50x2030
DATA-SMART AGRICULTURE

RESEARCH ON THE MEASUREMENT OF POST-HARVEST LOSSES

MINIMUM LOSSES BY COMMODITY AND REGION: INSIGHTS FROM THE LITERATURE

Sharon Mayienga
Franck Cachia

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Abstract

The reduction of agricultural losses, especially among smallholder farmers, should be an essential component of food security strategies in developing countries. The recognition of the importance of reducing food losses to achieve food security was the basis for the decision to include a dedicated target in the 2015 United Nations Sustainable Development Goals (SDG) agenda, with target 12.3 stating: "By 2030, to halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses''.

Loss reduction strategies should be informed by evidence on optimal loss levels, or the point below which loss reduction efforts becomes economically unviable, characterized by reduction costs greater than benefits. Information on minimum losses can help provide a benchmark for farm management, formulation of policies and investment decisions. When this information is connected to farming practices or production technologies, as done by the present study, it can also help in assessing the effectiveness of loss reduction practices and of the underlying policies and incentives that promote them.

While most empirical research and data collection activities on losses tend to focus on average losses, this paper provides evidence on minimum losses levels for a several commodities and regions of the world. Through a thorough meta-analysis, an original dataset has been compiled on minimum losses for a wide variety of activities, products and regions, reflecting the performance of the most efficient production systems. Following an adapted and replicable statistical methodology, minimum loss percentages have been calculated by commodity, commodity group and region to establish a benchmark to which average country results can be compared. One of the main findings of this meta-analysis – in line with other recent studies - is the clear split between commodity groups with oil crops, pulses and cereals on one end (with minimum losses of 2.0 percent, 4.0 percent and 4.2 percent, respectively) and fruits, roots and tubers, sugar crops and vegetables on the other end (17.1 percent, 18.4 percent, 18.5 percent and 20.7 percent, respectively). There are instances where the losses for some commodities fall below the documented minimum losses, the results are therefore not conclusive. There is limited information on minimum losses and therefore only 48 studies were used in this meta-analysis, this work in progress and quality of data is envisioned to improve as more research is conducted in this area.

This new and - to our knowledge - unique source of information constitutes a starting point in the establishment of optimal or minimum loss levels for a wider set of products, countries and regions, connecting losses to production practices or technologies.

Contents

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The 50x2030 Initiative to Close the Agricultural Data Gap is a multi-agency effort between the World Bank, FAO and the International Fund for Agricultural Development. It aims at supporting 50 low- and lower-middle-income countries to produce fundamental agricultural and rural data through the use of integrated agricultural and rural surveys. For more on the Initiative, please visit https://www.50x2030.org/.

1. Introduction, rationale and objectives

We define agricultural post-harvest losses as all quantitative losses occurring on the farm from harvest to storage. Minimum losses, the focus of this study, refer to the lowest level of losses that could be achieved for a given commodity and agricultural production context. These minimum losses, expressed as a proportion of harvested quantities, should in principle reflect the most efficient technology available to farmers: producers that have access to a similar production technology are characterized by the same minimum loss factor.

Information on minimum losses is useful for several purposes: it provides a benchmark for farm management, policy and investment decisions; used as a lower bound for loss estimates, it contributes to reduce the uncertainty on loss data, which is generally high. Furthermore, it can be used for comparison and cross-validation of relevant data. The last two aspects are useful in improving the quality of the international reporting on food losses, for example in the framework of indicator SDG 12.3.1a (Food Loss Index). This indicator is constructed partly from country data, of unequal quality, partly from imputations often based on generic models that fail to take into account the specificities of the countries and their heterogeneity. The existence of a solid evidence base on minimum losses would therefore be valuable in cross-validating country-level data available in datasets such as the Food and Agriculture Organization of the United Nations (FAO) Food Loss and Waste dataset[1], and in improving the quality of the loss estimates at country, regional and global level.

To our knowledge there is no similar exercise that has been conducted so far. Hence, this new evidence base helps to improve the quality of loss factors obtained from household or farm surveys. Indeed, minimum loss percentages could be introduced in the CAPI[2] survey questionnaires, to validate farmer estimates and thus improve the quality of the raw microdata. Similar validations could be performed - after data collection - to improve the quality of the estimations derived from physical measurements, highly prone to non-sampling errors.

To construct such an evidence base, this study has compiled data on harvest loss levels by commodity, region and other relevant dimensions that seek to reflect the performance of highly efficient production processes in each region. This was done through a comprehensive meta-analysis of the scientific and grey literature, as described in Section 2. The characteristics of the references compiled for this study are presented in Section 3. Section 4 presents the minimum loss estimates and compares them with other information sources, such as the FAO Food Loss and Waste (FLW) dataset and, for sub-Saharan Africa, the African Postharvest Losses Information System (APHLIS) dataset[3] Section 5 discusses results and concludes by highlighting their relevance to current research, highlighting possible improvements to this study. A structured list of references included in the meta-analysis is given in Section 6. Detailed minimum loss estimates are presented in Annexes.

[1] http://www.fao.org/platform-food-loss-waste/flw-data/en/
[2] Computer-Assisted Personal Interviews (CAPI)
[3] www.aphlis.net

2. Methodology

2.1 Identification and review of literature sources

A relevant list of references was compiled through a two-step screening process: a first screening, to identify references addressing farm losses in general; and a second screening, to select relevant information on minimum harvest losses.

First selection and screening: identifying references related to food losses. The first search was largely based on the references previously identified for the construction of the FAO Food Loss and Waste (FLW) database. This list of references, comprising journal articles, research reports, policy reports and other types of grey literature, was initially compiled using a text-mining algorithm, succinctly described below in Box 1References were organized according to the regions and commodities covered to identify the groups (commodity-region) with few references and for which additional search was required.

