postharvest quality and shelf-life of tomato (Solanum lycopersicum L.) fruits. *Tanzania Journal of Agricultural Sciences*, 21, 11-21.

Makinya, K. J., Wagacha, J. M., Odhiambo, J. A., Likhayo, P., Edoh-Ognakossan, K., Tefera, T., Abass, A., Mutungi, C. M. (2021). The importance of store hygiene for reducing post-harvest losses in smallholder farmers' stores: Evidence from a maize-based farming system in Kenya. *Journal of Stored Products Research*, *90*, 101757.

Manu, N., Osekre, E.A., Opit, G.P., Arthur, F.H., Mbata, G.N., Armstrong, P.R., Danso, J.K., McNeill, S.G., Campbell, J. (2019). Moisture content, insect pests and mycotoxin levels of maize on farms in Tamale environs in the northern region of Ghana. *Journal of Stored Products Research* 83, 153-160.

Matin, M.A., Bhuiya, A.D., Ahmed, M., Karim, A., Rahman, S., Khatoon, J., Hossain, M.M., Islam, S., Islam, M., Amin, M.R., Hossain, M.A., Siddiqui, A.K. (1992). Commercialization, storage and transportation of irradiated dried fish and onions. Proceedings of the Final Research Co-ordination meeting on the Asian Regional Co-operative project on Food Irradiation: Technology Transfer. Bangkok, Thailand, 31 October-4 November 1988, 99-119.

Mazhar, M.S., Amin, M., Malik, A.U., Campbell, J., Johnson, P. (2011). Improved harvest and desapping practices affect mango fruit quality along the supply chains. *International Journal of Agriculture and Biology*, 13, 776-780.

Mdangi, M., Mulungu, L.S., Massawe, A.W., Eiseb, S.J., Tutjavi, V., Kirsten, F., Mahlaba, T., Malebane, P., von Maltitz, E., Monadjem, A., Dlamini, N., Makundi, R.H., Belmain, S.R. (2013). Assessment of rodent damage to stored maize (*Zea mays* L.) on smallholder farms in Tanzania. *International Journal of Pest Management* 59, 55-62.

Mehta, A., Kaul, H.N. (1991). Effect of sprout inhibitors on potato tubers (Solanum tuberosum L.) stored at ambient or reduced temperatures. *Potato Research,* 34, 443-450.

Mehta, A., Singh, B. (2015). Effect of CIPC treatment on post-harvest losses and processing attributes of potato cultivars. *Potato Journal*, 42, 18-28.

Mehta, A., Singh, B., Ezekiel, R. (2011). Effect of CIPC treatment on keeping and processing attributes during short term storage. *Indian Journal of Plant Physiology*, 16, 85-92.

Melese, B., Satheesh, N., Fanta, S.W., Bishaw, Z. (2022). Effects of storage bags type and storage duration on seed quality and proximate composition of emmer wheat (Triticum dicoccum L.) in Ethiopia. Heliyon, 8(12).

Mesta, R.K., Kukanur, L. (2013). Management of postharvest smudge infections in onion through fungicides. *Acta Horticulturae*, 1012, 627-632.Mishra, B.K., Jain, N.K., Kumar, S., Doharey, D.S., Sharma, K.C. (2009). Shelf life studies on potato and tomato under evaporative cooled storage structure in southern Rajasthan. *Journal of Agricultural Engineering (New Delhi),* 46, 26-30.

Mishra, B.K., Jain, N.K., Kumar, S., Doharey, D.S., Sharma, K.C. (2009). Shelf life studies on potato and tomato under evaporative cooled storage structure in southern Rajasthan. *Journal of Agricultural Engineering (New Delhi),* 46, 26-30.

Mishra, D., Satapathy, S. (2021). Technology adoption to reduce the harvesting losses and wastes in agriculture. *Clean Technologies and Environmental Policy* 23, 1947-1963.

Mlambo, S., Mvumi, B. M., Stathers, T., Mubayiwa, M., Nyabako, T. (2017). Field efficacy of hermetic and other maize grain storage options under smallholder farmer management. *Crop Protection*, *98*, 198-210.

Mozie, O. (1982). Effect of air flow on weight losses and sprouting of white yam tubers (Dioscorea rotundata) stored in the conventional barn. *Tropical Root and Tuber Crops Newsletter* 12/13, 32-37 (1981-2).

