

The NUTRI-P-LOSS (NUTRItional Postharvest Loss) methodology: a guide for researchers and practitioners

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The London Centre for
Integrative Research
on Agriculture & Health

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Legend:

- Text in black font is for general recommendations
- Text in *blue italic font* is for specific examples from NUTRI-P-LOSS

Summary:

Postharvest losses and food security are important concerns in low- and middle-income countries (LMICs) and research in these areas has become a global priority. Measuring nutritional losses along the crop value chain (VC) can deepen quantitative and qualitative understanding of these losses, which is critical for understanding the contribution of agricultural interventions to nutritional improvement. Nutritional loss estimation methods and metrics can provide crucial information for improving food security strategies at local and global levels.

The NUTRI-P-LOSS Project developed a methodology to estimate nutritional postharvest losses (NPHLs) throughout the VCs of key staple food crops (maize, sweet potato and cowpea) in two sub-Saharan African countries (Zimbabwe and Uganda). The project focused on key nutrient losses: energy, macronutrients (protein, lipid, carbohydrate, dietary fibre) and micronutrients, considered the most important in terms of deficiencies (vitamin A, zinc, and iron) in developing countries, especially sub-Saharan Africa.

We covered estimation of nutritional losses related to:

- (1) physical weight losses (building on existing weight loss methodologies)
- (2) other changes not associated with weight loss (i.e. quality losses).

Based on our experience during the NUTRI-P-LOSS Project, we are proposing a methodological approach for model dissemination to other countries and other commodities (*i.e.* other cereals, pulses and roots and tubers, as well as commodities from any other food group) in a cost-effective and sustainable way (*e.g.* through an open-line, open access platform such as APHLIS). We describe here the method and lessons learned, including challenges that arose in the development of the tool.

A key feature for the success of the NPHL estimate is **obtaining reliable data** on postharvest loss. A second key facet is managing the **combination of the data** in a coherent way to produce a reliable model estimate. This requires making choices on the presentation of the data (for example selecting field work data as opposed to laboratory data or vice versa) in order to produce a coherent model. Assumptions must be made carefully and stated clearly to ensure credibility. Lastly, in order to make an impact on nutritional outcomes, the model has to be **integrated in an online platform** (*e.g.* APHLIS) that can provide open access to data and enable stakeholders, such as LMIC policy makers, researchers and development partners, to obtain estimates of the nutritional postharvest losses in their focal country, VCs and contexts of interest.

Preamble

This methodology document includes material to guide practitioners in postharvest loss reduction related to nutrition. The document both supports and describes the methodology used by NUTRI-LOSS and hence includes background material, the approach and information about the methodology (including examples from this project).

Background

With the human population projected to reach 9 billion by 2050, global food security and access to nutrition is a major concern and has become a global priority. The Food and Agriculture Organization (FAO) reports that up to a third of the food produced is lost between harvest and the consumer, amounting to 1.3 billion tonnes per year with an estimated value of US\$ 310 billion (Gustavsson *et al.*, 2011). Postharvest losses (PHLs) are significant throughout the food system and the level of PHL varies by commodity, season, geography, culture, socio-economic circumstances, step of the value chain and postharvest system (Hodges *et al.*, 2010; Stathers *et al.*, 2013; Kaminski & Christiaensen 2014; Naziri *et al.*, 2014). Opportunities for increasing food production and productivity are limited by availability of agricultural land and natural resources. Reducing PHLs is a practical way to ensure more of the increasingly valuable harvested food is available for human consumption. The EAT-Lancet Commission on healthy diets identifies postharvest loss reduction strategy as one of the key approaches to make food systems more sustainable (Willet *et al.* 2019). This is particularly crucial in many Low- and Middle-Income Countries (LMICs) where malnutrition is a serious problem and PHLs are frequently high due to pests, poor storage conditions and marketing constraints. Additionally, decreasing PHLs means that valuable resources (*e.g.* water, energy, land, labour) are not wasted on producing food that is never consumed by humans thus reducing the unit cost and increasing resource efficiency of producing food (Aulakh & Regmi 2013).