This complementary search was done “manually,” using different repositories. First, through the FAO online library[4], filtering the references by commodity, region and country. Second, through the AGRIS repository,[5] to identify relevant publications, which were then searched via Google Scholar. Third and final, Google Scholar was used to identify references for specific regions, countries and commodities (e.g. those significant for food security). The search from the different repositories resulted in very similar sets of documents, indicating that the set of references identified and used for further screening is likely to constitute a good approximation of the literature on food and farm losses, for the commodities, regions and periods prioritized.

The main keywords used for the search were *food losses*, *storage losses, post-harvest losses and food waste*. Different filters were applied iteratively, to narrow down the search to the regions, countries and commodities of interest. For example, if a commodity-specific search provided too many results (e.g. post-harvest losses in maize), a regional filter was used (e.g. post-harvest losses in maize in Eastern Africa) and, if needed, the search was narrowed down to specific countries (e.g. post-harvest losses in maize in Malawi). The keywords were also translated in French, Portuguese and Spanish to capture the publications written in these languages.

Priority was given to the most recent articles in order to capture recent data on farm losses: most of the references identified were publish in the 21st century, except in few cases where older articles were retained because of their relevance (see Table 1). The table below shows how the articles were distributed in the years.

Table 1. Articles by period of publication

Year	% of articles
2010 and after	60
2000-2010	22
1990 - 2000	4
Before 1990	16

Source: Authors, based on the results of the literature review.

[4] http://www.fao.org/library/libraryhome/en/

[5] http://www.fao.org/agris/

Box 1 – The FAO text-mining tool

The information extraction system set up by FAO to obtain data on food loss from documents consists of three main steps: 1) automated document collection and pre-processing; 2) assessment of the relevancy of documents; 3) guided extraction of data.

In the first step, different sources are queried to obtain documents related to food loss by using generic loss-related keywords such as “post-harvest food losses” or “food loss”. Scientific articles are obtained by passing through the FAO library to check whether the Organization has a subscription that allows accessing the document. Other types of documents, such as working papers, conference proceedings, or technical notes, are obtained by processes designed to query specific websites, such as the World Bank and World Food Program document repositories. Once the documents are collected, useful metadata is automatically extracted, such as authors’ names, title, date of publication or language. A short summary of the document is constructed using a text summarization routine based on Natural Language Processing (NLP). Keywords used in identifying loss factors for countries and commodities are also retained.

The second step of the process consists in checking if the document is likely to contain information of loss factors for commodities and countries. This check is based on a machine learning classifier that uses specific text-features (such as the number of occurrences of percentages and whether these are placed near words associated to loss, word frequency scores, bigrams, etc.) that was trained on a set of nearly 320 pre-validated documents. Each document then is passed through the classifier, which returns a probability for it to be relevant or not.

The last step consists in a manual intervention to confirm and assemble the information automatically extracted in the first step. In this step, the analyst can also eventually add more details (e.g., food chain stage, sample size, methodology).

This tool is being constantly updated to expand the set of references and improve their relevance, reducing the need for manual validations and improving the quality of the estimations.

Source: Christian Mongeau, Data Lab, Statistics Division, FAO

Second screening: identifying references with information on minimum losses. To be considered as a benchmark or minimum, the loss percentages should ideally explicitly refer to an efficient technology that is within the reach of producers (i.e. pertaining to its production frontier) or to optimal production conditions. In practice, the technology was not always stated and hence the data contained in the article not considered for further analysis. To ensure that a sufficient number of references was retained for the analysis, the scope was extended to articles that provided a range of estimates of losses for a given crop, assuming that the minimum of the range could be a good approximation of the minimum. Articles were retained for data extraction and further analysis if at least one of the two conditions was met:

- The loss percentages contained in the study explicitly referred to an efficient technology[6] or practice, such as an efficient harvesting method or an adapted storage facility, or;

[6] An efficient technology here refers to a technology that minimizes losses.

- The study provided a range of loss percentages from which it was possible to identify the minimum.

The systematic application of these two inclusion criteria led to the rejection of a majority of the articles initially identified (roughly 70 percent). In as much as the articles were relevant in regard to food losses, those that were screened out lacked information on minimum losses as there was no range indicated and/or did not have information about the use of an efficient technology. Most of the articles that were rejected contain useful information on food losses that will be used to enrich the FAO Food Loss and Waste database. The results of the screening process are presented by region and commodity groups in Tables 2 and 3, respectively. The percentage of rejected articles is rather stable across commodity groups (63-69 percent) but more variable across regions (56-90 percent). The highest percentage of relevant articles was found in Southern Asia, Eastern and Southern Africa and Latin America.

Table 2. Final screening process: results by region

Region	Articles retained	Articles rejected	% of rejection
West and Central Africa	7	21	75
Europe	8	17	68
North America	1	9	90
Latin America	15	21	60
Northern Africa and Western Asia	1	9	90
Eastern and South-Eastern Asia	3	14	82
Central and South Asia	13	15	56
Eastern and Southern Africa	7	22	61
Caribbean	1	4	80
Oceania	1	2	67

Source: Authors, based on the results of the literature review.

Table 3. Final screening process: results by commodity groups

Commodity group	Articles retained	Articles rejected	% of rejection
Cereals and Pulses	28	47	63
Fruits and vegetables	10	18	64
Roots tubers and Oil crops	10	22	69

Source: Authors, based on the results of the literature review.

2.2 Extracting and compiling information on losses

The final set of documents retained for the meta-analysis have been read through and the information pertaining to each relevant loss data point extracted and tabulated in an Excel template. The main information that was extracted included: the commodity under study; the country where the assessment was made; the year of the study; the type of farm operation for which losses refer to; the loss percentage; the denominator of this percentage; the justification to consider the percentage as a potential minimum; and; the technology to which the assessment refers to.