Mozie, O. (1996). Effect of mechanical injury and regulated air flow on storage losses of white yam tubers. *Tropical Science,* 36, 65-67.

Mozie, O. (1982). Evaluation of weight losses and rate of rotting due to mechanical injuries sustained during harvesting of white yam (Dioscorea rotundata) stored in the conventional barn. *Tropical Root and Tuber Crops Newsletter* 12/13, 18-21 (1981-2).

Msogoya, T.J., Kimaro, E.S. (2011). Assessment and management of post harvest losses of fresh mango under small-scale business in Morogoro, Tanzania. *Journal of Animal & Plant Sciences*, 11, 1358-1363.

Mubayiwa, M., Mvumi, B.M., Stathers, T., Mlambo, S., Nyabako, T. (2021). Field evaluation of hermetic and synthetic pesticide-based technologies in smallholder sorghum grain storage in hot and arid climates. *Scientific Reports*, 11(1), 3692.

Mutambuki, K., Ngatia, C.M., Mbugua, J.N. (2010). Post-harvest technology transfer to reduce on farm grain losses in Kitui district, Kenya. Proceedings of the 10th International Working Conference on Stored Product Protection, Estoril, Portugal, 27 June-2 July, 2010, 984-990.

Mutungi, C., Chamwilambo, M., Masanja, S., Massam, C., Wayda, P., Tungu, J., ... & Abass, A. (2020). Quality and storability of common beans in small-holders farm stores in Northern Tanzania: A multivariate analysis of agro-location, variety, and storage method effects. *Journal of Stored Products Research*, 89, 101723.

Mutungi, C., Abass, A., Fischer, G., Kotu, B. (2022b). Improved technologies for reducing post-harvest losses. Sustainable agricultural intensification: a handbook for practitioners in East and Southern Africa, 91-105.

Mutungi, C., Muthoni, F., Bekunda, M., Gaspar, A., Kabula, E., Abass, A. (2019). Physical quality of maize grain harvested and stored by smallholder farmers in the Northern highlands of Tanzania: effects of harvesting and pre-storage handling practices in two marginally contrasting agro-locations. *Journal of Stored Products Research,* 84, 101517.

Mutungi, C., Tungu, J., Amri, J., Gaspar, A., Abass, A. (2022a). Nutritional benefits of improved post-harvest handling practices for maize and common beans in Northern Tanzania: A quantitative farm-level assessment. *Journal of Stored Products Research*, *95*, 101918.

Mwebaze, P. Mugisha, J. (2011). Adoption, utilisation and economic impacts of improved post-harvest technologies in maize production in Kapchorwa district, Uganda. *International Journal of Postharvest Technology and Innovation*, 2, 301–327.

Nabi, G., Rab, A., Sajid, M., Farhatullah, Abbas, S.J., Ali, I. (2013). Influence of curing methods and storage conditions on the post-harvest quality of onion bulbs. *Pakistan Journal of Botany,* 45, 455-460.

Nagaraju, C.G., Reddy, T.V. (1995). Deferral of banana fruit ripening by cool chamber storage. *Advances in Horticultural Science*, 9, 162-166.

Nahdy, S., Agona, A. (1992). Studies on the control of the bean bruchids *Acanthoscelides obtectus* (Say) and *Zabrotes subfasciatus* (Boheman) (Coleoptera: Bruchidae) in the East African region. CIAT African workshop series (CIAT).

Nasir, A., Zia-Ul-Haq, M. Y., Iqbal, T., Ansar, M., Yaseen, G., Karim, F., Mirani, A.A., Saad, A., Zaman, M. A. U. (2023). 30. Testing of tractor mounted groundnut pods collector and its comparison with traditional method. *Pure and Applied Biology (PAB)*, *12*(1), 342-348.

Nasrin, T.A.A., Islam, M.N., Rahman, M.A., Arfin, M.S., Ullah, M.A. (2018). Evaluation of postharvest quality of edible coated mandarin at ambient storage. *International Journal of Agricultural Research, Innovation and Technology (IJARIT)*, 08, 18-25.

Nath, B. C., Paul, S., Huda, M. D., Hossen, M. A., Bhuiyan, M. G. K., Islam, A. S. (2022). Combine Harvester: Small Machine Solves Big Rice Harvesting Problem of Bangladesh. *Agricultural Sciences*, *13*(2), 201-220.