Three types of PHLs occur in the crop postharvest VC ((Zorya *et al.* 2011):

1. Physical: quantitative food loss measured in weight loss of the food
2. Economic: loss in value of the food due to qualitative loss (*e.g.* due to insect damage and other quality decreases such as spoilage)
3. Nutritional: loss in nutritional value of the food that can result in both quantitative and qualitative losses

Considerable work on physical losses occurred in the 1970s and 80s (World Bank *et al.*, 2011; Affognon *et al.*, 2015). More recently, the focus has also encompassed economic losses, which in some cases can account for more than the physical losses (Compton *et al.*, 1998; Mishili *et al.*, 2011; Jones *et al.*, 2011; Naziri *et al.*, 2014; Kadjo *et al.*, 2016). However, there is still a major knowledge gap regarding nutritional losses, and in regions suffering from high levels of malnutrition, addressing this problem needs to be a priority. Incorrectly assuming that sufficient quantity of a foodstuff equates to sufficient nutritional quality could cause health problems for those subsisting on staples that have been stored for long periods in poor conditions.

In previous research, nutritional loss was measured at one step in the VC: typically, processing or storage. For example, the loss of a specific nutrient (*e.g.* provitamin A) in a crop may be measured during home cooking or commercial processing under certain processing and storage conditions (temperature, light, *etc.*) (Bechoff *et al.*, 2010a; 2010b). There are standard methods to record those

nutritional losses. However, little information is available on nutritional loss metrics that occur throughout the postharvest VC (NPHLs) and how these differ between crops in different countries, seasons, environments and agro-ecological situations and for different loss-causal factors.

APHLIS ([African Postharvest Losses Information System](#)) is a well-known global network that provides PHL weight loss metrics on sub-Saharan African cereal crops to help support PHL reduction, food security and agricultural strategies and policies. APHLIS provides evidence-based data on postharvest loss at a large scale that would be prohibitively expensive to obtain by direct observation. It does this by combining loss data from academic research with contextual observations from local experts. The APHLIS approach generates PHL estimates for each stage of the value chain from an algorithm that uses high quality existing scientific literature data (postharvest weight loss data) and contextual seasonal data collected by local APHLIS experts (*i.e.* updated weather information and pest and disease occurrence). This tool has an open-access downloadable calculator (http://www.aphlis.net/?form=downloadable_calculator) which provides accurate and relevant PHL estimations to agricultural practitioners, donors, development agents and policy makers. In January 2016, APHLIS+, a new project funded by the Bill and Melinda Gates Foundation through a \$3.7 million grant over 5 years, was launched. The overall aim of APHLIS+ is to further the development and awareness of the PHL estimates by expanding the information system to cover commodities other than cereals, such as legumes and root and tuber crops and to include nutritional and economic losses in the model.

Postharvest losses (PHLs) are a global concern, since the growing population could reach a point when the associated required increase in food production and productivity will be extremely challenging. Developing a scientific approach to estimate PHLs is therefore critical to developing strategies for their reduction. Reliable PHL metric figures are essential for both advocating for new loss reduction programmes and better targeting, monitoring and evaluation of such initiatives, as well as more accurate estimation of food and nutrition availability in countries threatened by food insecurity. Tools and methodologies have been developed to estimate weight losses and to a lesser extent to estimate losses in economic values (Hodges *et al.*, 2014). These are currently implemented as part of the APHLIS project, one of the few initiatives that uses a reliable and scientific-based approach to estimate PHLs. There is a need for the development of methods and metrics that could also account for nutritional losses and hence contribute to a better understanding on how PHLs affect food security and nutrition (*i.e.* in LMIC). Currently there is a knowledge gap regarding the extent of NPHLs throughout the VC and this calls for the development of both new methodology and metrics.