When available and relevant, additional information was also collected on: the crop variety; the farm type and size; the standard deviation associated to the estimate and/or the number of observations on which it is based, and; the name or description of the specific technology used. The full list of variables is presented and described in Table 4.

Table 4. Variables included in the minimum loss dataset and their description

Variable	Description	Values or modalities	Comments
Commodity	Type of crop or product: e.g. rice, bananas, etc.	Standard commodity name, following the CPC 2.1 Expanded and FAO Commodity List (FCL) classifications.	
Variety	Crop variety.	Variety names as given in the study.	Ensure harmonization in the variety names; relevant only for crops.
Country	Country where the study has been conducted.	Standard country names, following the United Nations M-49 geographical classification.	
Year	Year when the assessment was conducted (e.g. data collected or compiled).	Years.	In the absence of information on the period of the study, the publication year was used.
Operation	Farm operation or activity to which the loss % refers to.	All Farm; Harvest; Post-Harvest; Processing; On-Farm Storage; Other On-Farm	In certain cases, the operation to which the loss % refers to was not explicitly stated and some interpretation was required.
Loss percentage	Loss percentage indicated in the study.	0-100	Only the loss % considered as "minimum" were considered (see **Error! Reference source not found.**).
Reference	The variable used as reference (i.e. as denominator) for the loss percentage.	Harvest/Production; Expected Harvest/Expected production; Quantities Handled (excl. Harvest)	In certain cases, the denominator of the loss % was not explicitly mentioned and additional search in the article or interpretation was required. In very few cases, a manual adjustment was made to express percentages in reference to harvested quantities, instead of stored quantities for example.
Number of observations	Sample of farms/units from which the loss % has been calculated.	> 0	Can be used as weights in the aggregation procedure.
Variability of the loss percentage	The standard deviation of the estimate.	> 0	Can be used as weights in the aggregation procedure.
Justification	The justification for the loss percentage to be reported in the dataset.	Efficient technology; Bottom of range	
Practice	The practice to which the efficient technology refers to.	Harvesting method; Post-harvest equipment/processes; Storage facility; Packaging or containers; Pest control during storage; Other	
Technology	The technology to which the loss % refers to.	Name or description of the technology (e.g. PICS bags)	
Farm type	Type of farms for which the assessment is made	Mostly commercial; Mostly own consumption	
Farm size	Size of the farms/units sampled	Small-scale; medium and large-scale	This classification is based both on physical and economic size, e.g. small-scale farmers are those with relatively little land and/or with low agricultural income.
Literature reference	Article title, with hyperlink if available	Surname of the first author (year of publication)	

Source: Authors

2.3 Estimating minimum losses: the aggregation procedure

The objective of this research activity was to provide quantitative evidence on minimum harvest losses for a range of agricultural commodities. To ensure that the evidence was useful for policy analysis and for data comparisons and validations, the results were presented at the highest possible level of granularity allowed by the data: by commodity and region. Higher-level aggregates are also presented, such as loss percentages by commodity group.

Across time. The indicators are presented as averages across all references for a given crop and region, with no further breakdown per period or year. The inclusion of a time dimension is not permitted by the relatively limited number of data points that were gathered. In principle, this may lead to add noise to the results, as loss percentages may be expected to decrease in time in line with the improvement of the production practices. In the present meta-analysis, this bias is limited, for the following reasons: first, there is a high homogeneity in the references with respect to time, as most of the literature sources are recent (e.g. from 2000 onwards). Few older sources, from the 80s or 90s, were considered when the results presented were deemed highly relevant, for example when they included detailed information on losses associated with specific technologies or practices. Second, loss factors are structural parameters which tend to change slowly, as they reflect production practices. Third, even if there is some variability that can be attributed to time, it is certainly minor compared to differences across crops or regions, for example.

Across varieties. In certain cases, information on the crop variety was collected. The variety was not used, however, to present the results. There are certainly differences in losses across crop varieties but these are likely to be minor compared to differences across products (crops) and geographical areas. Furthermore, the existing loss estimates will likely reflect the dominant variety for each crop and the result will therefore be usable for benchmarking purposes at country or regional level.

Across farm operations. The focus of this study is on total farm losses (or as close a proxy as possible) and not on providing information by farm operations - e.g. harvesting, cleaning, drying or storage, to name the main ones. While this granularity is certainly interesting both for producers and policy-makers, our main objective is to provide an overall benchmark for on-farm losses to facilitate the validation, interpretation and comparability of aggregate country-level information. In addition, there is little uniformity in the literature on how the different farm operations are defined and broken down. For example, some studies lump all post-harvest losses together, while others present results for each individual operation; some combine the operations of cleaning and drying, while others keep them separate; some include losses during harvest, while others use the net harvest as reference, etc. This lack of consistency leads to higher biases and uncertainties for operation-specific aggregates.

In certain cases, the loss percentages referred to the entire farm activities (from harvest to storage) and in others to specific operations, such as harvesting, storage or on-farm processing. The results aggregate the percentages without differentiating the operation to which the loss refers to. This may introduce biases in the results and affect the comparability of the results across crops and regions. However, restricting the search only to total farm losses would not have allowed to gather sufficient evidence.

Estimating minimum losses. Different aggregation procedures may be used depending on the availability of the data. The ideal approach is to attribute different weights to reflect the varying quality of the information conveyed by the different references: studies that convey more precise information should be given higher weights, and conversely. This can be done by weighting the percentage losses of each study by their respective sample size or, better, by the inverse of their variance. As studies differ with respect to their target populations and to the samples used for the assessment (as well as on the assessment methodologies used), the variance should account for the variability within studies (due to sampling) and across them (due to differences in target populations). In statistical metadata analysis, this is done by assuming a random effects model. In that framework, the variance used to weight the individual loss percentages is the inverse of the variance within studies plus an estimate of the between-studies variance. The latter is calculated by decomposing the total observed variance into the sum of the variance within and between studies. For a simplified description of this approach, see for example Borenstein *et al.* (2007)[7].

