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# Unpacking Postharvest Losses in Sub-Saharan Africa: A Meta-Analysis

HIPPOLYTE AFFOGNON[a], CHRISTOPHER MUTUNGI[a,b], PASCAL SANGINGA[c] and CHRISTIAN BORGEMEISTER[a,d,*]

[a] *International Centre of Insect Physiology and Ecology (icipe), Nairobi, Kenya*
[b] *Egerton University, Kenya*
[c] *International Development Research Centre, Nairobi, Kenya*
[d] *University of Bonn, Germany*

**Summary.** — Reducing postharvest losses (PHL) is a key pathway to food and nutrition security in sub-Saharan Africa. However, knowledge of PHL magnitudes is limited. A meta-analysis has been conducted to expose nature and magnitude of PHL, and the kinds of interventions that have been attempted to mitigate the losses. Findings reveal inadequacies of loss assessment methodologies that result in inaccurate PHL estimates. Moreover, losses are often economic rather than physical product losses. Overall, technologies for loss mitigation fail to address dynamics of supply chains. Consequently, rigorous PHL assessment using systematic methodologies, as well as holistic approaches for losses mitigation are in need.

*Key words* — postharvest, losses, innovations, value chains, sub-Saharan Africa

## 1. INTRODUCTION

A main challenge for agricultural research, development, and policy is how to feed over 9.1 billion people with safe food by the year 2050 (Parfitt, Barthel, & Macnaughton, 2010). While considerable attention is directed toward increasing food production by 50–70% to meet this target, one important and complementary factor that is often forgotten is reducing food loss and food waste (Hodges, Buzby, & Bennett, 2011). It is suggested that about one third of the food produced globally is lost or wasted (FAO–World Bank, 2010; Prusky, 2011), representing a loss of 1.3 billion tons of food per year in a world where over 870 million people go hungry (Gustavsson, Cederberg, Sonesson, van Otterdijk, & Meybeck, 2011). A recent report by the World Bank (World Bank, 2011) revealed that, each year, significant volumes of food are lost after harvest in sub-Saharan Africa (SSA), the value of which is estimated at USD 4 billion for grains alone. The report demonstrates that this magnitude of food loss exceeds the value of total food aid received in SSA over the last decade, and further equates to the annual value of cereal imports to SSA. In addition, such losses are estimated to be equivalent to the annual caloric requirement of 48 million people. Based on these reasons, experts now agree that investing in postharvest losses (PHLs) reduction is a quick impact intervention for enhancing food security (GIZ, 2013a). The FAO and World Bank, approximated that up to 47% of USD 940 billion needed to eradicate hunger in SSA by 2050 will be required in the postharvest sector (FAO–World Bank, 2010). Reducing food losses therefore offers an important pathway of availing food, alleviating poverty, and improving nutrition. Moreover, reducing PHL has positive impacts on the environment and climate as it enhances farm-level productivity and reduces the utilization of production resources or expansion into fragile ecosystems to produce food that will be lost and not consumed (GIZ, 2013b, Hodges *et al.*, 2011).

Interest in PHL dates back from the first World Food Conference of 1974, that resolved to bring about a 50% reduction by 1985 (Parfitt *et al.*, 2010). Consequently, the FAO established the *Special Action Programme for the Prevention of Food Losses* in 1977. The initial focus targeted reducing losses of grain, but by the early 1980s, the scope was broadened to additionally cover roots and tubers, and fresh fruits and vegetables (FAO, 1989). There is, however, no account of progress toward the 1985 PHL reduction target. Moreover, despite this action plan and other subsequent initiatives, PHLs still remain a persistent problem in SSA and present an enormous threat to food security. With the surge in food prices that began in 2006 and peaked in mid-2008, and resumed with its rising trend in 2011, a renewed attention to address food security has emerged. As a result, many global food security initiatives and organizations such as the Comprehensive Framework for Action of the United Nations High-Level Task Force for Food Security and Nutrition, the World Bank's Global Agriculture and Food Security Program, the Reformed Committee on World Food Security, and the United States Department of Agriculture, have positioned themselves to tackle PHLs. In SSA, PHL reduction is also prioritized in the Africa Union's Comprehensive African Agricultural Development Program (CAADP) as well as in agricultural and food security strategic plans of national governments. Ever since the first World Food Conference of 1974, various approaches and technologies have been applied and promoted to counter PHLs. Despite the endeavors success stories are not many (World Bank, 2011), implying that

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approaches for tackling PHLs have not yielded compelling impacts in SSA.

A major obstacle in the efforts to achieve PHL mitigation is the lack of clear knowledge of the real magnitudes of losses, which makes it impossible to measure progress against any loss reduction targets. Uncertain estimates of PHL, coupled with imprecise understanding of the points in value chains where the losses occur as well as the socio-economic factors for the losses could end in policy errors and sub-optimal choices of mitigation approaches. In the literature, estimates of PHL magnitudes vary widely. Figures between 10–40%, and as high as 50–70% are regularly quoted (FAO–World Bank, 2010; Kader, 2005; Lundqvist, de Fraiture, & Molden, 2008; Parfitt *et al.*, 2010; Prusky, 2011), often from untraceable sources. Furthermore, many estimates link to datasets collected 30 years ago, and are fragmentary and unconsolidated. Whereas the FAO–World Bank "Missing Food" report (World Bank, 2011) made a significant contribution in demonstrating current knowledge on the nature, magnitude, and economic value of PHL for stored grains in SSA, a lot more information is still lacking especially concerning commodities other than cereal grains that are equally important for nutrition and food security. Moreover, the report and several other studies (FAO–World Bank, 2010; Gustavsson *et al.*, 2011; Parfitt *et al.*, 2010; Prusky, 2011) also point out that major data gaps do exist on the quantification of PHL in SSA. They concluded with a pressing need for more quantitative evidence of the actual level and nature of PHL across different commodities.

This study provides a critical and comprehensive review and state-of-the-art synthesis of evidence on the nature, magnitude, costs, and value of current PHLs of various groups of commodities along the value chain in sub-Saharan Africa. It is based on a comparative analysis across commodity (cereals, pulses, fruits, roots and tubers, vegetables, animal products, and oil crops), value chains and different contexts in six African countries (Benin, Ghana, Kenya, Malawi, Mozambique, and Tanzania). The study uses a robust and rigorous meta-analysis method of consolidating available evidence form many studies conducted in the past. It identifies gaps in PHL assessment and mitigation, and their implications for future PHL research in SSA. The study provides some insights for the design and implementation of a portfolio of applied, action research interventions to reduce food losses in sub-Saharan Africa.

## 2. METHODOLOGY

### (a) *Conceptual framework*

Postharvest losses are a measurable reduction in foodstuffs, which may affect quantity or quality (Grolleaud, 2002). For many households, such losses threaten food, nutrition, and income security (World Bank, 2011). They also contribute to high food prices by removing part of the food from the supply chain. Quality losses lead to inferior nutritional value, food-borne health hazards, and economic losses when the produce misses market opportunity or loses attributes that make it appealing to consumers (Hodges *et al.*, 2011; Kader, 2005).

A multidisciplinary and multi-institutional team of African and international postharvest experts convened in a workshop in Nairobi during the month of April 2012, to develop and validate a conceptual framework that considers the whole postharvest system (Figure 1). The term "system" denotes logically interconnected functions within the post-production chain. In considering the system as a whole, losses can occur: (i) at harvest; (ii) during preliminary processing; (iii) at handling; (iv) during transportation and distribution; (v) at storage due to pests, spillage, spoilage, and contaminations; (vi) during processing due to inefficient technologies; and finally (vii) during commercialization. The framework thus associates PHL to activities and practices from farm-to-fork, and recognizes quantity and quality losses. The losses attract innovations whose overall usefulness in preventing or reducing them is governed by the type, of innovations, their technical efficacy, cost-effectiveness, adoption, and impacts. If users do not acknowledge the innovations as being helpful within the contexts of their social, cultural, and economic settings, the innovations become abandoned, and loss mitigation is not achieved. Within this framework, we located relevant literature based on standard guidelines for systematic reviews (Carr *et al.*, 2011; Higgins & Green 2006; Masset, Haddad, Cornelius, & Isaza-Castro, 2011) as means of identifying, evaluating, and interpreting all available studies relevant to PHLs assessment and mitigation as presented in Figure 1. A protocol for the meta-analysis was developed and validated by the team of experts (Affognon & Mutungi, 2012).

### (b) *Selection of countries and commodities*

In order to ensure a representative inclusion of available data in the meta-analysis, six countries in SSA were selected based on geographical locations: Ghana and Benin in western, Kenya and Tanzania in eastern, and Malawi and Mozambique in southern Africa. The selection of the specific countries was based on existing networks of postharvest experts and evidence of considerable postharvest works conducted in these countries. Seven commodity categories, i.e. cereals, pulses, fruits, roots and tubers, vegetables, animal products, and oil crops were targeted. Within the different categories, specific commodities were selected based on their importance to household food and income contribution in the individual countries as provided by the group of postharvest experts during the inception workshop at the beginning of this study. For each country, the commodities are presented in Table 1.

### (c) *Literature search strategy*

A broad-based multi-disciplinary literature search strategy was adopted. The rationale was to build a comprehensive database of studies in line with the conceptual framework (Figure 1) while ensuring a broad coverage of available data from the wide pool of PH research in SSA. In this approach, we searched systematically for documents that reported PHL assessments and/or interventions, looking for published as well as gray literature in electronic and non-electronic databases of organizations dealing with food security related themes. The key databases that were searched included EconLit, ELDIS, PubMed, IBSS, Scopus, Science Direct, CAB Direct, AGRICOLA, JSTOR, Harvest Plus, AGRIS, and IDEAS. Additional documents were located by contacting universities, national research institutions, government departments, non-governmental organizations, and technical agencies including the FAO, The World Bank, International Food Policy Research Institute (IFPRI), Department For International Development (DFID), International Fund for Agriculture Development (IFAD), AGRA, International Centre of Cooperation in Agronomic Research for Development (CIRAD) and German Agency for International Cooperation (GIZ). Other documents were located by tracking citations, following reference lists of key articles, and performing