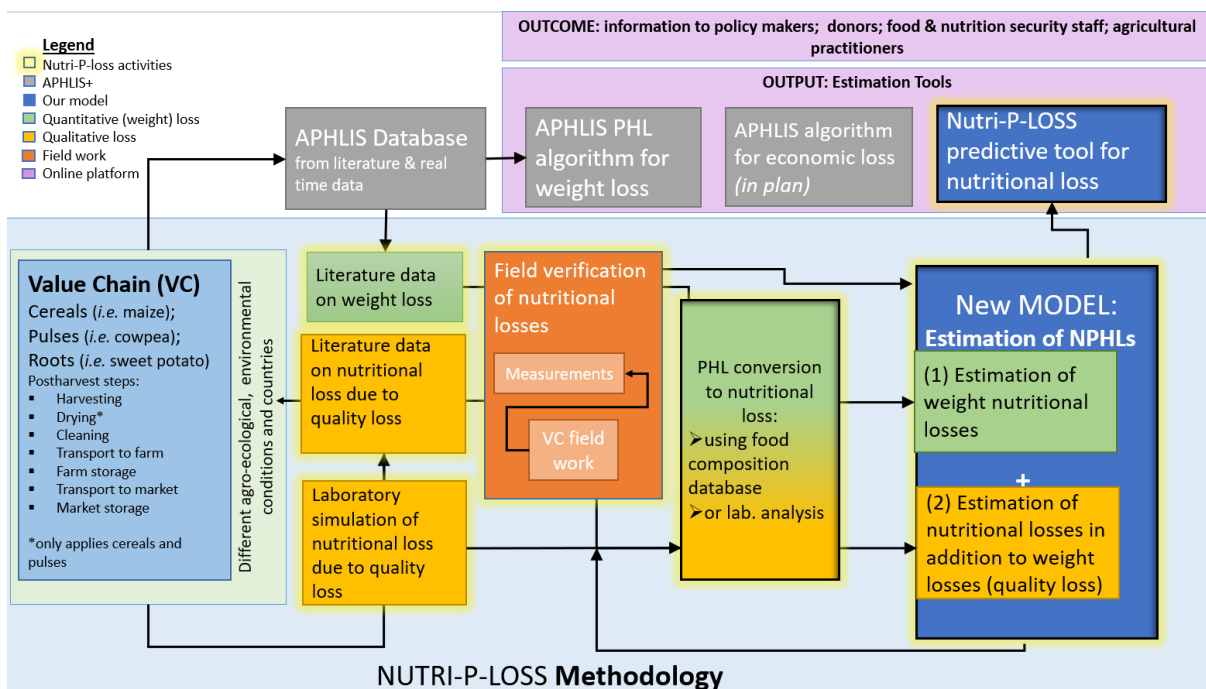
Understanding nutrition losses is critical because malnutrition is a serious public health issue that affects LMICs in particular and is responsible for almost half of the deaths of children under-five throughout the world (Global Nutrition Report 2018). Malnutrition occurs as a result of undernutrition, protein malnutrition, and deficiency in specific micronutrients, with deficiencies in iron, zinc and vitamin A being the most prevalent in LMICs and causing major health problems and knock-on effects for economic development (Global Nutrition Report 2018).

Nutritional losses can happen throughout the postharvest stages of the food VC when food is either physically lost or its quality is degraded through spoilage. Despite the potential crucial impact of nutritional losses on human health and economic growth, such losses have often been overlooked and there is an absence of suitable methodology to estimate them. Estimating these losses is important because they have a direct impact on food and nutrition security.

The proposed methodology provides an innovative way to measure the nutritional losses that could affect people who are at high risk of malnutrition in LMICs. It will support agricultural/nutritional policy formulation; improve food and nutrition security by improving food loss estimates and monitoring of loss reduction activities.

The Approach

The envisaged outcome pathway and main activities for the IMMANA funded NUTRI-P-LOSS project and the relationships with the existing APHLIS+ are described:



The NUTRI-P-LOSS methodological approach

NUTRI-P-LOSS has developed and tested a methodology to estimate NPHLs throughout the value chain (VC) (*light blue box*). This shall feed into the APHLIS+ model and use their existing tool to predict those NPHLs. Our approach is based on the fact that nutritional losses can occur in one of two ways:

(1) **Nutritional quantitative (weight) losses:** This assumes that the nutrition composition of the product remains constant. Hence, quantitative NPHLs can be estimated from postharvest weight losses (current APHLIS tool (*grey box*) and other literature (*green box*) converted into nutrients (*green-orange box*). Nutritional food composition can be obtained from literature but also from laboratory analysis of food samples (for example field samples (*dark orange*)).