The calculation procedure is the following: $\hat{l}_G = \sum_{i \in G} \theta_i l_i$.

Where $\hat{l}_G$ is the average minimum loss calculated for the grouping G (e.g. maize losses in West Africa), l_i is the observed loss percentage for reference i and θ_i the weight attributed to the reference i.

Three different indicators can be generated for each grouping G based on the different values that can be attributed to θ:

- $\theta_i = \frac{1}{card(G)}$ $\forall i$, the estimate is a simple average (uniform weights) of the references relevant for grouping G.
- If $\theta_i = \frac{V_i}{\sum_i V_i}$ the estimate follows an inverse-variance weighting approach. If V_i is the simple variance of the loss percentage obtained from reference i, the approach follows a fixed effects model. If V_i is the sum of the variance within and between studies, the approach follows a random effects model.

In practice, information on standard deviations was only available for a limited number of studies and it was only possible to estimate minimum losses using fixed and random effects model for a small number of groupings. Most of the estimates were therefore based on simple averages. When several estimates were available for a given commodity or commodity group (e.g. simple average and inverse-variance weighted averages), the median across the different approaches was calculated and displayed (as in Figure 4, for example).

[7] Borenstein, M., Hedges, L., Higgins, J., Rothstein, H. 2009. Introduction to Meta-Analysis. West Sussex, United Kingdom: John Wiley & Sons.

3. Statistics on the literature review

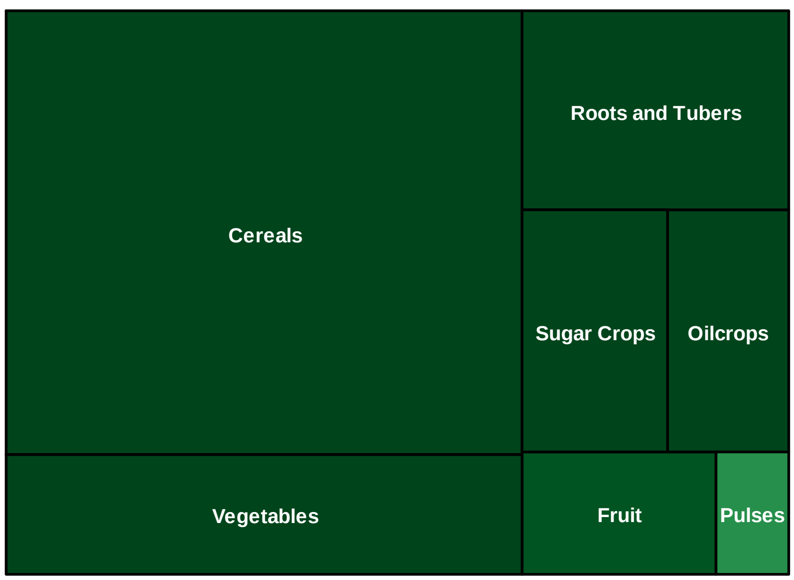
3.1 Characterization of the references

The screening of articles, reports and other sources led to identify 150 data points that provide information on minimum losses, as per the operational definition presented in section **Error! Reference source not found.**. This dataset covers 33 crops, representing seven commodity groups and spanning 15 regions across the five continents. Most of the loss percentages extracted reflect an efficient technology or practice (62 percent), the remaining referring to the minimum of a range of estimates.

More than half of the studies that were identified focused on cereals (see Figure 1). The commodity groups that were the least represented were fruits and pulses, with respectively 5 percent and 2 percent. The coverage of the other commodity groups (roots and tubers, sugar crops, oil crops and vegetables) varied between 7 percent and 14 percent.

In light of the relative scarcity of data points on which the statistical analysis is based, the results should be interpreted with precaution. However, as it will be shown in Section 4, the main findings of this study are consistent with other studies that use a broader scope (e.g. focusing on losses in general and not on minimum losses) and rely on a wider set of evidence (such as FAO[8] ,2019). This indicates that while the loss percentages presented in this study may be affected by a relatively high uncertainty, the comparisons of the results across crops and/or regions may be sufficiently robust to draw meaningful conclusions.

Figure 1. Commodity groups covered



Source: Authors, based on the results of the literature review.

[8] FAO. 2019. The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction. Rome. Licence: CC BY-NC-SA 3.0 IGO. http://www.fao.org/3/ca6030en/ca6030en.pdf

Maize is by far the commodity better represented in the current literature review (see Table 5), with more than a quarter of the data. The following best-covered two crops were also cereals - wheat and rice - with 11 percent and 8 percent of coverage, respectively. Among the top ten commodities, three root crops were represented – sugar beet, potatoes and cassava, by order of importance.

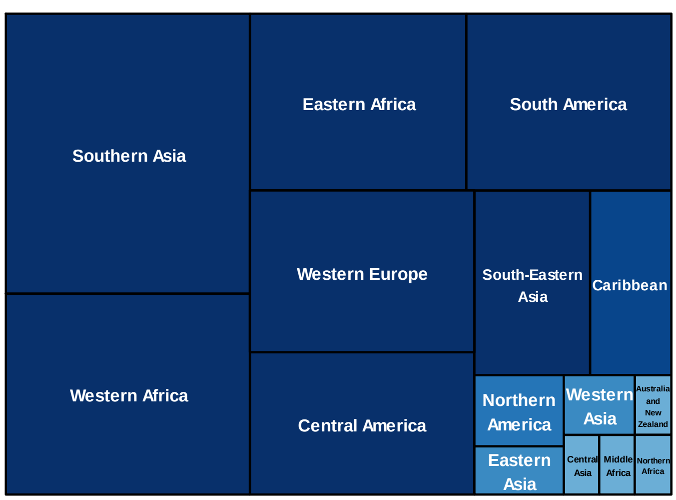
Table 5. Commodities covered

Commodity	# of data points	%
Maize	41	27
Wheat	16	11
Rice	12	8
Sugar beet	11	7
Potatoes	10	7
Sorghum	6	4
Soybeans	6	4
Cassava	5	3
Onions	5	3
Tomatoes	5	3
Other crops	33	22
Total	**150**	**100**

Source: Authors, based on the results of the literature review.