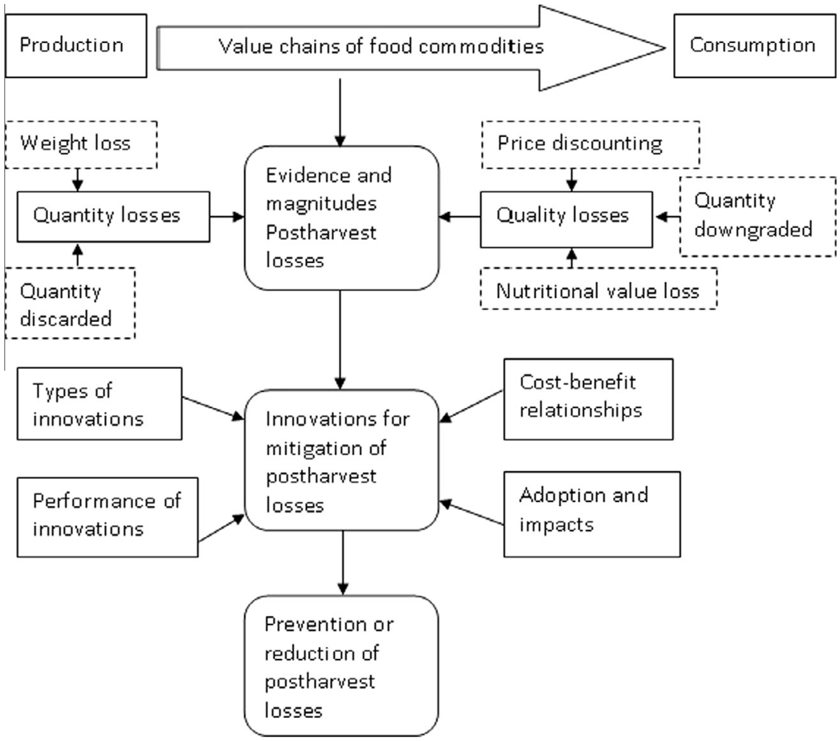

Figure 1. *Conceptual framework: how PHL accrue and the dynamics of mitigation (Source: Authors).*

Table 1. *Commodities selected for review in the various countries*

| Commodity category | Specific commodities by country | | | | | |
|---|---|---|---|---|---|---|
| | Benin | Ghana | Kenya | Malawi | Mozambique | Tanzania |
| Cereals | Maize, rice | Maize, rice | Maize, rice | Maize, rice | Maize, sorghum | Maize, sorghum |
| Pulses | Cowpeas | Cowpeas | Common beans | Common beans | Common beans, cowpeas | Common beans |
| Fruits | Mango, oranges | Mango, oranges | Mango, banana | Mango, banana | Mango, banana | Mango, oranges |
| Vegetables | Tomato, leafy vegetables | Tomato, okra | Tomato, cabbage | Tomato, cabbage | Tomato, cabbage | Tomato, cabbage |
| Roots & tubers | Cassava, yam | Cassava, yam | Cassava, Irish potato | Cassava, sweet potato | Cassava, sweet potato | Cassava, sweet potato |
| Oil crops | Groundnuts | Groundnuts | Groundnuts | Groundnuts | Groundnuts | Sunflower |
| Animal products | Fish | Fish | Milk, meat | Fish | Fish | Fish |

unsystematic online exploration using Google search engine. Diverse thematic areas, among them agricultural economics, food policy, marketing, agro-processing, crop protection, crop storage, and nutrition were included in the search.

### (d) *Screening of relevant documents*

A two-tier screening approach was used to assess the appropriateness of the studies retrieved by our search strategy so as to select those studies that were not only relevant but also whose methodologies for data generation were suitable. First, restricting the search to the six countries and the various commodities, we reviewed titles, abstracts, and keywords of publications and documents available in English, French, or Portuguese in the last three decades (1980–2012). The time frame of the review (30 years) was based on the history of postharvest research in SSA. We identified documents that described PHL assessment, magnitude of losses, or innovations within any of the value chain levels described under the conceptual framework. Secondly, the identified articles were evaluated for methodological appropriateness. This step screened out articles that contained serious methodological weaknesses. When appraising methodological quality of studies, we established whether the study involved actual data, and whether a credible methodology for data collection and analysis was used. Specifically we assessed whether the methodology was well anchored in the literature, an appropriate sampling technique was applied, data were analyzed using suitable statistical techniques and results were accurately interpreted. Where no actual data was collected, we established whether the sources of secondary data were accurately disclosed. Guided by these methodological needs, an overall rating of suitability of articles was assigned on a scale of 1–5, where: 1 = poor; 2 = fair; 3 = satisfactory; 4 = good; and 5 = excellent. Only articles with ratings of 3 (satisfactory) or higher were selected for the full text review.

### (e) *Statistical analysis*

Magnitudes of PHL reported in the various studies were combined using statistical meta-analysis. We assumed that PHL magnitudes provided in the various documents are heterogeneous and representative of a wider distribution of loss magnitudes. When data are collected from studies performed by different researchers for different programs and different populations, a random effects model is more appropriate (Borenstein, Hedges, Higgins, & Rothstein, 2009). Therefore, using the random effects model, the mean value of PHL, the standard deviation (SD), and the 95% confidence interval (CI) were estimated. Within the model, two sources of variability arise: sampling error and heterogeneity of the different studies providing loss magnitudes (Hedges & Vevea, 1998; Hunter & Schmidt, 2000). We assumed that sampling error was minimized by the systematic screening of articles, whereas heterogeneity was reflected in the random effects variance component ($\tau^2$). Upon estimation, $\tau^2$ was added to each individual variance ($v_i$) associated with each individual PHL estimate ($T_i$) in order to compute the SD and the 95% CI of the pooled PHL mean (Cohn & Becker, 2003). Theoretically $\tau^2$ should be non-negative as it represents the variance of a random variable, but may be negative if large data variability exists. Where this was the case, the negative estimates were constrained to zero (Gao, Li, & Li, 2008). In the random effects model, each $T_i$ is weighted using a variable $w_i$ which is the inverse of the corresponding $v_i$ to provide the best estimate of the pooled mean ($\overline{T}$). Thus $\overline{T}$ was calculated using the expression: $\equiv \sum w_i T_i / \sum w_i$ (Hedges & Olkin, 1985). Further, $\tau^2$ was calculated using the expression: $\tau^2 = [Q - (K - 1)]/c_i$ where $K$ is the number of individual PHL magnitudes. The component $c$ was derived as follows: $c = \sum w_i - [\sum (w_i)^2 / \sum w_i]$, whereas the parameter $Q$ was computed using the formula: $Q = \sum w_i (T_i - \overline{T}.)^2$.

## 3. RESULTS

### (a) *Profile of PHL studies*

A large pool of published and unpublished literature was found. The search resulted in a considerable number of hits, in the tens of thousands, which were screened for relevance according to the pre-set criteria, giving a total of 838 documents for the six countries, over the 32-year period (1980–2012). Screening through the methodologies of these records yielded 213 documents (25.4%) that were considered to be of satisfactory, good, or excellent methodological quality. Figure 2 shows the profile of the 213 documents, and reveals a number of observations:

- A large amount of PHL research is unpublished. More than half of the documents (57.3%) comprised gray literature (Figure 2a) held in universities, national research institutions, and non-governmental organizations in the form of student theses, conference proceedings, working papers, or project reports. The search found only 91 articles published in peer review journals, representing 42.7% of documents available for review.
- The quality of most PHL research is poor. The majority of the studies (67.4%) were rated satisfactory, with the remaining 32.7% being rated good and excellent (Figure 2b).
- A considerable number of the studies (70%) were completed in the period during 2000–12, compared to 21.6% and 8.4% dated 1990–99 and 1980–89, respectively, which indicates a growing interest in PHL research and development or simply an improvement of the communication of PHL research results in the last decade (Figure 2c).
- Most studies were based on household surveys (37.9%), field trials (28.9%), and laboratory experiments (16.1%) (Figure 2d).
- Most work targeted storage (45.6%), followed by marketing (12.9%) and harvesting (11.0%), whereas the attention to other levels of value chains has been minimal (Figure 2e).
- About half of the studies (53.1%) reported PHL and the methodologies used to assess the losses. The different methodologies for losses assessment and the relative frequencies in the various works are summarized in Figure 2f. Count and weigh method, which is common for evaluating storage losses due to insect feeding in cereals and pulses, was the most dominant (35.4%). Bulk density, and sorting and weighing methods were each used in 17.7% of the studies.

Table 2 presents the number of documents reviewed, by country and commodity. More work was conducted in western Africa (57.6%), than in eastern (34.7%) and southern Africa (8%) combined. Moreover, out of the 18 commodities, maize alone was represented in over 43% of the documents (23.9% western Africa; 13.6% eastern Africa; 5.6% southern Africa). Substantial information was also found on cowpea in western Africa (8% of the literature reviewed: Benin 3.3%, and Ghana 4.7%) and on beans in eastern and southern Africa (5.6% of the literature reviewed: Kenya 2.3%, Tanzania 2.3%, Malawi 1%). Cassava and yam, the third group of commodities on which considerable information was found represent 6.1% each of the literature reviewed. The articles reviewed on fruit and vegetable represented by mango and tomato were mainly found in western Africa (7.5%) though considerable information was also found in eastern and southern Africa regions (2%). Other commodities including banana, Irish potato, groundnuts, leafy vegetables, oranges, okra, meat, and milk are poorly investigated. Generally, these results show that information on PHL research is spotty and scanty, and the dearth is more severe in southern and eastern Africa, where past research concentrated mainly on maize.

### (b) *Evidence and magnitudes of PHL*

#### (i) *Quantity losses*

Out of the 213 documents, 139 estimated quantity losses, either as weight of edible mass lost or the volume of food that became discarded due to apparent damage or spoilage. As described in the conceptual framework (Figure 1), these aspects constitute the main components of quantity losses whose intensities need to be determined in order to demonstrate evidence and magnitude of PHLs. Table 3 provides a simplified aggregation of the losses. These have been derived by computing the means and SD of estimates provided in the various documents. The majority of the loss estimates (80.4%) were related to storage. The large SDs reflect the big variations in estimates and could be explained by the loss agents involved, the method used to assess the loss, the differences in production and post-production circumstances, including agro-ecological conditions, food situations, environmental conditions, socio-cultural factors, technology exposure, and food consumption patterns, among others. Results show that cereals (maize, rice) suffer losses amounting to 25.6 ± 27.4% without any intervention. However, these could be decreased to about 5.6 ± 5.4%. The losses in pulses (cowpea, beans) could reach 23.5 ± 22.0 without any intervention and be lowered to 2.1 ± 3.0 when various types of losses