Ndegwa, M. K., de Groote, H., Gitonga, Z. M. Bruce, A. Y. (2016). Effectiveness and economics of hermetic bags for maize storage: results of a randomized controlled trial in Kenya. *Crop Protection*, 90, 17–26.

Ngwenyama, P., Mvumi, B. M., Nyanga, L. K., Stathers, T. E., & Siziba, S. (2020). Comparative performance of five hermetic bag brands during on-farm smallholder cowpea (Vigna unguiculata L. Walp) storage. *Journal of Stored Products Research*, *88*, 101658.

Nkolisa, N., Magwaza, L.S., Workneh, T.S., Chimphango, A. (2018). Evaluating evaporative cooling system as an energy-free and cost-effective method for postharvest storage of tomatoes (Solanum lycopersicum L.) for smallholder farmers. *Scientia Horticulturae*, 241, 131-143.

Nwankiti, A.O., Atu, U.G., Alozie, S.O., Igbokwe, M., Okpokiri, A., Nnodu, E. (1988). Effect of modifying two traditional yam barn structures on storability of four cultivars of yam (Dioscorea spp.). *Tropical Agriculture*, 65, 125-128.

Nyarko, S.K., Akyereko, Y.G., Akowuah, J.O., Wireko-Manu, F.D. (2021). Comparative studies on grain quality and pesticide residues in maize stored in hermetic and polypropylene storage bags. *Agriculture*, *11*(8), 772.

Odey, S.O., Agba, O.A., Ogar, E.A. (2007). Spoilage of freshly harvested mango fruits (Mangifera indica) stored using different storage methods. *Global Journal of Agricultural Sciences*, 6, 145-148.

Odeyemi, O. M., Kitinoja, L., Dubey, N., Musanase, S., & Gill, G. S. (2022). Preliminary study on improved postharvest practices for tomato loss reduction in Nigeria, Rwanda and India. *African Journal of Science, Technology, Innovation and Development*, *14*(6), 1500-1505.

Omotilewa, O.J., Ricker-Gilbert, J., Ainembabazi, J.H., Shively, G.E. (2018). Does improved storage technology promote modern input use and food security? Evidence from a randomized trial in Uganda. *Journal of Development Economics* 135, 176-198.

Opoku, B., Osekre, E. A., Opit, G., Bosomtwe, A., Bingham, G. V. (2023). Evaluation of hermetic storage bags for the preservation of yellow maize in poultry farms in Dormaa Ahenkro, Ghana. *Insects*, *14*(2), 141.

Orovwode, H., Afolabi, G., Agbetuyi, F., Adoghe, A., Adeyemi-Kayode, T.M., Elizabeth, A. (2022). Development and performance evaluation of a solar powered tomatoes storage chamber. *IOP Conference Series: Earth and Environmental Science*, 1054.

Osunde, Z.D., Orhevba, B.A. (2009). Effects of storage conditions and storage period on nutritional and other qualities of stored yam (Dioscorea spp.) tubers. *African Journal of Food Agriculture Nutrition and Development,* 9, 678-690.

Otitodun, G., Ala, A., Nwaubani, S., Omobowale, M., Ogundare, M., Abel, G., Ajao, K., Braimah, J., Olenloa, A., Kolayemi, O., Ogwumike, J., Opit, G., Ileleji, K., McNeill, S.G. (2018). Evaluation of five storage technologies to preserve quality composition of maize in Nigerian markets. Proceedings of the 12th International Working Conference on Stored Product Protection (IWCSPP), Berlin, Germany, 7-11 October, 2018, 900-909.

Palanisami, A., Manickam, A., Neelakantan, S. (1990). Fungal flora and aflatoxin production in relation to post-harvest practices in groundnut. *Madras Agricultural Journal* 77, 26-31.

Patel, C.K., Sasani, G.V., Patel, S.H., Patel, N.H. (2001). Comparison of some traditional storage methods of potato. *Journal of the Indian Potato Association*, 28, 152-153.

Paul, V., Ezekiel, R. (2003). Improved heap method of potato storage for central Indo-Gangetic plains. *Journal of the Indian Potato Association,* 30, 159-160.