The geographic distribution of the results reflects the predominance of low and middle income regions, especially southern Asia, Western Africa and Eastern Africa which, combined, represented half of the studies (Figure 2). Latin America and the Caribbean were also well represented, with 26 percent of the results. At the opposite of the spectrum, few usable results were identified for Central Africa, Northern Africa, Central Asia and Oceania. The higher representation of developing regions tends to confirm that the literature on food losses is likely to over-represent regions where the problem of food losses and its potential impact on food security is the most acute, such as in Southern Asia or sub-Saharan Africa.

Figure 2. Regions covered

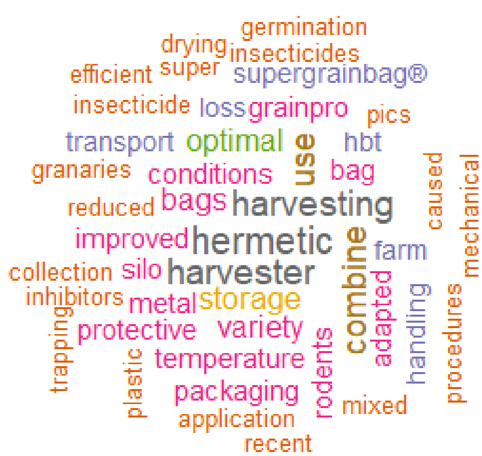


Source: Authors, based on the results of the literature review.

The literature reviewed focused as much as possible on loss assessments explicitly referring to certain practices and specific technologies. Out of the 150 data points compiled, 94 were based on the efficient technology criteria (see Section 2.2). Of these, 68 data points provided information on the specific technology or production practice assessed. The majority of these results (54 percent) focused on storage practices (storage facilities, packaging or containers, pest control during storage) and a significant proportion on harvesting methods (21 percent).

Additional information was collected on the specific technology or practice assessed. The *word cloud* presented in Figure 3 illustrates the predominance of efficient practices related to storage, particularly related to packaging or containers ("PICS bags", "supergrainbag", "adapted packaging", "hermetic bags" etc.) and to storage conditions or facilities ("metal silo", "temperature", etc.). Figure 3 also illustrates that several of the loss reduction practices are linked to pest protection during storage ("insecticides", "application", etc.). Several of the studies assessed the adoption of efficient harvesting methods, especially through the use of appropriate machinery ("combine", "harvester"," recent", "efficient", etc.).

Figure 3. Technologies or practices related to loss reduction



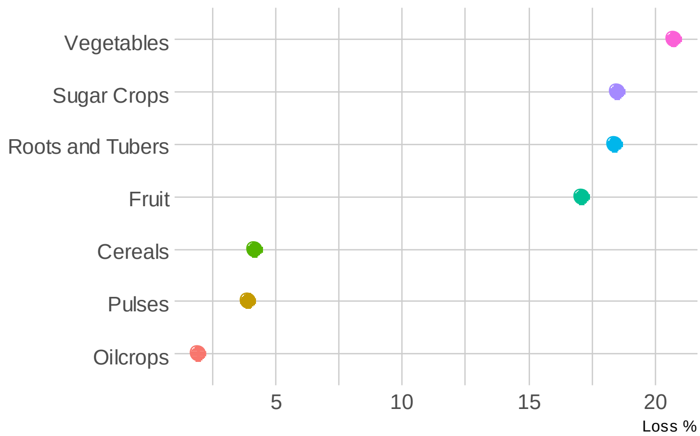
Source: Authors, based on the results of the literature review.

4. Minimum losses: evidence from the literature

4.1 Global commodity averages

The results of the meta-analysis show a clear split between commodity groups according to their estimated minimum losses. Those with the lowest minimum losses are oil crops, pulses and cereals with percentage losses of two percent for the former and four percent for pulses and cereals. The other four commodity groups covered in this study - fruits, roots and tubers, sugar crops and vegetables – all presented much higher minimum losses, of 17 percent, 18 percent, 19 percent and 21 percent, respectively. The ordering of commodity groups resulting from this meta-analysis is in line with current literature (e.g., FAO[9], 2019), for example.

Figure 4. Minimum losses by commodity group



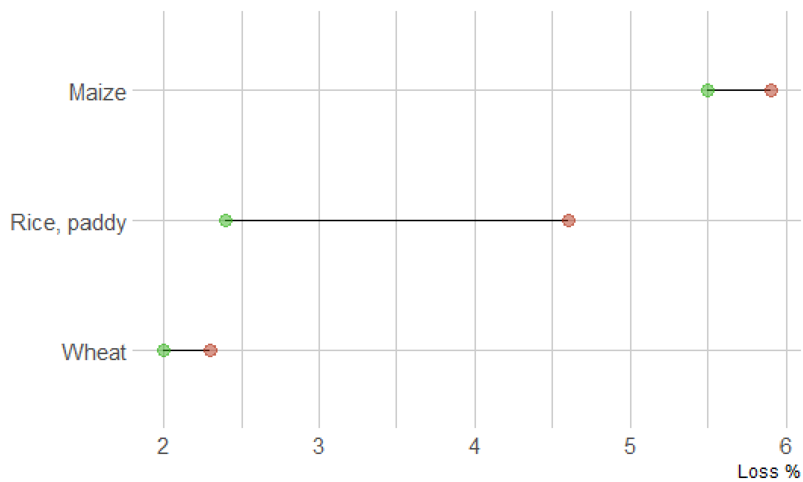
Note: Median of the results for the three weighting approaches
Source: Authors, based on the results of the meta-analysis

By disaggregating further the cereals category (the group for which most references were gathered – 78), the commodity for which minimum losses are the lowest was wheat (about two), followed by rice (two – five percent) and maize (six percent), as illustrated in Figure 5. The fact that the ranges are not overlapping suggests that the ordering across crops is likely statistically robust. This result is consistent with the physical characteristics of these grains, for example the fact that wheat is harvested at lower moisture

[9] FAO. 2019. The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction. Rome. Licence: CC BY-NC-SA 3.0 IGO. http://www.fao.org/3/ca6030en/ca6030en.pdf

contents compared to rice and maize[10], considering that lower moisture content at harvest generally results in lower losses.