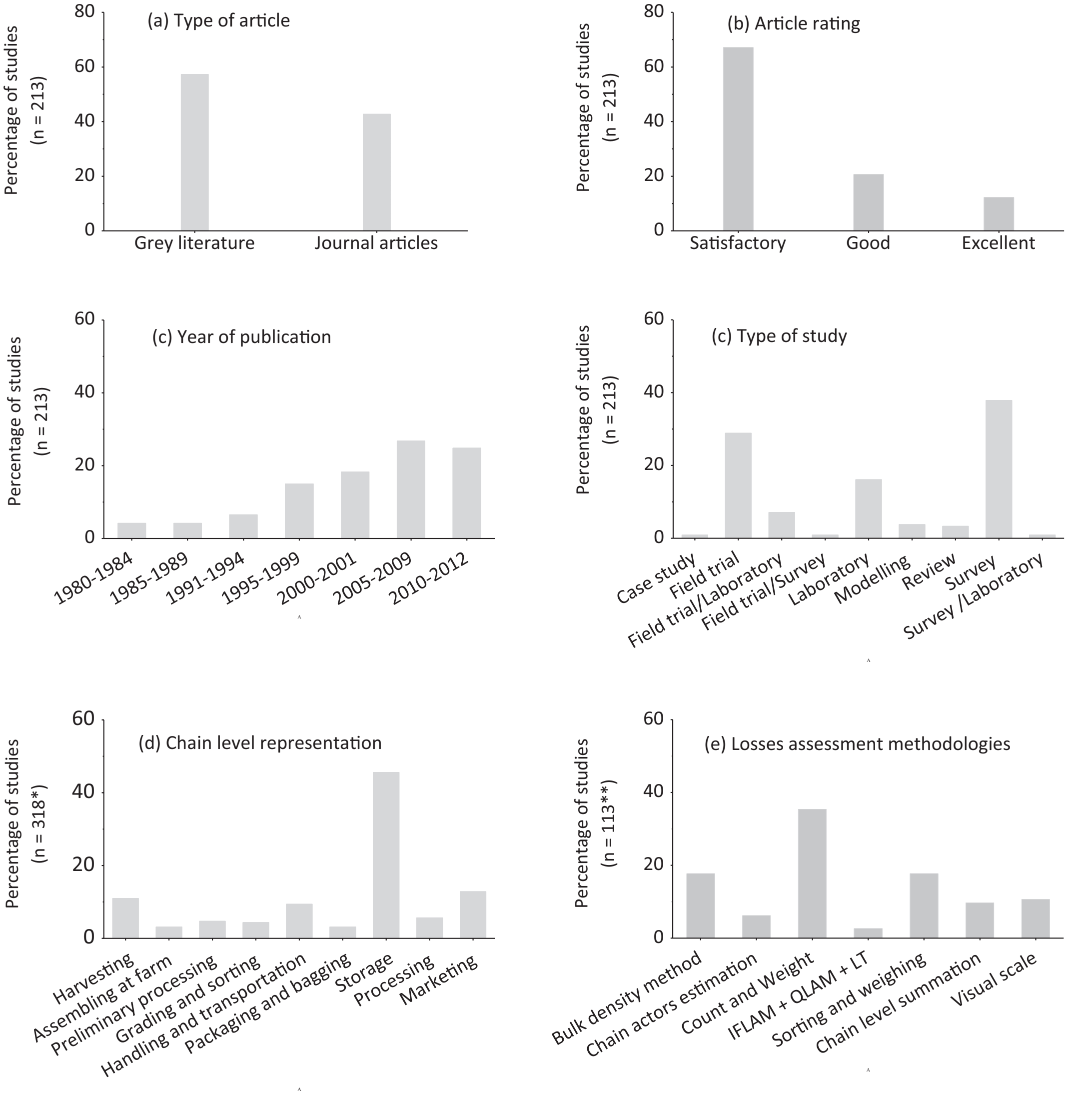

Figure 2. *Profile of PHL studies included in the analysis.* **Some articles reported losses and interventions at more than one level of value chain.* ***Some articles did not assess losses.*

mitigation strategies are applied. Similarly, highest losses for roots and tubers, fruits, vegetables, and fish without interventions could amount to 43.7 ± 27.4%, 55.9 ± 25.4%, 43.5 ± 16.6%, and 27.3 ± 14.3%, respectively. These losses can be reduced to 7.0 ± 2.8%, 24.8 ± 15.6%, 10.7 ± 13.8%, and 14.7 ± 11.9%, respectively with various types of interventions. The largest magnitudes of losses occur in fruits, vegetables, root crops, and tuber crops, which is expected especially because of the perishable nature of these commodities, and the poor post-production infrastructure for handling perishable produce across SSA.

More accurate PHL estimates can be obtained when a statistical method is employed to combine the findings of the different studies. We therefore performed a statistical meta-analysis using the random effects model to address variability in PHL magnitudes reported. For the model, PHL estimates from each study together with the respective SD were required. Thus, from the 139 documents that reported PHL magnitudes, a further screening was conducted to identify those studies that reported PHL estimate with SD. Also, studies that provided multiple datasets from which a SD could be computed were considered (Furukawa, Barbui, Cipriani, Brambilla, & Watanabe, 2006). From this screening, only 21 studies (14 on maize, two on mango, three on dried cassava chips, and two on sweet potato) were found meaning that 85% of loss estimates generated using appropriate methodologies did not qualify for statistical meta-analysis because a SD was not assigned to them or could not be computed. The 21 studies are presented in Table 4, together with the loss magnitude reported by each individual study ($T_i$) when various interventions are applied (minimum loss), and when no interventions are applied (maximum loss). The respective SD of each of the loss magnitudes is also presented, from which a weighting factor ($w_i$) has been computed. As expected, the weighting factor varied widely across studies and for the various commodities; it ranged from 0.00–2.78 for maize, 0.00–0.25 for mango, 0.00–0.19 for dried cassava chips, and 0.00–0.01 for fresh sweet potatoes. A low weighting factor is an indicator of large variance associated with the dataset related to the individual study and vice versa. Thus applying the weighting factor in the random effects model introduces a benefit of ensuring that $T_i$ values associated with small variances contribute more to

Table 2. *Number of articles that were reviewed by commodity and country; a dash (–) means the particular commodity was not considered in the particular country*

| Commodities | Country | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | Benin | Ghana | Kenya | Malawi | Mozambique | Tanzania | |
| Maize | 40 | 11 | 14 | 7 | 5 | 15 | 92 |
| Cowpea | 7 | 10 | – | – | 0 | – | 17 |
| Cassava | 3 | 5 | 1 | 0 | 0 | 4 | 13 |
| Yam | 4 | 9 | – | – | – | – | 13 |
| Beans | – | – | 5 | 2 | – | 5 | 12 |
| Mango | 6 | 3 | 2 | 0 | 0 | 1 | 12 |
| Sweet potato | – | – | – | 0 | 1 | 11 | 12 |
| Tomato | 2 | 5 | 1 | 0 | 0 | 1 | 9 |
| Fish | 0 | 3 | – | 1 | 1 | 3 | 8 |
| Rice | 2 | 4 | 0 | 0 | 0 | – | 6 |
| Banana | – | – | 3 | 0 | 0 | – | 3 |
| Irish potato | – | – | 3 | – | – | – | 3 |
| Groundnuts | 0 | 2 | 0 | 0 | 0 | – | 2 |
| Leafy vegetables | 2 | – | – | – | – | – | 2 |
| Orange | 1 | 1 | – | – | 0 | 0 | 2 |
| Okra | – | 2 | – | – | – | – | 3 |
| Meat | – | – | 2 | – | – | – | 2 |
| Milk | – | – | 2 | – | – | – | 2 |
| Total | 67 | 55 | 33 | 10 | 7 | 41 | 213 |

Table 3. *Magnitudes of quantity PHL presented in the various documents that were reviewed*

| Commodities | PHL magnitudes (%)[a] | | | |
|---|---|---|---|---|
| | Minimum[b] | | Maximum[c] | |
| | Number of documents | Mean (SD) | Number of documents | Mean (SD) |
| Maize[d] | 63 | 5.6 (5.4) | 66 | 25.5 (15.3) |
| Cowpea[d] | 8 | 4.3 (6.9) | 9 | 23.5 (220) |
| Cassava[d] | 7 | 28.0 (24.3) | 9 | 42.3 (27.6) |
| Yam[e] | 8 | 18.8 (11.4) | 7 | 41.6 (10.3) |
| Beans[d] | 2 | 2.1 (3.0) | 2 | 14.0 (1.0) |
| Mango[e] | 7 | 24.8 (15.6) | 9 | 55.9 (25.4) |
| Sweet potato[e] | 12 | 7.4 (3.5) | 6 | 43.6 (27.4) |
| Tomato[e] | 2 | 10.7 (13.8) | 8 | 33.7 (19.3) |
| Fish[e] | 7 | 14.7 (11.9) | 7 | 27.3 (14.3) |
| Rice[d] | 3 | 5.4 (5.3) | 4 | 25.6 (27.4) |
| Banana[e] | 1 | – | 1 | 35.7 (–) |
| Ground nuts[e] | 1 | 3.1 (-) | 1 | 10.1 (–) |
| Irish potato [e] | 3 | 7.0 (2.8) | 3 | 21.6 (7.5) |
| Leafy vegetables[e] | – | – | 1 | 43.5 (16.6) |
| Okra[e] | – | – | 3 | 23.4 (4.5) |
| Orange[e] | 1 | 3.0 (–) | 2 | 18.8 (15.6) |
| Meat | – | – | 1 | 3.0 (–) |
| Milk | – | – | 1 | 12.7 (–) |

[a] Represents the means of PHL magnitudes provided in the various studies regardless of value chain level involved (80.4% of all losses estimates available were related to storage).
[b] Losses incurred when various type of innovations are applied.
[c] Losses incurred when no innovations are applied.
[d] Weight loss.
[e] Quantities sorted and discarded because of deterioration.

the pooled mean ($\overline{T}.$) than those with large variances (Cohn & Becker, 2003).

Results of the random effects model analysis are shown in Table 5. Since a meta-analysis can be carried out when data from a minimum of two studies exist (Valentine, Pigott, & Rothstein, 2010), we carried out analysis for the four commodities (maize, mango, dried cassava chips, and sweet potatoes) for which weighting factors ($w_i$) were calculated. For each commodity the random effects variance component ($\tau^2$) is given. This variance component becomes incorporated as additional source of variability when the SD of $\overline{T}.$ is calculated, thereby providing a wider confidence interval (CI) around the average loss magnitude (Cohn & Becker, 2003). Results of this analysis offer more accurate approximation of losses because they combine estimates drawn from different studies. However, the figures are to be taken with caution