Paul, U.V., Lossini, J.S., Edwards, P.J., Hilbeck, A. (2009). Effectiveness of products from four locally grown plants for the management of Acanthoscelides obtectus (Say) and Zabrotes subfasciatus (Boheman) (both Coleoptera: Bruchidae) in stored beans under laboratory and farm conditions in Northern Tanzania. *Journal of Stored Products Research,* 45, 97-107.

Plaisier, C., Sibomana, M., van der Waal, J., Clercx, L., Van Wagenberg, C.P.A., Dijkxhoorn, Y. (2019). Approach for Designing Context-Specific, Locally Owned Interventions to Reduce Postharvest Losses: Case Study on Tomato Value Chains in Nigeria. *Sustainability*, 11, 247.

Prasad, K., Sharma, R.R., Asrey, R., Sethi, S., Srivastav, M., Singh, D., Arora, A. (2022). Hydrocolloid edible coatings extend shelf life, reduce postharvest decay, and maintain keeping quality of mango fruits (Mangifera indica L.) under ambient storage. *Journal of Food Biochemistry*, 46(12), e14481.

Prasanna, P.H.S.N., Gunaratne, L.H.P., Withana, W.D.R.S. (2004). Economic Analysis of Paddy Threshing Methods. *Sri Lankan Journal of Agricultural Economics*, 6, 51-66.

Pretari, A., Hoffmann, V., Tian, L. (2019). Post-harvest practices for aflatoxin control: evidence from Kenya. *Journal of Stored Products Research*, 82, 31-39.

Pujari, K.H., Joshi, M.S., Shedge, M.S. (2016). Management of postharvest fruit rot of mango caused by Colletotrichum gloeosporiodes. *Acta Horticulturae*, 1120, 215-218.

Puttaraju, T.B., Reddy, T.V. (1997). Effect of precooling on the quality of mango (cv. 'Mallika'). *Journal of Food Science and Technology (Mysore)*, 34, 24-27 (1997).

Rahman, M.A., Alam, S.M.K., Reza, M.H., Uddin, M.S., Amin, M.N., Nasrin, T.A.A. (2019). Impact of pre-harvest fruit bagging and improved postharvest practices in reducing losses and managing quality of mango in the value chain system. *International Journal of Postharvest Technology and Innovation*, 6, 117-136.

Rahman, M.A., Esguerra, E.B., Saha, M.G., Rolle, R. (2018). Managing quality and reducing postharvest losses in the mango value chain. *Acta Horticulturae*, 1210, 1-11.

Randhawa, K.S., Arora, S.K., Singh, M., Gupta, A.K. (1985). Effect of different chemicals on storage of onions under ordinary conditions. *Journal of Research Punjab Agricultural University*, 22, 261-266.

Rashid, M.Z., Ahmad, S., Khan, A.S., Ali, B. (2020). Comparative efficacy of some botanical extracts and commercial coating materials for improving the storage life and maintain quality of kinnow mandarin (Citrus reticulata L.). *Applied Ecology and Environmental Research*, 18, 713-729.

Ratnadass, A., Cisse, B., Diarra, D., Sidibe, B., Sogoba, B., Thiero, C.A.T. (1999). Faune des stocks de sorgho dans deux régions du Mali et comparaison des pertes infligées aux variétés locales ou introduites pour améliorerle rendement. [Fauna of stored sorghum grain in two regions of Mali and comparison of losses inflicted to local or high-yielding introduced varieties]. *Annales de la Societe Entomologique de France,* 35, 489-495.

Roy, K. (2005). Postharvest handling of mango and banana to minimize losses: a case study in Bangladesh. Proceedings of the International Conference on Postharvest Technology and Quality Management in Arid Tropics, Sultanate of Oman, 31 January-2 February 2005, 83-87.

Sajwan, K.S., Mittra, B.N., Pande, H.K. (1993). Influence of time of harvesting and post-harvest operations on yield and milling out-turn of rice. *Indian Journal of Agricultural Research,* 27, 146-154.

Sanneh, L. (2015). Effects of threshing and post-threshing recovery methods on postharvest losses in two varieties of rice. MPhil Thesis, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, 71 pp.

Saran, S., Dubey, N., Mishra, V., Dwivedi, S.K., Raman, N.L.M. (2013). Evaluation of coolbot cool room as a low cost storage system for marginal farmers. *Progressive Horticulture*, 45, 115-121.