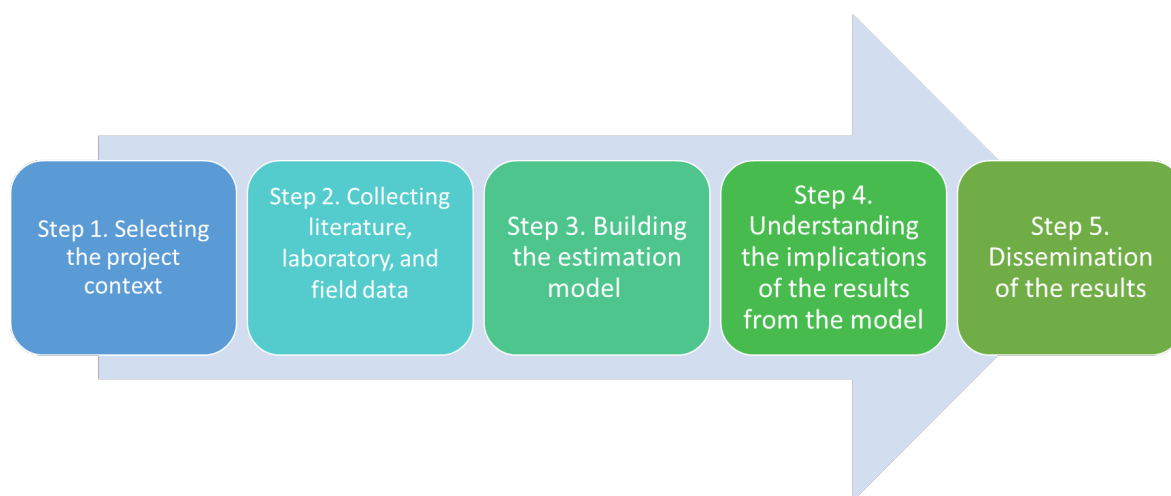
(2) **Nutritional qualitative losses:** This assumes that the nutritional composition of the product changes along the value chain (usually a decline). Quality NPHLs comprise losses that are not directly related to weight loss but may be even more significant (e.g. selective consumption of only certain parts of grain by insects; nutrient degradation due to high temperature, or oxidation). These typically occur during long storage of crops. These were estimated from available literature and simulated and analysed in laboratory experiments (*orange*) and in field trials (*dark orange*).

Quantitative or (2) qualitative NPHLs (*dark blue*) were produced using crop nutritional composition or nutritional changes at each of the steps of the value chain obtained either by literature or laboratory analysis (*green-orange box*). In addition, data were generated from field trials, in our case, in Uganda and Zimbabwe for sweet potato, maize and cowpeas. These data were critical for the development of a model that is close to the ‘reality on the ground’ and was key in fine-tuning the model.

At the start, we surveyed members of the APHLIS network and food and nutrition policy specialists to understand their needs regarding nutritional postharvest losses. These stakeholders were also consulted about the practicality and user-friendliness of the tool (*pink*). In the same way as for the APHLIS predictive tool for physical and quality loss (*grey*), the new model was developed with the purpose to fit as an add-on to the APHLIS website and presented as the Nutri-P-LOSS algorithm (*dark blue*). Currently we do have a tool that presents as an Excel file, which is independent of the APHLIS+ platform and could be integrated on the APHLIS platform. The NUTRI-P-LOSS model will help practitioners predict NPHLs for the focal crops studied. It allows for the scaling up of the methodology to other crops using a similar approach (*yellow highlight*). The results of the model have agricultural and nutritional intervention implications that shall be communicated to key agriculture and food security decision-makers (*pink*) through the use of the open access tool and policy recommendations.

Nutritional postharvest loss: step-by-step

The development of a NPHL estimate is based on a step-wise approach which is described as follows:



Step 1. Selecting the project context

Firstly, the food products and countries have to be identified.

- ✓ *Countries*: if limiting food insecurity and poverty is the aim of the work, countries in LMICs could be selected. A list of [DFID priority countries](#) can be helpful in identifying countries of interest.
- ✓ *Crops*: In addition the [FAOstat](#) website can help find about the annual production of crops in those countries.
- ✓ *Nutritional situation*: [Demographic Health Surveys](#) (DHS) give information about the major micronutrient undernutrition/overnutrition deficiencies, in those countries.