Table 4. *Elements ($T_I$ and $w_i$) of Random effects analysis for consolidation of PHL estimates*

| Commodity and source of PHL estimate | Maximum losses[a] | | | Minimum losses[b] | | |
|---|---|---|---|---|---|---|
| | Percent PHL ($T_I$) | Standard deviation | Weighting factor ($w_i$) | Percent PHL ($T_I$) | Standard deviation | Weighting factor ($w_i$) |
| *Maize*[c] | | | | | | |
| Borgemeister *et al.* (1998); Benin | 16.4 | 3.4 | 0.09 | 5.5 | 1.6 | 0.37 |
| Meikle *et al.* (1998); Benin | 41.3 | 3.2 | 0.10 | 15.8 | 6.9 | 0.02 |
| Schneider *et al.* (2004); Benin | 18.7 | 2.3 | 0.18 | 3.0 | 1.0 | 1.06 |
| Meikle *et al.* (2002); Benin | 23 | 3.5 | 0.08 | 7.0 | 4.5 | 0.05 |
| Affognon *et al.* (2000); Benin | 33.5 | 4.9 | 0.04 | 2.1 | 0.6 | 2.78 |
| Adda, Borgemeister, Biliwa, and Aboe (1997); Benin | 12.0 | 1.5 | 0.44 | 7.0 | 1.2 | 0.69 |
| Compton & Sherrington (1999); Ghana | 21.5 | 4.5 | 0.05 | 4.8 | 1.8 | 0.31 |
| Ofosu (1987); Ghana | 35.9 | 4.2 | 0.06 | 11.7 | 2.1 | 0.24 |
| Mutambuki and Ngatia (2012); Kenya | 20.6 | 7.9 | 0.02 | 9.7 | 2.4 | 0.17 |
| Komen, Mutoko, Wanyama, Rono, and Mose (2006); Kenya | 7.6 | 12.4 | 0.01 | 3.9 | 5.2 | 0.04 |
| Mutambuki and Ngatia (2006); Kenya | 29.1 | 1.6 | 0.41 | 19.3 | 2.8 | 0.13 |
| Makundi *et al.* (2010); Tanzania | 16 | 1.5 | 0.44 | 1.0 | 1.5 | 0.44 |
| Golob and Hodges (1982); Tanzania | 11.1 | 12.9 | 0.01 | 5.2 | 6.7 | 0.02 |
| Golob and Boag (1985); Tanzania | 26.4 | 17.0 | 0.00 | 2.5 | 1.6 | 0.39 |
| *Mango*[d] | | | | | | |
| Vayssières, Korie, and Ayegnon (2009); Benin | 75.4 | 8.5 | 0.01 | 17.6 | 5.3 | 0.04 |
| Vayssières, Korie, Coulibaly, Temple, and Boueyi (2008); Benin | 70.0 | 23.0 | 0.00 | 17.0 | 2.0 | 0.25 |
| *Dried cassava chips*[c] | | | | | | |
| Chijindu, Boateng, Ayertey, Cudjoe, and Okonkwo (2008); Ghana | 75.5 | 2.3 | 0.19 | 20.9 | 5.0 | 0.04 |
| Isah, Ayertey, Ukeh, and Umoetok (2012); Ghana | 75.5 | 5.6 | 0.03 | 68.5 | 5.7 | 0.03 |
| Hodges, Meik, & Denton 1985; Tanzania | 73.6 | 25.9 | 0.00 | 52.3 | 12.0 | 0.01 |
| *Sweet potato*[e] | | | | | | |
| Rees *et al.* (2003); Tanzania | 35.8 | 10.8 | 0.01 | 32.5 | 21.7 | 0.00 |
| Tomlins *et al.* (2007); Tanzania | 66.9 | 22.8 | 0.00 | 23.7 | 11.3 | 0.01 |

[a] Losses incurred with no any interventions in place.
[b] Losses incurred with interventions in place.
[c] weight losses due to insect feeding at storage level alone without adjustment for store emptying.
[d] Losses due to insect damage.
[e] quantities discarded due to deterioration.

Table 5. *Consolidated PHL magnitudes using random effects analysis*

| Commodity | Random effect variance component ($\tau^2$) | Weighted average loss ($\overline{T}.$) | SD | 95% CI | |
|---|---|---|---|---|---|
| | | | | Lower limit | Upper limit |
| *Maize*[a] | | | | | |
| Maximum[b] | 78.05 | 20.83 | 2.76 | 15.42 | 26.23 |
| Minimum[c] | 12.23 | 3.98 | 1.15 | 1.72 | 6.24 |
| *Mango*[d] | | | | | |
| Maximum | 74.77 | 74.77 | 7.97 | 59.16 | 90.38 |
| Minimum | 0.00 | 17.07 | 1.87 | 13.41 | 20.73 |
| *Dried cassava chips*[a] | | | | | |
| Maximum | 0.00 | 75.49 | 2.12 | 71.34 | 79.64 |
| Minimum | 859.99 | 42.52 | 17.55 | 8.12 | 76.92 |
| *Sweet potato*[e] | | | | | |
| Maximum | 167.34 | 41.53 | 14.16 | 13.77 | 69.29 |
| Minimum | 0.00 | 25.52 | 10.00 | 5.91 | 45.13 |

[a] PHL reflected are weight losses to insect feeding during storage without adjustment for store emptying.
[b] PHL without interventions in place.
[c] PHL with interventions in place.
[d] PHL reflected are losses due to insect damage at harvesting.
[e] PHL reflected are quantities discarded due to deterioration; SD is the consolidated standard deviation.

when viewed from the point of value chain dynamics of the four commodities. The loss magnitudes for maize (4.0 ± 1.2% with intervention; 20.8 ± 2.8% without intervention) represent storage losses at farm level due to insect feeding alone, over an average storage period of 6.9 ± 1.3 months. Similarly, the losses on dried cassava chips which amount to 42.5 ± 17.5% with intervention and 75.5 ± 2.1% without intervention, are due to insect infestations at farm-level over a storage period of 3.0 ± 1.0 months. A limitation of these figures is that they are not corrected for storage withdrawal as majority of the data used in the meta-analysis did not account for store emptying in the derivation of loss magnitudes. During farm-level storage, households progressively remove part of the produce for consumption, sale, or other uses. This widespread practice throughout the storage period leads to the actual losses being overestimated if not taken into account. In Kenya for instance, Mutambuki and Ngatia (2006), found an average monthly removal rate of 15.4 kg and 225 kg for household consumption and other uses, respectively, among farmers who stored about 1860 kg of maize in a typical harvest season, translating to an average monthly removal rate of 12.8% over 7–8 months of storage. This consideration is important because some amounts of the produce that is initially stored are used up before deterioration reaches significant levels, and only a small proportion will remain in store until the end of the storage period when insect attack increases considerably in poorly managed stores (Bell, Mück, Mutlu, & Schneider, 1999; Bengtsson, 1991; Hodges, Bernard, Knipschild, & Rembold, 2010). Where no interventions are used, such severe losses begin in the third or fourth storage month, when practically half of the initial quantity consigned to storage has been emptied (Henckes, 1994; Mutambuki & Ngatia, 2006). The loss figures for mango (20.7% with intervention; 90.3% without intervention), on the other hand, comprise losses incurred at harvesting when farmers have to discard fruits that are visibly damaged by insects. The losses on sweet potato that range from 45.1% with intervention to 69.3% without intervention, cover the proportion of fresh roots that undergo deterioration (rotting, sprouting and shriveling) during on-farm storage or marketing, thus becoming unsuitable for human consumption.

#### (ii) *Quality losses*

Out of 213 documents that were reviewed, 28 documents (13.1%) reported quality losses, in terms of price discounting, nutritional value loss, or volume of downgraded produce as envisaged in the conceptual framework (Figure 1). Table 6 summarizes key information gathered from the studies. First, consumers endorse critical tolerance limits for low-quality produce, beyond which they pay discounted prices leading to significant revenue losses for producers and traders. Roots and tubers suffer monetary value loss of 11–63% due to physical damage at harvesting, handling, transportation, and biodeterioration during storage and marketing (Bancroft, Crentsil, Gray, Gallat, & Gogoe, 1998; Mtunda *et al.*, 2001; Ndunguru, Thomson, Waida, Rwiza, & Westby, 1998; Tomlins, Ndunguru, Rwiza, & Westby, 2000). More specifically, the quality loss agents include weevil infestation, cuts inflicted by poor harvesting methods, breakage, and surface scuffing caused by poor handling during transportation, and insect infestation and mold infection of dried products during storage. Mold infection of dried cassava and sweet potato chips attracts a price discount of 15–45% (Thomson, Ndunguru, Waida, Rwiza, & Jeremiah, 1997; Wright, Jeremiah, Wareing, Rwiza, & Msabaha, 1996), whereas sweet potato roots that reach the market with breakages, cuts, surface weevil, and internal weevil damage could attract price discounts of 20–25%, 25–30%, 30–40%, and 45–55%, respectively (Thomson *et al.*, 1997).

The proportions of the roots delivered to the market with these damages could range from 4–45% for shriveled, 25–65% for broken, 6–36% for cuts; 14–35% for surface weevil, and 3–24% for internal weevil damage resulting in averaged value loss of 12–34%. For yam, up to 60% of produce reaching the market was sold at 33% discounted price due to quality deterioration culminating in about 20% income loss (Bancroft *et al.*, 1998) Likewise, insect damage to cereals and pulses during storage attracts a wide range of price discounting in various markets estimated at 0.2–2.3% for every 1% increase in insect damage (Compton *et al.*, 1998; Langyintuo, Ntoukam, Murdock, Lowenberg-DeBoer, & Miller, 2004; Langyintuo *et al.*, 2003; Mishili, Temu, Fulton, & Lowenberg-DeBoer, 2011; Mishili *et al.*, 2007). As a consequence, overall economic losses could reach 12–30% (Compton *et al.*, 1998; Golob *et al.*, 1999).

Fruits and vegetables also incur substantial monetary value losses due to quality deterioration. For different kinds of fruits and vegetables (tomato, amaranth, okra, oranges, mango) crop volumes ranging from 4.8–81% at farm levels, 5.4–90% at wholesale level, and 7–79% at retail level undergo damage, spoilage or decay, and such produce becomes only sellable at reduced prices culminating in economic value losses estimated at 16–40% (Kitinoja, 2010). Similarly, about 5–87% quality losses occur along entire fish value chains due to discoloration, bad weather, damage during handling and transportation, insect infestation, and spoilage depending on the fish species (Akande & Diei-Ouadi, 2010; Cheke & Ward, 1998; Mgawe, 2008). Such losses culminate in income losses that could exceed 32–50% (Cheke & Ward, 1998; Mgawe, 2008). Besides loss of revenue, a main manifestation of quality deterioration is nutrient degradation and bio-contamination, meaning loss of food value and occurrence of foodborne health hazards.

Within the scope of the present study, we did not locate conclusive empirical works that estimated nutritional value or food safety implications of quality losses. Our review, however, found evidence that processing, preservation, and storage technologies used in SSA often result in significant losses of important micro-nutrients (Bechoff, Tomlins, Dhuique-Mayer, Dove, & Westby, 2011; Lyimo, Nyagwegwe, & Mnkeni, 1991; Mosha, Pace, Adeyeye, Laswai, & Mtebe, 1997; Mulokozi & Svanberg, 2003; Tekpor, 2011). Furthermore, some technologies favor mold infections (Thomson *et al.*, 1997; Wright *et al.*, 1996), which raises concerns about their appropriateness in delivering products that are nutritious and safe, and that retain desirable quality attributes.