Savita, S.M., Srinivasappa, K.N., Suresha, S.V., Vasanthi, B.G., Anand, G.M., Sujith, G.M. (2010). Drudgery reduction using scientifically designed mango harvesters over conventional methods. *Journal of Dairying, Foods and Home Sciences* 29, 222-226.

Schwab, B., Yu, J. (2024). Guaranteed storage? Risk and credit constraints in the demand for postharvest technology. *Oxford Economic Papers*, gpae027.

Shah, S., Hashmi, M.S. (2020). Chitosan-aloe vera gel coating delays postharvest decay of mango fruit. *Horticulture, Environment and Biotechnology*, 61, 279-289.

Shah, S., Hashmi, M.S., Qazi, I.M., Durrani, Y., Sarkhosh, A., Hussain, I., Brecht, J.K. (2021). Pre-storage chitosan-thyme oil coating control anthracnose in mango fruit. *Scientia Horticulturae*, 284, 110139.

Sharma, P.K., Kumar, S., Yadav, G.L., Verma, R., Gupta, A. (2007). Effect of last irrigation and field curing on yield and post-harvest losses of rabi onion (Allium cepa). *Annals of Biology*, 23, 145-148.

Sharma, P., Sharma, S.R., Dhall, R.K., Mittal, T.C. (2020). Effect of ɣ-radiation on post-harvest storage life and quality of onion bulb under ambient condition. *Journal of Food Science and Technology (Mysore),* 57, 2534-2544.

Shazali, M.E.H., El Hadi, A.R., Khalifa, A.M.H., Ahmed, M.A. (1998). Environmental changes, insect control and reduction of losses in sorghum stored in matmoras (storage pits). *Sudan Journal of Agricultural Research,* 1, 73-78.

Shukla, P., Pullabhotla, H. K., & Baylis, K. (2023). The economics of reducing food losses: Experimental evidence from improved storage technology in India. *Food Policy*, *117*, 102442.

Sibanda, S., Workneh, T.S. (2019). Effects of indirect air cooling combined with direct evaporative cooling on the quality of stored tomato fruit, *CyTA - Journal of Food,* 17, 603-612.

Silue, Y., Nindjin, C., Cisse, M., Kouame, K.A., Amani, N.G., Mbeguie-A-Mbeguie, D., Lopez-Lauri, F., Tano, K. (2022). Hexanal application reduces postharvest losses of mango (Mangifera indica L. variety "Kent") over cold storage whilst maintaining fruit quality. *Postharvest Biology and Technology*, 189, 111930.

Singano, C. D., Mvumi, B. M., Stathers, T. E. (2019). Effectiveness of grain storage facilities and protectants in controlling stored-maize insect pests in a climate-risk prone area of Shire Valley, Southern Malawi. *Journal of Stored Products Research*, *83*, 130-147.

Singh, K., Mann, S.S., Mohan, C. (1988). Effect of fungicides and wax emulsion on storage of Kinnow mandarin at ambient storage conditions. *Haryana Journal of Horticultural Sciences*, 17, 14-19.

Singh, R., Sharma, R.K., Kumar, J., Goyal, R.K. (2003). Effect of oil emulsions and precooling on the shelf life of mango cv. Amarpali. *Haryana Journal of Horticultural Sciences*, 32, 54-55.

Singh, K., Singh, D. (1973). Effect of various methods of storage on the keeping quality of onion bulbs. *Haryana Journal of Horticultural Sciences*, 2, 116-122.

Smit, N.E.J.M. (1997). The effect of the indigenous cultural practices of in-ground storage and piecemeal harvesting of sweetpotato on yield and quality losses caused by sweetpotato weevil in Uganda. *Agriculture, Ecosystems and Environment*, 64, 191-200.

Srinivasappa, K.N., Savita, S.M., Rajanna, N. (2015). Evaluation on efficacy of farmer friendly mango harvesters. *Mysore Journal of Agricultural Sciences* 49, 484-491.

Stathers, T., Holcroft, D., Engelbert, M., Ravat, Z., Marion, P. (2024a). Crop postharvest loss reduction interventions in sub-Saharan Africa and South Asia: Systematic scoping review update 2024. 81 pp. Natural Resources Institute (NRI), Chatham, UK.