✓ *Value chain*: Information regarding the value chain can be obtained from literature on the specific crops and by consultation with country-partners.

Below are the different food groups according to the [Kenyan National Guidelines for Healthy Diets and Physical activity](#)

If the food group value chains are known (from harvest to the market), those could be considered for determining the NPHL estimate:

1. Starchy foods
2. Fruits and vegetables
3. Legumes and pulses, nuts and seeds
4. Meat, fish and animal protein
5. Fats and oils
6. Sugar and sweet
7. Condiments, spices and beverages

Selecting crops of importance for a country based on availability, affordability and accessibility as well as micronutrient-rich foods is advisable in developing strategies to tackle food and nutrition insecurity. As this approach relies on published information and local inputs, it is recommended that the selected crop should be produced at a sufficiently large scale and that their PHL could have a nutritional impact at the country/regional level. In order to tackle malnutrition, selection of commodity value chains should be based on the nutritional context of the target country or target population. A feature of this is the double burden of malnutrition, which is characterised by the coexistence of undernutrition and micronutrient deficiency, along with overweight and obesity, or diet-related non-communicable diseases, within individuals, households and populations.

Step 2. Collecting literature, laboratory, and field data

Collecting robust data is critical to ensure the quality of the NPHL estimate. Initially data from literature can be explored and gaps identified. If those gaps in information are important, it may be necessary to conduct laboratory experiments and field studies to generate the missing data.

(1) Estimating NPHLs based on weight loss: The quantitative loss estimate is based on the conversion of physical losses into nutrient losses using nutritional food composition of crops.

- Weight or physical losses of crops at the various value chain nodes can be obtained from the existing APHLIS database on physical losses. If the crops are not in the database, a literature review may be necessary. Conducting a value chain study of the crops in the countries of interest and with a step-by-step measure of postharvest losses (Parmar *et al.* 2017) is the gold-standard approach but this may require additional funds and time.
- Nutritional composition (macronutrients and micronutrients) can be obtained either from nutritional databases ([USDA](#), [INFOODS](#)), food composition tables from the countries of interest, or from laboratory analysis of crop samples. Selecting a food composition that is suitable to the country and crop(s) of interest is critical: an example is the USDA database that provides food composition of an extensive number of crops. However, those are mostly from the USA and may be different to that of LMICs.

Example from the NUTRI-P-LOSS project:

Weight loss: We conducted focus groups with farmers in Uganda and Zimbabwe on the reported levels of losses, but a weakness was that these estimate levels were not measured (using weight measurement) and we did not include them in the model. Finally, the weight losses for sweet potato, maize and cowpea were estimated using APHLIS (the literature review was conducted by APHLIS+ (Tanya Stathers) on all the postharvest cereal, root and tuber and legume studies).

Nutritional composition: In our experience, laboratory analysis of crops in-country was a preferred approach to published food composition because a general food composition table may not give context-specific nutrient values. Macronutrients and micronutrients were analysed from field samples at baseline (harvest for sweet potato or after drying for maize) either by laboratories in-country or laboratories abroad and compared to the nutritional database (USDA Standard Reference).

(2) Estimating NPHLs due to qualitative changes in the nutritional composition of the product: Key-VC steps, where nutritional qualitative changes can occur, have to be identified in the first place. In our experience, the nutritional qualitative changes in the product are better estimated using laboratory and field experiments rather than literature. At critical steps during laboratory and field experiments, samples should be collected for nutritional composition analysis (by a laboratory of reputable quality with inter-laboratory cross-checked analyses performed). Laboratory and field studies should preferably include the effects of key loss-causing factors such as storage insect pests, which are a major cause of quality deterioration during storage of durable cereals and pulses. For the field storage experiment, typical storage time durations and typical ambient conditions (temperature/humidity) should be considered in order to produce a realistic prediction model estimate.

Literature did not give enough robust data to build a qualitative estimate of NPHLs in sweet potato. The sweet potato nutritional changes were reviewed, but it was difficult to draw conclusions because the results of the studies varied and there were insufficient studies of the same kind to compare conditions. Overall, fresh sweet potato extended storage tends to result in increasing sugar content (Zang et al. 2002) whilst dried sweet potato storage results in a sharp loss of carotenoids (Bechoff et al. 2010). Sweet potato nutritional composition was measured at key-steps of the value chain (fresh, after a few days of storage, after drying) along the value chain in the field in Uganda.