### (c) *Evidence of postharvest innovations*

#### (i) *Types of innovations*

A large number of the reviewed documents (147 out of 213) reported various types of technologies that were either used or proposed for PHL mitigation (Figure 3). Many of these technologies (81%) correspond to strategies for combating storage losses in cereals and pulses through containment of insect pests, and include variety selection, biological control, improved storage structures, modified atmosphere facilities, and treatment with chemical insecticides. There exist also indigenous technologies such as use of botanicals, vegetable oils, inert dusts (ashes, diatomaceous earths), solar treatment, and underground/pit storage that farmers use to preserve food and therefore combat losses. A considerable proportion of the available information is centered on the technical efficacy of

Table 6. *Evidence of quality losses*

| Evidence source | | | | Key findings |
|---|---|---|---|---|
| Study | Commodity and (location) | Chain level | Research | |
| Bechoff *et al.* (2011) | Sweet potato (Tanzania) | Processing | Nutritional value loss | 2–13% carotenoid loss during drying |
| Mishili *et al.* (2011) | Common beans (Tanzania) | Storage | Insect damage–price relationship | 2.3% price discount for every one bruchid hole per 100 grains |
| Tekpor (2011) | Okra (Tanzania) | Processing | Nutritional value loss. | 53–61% loss of vitamin C |
| Akande and Diei-Ouadi (2010) | Fish (Ghana) | Entire chain | Quality losses | 42–87% quality losses depending on type and condition of fish |
| Kitinoja (2010) | Tomato (Ghana) | Harvesting; Marketing | Quality losses due damage and decay | 50.5% of tomatoes at farm, 35.5% at wholesale, 22.5% at retail sold at discounted price |
| Kitinoja (2010) | Tomato (Benin) | Harvesting; Marketing | Quality losses due damage and decay. | 53% of tomatoes at farm, 48.7% at wholesale, 58.7% at retail sold at discounted price. Economic loss 40% |
| Kitinoja (2010) | Okra (Ghana) | Harvesting; Marketing | Quality losses due damage and decay | 34% of okra at farm, 4.5% at wholesale, 23.5% at retail sold at discounted price |
| Kitinoja (2010) | Amaranths (Benin) | Harvesting; Marketing | Quality losses due damage and decay | 81.5% of amaranth at farm, 89.5% at wholesale, 79% at retail sold at discounted price; Economic loss 30% |
| Kitinoja (2010) | Oranges (Benin) | Harvesting; Marketing | Quality losses due damage and decay | 20% of oranges at farm, 51.4% at wholesale and 84% at retail sold at discounted price |
| Kitinoja (2010) | Mango (Ghana) | Harvesting; Marketing | Quality losses due damage and decay | 4.8% of mango farm level, 5.4% at wholesale 9% at retail sold at discounted price |
| Kitinoja (2010) | Mango (Benin) | Marketing | Quality losses due damage and decay | 16% economic loss at retail |
| Mgawe (2008) | Fish (Tanzania) | Fishing; Processing, Handling; Transportation | Physical losses of dagaa | 32% economic loss due to 49% quality losses: 30%, 11%, 8% due to discoloration, bad weather, damage, respectively |
| Mishili *et al.* (2007) | Cowpeas (Ghana) | Storage | Consumer preference for quality | 0.5% price discount for every bruchid hole in 100 grains; consumers willing to pay a premium for quality |
| Langyintuo *et al.* (2004) | Cowpeas (Ghana) | Marketing | Insect damage – price relationship | 0.2–0.5% price discount for every bruchid hole per 100 grains |
| Langyintuo *et al.* (2003) | Cowpeas (Ghana) | Storage | Insect damage –price relationship | 1.2% price discount for every bruchid hole in 100 grains |
| Mulokozi and Svanberg (2003) | Sweet potato leaves (Tanzania) | Processing | Nutritional value loss | 31–43% pro-vitamin A loss during drying |
| Mtunda *et al.* (2001), Rees *et al.* (2001) | Sweet potato (Tanzania) | Marketing | Effect of damage on market value | 11–36% Market value loss depending on type and degree of damage |
| Tomlins *et al.* (2000) | Sweet potato (Tanzania) | Harvesting; Handling; Transportation | Effect of damage on market value | 13% market value loss |
| Golob *et al.* (1999) | Cowpea (Ghana) | Storage | Insect damage–price relationship | 12–18% price discounting for insect damage ranging 2.6–70% |
| Bancroft *et al.* (1998) | Yam (Ghana) | Marketing | Effect of quality on price | 25–63% price discounting depending on degree of quality deterioration |
| Cheke &Ward (1998) | Fish (Tanzania) | Fishing; Processing, Transportation; Storage | Physical losses of high value Nile perch | 4.5–13.5% of fish undergo quality deterioration |
| Compton *et al.* (1998) | Maize (Ghana) | Storage | Insect damage–price relationship | 0.6–1% price discounting for every 1% increase in damage; 25–30% overall value loss |
| Ndunguru, *et al.* (1998) | Sweet potato (Tanzania) | Marketing | Market value of roots with different quality attributes. | 11%, 15% and 37% price discounting for roots with breakage, cuts, weevil infestation, respectively |
| Mosha *et al.* (1997) | Sweet potato leaves (Tanzania) | Processing | Nutritional value loss | 14% pro-vitamin A loss during blanching; 40–58% loss during cooking; 86–95% loss during drying |
| Thomson *et al.* (1997) | Sweet potato (Tanzania) | Marketing | Market value of roots with different quality attributes | 20–25%, 25–30%, 30–40% and 45–55% price discounting for roots with breakages, cuts, surface weevil and internal weevils, respectively. Overall value loss of 12–34% |
| Thomson *et al.* (1997) | Cassava chips (Tanzania) | Processing; Storage | Effect of mold infection on price | Market value loss of 15–45% for mold infected chips |
| Wright *et al.* (1996) | Cassava chips (Tanzania) | Processing; Storage | Effect of insect damage and mold infection on market value | 30% and 40% price discounting for insect damaged and mold infected chips, respectively |
| Lyimo *et al.* (1991) | Cassava leaves (Tanzania) | Processing | Nutritional value loss | 13%, 53%, 58%, 16% loss in protein, Vitamin A, Vitamin C, and iron, respectively |

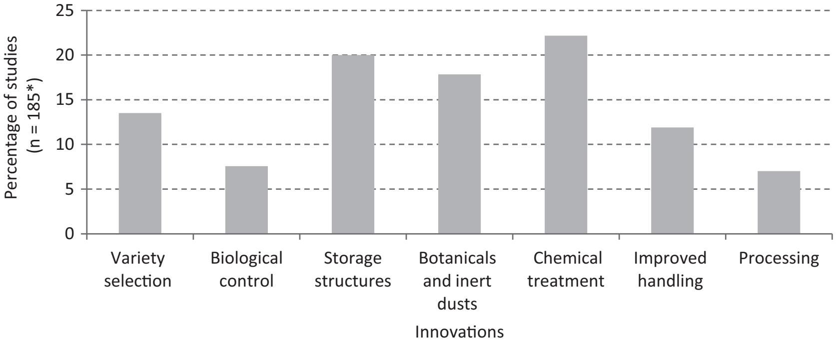

Figure 3. *Types of innovations represented in reviewed documents.* **Some articles reported more than one innovation.*

these technologies. Consequently, many technologies are available for protecting grains against insect pest infestations during storage in SSA, and the majority target primarily farm-level undertakings by small-scale farmers. Technologies that are developed to address PHLs arising from off-farm activities are limited. Combined together, approaches for improved handling, transportation, and processing were found in only 19% of the documents reviewed. We found many technologies that were tested for efficacy at laboratory level, but which were not extended to user interface. For instance, technologies involving variety selection and use of botanicals did not reach field-level implementations because they were not scaled for possible commercialization. Field applications of these technologies are therefore limited. Other technologies include modified atmosphere facilities or airtight containers such as metal silos and hermetic bags, which are more effective for grain storage (CIMMYT, 2011; Jones, Alexander, & Lowenberg-DeBoer, 2011a, 2011b). Improved handling (e.g. icing, use of rigid boxes for transportation), and processing technologies (e.g. blanching, parboiling, solar dehydration, smoking, salting, fermentation, and upgraded processing equipment) were reported in studies that described techniques for the control of PHLs related to root and tuber crops, fruits, vegetables, and fish. Cultivar selection and pre-harvest curing were also investigated for better harvest quality and improved shelf-life of root and tuber crops (Rees *et al.*, 2003; Tomlins *et al.*, 2002). We found that majority of the technologies target the abatement of losses occurring at farm-level.

### (ii) *Performance and technical efficacy of innovations*

A fundamental hypothesis underlying the analysis of performance and technical efficacy of innovations is that technologies tried at fairly experimental level in the past could actually be adapted to mitigate PHL without the need to develop new ones. Without reference to the specific PHL agents, the potential for reducing physical quantity losses using existing technologies for some commodities can be deduced from results presented in Table 5. Storage losses for maize and dried cassava chips could be lowered by about 81% and 44%, respectively, whereas losses arising from insect damage in mango could be decreased by 77%, indicating a tremendous potential if various technologies were adequately applied. However, efficacies of technologies are not always unfailing. In Benin, for instance, Meikle *et al.*, 2002 concluded that when taking into account market prices, pesticide costs, and price discounting due to grain damage, use of chemicals was not profitable, thus, the frequent recommendation that farmers should treat their grain prophylactically so as to achieve best control of insect attack was not strictly adhered to because the practice was not economically viable. Similar observation was reported in Tanzania (Golob, 1991). Also, failures to follow best practices by users are not uncommon. In Kenya, Mutambuki and Ngatia (2012) have shown that delayed treatment, non-treatment, incorrect dosage, and lack of re-treatment especially for those storing for more than 6 months and use of adulterated and non-recommended chemicals are main causes for low technology efficacy and hence, high storage losses. Other factors for poor performance of technologies could include weak innovation delivery systems, user perceptions, poor adaptability to socio-cultural and economic settings, and lack of follow-up (Bediako, Chianu, & Dadson, 2009; Obeng-Ofori, 2011). For example, not many innovations were developed or tested using participatory approaches, and relatively few evaluations (10 out of 213) of user perceptions were found.

There are also instances where effective technologies failed because they did not match with user needs, or the markets were unrewarding, unavailable or inaccessible. In Kenya, the findings of Kiura, Ndung'u, and Muli (2010) showed that processing cassava into dried chips was only viable if done in partnership with potential buyers as ready market for the product is not assured. The work of Tomlins *et al.* (2007) on sweet potato in Tanzania demonstrated that loss reduction innovations such as on-farm storage of fresh sweet potato roots in heaps or underground pits was unattractive because the stored roots were of inferior quality and less acceptable in the market; they could only be used at household level. Similarly, improved packaging of sweet potato in small-sized rigid boxes to minimize damage during transportation (Tomlins *et al.*, 2000) did not guarantee price advantage in the market yet it increased cost of transporting the produce to market. Firstly, traders transport in huge overly filled bags so as to reduce transportation costs often based on the number of bags transported. Secondly, transportation in rigid boxes only reduced surface scuffing of roots which consumers and traders do not see as a serious defect deserving a price advantage.