Stathers, T., Holcroft, D., Kitinoja, L., Mvumi, B. M., English, A., Omotilewa, O., Kocher, M., Ault, J., Torero, M. (2020). A scoping review of interventions for crop postharvest loss reduction in sub-Saharan Africa and South Asia. *Nature Sustainability*, 3(10), 821-835. https://www.nature.com/articles/s41893-020-00622-1

Stathers, T.E., Riwa, W., Mvumi, B.M., Mosha, R., Kitandu, L., Mngara, K., Kaoneka, B., Morris, M. (2008). Do diatomaceous earths have potential as grain protectants for small-holder farmers in sub-Saharan Africa? the case of Tanzania. *Crop Protection*, 27, 44-70.

Stathers, T.E., Mvumi, B.M., Golob, P. (2002). Field assessment of the efficacy and persistence of diatomaceous earths in protecting stored grain on small-scale farms in Zimbabwe. Crop Protection 21, 1033-1048.

Stathers, T., Onumah, G., Lamboll, R. (2024b). Postharvest loss reduction interventions in sub-Saharan Africa: experiences and perspectives. 127pp. Natural Resources Institute (NRI), Chatham, UK.

Subedi, P.P., Bhattarai, S.P. (1995). The effects of a low cost cellar structure upon the storage of mandarin oranges in the sub-tropics. Postharvest physiology, pathology and technologies for horticultural commodities: recent advances. Proceedings of an International Symposium held at Agadir, Morocco, 16-21 January 1994, 137-151.

Sugri, I., Abubakari, M., Owusu, R. K., Bidzakin, J. K. (2021). Postharvest losses and mitigating technologies: evidence from Upper East Region of Ghana. *Sustainable Futures*, *3*, 100048.

Tadesse, E.E., Assaye, H., Delele, M.A., Fanta, S.W., Huluka, D.F., Alemayehu, M., Alemayehu, G., Adgo, E. (2022). Assessing tomato postharvest loss through the supply chain using load tracking technique in Northwest Ethiopia. *International Journal of Postharvest Technology and Innovation*, *8*(4), 360-381.

Tata-Hangy, K., Lutete, D. (1997). Observations on the effects of different methods of processing cassava chips on chips damage due to insect attacks during storage. *Tropicultura,* 15, 173-176.

Tola, Y.B., Muleta, O.D., Hofacker, W.C. (2020). Low-cost modified-atmosphere hermetic storage structures to reduce storage losses of maize (Zea mays L.) cobs and sorghum (Sorghum bicolor L.) heads. *Journal of the Science of Food and Agriculture*, 100, 1132-1141.

Tripathi, P.C., Sankar, V., Mahajan, V.M., Lawande, K.E. (2011). Response of gamma irradiation on post harvest losses in some onion varieties. *Indian Journal of Horticulture,* 68, 556-560.

Turner, P.C., Sylla, A., Gong, Y.Y., Diallo, M.S., Sutcliffe, A.E., Hall, A.J., Wild, C.P. (2005). Reduction in exposure to carcinogenic aflatoxins by postharvest intervention measures in west Africa: a community-based intervention study. *Lancet (British edition)* 365, 1950-1956.

Vandercasteelen J, Christiaensen L. (2020). Breaking down silos - on post-harvest loss interventions in Tanzania. (No. 653201). KU Leuven, Faculty of Economics and Business (FEB), LICOS-Centre for Institutions and Economic Performance. 43pp.

Venugopal, A.P., Viswanath, A., Ganapathy, S. (2017). Development of night time on-farm ventilated potato storage system in Nilgiri Hills of Southern India. *International Journal of Processing and Post Harvest Technology,* 8, 37-43.

Verma, S.C., Sharma, T.R., Verma, S.M. (1974). Effects of extended high-temperature storage on weight losses and sugar content of potato tubers. *Indian Journal of Agricultural Sciences,* 44, 702-706.

Waongo, A., Traore, F., Ba, M.N., Dabire-Binso, C., Murdock, L.L., Baributsa, D., Sanon, A. (2019). Effects of PICS bags on insect pests of sorghum during long-term storage in Burkina Faso. *Journal of Stored Products Research*, 83, 261-266.

Warade, S.D., Desale, S.B., Shinde, K.G. (1997). Effects of different storage recommendations on storability of onion bulbs. *Journal of Maharashtra Agricultural Universities*, 22, 283-285.

Wauters, P., Naziri, D., Turinawe, A., Akello, R., Parker, M. L. (2022). Economic analysis of alternative ware potato storage technologies in Uganda. *American Journal of Potato Research*, *99*(3), 217-228.