Figure 5. Minimum losses for cereal crops



Notes: Ranges across the three weighting approaches
Crops with more than 10 observations
Source: Authors, based on the results of the meta-analysis

4.2 Averages across regions and commodity groups

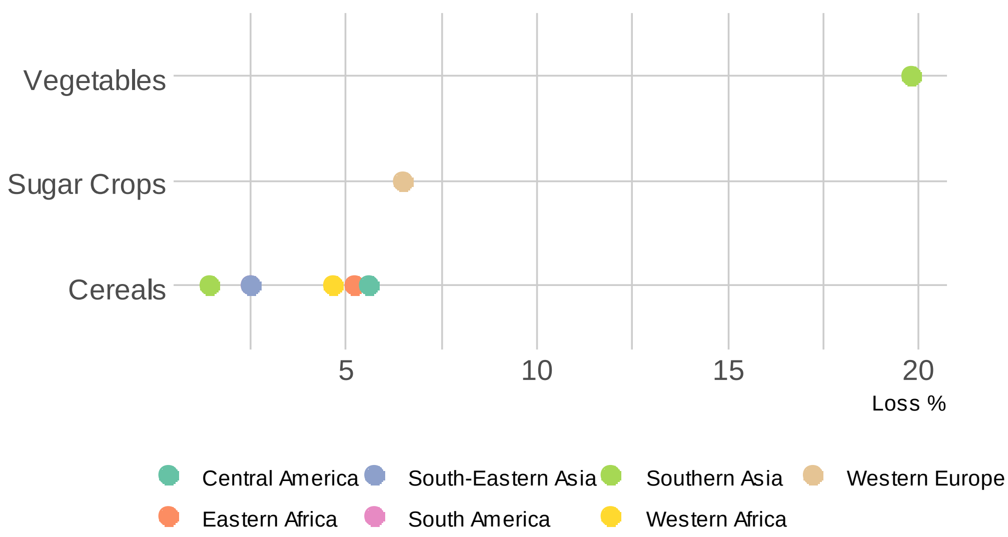
For cereals, enough data was compiled to support meaningful comparisons of minimum losses across regions: those with the lowest income levels – Central America, Western Africa and Eastern Africa – were also those with the highest minimum losses, about five percent of harvested commodity. South America (many articles were found for Argentina, in particular) and South-Eastern Asia were found to have much lower minimum losses (2.5 percent). Regional differences should be interpreted with care. Indeed, given the relative small sample of studies on which these calculations are based, the estimates by region also reflect, to a certain extent, differences in crop specialization. For example, references found for South America tend to focus on cereals and oil crops, wheat and soybeans in particular, crops which tend to be less prone to losses than others, such as maize for example.

These results suggest clear differences in production technology and efficiency between regions, and consequently point to structurally different minimum loss percentages. In particular, they underline that while five percent losses may be a reasonable objective for farmers in sub-Saharan Africa and in Central America, this value may not be economically viable in more intensive and competitive farming systems of other regions, for instance South America and South-Eastern Asia. This is confirmed by some of the references gathered for this study. For example, Giordano and Bianchi (2006) indicated that in Argentina, "tolerable losses" for wheat were approximately 90kg/ha, or three percent of the harvest

[10] Wheat is generally harvested when it reaches 14-20 percent moisture content, compared to 20-25 percent for rice and 18-24 percent for maize.

(when using a typical country yield of 3 tons/ha). Above this percentage, the cultivation of wheat would likely become unprofitable under current standard market condition.

Figure 6. Minimum losses by commodity group



Notes: Median across the three weighting approaches
Groups with more than 5 observations
For cereals, South-Eastern Asia and South America have the same value (2.5%)
Source: Authors, based on the results of the meta-analysis

4.3 Comparison with other data sources

The information on minimum losses can provide a benchmark for losses arising from efficient production technologies, against which other estimates can be assessed.