### (iii) *Costs and benefits analysis, gender, adoption and impacts of innovation*

Out of 147 documents that reported innovations, only 22 (15%) disclosed cost-benefit analysis. These are summarized in Table 7 together with the key information gathered from the studies. The majority (76%) of these were conducted for grain storage technologies. Nevertheless, it is revealed that high initial cost, low technical effectiveness, lack of rewarding markets, and poor scalability and reusability diminished the benefit-cost ratio of technologies, hence the prospect for adoption. For instance, work conducted by CIMMYT (2011) to compare costs and benefits of hermetic maize storage technologies in Kenya demonstrated that the use of super grain® bags were profitable if the bags could be used for three subsequent storage seasons. Similarly, metal silos were profitable if

Table 7. *Evidence of costs and benefits analysis of innovations*

| Evidence source | | | | Key findings |
|---|---|---|---|---|
| Study | Commodity and (location) | Chain level | Research | |
| CIMMYT (2011) | Maize (Kenya) | Storage | Profitability of alternative storage technologies | Polypropylene bag with actellic profitable. Super grain bags profitable if reused for three years. Metal silo profitable when capacity exceeds 0.5 tons. Larger silos more cost-effective but unaffordable to many farmers |
| Ibengwe and Kristófersson (2012) | Fish (Tanzania) | Processing | Cost-benefit analysis of reducing PHL of dagaa | Drying on raised platforms offers higher profit margins, shorter drying times and quality product |
| Arouna and Adegbola (2011) | Maize (Benin) | Storage | Profitability of improved storage structures | Wooden granary combined with Sofagrain more profitable compared to traditional structures |
| Arouna *et al.* (2011b) | Maize (Benin) | Storage | Costs of improved storage structures | Wooden granary combined with Sofagrain more profitable compared to other traditional structures |
| Jones *et al.* (2011a) | Maize (Tanzania, Kenya, Ghana Malawi, Mozambique) | Storage | Cost-benefit analysis of hermetic bag (PICS) storage and insecticide use | Superior profitability with PICS bag, and potential for adoption in Malawi, Mozambique, Tanzania and Ghana. Profitability dependent on markets, probable grain damage and losses. |
| Jones *et al.* (2011b) | Beans (Tanzania) | Storage | Profitability of alternative technologies: PICS bag, actellic, botanicals, and sieving & solarization | Sieving & solarization has highest net returns followed by PICS bag and actellic dust. PICS bag not profitable when high storage losses are not expected. Botanicals cost effective when losses are low. Profitability depends on markets, grain damage and probable losses |
| Moussa *et al.* (2011) | Cowpea (Benin) | Storage | Economic impact of alternative storage technologies | Double/ triple bagging, metal drum, improved ash are profitable; internal rate of return generally greater than the cost of capital |
| Kitinoja (2010) | Fruits and vegetables (Ghana; Benin) | Handling; Packaging; Storage; Processing. | Cost-benefit analysis of various technologies | Various technologies capable of raising the incomes by 33% or more |
| Kiura, Ndung'u, and Muli (2010) | Cassava (Kenya) | Processing | Profitability of processing into chips or flour | Processing into chips unprofitable unless done in partnership with potential buyers |
| Komen *et al.* (2006) | Maize (Kenya) | Storage | Economics of storage | Short-term storage (<3 months) does not increase farmer earnings |
| Afomasse and Arouna (2004) | Yam (Benin) | Storage | Profitability of improved storage systems for yam | Wooden tent with application of ash most profitable although construction costs are 67% higher than costs for traditional structure construction |
| Arouna (2002) | Maize (Benin) | Storage | Profitability of improved maize storage systems. | Improved wooden granary with Sofagrain more profitable compared to traditional granaries with local plant protectants |
| Bokonon-Ganta *et al.* (2002) | Mango (Benin) | Harvesting | Biological control of mango mealybug with *G. Tebygi* | Gain of USD 328 per year per farmer |
| Meikle *et al.* (2002) | Maize (Benin) | Storage | Returns on traditional maize stores with Sofagrain | Positive returns where LGB pre-storage infestation absent. Prophylactic treatment with Sofagrain unprofitable when market prices, pesticide costs and price discounting due to grain damage are taken into account |
| Morris *et al.* (2002) | Cowpea (Ghana) | Storage | Cost-effective technologies for improved storage and marketing quality | Solarization attracts 42.5% net-return on storage |
| Agbodza (2001) | Yam (Ghana) | Storage | Economics of storage | 18% net return on storage |
| Affognon *et al.* (2000) | Maize (Benin) | Storage | Profitability of technologies for maize storage | Net margin of USD 54.2–64.6 for Sofagrain users as compared to USD 0.6 for non-users |
| Bell *et al.* (1999) | Maize (Benin) | Storage | Cost-benefit analysis of biological control of LGB | Benefit cost ratio of 1.3 |
| Cheke and Ward (1998) | Fish (Tanzania) | Transportation | Evaluation of interventions designed to reduce PHL | Net benefit of USD 6.5 per 100 kg shipment of by air compared to rail due to lower PHL, better quality and premium markets access |
| Walingo, Kabira, Alexandre, and Ewell (1997) | Irish-potato (Kenya) | Processing | Gross margins for Irish-potato processors | Sales-cost ratio of 1.7:1 |
| Henckes (1994) | Maize (Tanzania) | Storage | Economic threshold for insecticide use | Insecticide use optimized by part-treatment of produce intended for long-term storage only |

capacity exceeded 0.5 tons, meaning that larger silos would be more cost-effective, but were unaffordable to many small scale farmers due to high initial cost involved. Jones *et al.* (2011a, 2011b) also demonstrated that the profitability of hermetic Purdue Improved Crop Storage (PICS®) bags for grain storage varied tremendously with grain damage and probable losses in different regions, and across markets in western, eastern, and southern Africa. The technology was judged to be unprofitable in regions where high storage losses are not expected, seasonal price variability is low and opportunity cost of capital of the farmers is high. The work of Afomasse and Arouna (2004) on yam storage in Benin also demonstrated that although improved wooden tents for yam storage were profitable the costs for their construction was 67% higher than that of constructing traditional storage structures, meaning cheaper alternatives existed.

With regard to gender, out of the 213 documents reviewed, only three (or less than 1.5%) explored gender issues, and these appraised participation levels of women and men in postharvest operations (Rugumamu, 2009) and constraints faced by women in adoption of technologies (Morris, Tran, Andan, Agona, Ecwinyu, & Okurut-Akol, 2002; Okorley, Zinnah, Kwarteng, & Owens, 2001). This finding indicates that generally, gender dimensions in postharvest issues are under-researched. In many SSA countries, postharvest systems underperform because women lack the resources and opportunities they need to access technologies and services to help transform agricultural produce (Okorley *et al.*, 2001). Women also face more severe constraints than men in accessing productive resources and markets. Large-scale comparative studies have demonstrated that gender inequalities are costly and inefficient (FAO, 2011), and that improving gender equality contributes to food security. In West Africa, Kroma (2002) examined the nature of existing postharvest technologies and the labor and health implications for women and argued for participatory extension practice that incorporates women's interests, local skills, and knowledge as critical resources in postharvest technology innovation. Similarly, in an assessment of production constraints and training needs of women involved in fish processing in Ghana, Okorley *et al.* (2001) concluded that inadequate capital and high cost of inputs were key constraints that led to only slight to moderate degree of technology adoption, and highlighted the need for training on technologies and business skills including credit acquisition, record keeping, working of cooperatives and marketing strategies, among others.

Table 8 summarizes key findings on adoption and impacts. There are not many studies that assessed adoption despite indications that various technologies could substantially reduce PHLs (Table 5). Similarly, the review did not find many assessments of impacts. Just as with cost-benefit analysis, the majority of adoption studies were related to improved grain storage structures, mainly in West Africa. Adoption rates of improved grain storage structures varied between 12.7% and 74% (Adegbola, Olou, & Afomassè, 2003; Aguessy, 2009; Arouna, Adegbola, & Biaou, 2011; Maboudou, 2003), but at the same time, a 56–73% abandonment rate was also reported within six years of use (Adegbola, 2010). In Benin, Moussa, Lowenberg-DeBoer, Fulton, and Boys (2011) reported 12.7% adoption of metal drum for storage of cowpea, whereas Arouna, Adegbola, and Biaou (2011) determined 48.9% adoption of traditional granaries for maize storage as compared to 40.9% for the improved ones. With participatory approach for development of maize storages technologies Affognon, Kossou, and Bell (2000) reported 80% adoption in Benin. Aguessy (2009), on the other hand, reported adoption rates of 74% for wooden granaries for storing maize cobs and adoption rates of 45% and 41% for metal cans and polyethylene bags, respectively, for storage of maize grain. Djaglo (2006) also reported more than 50% adoption of wooden granaries with chemical treatment (Sofagrain®) for maize in Benin, whereas Maboudou (2003) reported 27% adoption of the same citing low income, lack of construction skills and fear for intoxication as main causes for low adoption. For yam, Adegbola *et al.* (2003) reported adoption of improved storage technologies for fresh yam to be 20%, 46%, and 16% for wooden tent, sifted ash, and wooden tent-ash, respectively.

Limited efficacy, high costs, low returns, and lack of technical know-how are identified as main deterrents to adoption of the improved structures. In Benin, Adegbola, Arouna, and Ahoyo (2011), Adegbola, Arouna, and Houedjissin (2011) found out that the possession of formal education, participation in extension programs, market orientation of farmers, production experience, and technology effectiveness enhanced the adoption of improved maize storage structures. Likewise, Djaglo (2006) reported that the costs of constructing such structures, production level, and frequency of maize removal for consumption influenced the adoption of improved wooden granaries in combination with chemical treatment of maize storage. In addition, access to credit and extension services, and membership to farmer association were reported to contribute to adoption of improved maize storage structures in Mozambique (Cunguara & Darnhofer, 2011). In Ghana, however, the adoption of fish processing technologies by small-scale women fish processors was shown to be not only encouraged by active extension but discouraged by inadequate capital, prohibitive costs, limited technical know-how, lack of skills to run business, as well as limited access to credit and markets (Okorley *et al.*, 2001). Imperfect flow of market information culminating in failure of farmers to benefit from competitive market prices also discouraged adoption of improved storage technologies for cowpeas (Bediako *et al.*, 2009). On the contrary, for yam, Agbodza (2001) found that the socio-economic factors such as credit availability, labor, nature of roads, and market information flow perceived to be determinants of farmers' choice of storage methods were not significant. These results demonstrate that adoption drivers of postharvest technologies are different for different commodities, and socio-economic contexts. Furthermore, case-specific factors could contribute to the abandonment of technologies. In Benin, for instance, abandonment of improved wooden granaries and chemical treatment after adoption was precipitated by high construction costs, non-availability and high cost of chemicals, and lack of know-how to sustainably keep the technologies (Adegbola, 2010).