Based on our value chain steps, we stated that storage was the major key-step where nutritional qualitative changes would occur, because of the extent of storage time. Parallel to storage studies in the laboratory, using artificial infestation in the UK, field storage experiments were conducted in Zimbabwe for cowpea and maize grain with natural infestation and stored in different types of storage bags (e.g. hermetic bags vs woven polypropylene bags) for typical storage periods.

Laboratory trials in the UK were carried out for a duration of 6 months for white maize and cowpea and for 4 months on orange maize and dried orange fleshed sweet potato at controlled temperature/humidity (26°C/47%). In the field (Zimbabwe), white and orange maize and cowpea were stored for 8 months in two districts (Guruve and Mbire) in the Zambezi Valley.

We did not use fresh sweet potato in the laboratory storage study because, according to initial discussions, farmers would physically remove sweet potato that was damaged; therefore, losses in fresh sweet potato equated with quantitative losses. In addition, the storage step would be shorter compared to grains and therefore it was hypothesized that changes would be minimal in the sweet potato root.

(3) Collecting additional information from the field: Additional information should be collected from the field to refine the model through a better understanding of the crop value chain postharvest loss. Furthermore, qualitative research could help understand the constraints facing various stakeholders in managing the crop and reducing postharvest losses along the VC.

We conducted focus groups and key informants' interviews in the field. We collected data about the determinants of postharvest losses and postharvest loss management as reported by farmers in Uganda for maize and sweet potato and in Zimbabwe for maize and cowpea. We also collected data regarding gender roles and responsibilities along the sweet potato value chain in Uganda. This information was useful to understand the context and constraints of postharvest losses. Most of the interviews focused on physical postharvest losses and also on the quality deterioration of the product. The concept of 'nutritional qualitative postharvest losses' was difficult to grasp for the interviewees because it is not necessarily linked to a visible quality change in the product and there was an apparent lack of general awareness of the nutritional postharvest loss.

Step 3. Building the estimation model

The estimation model reconciles the results from the field work, laboratory work and literature. In order to build the model, quantitative and qualitative nutritional postharvest losses have to be combined.

The approach is as follows:

- 1) The estimated quantitative NPHLs, presented as predictive macronutrient and micronutrient losses, are calculated for each crop at each step of the VC based on weight loss.
- 2) The qualitative NPHLs (from data collected from laboratory and/or field trials) are built into a predictive model. The predictive model needs to include factors such as:
 - storage time
 - percentage insect damage or weight loss due to insect damage
 - temperature/humidity
 - changes in nutrient composition at key-steps of the VC (i.e. storage)
 - Other factors that are specific to the commodity and VC

The laboratory data and field data should be compared and if in agreement, potentially combined. Overall, the data selected have to be as 'realistic' as possible and describe the reality on the ground.

- 3) Once all the data have been collected, the next part of the work is to combine data appropriately. This requires an understanding of the value chain, the commodity and having a robust qualitative prediction of nutrient changes (qualitative NPHLs).

We developed two predictive models for nutritional qualitative changes: one from laboratory data and one from field data. The laboratory model measured nutritional changes in cowpea and maize during storage with artificial insect infestation, whilst the field model measured nutritional changes in cowpea and maize with natural infestation. Factors were storage time, percentage damaged grain and temperature. The laboratory and field models could not be reconciled and we included both with separate outcomes.

Physical nutritional losses were calculated at each step of the value chain and qualitative nutritional changes (given by the laboratory and field models) were included at the farm storage level. Other qualitative changes, at the drying stage for sweet potato and milling stage for maize, were included.

Step 4. Understanding the implications of the results from the model

In addition to the NPHL estimate, the predictive model includes a prediction estimate of loss in daily nutritional requirements for average individuals in the country/population of interest and also for vulnerable groups (selected based on the country-specific context), for e.g. pregnant and lactating women, children under five years-old, HIV-infected people and elderly people.

Once the NPHL estimate has been developed and validated, the implication of the nutritional losses (for the whole value chain or individual steps in the value chain where nutritional losses are the most critical) are formulated in terms of nutrition and food security and together with recommendations to reduce nutritional losses, are communicated via publications. Qualitative information collected in the field is useful to advise on postharvest loss mitigation at this stage.