Woldemariam, H.W., Abera, B.D. (2014). Development and evaluation of low cost evaporative cooling systems to minimise postharvest losses of tomatoes (Roma vf) around Woreta, Ethiopia. *International Journal of Postharvest Technology and Innovation*, 4, 69-80.

World Bank, NRI and FAO. (2011), Missing Food: the case of postharvest grain losses in sub-Saharan Africa. The World Bank, Washington, US, Report No: 60371-AFR. 116pp. http://siteresources.worldbank.org/INTARD/Resources/MissingFoods10_web.pdf Accessed 20/11/2024

Worku, A. F., Kalsa, K. K., Abera, M., Tenagashaw, M. W., Habtu, N. G. (2022). Evaluation of various maize storage techniques on total aflatoxins prevalence and nutrient preservation. *Journal of Stored Products Research*, *95*, 101913.

Wu, F., Khlangwiset, P. (2010). Health economic impacts and cost-effectiveness of aflatoxin-reduction strategies in Africa: case studies in biocontrol and postharvest interventions. *Food Additives and Contaminants*, 27 (4), 496e509. https://doi.org/10.1080/19440040903437865.

Xu, Y., Doel, A., Watson, S., Routledge, M.N., Elliett, C.T., Moore, S.E., Gong, Y. (2017). Study of an Educational Hand Sorting Intervention for Reducing Aflatoxin B in Groundnuts in Rural Gambia. *Journal of Food Protection* 80, 44-49.

Zade, V.R., Babhulkar, V.P., Paslawar, A.N., Pardey, V.P. (2005). Extension of storage life of fungicidal waxol dip treated Nagpur mandarin under ambient conditions. *Annals of Plant Physiology* 19, 150-153.

Zagory, D. (2013). Wash water sanitation and validation. Center for Produce Safety seminar. https://fpsc-anz.com/wp-content/uploads/2013/02/devon-zagory-ppt-washwaterworkshopcps-jan-2013.pdf

Further resources which may be of interest

Hodges, R.J., Stathers, T.E. (2012). Training Manual for Improving Grain Postharvest Handling and Storage. WFP, 246pp.

Kitinoja, L., Kader, A. (2015). Small-scale postharvest handling practices: a manual for horticultural crops. https://postharvest.ucdavis.edu/publication-category/small-scale-postharvest-technology

Stathers, T., Tran, B., Chancellor, T., Matumba, L. (2016). Training manual for improving groundnut production and postharvest handling and storage. 160 + viii pp. New Rotations Farming Zambia, Lusaka, Zambia and Moyo Nuts and Seeds, Lilongwe, Malawi.

Teuth, B., Kitinoja, L., (2019). 100 under $100: Tools for Reducing Postharvest Losses. https://postharvest.org/publications-whitepapers-books-papers-etc/

WFP. (2023). Postharvest Loss Management Solutions for Fruits and Vegetables. WFP, 140pp.

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APPENDICES

Appendix 1 Summary of the PHL reduction interventions evidence-base for sub-Saharan Africa and South Asia identified in the SSR