Regarding impacts of postharvest technologies, indicators that were reported include reduction of losses, income security, household expenditure, and productivity. In Benin, Arouna, Adegbola, and Adekambi (2011) and Adegbola (2010) reported that the adoption of improved maize granaries increased incomes, which in turn improved expenditures of households in social welfare, health, education, and factors of production. The adoption was shown to increase schooling expenditures by 187% (Adegbola, 2010). Participatory technologies developed for maize storage (Affognon *et al.*, 2000) reduced storage losses from 29.5% to 1% and 10.8% among participants and non-participants, respectively, and increased length of storage period by 2.5–3 months. Biological control of mango mealybug using *G. tebygi* increased productivity by 142% (Bokonon-Ganta, de Groote, and Neuenschwander (2002). In Mozambique, however, the impact of improved storage structures on household incomes was not found to be significant because of infrastructural impediments to market access (Cunguara & Darnhofer, 2011).

Table 8. *Evidence of adoption and impacts of postharvest innovations*

| Evidence source | | | | Key findings |
|---|---|---|---|---|
| Study | Commodity (location) | Chain level | Research | |
| Adegbola, Arouna, and Ahoyo (2011a) | Maize (Benin) | Storage | Factors affecting adoption of improved storage structures | Formal education, contact with extension agent, market orientation, production experience, and technology efficiency influence adoption |
| Adegbola, Arouna, and Houedjissin (2011b) | Maize (Benin) | Storage | Farmer perceptions of improved storage technologies | Construction costs deter adoption |
| Arouna *et al.* (2011a) | Maize (Benin) | Storage | Impact of adoption of improved granaries. | Increased income which in turn increased expenditures on social, domestic, health, education and production factors |
| Arouna *et al.* (2011b) | Maize (Benin) | Storage | Adoption of improved granaries | A higher adoption (48.9%) of traditional granaries as compared to improved ones (40.9%) |
| Cunguara and Darnhofer (2011) | Maize (Mozambique) | Storage | Factors affecting adoption, and impact of improved granaries adoption | Access to credit, extension services, and membership to farmer association boost adoption. No significant impact on household income due to infrastructural impediments to market access |
| Moussa *et al.* (2011) | Cowpea (Benin) | Storage | Economic impact of alternative storage technologies | 12.7% adoption of metal drum. Impact: 95% internal rate of return |
| Adegbola (2010) | Maize (Benin) | Storage | Factors for adoption, and impacts of improved granaries | Technology effectiveness, storage periods, costs, and participation in extension programs promote adoption. Adoption increased schooling expenditures by 187%. Technology abandonment of 56% to 73% |
| Aguessy (2009) | Maize (Benin) | Storage | Adoption of various traditional storage structures | Wooden granaries for storing cobs have highest adoption rate (74%) followed by metal cans (45%) and polyethylene bags (41%) for grains |
| Djaglo (2006) | Maize (Benin) | Storage | Adoption of Sofagrain in improved granaries | <50% adoption. Construction costs, production level, and frequency of maize removal for consumption influence adoption |
| Adegbola *et al.* (2003) | Yam (Benin) | Storage | Adoption of improved storage technologies for fresh yam | 20%, 46% and 16% adoption for wooden tent, sifted ash and wooden tent-ash, respectively. Proportion intended for sale, availability of household labor, and contact with extension influence adoption |
| Maboudou (2003) | Maize (Benin) | Storage | Adoption of improved storage: sandy granaries combined with Sofagrain | 27% adoption. Low income, lack of construction skills, fear for intoxication, trigger abandonment |
| Bokonon-Ganta *et al.* (2002) | Mango (Benin) | On-farm | Impact of biological control of mango mealybug with *G. tebygi* | Productivity increase by 142% |
| Morris *et al.* (2002) | Cowpea (Ghana) | Storage | Constraints to on-farm storage | Market orientation: indigenous treatments (botanicals, oils, ashes) good for small quantities not intended for market |
| Agbodza (2001) | Yam (Ghana) | Storage | Effect of socio-economic factors on choice of storage methods | Credit availability, labor, road infrastructure, landholding, and market information, not responsible for farmers' choice of storage methods |
| Okorley *et al.* (2001) | Fish (Ghana) | Processing | Adoption of technologies and constraints for small scale women fish processors | Adoption encouraged by active extension; discouraged by inadequate capital and costs. Major constraints: technical know-how, credit, business skills |
| Affognon *et al.* (2000) | Maize (Benin) | Storage | Participatory development of storages technologies | 80% adoption. Impacts: storage losses reduced from 29.5% to 1% and 10.8% among participants and non-participants, respectively. Length of storage increased by 2.5–3 months |
| Fiagan (1994) | Maize (Benin) | Storage | Adoption of storage systems | Traditional storage systems commonest; only 5% adoption of improved structures |
| Golob (1991) | Maize (Tanzania) | Storage | Uptake of extension knowledge for control of LGB | 55–64% uptake rate, but only 17% adherence due to socio-economic reasons |

## 4. DISCUSSION AND IMPLICATIONS OF FINDINGS

### (a) *Evidence of postharvest losses*

The present meta-analysis reveals that evidence of PHL in SSA is spotty, and quantitative estimates are often derived from inadequate data sets. Unpublished articles dominate the available literature, and only a third of these articles use appropriate methodologies. Moreover, there is paucity of data at different value chain levels as the larger proportion of assessments relates to farm-level grain storage. It is pragmatic for research to focus on losses at a particular level of the value chain where the loss is considered to be significant and potentially recoverable. However, this requires preliminary identification of loss hotspots along the value chains. A number of other commodities in the categories of fruits, vegetables, root and tuber crops, and animal products also substantially support the nutrition, and incomes of millions of people in SSA. These too incur considerable losses (Akande & Diei-Ouadi, 2010; Kitinoja, Saran, Roy, & Kader, 2011; Lore, Omore, & Staal, 2005). Commodities in these categories have been neglected in past postharvest research. Investigations that target to reduce PHLs in these commodities have the potential for expanding the scope of livelihood opportunities for poor and food insecure households, especially when seen in light of emerging food trends toward diversified diets (Kearney, 2010).

A main reason for many unreliable PHL estimates is weak assessment methodologies. Many datasets do not account for the interaction of various loss agents, and are single-point measurements which omit influence of exogenous factors such as local food use patterns, practices, and coping strategies. The omission of social, cultural, economic, and ecological factors in loss assessment could lead to over or under estimation of actual losses (Adegbola, 2010; Harris & Lindblad, 1978; World Bank, 2011). Such factors could include level of wealth and vulnerability, awareness, and technology exposure, perceptions and attitudes, destination of products, farming systems, agro-climatic conditions (temperature, rainfall patterns, humidity), and pest prevalence, among other factors. Variability in accuracy and practical application of different losses assessment methods also exist depending on the nature of the commodity and the type of loss agents (Alonso-Amelot & Avila-Núñez, 2011; Compton & Sherington, 1999; Compton *et al.*, 1998; Ngatia & Mutambuki, 2011). For some commodities such as fresh produce and fish, there are no reliable methods for evaluating postharvest losses as most methods are often subjective (Akande & Diei-Ouadi, 2010; Kitinoja *et al.*, 2011). Any assessment can only refer to a particular value chain on a particular occasion and, even then, it is difficult to account for quality loss or to differentiate between unavoidable moisture loss and losses due to adverse postharvest procedures. Other methodological inadequacies relate to timing of the assessment, sampling, statistical analysis, and interpretation of findings. Moreover, the lack of accurate records of losses at various stages of value chains could make reliable assessment of the potential cost-effectiveness of interventions at different stages of the chain difficult. The lack of such information may lead to misplaced interventions. These limitations imply the need for standardizing PHL assessment methodologies.

### (b) *On-farm storage versus value chain*

Many biotic and abiotic factors are responsible for PHL in SSA. However, most efforts to assess PHL have targeted smallholder farm-level activities, particularly storage, whereby insect infestations and biological deteriorations are the two factors that strongly attracted attention. A reason for the skewed focus toward storage losses is because harvested produces are stored for considerable periods so as to counter erratic production patterns, to speculate on price and to guarantee smooth income tenures (Alderman & Shively, 1996). The scope has, however, been limited considering that contributions of other food loss agents including rodents, molds, spillage and pilferage remain untracked.

Food consumption trends in developing countries, including SSA, are undergoing transitions. Rapid urbanization and changes in social and cultural practices have modified food habits of communities (Kearney, 2010). Urbanization and growing middle-class incomes have pushed for new consumer needs and extended value chains that now comprise sorting, grading, processing, packaging, distribution, value addition, and retailing as integral undertakings (Parfitt *et al.*, 2010). Furthermore, important characteristics of emerging food markets are the demand for food quality and safety that should be traceable across the food supply chain, and products' labeling which helps handlers to keep track of the produce as it moves through the postharvest system (Bollen, Riden, & Opara, 2006; Opara, 2003). Thus, unlike in the past, strategies for managing PHL can no longer concentrate on farm-level activities, ignoring the rest of the post-production chain where value addition also takes place. When considering value addition, alternative uses and by-product utilization are likely to be strategic options for PHL mitigation. Sorting and grading losses, for instance are often very important, especially in markets that thrive on quality. Products that are regarded unfit at one market level could be channeled to lower-end markets or be diverted to alternative uses thereby minimizing the overall economic impact of losses. Some alternative uses like bioenergy generation and animal feed processing can generate employment and incomes, or directly support the main PHL reduction investment (GIZ, 2013a). Identifying and strengthening such alternative markets can also enable chain actors to proactively align their production, collection, distribution, processing, and retailing procedures to minimize losses.

### (c) *Economic, quantity, and quality losses*

As part of PHL, quality losses impact on food safety, nutritional value, and often economic value as successful markets depend on a consistent supply of good quality produce (Kader, 2004; Kitinoja *et al.*, 2011). An overlap between quantity and quality losses exists although many PHL assessments in the past targeted quantity losses alone. Extremely high-quality losses could translate to 100% quantity loss when entire lots have to be discarded as in the cases of severely insect damaged or aflatoxin-contaminated grains (Daniel *et al.*, 2011; Hodges *et al.*, 2011). Similarly in fresh produce, weight loss is physiologically linked to bio-deterioration and therefore loss of quality (Kader, 2004). Across the various commodities, evidence of quality deterioration at harvesting, handling, and storage is overwhelming (Bancroft *et al.*, 1998; Compton *et al.*, 1998; Golob *et al.*, 1999; Kitinoja, 2010; Langyintuo *et al.*, 2004; Mishili *et al.*, 2007; Mtunda *et al.*, 2001; Ndunguru *et al.*, 1998; Rees *et al.*, 2001; Tomlins *et al.*, 2000; Wright *et al.*, 1996) although the coverage is relatively meager compared to that given to quantity losses.