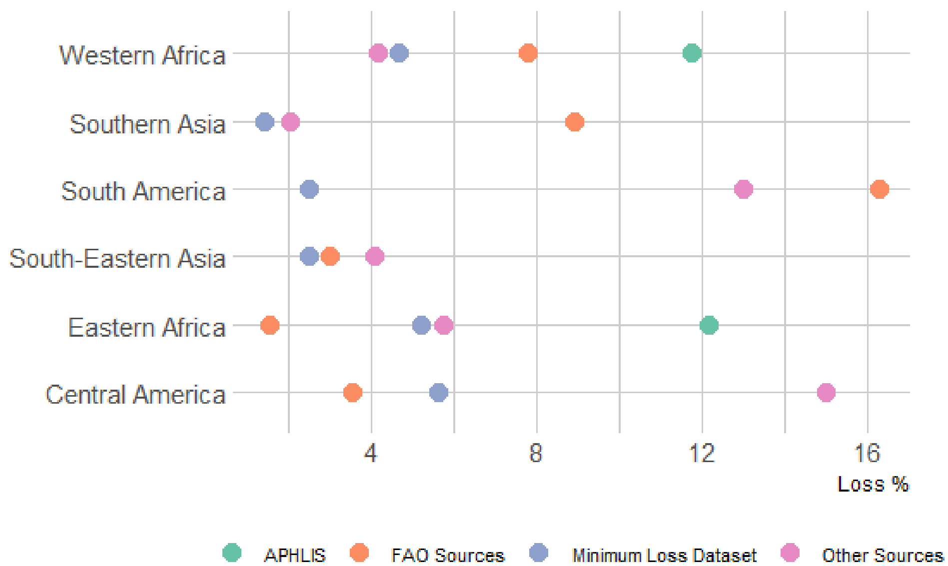
Results for cereals, the commodity group best represented in the current minimum loss dataset, were compared to those obtained from independent sources, including APHLIS, FAO (estimates obtained from FAOSTAT food balance sheets) and additional scientific and grey literature. From this initial comparison, we find that estimates based on the FAO food balance sheets (FBS) framework might may underestimate country-level losses in two out of six regions considered[11] (Figure 7). In Eastern Africa and Central America, for example, median losses were estimated at 1.6 percent and 3.5 percent from FAO sources, compared to the minimum losses estimated herein for the same regions of about 5-6 percent.

This is consistent with the fact that losses estimated in FAO food balance sheets are indirectly obtained by deducing all other uses from produced quantities. An additional explanation is the fact that production quantity reported in FBS is measured net of harvest losses, while harvest losses is typically included in scientific articles and in the APHLIS estimates. Several studies have shown that harvest losses tend to represent a high share of total farm losses (GSARS, 2017; FAO, 2020a; FAO, 2020b)). On top of these specific issues, lack of a unified definition of losses (e.g. how to handle the quantities diverted to non-

[11] Three out of six, if South-Eastern Asia is counted, for which FAO-based estimates and minimum loss results are very close.

human uses), inconsistencies in the scope of the assessment (e.g. focusing on losses during storage and neglecting other on-farm operations, inclusion or not of transport losses, etc.) and variation in the measurements methods used (expert-based, survey-based, declarations, physical measurements, etc.) introduce further noise in the estimations.

Figure 7. Percentage losses for cereals: a comparison between different sources



Source: Meta-analysis, FLW dataset (FAO Sources, APHLIS, Other Sources)

Beyond the comparison across sources, the concentration or dispersion of the results illustrated by Figure 7 may reflect some of the distinctive features of the agricultural sector in the different regions of interest. For example, the distance between minimum losses and average losses for Latin America may indicate the coexistence of small-scale farming with highly intensive and efficient production systems, a feature shared by many countries of the region. On the contrary, the higher concentration of loss estimates in sub-Saharan African may confirm the high prevalence of small-scale subsistence farming in this region.

5. Conclusion

Through a thorough screening and review of the literature on agricultural losses, an original dataset has been compiled on minimum losses for seven commodity groups covering 15 regions spanned across seven continents. From this source of information, minimum loss percentages were determined by commodity, commodity group and region, in order to establish a benchmark for useful comparison of country-level results. These minimum loss estimates were determined following an appropriate statistical methodology based on three different weighting approaches: uniform weighting (i.e. simple average), weights based on the inverse of the variance within studies (fixed effects approach) and weights based on the inverse of the variance within and between studies (random effects approach).

The estimates were compared to results obtained from the FLW dataset (which include data for three separate sources – APHLIS, FAO/FAOSTAT and other sources) for similar groupings and helped identify areas where data gathering and compilation efforts could be focused to improve the quality of the latter. These include cereals in sub-Saharan Africa. These comparisons have also shed some light on or confirmed the distinctive features of the agricultural sector in different regions. For instance, the wide distance between minimum losses and country averages in Latin America is in line with the coexistence in this region of small-scale and traditional farming with highly intensive and efficient systems.

The rigorous screening of the articles and the complexity of identifying minimal losses led to retain a small proportion of the articles initially identified, approximately 30 percent. The limited number of data points (150) prevented us from constructing significant averages and performing meaningful comparisons for certain commodity groups, such as fruits and pulses, and regions, such as Oceania, Europe, North America and North Africa, among others. However, from the obtained results, it is observed that the minimum losses vary widely across the commodity groups but are consistent across regions. There are commodity groups with losses as low as 2 percent e.g oilcrops and others with high minimum losses e.g. vegetables that have 21 percent. Cereals had minimum losses of 4.2 percent with maize having the highest minimum losses ranging from 5.5 percent - 5.9 percent. These results form a starting point for intervention especially for the commodities that are essential for food security e.g. cereals. These results were however based on a limited dataset and therefore are not entirely conclusive, there is a need to pursue this work by expanding the dataset to obtain a better coverage of regions and commodities.

Through this study, many articles were identified that gather relevant information on the impact and implementation costs of loss reducing technologies. It would be of interest for policy design and evaluation to conduct additional research on these technologies, their effect on reducing food losses and their cost-efficiency.

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Annex 1. Averages across commodity groups and regions: results of the meta-analysis