<table>
<tr><th rowspan="2">Crop group
(focal crops)</th><th colspan="2">Technically effective interventions</th><th rowspan="2">Critical gaps in the evidence-base</th></tr>
<tr><th>Technologies/ tools/ equipment</th><th>Handling practices</th></tr>
<tr><td>**Cereals**
(maize, rice, sorghum, wheat)</td><td>*Maize storage*: in hermetic containers, or admixed with some synthetic chemical insecticides or diatomaceous earths (and combinations of these)
Wheat, rice, sorghum storage: in hermetic containers, underground pits, or admixed with some synthetic chemical insecticides, botanicals or diatomaceous earths
Wheat, rice harvesting: mechanised harvesters</td><td>Timely harvesting, protecting crop from direct ground contact while drying combined with postharvest and aflatoxin management training</td><td rowspan="5">• Interventions for loss reduction in the non-storage activity stages
• Evaluation of policy, training infrastructure, finance interventions on loss reduction
• Effect of sanitation, grain-cleaning, and timing of activities on subsequent losses
• Socio-economic, and environmental outcomes and trade-offs of uptake of different postharvest loss reduction interventions at any scale
• Factors facilitating and constraining the adoption and use of postharvest loss reduction interventions at different scales
• Stakeholder participation in the design and study of interventions to facilitate co-innovation and co-learning, and the need for more real-world scale on-farm participatory studies
• Standardised loss measurement metrics
• Consistency of intervention results confirmed through multi-season and multi-location studies</td></tr>
<tr><td>**Legumes** *(bean, cowpea, chickpea, pigeon pea, groundnut)*</td><td>Storage in hermetic containers, or admixed with synthetic chemicals, botanicals, diatomaceous earths or edible oil</td><td>Protecting crop from direct ground contact while drying; sorting to remove mouldy grains</td></tr>
<tr><td>**Root and tubers**
(cassava, potato, sweetpotato, yam)</td><td>Use of improved storage containers, ventilated storage, evaporative cool storage, cold storage, sprout suppressants and some pesticides</td><td>Piecemeal harvesting, curing, sorting to remove damaged roots or tubers, avoidance of rough handling, use of maturity indices</td></tr>
<tr><td>**Fruits**
(banana, plantain, mango, papaya, citrus)</td><td>Cold storage, evaporatively cooled storage
Harvesting poles/pickers *(mango)*
Use of improved packaging,
Waxing (alone or with fungicides or botanicals), hot-water treatments, ripening treatments, some fungicides</td><td>Use of maturity indices, gentle harvesting and handling, sorting to remove damaged fruits</td></tr>
<tr><td>**Vegetables**
(cabbage, onion, tomato, leafy vegetable)</td><td>Use of improved packaging
Cold storage, evaporative cool storage
Ventilated storage *(onions)*</td><td>Gentle handling
Curing *(onions)*</td></tr>
</table>

The interventions for which sufficient evidence existed of their efficacy in reducing PHLs are listed for each crop group. These interventions were either of the technologies/tools/equipment type or of the handling practices type, and they predominantly focused on reducing losses during crop storage. Critical gaps identified in the evidence-base for all crop groups are listed in the final column.

Appendix 2 Policy and practice investment recommendations from the SSR

- Studies should be conducted to increase the available data on PHL reduction interventions, particularly for legumes, fruits, vegetables, small grains and root and tuber crops. Notably effective PHL reduction interventions, along with critical gaps in the evidence-base, are presented in Appendix 1.
- Future studies should include the non-storage activities in the value chain and the key actors (such as farmers, traders, transporters and wholesalers), because to date the focus has been predominantly on tangible technical interventions to reduce losses during farmer-level storage.
- The limited evidence on PHL reduction interventions can be extrapolated to similar crops within each crop group, with participatory field-level studies to confirm and expand the evidence.
- The effects of training, finance, policy and infrastructure interventions on PHL reduction need to be studied to guide investments.
- More evidence is needed regarding verified socio-economic and environmental outcomes of PHL reduction interventions, because to date the focus has been on their technical efficacy and actual use will be determined by their acceptability, affordability, availability and efficacy.
- More evidence is needed on the efficacy of PHL reduction interventions, particularly when technologies are combined with interventions such as training, changes in handling practices, access to finance and policies.
- More follow-up is needed with participants of PHL reduction investments, because understanding and assessment of longer-term benefits and challenges, sustainability and cost-effectiveness of interventions is needed to guide investments.
- Future studies would benefit from collecting a wider array of data using uniform and more systematic methods to capture the quantitative, qualitative and socio-economic aspects of PHLs.
- For improved postharvest management and loss reduction, there is a need for:
    1. Greater efforts to raise the awareness of stakeholders of the ability to reduce losses and the benefits of doing so
    2. Recognition that all technologies have strengths and weaknesses and that due to the heterogeneity between households, agro-ecologies and crops, one-size-fits-all solutions are unlikely to be successful
    3. Technical solutions to be simultaneously promoted alongside good postharvest training and management to build understanding of why losses are occurring, how the technologies can best be used and the local costs and expected benefits of interventions
    4. More study of how national policies, financial access and infrastructure investments affect PHL reduction
    5. Implementation of policies that support quality-sensitive markets to provide incentives for PHL reduction
    6. Multi-stakeholder postharvest platforms or institutions to promote co-learning and co-innovation, support access to information, and support multi-location and multi-season studies with active participation of stakeholders along the commodity value chains
- Targeting of the aforementioned recommendations may be needed depending on limitations of financial resources and information, and whether the main objective for reducing PHLs is improved food security and nutrition or lower environmental impacts.