A reason why estimation of quality losses is not frequent is the complication arising from product seasonality and the extent to which markets are sensitive to quality. For example when there is low supply of grain, such as during droughts or the period just before a new harvest, there is hardly any good quality grain on the market so that poor quality grain may sell for a price that is greater than that received for better quality grain during abundant harvest (Hodges *et al.*, 2011). In many SSA countries also, quality standards are not enforced or do not exist, and so quality changes may be assessed differently by individual consumers. Findings of the present analysis, nonetheless, indicate that consumers have increasingly become quality conscious (Juma, Baltenweck, Drucker, & Ngigi, 2007; Langyintuo *et al.*, 2004; Mishili *et al.*, 2007), which should raise the perspectives for greater emphasis of quality losses in future PHL research. Quality losses also have implications on the success of innovations (Jones *et al.*, 2011a, 2011b; Meikle *et al.*, 2002), as technologies were found not to be attractive where the targeted users did not perceive a direct advantage, particularly in terms of monetary gain (Tomlins *et al.*, 2002) and opportunity to access markets (Tomlins *et al.*, 2007). An additional quality aspect that also requires, more attention relates to mycotoxins. We found minimal coverage of mycotoxins which cause extensive harm to human and animal health, productivity, and trade in SSA (Wangacha & Muthomi, 2008), yet any efforts to interrupt their exposures must entail postharvest systems from farm through market to fork (Daniel *et al.*, 2011).

### (d) *Costs and benefits analysis, transfer, adoption, and impacts of PHL innovations*

Cost-effective technologies differ by commodity and local conditions (Kitinoja *et al.*, 2011). Whereas sustainable transfer of technologies requires that they be profitable for users within their local contexts, paucity of such data in the present review implies that many innovations were transferred without a prior examination of economic suitability. For many rural farmers, liquidity constraints and opportunity costs of capital are high due to competing demands for limited cash resources (Jones *et al.*, 2011a, 2011b). Instant sales of harvested produce, for instance, are often triggered by temporary but immediate liquidity obligations rather than the impending risk of, and limited capacity to prevent PHL (Abebe & Bekele, 2006). For such farmers, investing in improved technologies is not always feasible. Factual knowledge of adoption and impacts of technologies is often lacking as only few empirical assessments exist. Numerous factors, also varying with context and culture, influence technology adoption, among them technology attributes, human capital characteristics, structural, financial, and institutional constraints (Negatu & Parikh, 1999; Oladele, 2006).

An important disclosure of the present review is that many PHL technologies were tested for efficacy under controlled conditions. Examples are botanicals and variety selection that were investigated in laboratory or on-station trials. Whereas it is shown that some of the technologies are effective, transfer for possible adoption is not demonstrated. The reasons are unclear, but could be linked to weak research-extension networks, insufficient funding for follow-up work, lack of linkages for commercialization, or lack of economic viability and incentives to bring the technologies to scale. Moreover, in SSA, transfers of technologies to farmers are carried out mainly through public extension services, and to a lesser extent by the private sector, in which cases, meager state budgets and low project support funds often limit effective transfer (Kormawa, Ezedinma, & Singh, 2004). Baributsa, Lowenberg-DeBoer, and Djibo (2010) pointed out weak innovation delivery systems, as one reason of poor adoption of postharvest technologies. In a pilot experience in West Africa, these authors have shown how modern communication technology using cell phone video could cheaply provide agricultural producers with technological advice to reduce postharvest losses. Other reasons of poor adoptions include poor adaptability to socio-cultural and economic settings. There are also instances where effective technologies failed to be adopted because they did not match with user needs and perceptions, or the markets were unrewarding, unavailable, or inaccessible (Bediako *et al.*, 2009; Kiura, Ndung'u, & Muli, 2010; Tomlins *et al.*, 2000, 2007).

## 5. CONCLUSIONS AND RECOMMENDATIONS

The present meta-analysis aimed at establishing PHL magnitudes, and identifying gaps in their assessment and mitigation in SSA, using a robust methodology for screening relevant studies, reviewing and analyzing the available evidence on the nature and magnitude of PHL. A further objective was to show the implications of the findings for future PHL research. The motivation was recent calls by global and regional food security initiatives to avail decisive information to fill gaps in knowledge of global food losses. With the current renewed interest in supporting agricultural research and development in SSA, and the emergence of new initiatives to deal with PHLs, there is the need for carving out a niche for innovative and impact-oriented PHL research. In this meta-analysis, evidence of PHLs and past technologies used to mitigate them has been drawn from systematically selected studies conducted on various commodities in six countries in SSA over the last three decades. A number of conclusions that have implications for future postharvest research and development can be made.

First, PHL data are scanty and spotty across regions, commodities, and point in value chain, and a lot of data is of poor quality. We found that the majority of available PHL estimates relate to on-farm storage, mainly of maize yet many people in SSA rely on a variety of other staples and PHL could also occur at various points of supply chains. There is a need to support complementary PHL assessments along entire value chains of the various food commodities of nutritional importance, more so in the eastern and southern regions of SSA where millions of food insecure people live. For some commodities such as maize, and at certain steps of the value chain (specifically storage) where fairly sufficient data exist, establishing the magnitudes of PHL may not necessarily need the collection of completely new data. Instead, the already existing data could be modeled by taking into account the most important factors that contribute to differences between losses under different circumstances to generate practical estimates. Some of these factors include agro-climatic factors, level of production, incidence of specific pests and other loss agents, storage duration, storage technologies, and consumption and marketing practices. An example of such modeling was demonstrated by the APHLIS to generate PHLs for grains in various SSA countries (Rembold, Hodges, Bernard, Knipschild, & Léo, 2011). A main limitation, however, is the over-simplification of a complex system that is common to all modeling exercises. Furthermore, the outcome of such modeling is also dependent on the quality of the available input data. It would be useful to examine who is conducting research on PHL and whether there is a pattern in research conducted by different groups. Such analysis might be helpful in elucidating whether there would be incentives for these groups to communicate their findings by publishing in peer review journals especially because most findings remain unpublished as demonstrated by this review.

Second, there are ambiguities in methodologies for PHL assessment. Consequently, PHL magnitudes are often exaggerated. For instance, using the example of maize, the present meta-analysis shows that storage losses due to insect infestations are lower than the 40–50% loss estimates frequently quoted by the development community (cited in World Bank, 2011). Without adjustment for withdraws by farmers for consumption, sale, and other uses, we found that the losses average 4–21%, whereby, the upper limit represents level of losses occurring when no intervention is used. With adjustment for withdrawals the losses would be lower. Moreover, PHL are often economic rather than complete physical loss, which is usually assumed to be the case. Avoidance of total loss is demonstrated in many places by demand from reuse options, and price discounting, which implies tolerance levels on the part of the consumers for damaged produce depending on supply among other reasons. However, there are considerable evidence gaps regarding types and implications of losses. Understanding what true losses are, and what may appear to be loss are also unclear, which makes it difficult to distinguish losses from the use and reuse part of the food.

Third, PHL generally refers to complete disappearance of food from supply chains, and is directly measurable in quantitative, qualitative, nutritional, or economic terms. To measure these losses, local knowledge of commodity chains, which includes not only mapping commodity paths, but also volumes moved, processes involved, and activities, behaviors, goals, and motivations of chain actors requires prioritization. The advantages are twofold: First, PHL hotspots and PHL magnitudes that take into account practices along the chain are elucidated. Such data provide reliable baselines against which impacts of innovations can be measured. Second, identification of feasible postharvest innovations is aided by engaging chain actors in diagnosis of postharvest constraints and cataloging of locally existent technologies, and in the development of technologies where none exist. However, to measure progress against any loss reduction targets, systematic assessments of PHL are needed to generate precise loss estimates as baseline information. To achieve this, we suggest that loss assessment methodologies need standardization which should comprise: (1) quantifying the level of production; (2) identifying the most important loss hotspots; (3) adopting a value chain approach by understanding how much of the initial produce reaches the particular step(s) of the value chain in question; (4) considering the interaction of the various loss agents at the particular level; (5) considering socio-economic aspects such as local food use patterns, practices, and coping strategies that often moderate loss estimates; (6) reflecting both quantity and quality losses by presenting the economic implications, and finally (7) quantifying produce that is regarded as loss but can be directed to alternative valuable uses.

Fourth, central to the present meta-analysis was also exploration into past PHL mitigation innovations. As demonstrated by the present meta-analysis, PHL innovation systems in the past did not explore value chains; they concentrated on technical efficacy of technologies focusing mainly on storage improvement at farm level, leaving out the socio-economic aspects and other dynamics that link knowledge to practice. The simplistic approach used in the majority of the studies, resulted in the deplorable lack of success stories. Thus, we suggest that future PHL research should regard the entire value chain and develop innovation packages that not only work in one segment but across it, based on clear identification of the loss hotpots and the socio-economic aspects. According to Supe (1983), some technologies require group action for adoption whereas others can be taken up on an entirely individual basis. Some postharvest technologies might therefore require strengthening partnerships among farmers into small enterprises that can help them take charge of more steps in value chains. These small enterprises are more likely to adopt technologies, and the technology adoption is driven by business orientation, economies of scale, access to credit and services, shared risk, and stronger negotiating power. They are also effective platforms for information sharing, and through them, public–private partnerships for advancement of resources mobilization, capacity building, and market access become more tenable. An important aspect will be to examine and encourage private sector role in taking innovations to scale with emphasis placed on strategies that provide economic incentives to chain actors. Also, collaborative initiatives that bring together the private and public sectors, research institutions, and donor agencies to better identify research, innovation, and business priorities, and to raise the profile of PHL prevention across the for-profit, government, and non-profit spheres will offer more fitting solutions. Another key failure is the lack of explicit attention to gender in past PHL research. Women are the backbone of small-scale agriculture in SSA. Because of this, interventions that target to benefit women are likely to have greatest impacts. Hence, future PHL research will require precise undertakings to integrate gender aspects.

Fifth, the factors leading to PHL are well understood, and whereas not all aspects of PHL have been fully investigated, there are quite a number of individual PHL reduction techniques that act on certain points in the value chain, but what is lacking is adaptive research that targets appraising the technical, social-cultural, economic, and policy contexts of technologies. To do so, evaluating the technologies in selected representative pilot sites, assessing their economic feasibility and social acceptability, and optimizing innovations for wider dissemination and uptake is vital. Participatory technology development approaches that build on farmer-based knowledge were found to enhance technology uptake (Affognon *et al.*, 2000) although a counter-argument for the approach is resource intensiveness especially where a high degree of heterogeneity among targeted users exists, requiring that certain conditions be satisfied if impacts are to be optimized (Conroy & Sutherland, 2004). These could require appropriate and innovative public–private partnerships to be effective. The central role of the private sector will further need to be recognized, and emphasis placed on strategies that provide economic incentives to chain actors. An important aspect will be to examine and encourage private sector role in taking innovations to scale. Also, collaborative initiatives that bring together the private and public sectors, research institutions, and donor agencies to better identify research, innovation, and business priorities, and to raise the profile of PHL prevention across the for-profit, government, and non-profit spheres will offer more fitting solutions.

Overall, the present findings suggest need for change in the way PHL research is conducted. Apart from being evaluated within the context of the entire value chains, approaches that entail broader user participation in dissemination, management, and application of knowledge, will be essential. In particular, identifying adoption pathways, that is, socio-economic incentives and barriers, within models for involving technology users should be integral considerations. As key component of innovation decision-making process, contextual knowledge of technology adoption and discontinuance behaviors has to be integrated into PHL research.

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