CommodityGroup	Region	Loss %	Observations
Cereals	Eastern Africa	5,2	13
Cereals	Southern Asia	1,4	17
Cereals	Western Europe	1,5	4
Cereals	South America	2,5	7
Cereals	Central America	5,6	12
Cereals	Eastern Asia	2,3	1
Cereals	South-Eastern Asia	2,5	7
Cereals	Western Africa	4,7	16
Cereals	Middle Africa	11,2	1
Fruit	Eastern Africa	10,6	2
Fruit	Southern Asia	6,3	2
Fruit	South America	7	2
Fruit	Western Africa	17,2	2
Oilcrops	Southern Asia	1,8	1
Oilcrops	Western Europe	1	3
Oilcrops	South America	2,9	5
Oilcrops	Northern America	1,5	1
Pulses	Central America	4,0	3
Roots and Tubers	Eastern Africa	41,3	3
Roots and Tubers	Southern Asia	23	1
Roots and Tubers	Western Europe	12	1
Roots and Tubers	South America	2,4	2
Roots and Tubers	Western Africa	37,6	4
Roots and Tubers	Caribbean	4,1	3
Roots and Tubers	Central Asia	10	1
Roots and Tubers	Northern Africa	10	1
Roots and Tubers	Western Asia	10	2
Sugar Crops	Western Europe	6,5	9
Sugar Crops	Caribbean	7,6	1
Sugar Crops	Northern America	18,7	2
Vegetables	Southern Asia	19,8	11
Vegetables	South America	8,8	1
Vegetables	Eastern Asia	22,7	1
Vegetables	South-Eastern Asia	35	3
Vegetables	Western Africa	5	1
Vegetables	Caribbean	15,7	3
Vegetables	Australia and New Zealand	28,7	1

Note: Loss % refer to the median of the estimates obtained from the simple average and from the two inverse-variance weighting approaches (fixed and random effects model). The weighted estimates could only be calculated when enough information (on standard-deviation in particular) was available for each commodity-region grouping The raw data has been collected at country-level and medians calculated and presented at regional level.

Annex 2. Averages across commodity groups and regions: results from FAO's Food Loss and Waste dataset

CommodityGroup	Region	Loss %		
		APHLIS	FAO Sources	Other Sources
Cereals	Eastern Africa	12.3	1.6	5.8
Cereals	Southern Africa	12.0		
Cereals	Western Africa	11.7	7.8	4.1
Cereals	Middle Africa	12.7		
Cereals	Nothern Africa	12.4	10.7	14.0
Cereals	Southern Asia		8.95	2.0
Cereals	Western Europe		3.3	
Cereals	South America		18.8	20.0
Cereals	Central America			15.0
Cereals	Eastern Asia		14.5	14.5
Cereals	South-Eastern Asia			5.0
Cereals	Southern Europe		0.15	
Cereals	Western Asia		3.0	4.7
Cereals	Caribbean		15.9	
Cereals	Northern Europe		2.1	6.6
Cereals	Central America		3.5	
Cereals	South-Eastern Asia		3.0	
Cereals	Northern America		2.8	
Fruit	Eastern Africa		1.8	15.0
Fruit	Southern Asia			2.9
Fruit	South America		13.7	16.6
Fruit	Western Africa			7.5
Fruit	Northern Africa		1.5	
Fruit	Caribbean		10.05	30.0
Fruit	Western Asia		6.7	
Fruit	Western Europe		13.5	
Fruit	Eastern Europe		0.9	
Fruit	Central America		6.5	17.0
Fruit	Northern America		18.0	
Fruit	Middle Africa			35
Fruit	Northern Africa			0.3

CommodityGroup	Region	Loss %		
		APHLIS	FAO Sources	Other Sources
Fruit	Northern Europe			8.8
Fruit	South-Eastern Asia			27.5
Oilcrops	Southern Asia		3	0.5
Oilcrops	Western Europe		4.5	
Oilcrops	South America		7.0	
Oilcrops	Northern America		2.7	4.6
Oilcrops	Western Africa		2.4	0.8
Oilcrops	Western Asia		2.2	
Oilcrops	Eastern Europe		1.4	
Oilcrops	Central America		7.5	
Oilcrops	South-Eastern Asia		5.2	
Oilcrops	Eastern Africa			5.0
Pulses	Central America			
Pulses	Western Africa		8.0	27.8
Pulses	Northern Africa		14.9	
Pulses	Caribean		0.7	
Pulses	Northern Europe		5.0	
Pulses	Western Asia		2.9	
Pulses	South America		20.1	10.0
Pulses	Western Europe		3.0	
Pulses	Eastern Europe		0.9	
Pulses	Central America		3.0	4.9
Pulses	Eastern Asia		10.2	
Pulses	Nortern America		2.0	
Pulses	Eastern Africa			2.3
Pulses	Northern Europe			11.3
Pulses	Southern Asia			2.5
Pulses	South-Eastern Asia			17.0
Roots and Tubers	Eastern Africa			19.2
Roots and Tubers	Southern Asia			14.2
Roots and Tubers	Western Europe		7.0	0.1
Roots and Tubers	Northen Europe		10.0	4.0
Roots and Tubers	South America		20.9	10.5
Roots and Tubers	Western Africa		2.0	
Roots and Tubers	Caribbean		2.1	
Roots and Tubers	Central Asia		7.5	17.5
Roots and Tubers	Northern Africa			25
Roots and Tubers	Western Asia		6.3	
Roots and Tubers	Southern Asia		4.45	
Roots and Tubers	Eastern Europe		5.7	

CommodityGroup	Region	Loss %		
		APHLIS	FAO Sources	Other Sources
Roots and Tubers	Central America		4.6	24
Roots and Tubers	Eastern Asia		7.3	
Roots and Tubers	Northern America		7.1	
Sugar Crops	Northern America		13.1	
Sugar Crops	Southern Asia			0.4
Vegetables	Southern Asia			3.0
Vegetables	South America		24.3	12.0
Vegetables	South-Eastern Asia			16.6
Vegetables	Western Africa			18.4
Vegetables	Caribbean		9.9	45.1
Vegetables	Eastern Africa		2.1	9.8
Vegetables	Northern Europe		13.3	6.5
Vegetables	Western Asia		9.3	21.9
Vegetables	Western Europe		12.5	
Vegetables	Eastern Europe		2.4	
Vegetables	Central America		10.0	24.0
Vegetables	Northern Africa			30

Note: Loss % refer to median losses for the given region and commodity group. The raw data in the FLW dataset is available at country-level and medians were calculated and presented at regional level.

CONTACT US AT

info@50x2030.org

www.50x2030.org