Several factors should be considered:

- Gender
- Demographics by age
- Nutritionally vulnerable groups (e.g. children under five, lactating women, HIV-infected people, elderly)
- Physical activity level (which will be high for manual workers)

Step 5. Dissemination of the results

Dissemination of the model can be carried out through an open-access platform such as [APHLIS+](#). Results of the project could also be shared on international platforms, for example, 'FAO Save Food' or [Global Postharvest loss](#). Policy implications of nutritional postharvest losses could be shared with stakeholders via various means, e.g. policy briefs and official meetings with policy makers, farmer field schools and consultations with farmers, meetings with private companies, stakeholder seminars/workshops, academic publications with researchers etc.

A detailed description of the key elements of the development of the methodology for NPHL estimate are presented in the rest of the document.

Selection of countries, crops, and partner institutions

Selecting the countries and crops of interest is the first step. Because the nutritional postharvest loss estimate has been designed mainly with food and nutrition security in mind, selecting countries where there is food insecurity and identifying the key-food security crops is a preferred approach. Selecting nutrient-rich foods could also be advisable in developing strategies to tackle food insecurity, especially if they are produced at large scale and the losses could have a nutritional impact at the country level.

In our project we conducted the field studies in two DFID priority countries in sub-Saharan Africa (Uganda and Zimbabwe) and in key food security crops including nutrient dense crops: maize - including orange maize and cowpea in Zimbabwe, and maize and sweet potato - including orange-fleshed sweet potato (OFSP) in Uganda. The inclusion of nutrient-dense crops in the project had two important goals: 1. Investigate improved crops that could help tackle nutrient deficiency and 2. facilitate the follow-up of those nutrients and losses throughout the VC, because their quantity is higher than in non-biofortified crops.

A key-component of the project is the choice of partner institutions in the countries where the study will take place. Having research institutions which have hands-on expertise of the selected crops is essential to the quality of the results, success of the project.

We worked in collaboration with partners in Uganda (NARO) and Zimbabwe (UZ), whilst the International Potato Center (CIP) was involved with the sweet potato study in Uganda.

<i>Local partners</i>	<i>Country</i>	<i>Type of food</i>	<i>Target crop</i>	<i>Main target nutrients</i>	<i>Wider application of the methodology</i>
<i>National Agricultural Research Organisation (NARO)</i>	<i>Uganda</i>	<i>Root</i>	<i>Sweet potato including orange fleshed sweet potato (developed & promoted by HarvestPlus)</i>	<i>Carotenoids (provitamin A), carbohydrates</i>	<i>Other roots and biofortified crops containing provitamin A, such as orange maize and yellow cassava</i>
		<i>Cereal</i>	<i>Maize</i>	<i>Proteins, carbohydrate, (iron, zinc)</i>	<i>Other cereals (wheat, rice)</i>
<i>University of Zimbabwe (UZ)</i>	<i>Zimbabwe</i>	<i>Legume</i>	<i>Cowpea</i>	<i>Proteins, carbohydrate, lipids, (iron, zinc)</i>	<i>Beans and other legumes</i>
		<i>Cereal</i>	<i>Maize including Orange maize (developed & promoted by HarvestPlus)</i>	<i>Proteins, carbohydrate, (iron, zinc), carotenoids (provitamin A)</i>	<i>Other cereals (wheat, rice)</i>

In our case, our African partners in Uganda and Zimbabwe are also key country partners in the APHLIS+ project. Due to the limited project duration (2.5 years), having partnerships that are already established and working actively on the ground was important to us as it enabled the focus to be on the tool's development as opposed to building new partnerships. Long term sustainability will come through the linkage with APHLIS and other interested programmes.

A multi-disciplinary team with expertise in nutrition, postharvest loss, value chains, food technology, and predictive modelling is needed to develop a complete tool. One of the most essential skills is the predictive modelling expertise that will be used for the nutritional qualitative losses.

Selection of nutrients

An understanding of the importance of various nutrients for public health is critical for the selection of relevant nutrients and a contextualised situation analysis of the country(ies) of interest (*i.e.* most common nutrient deficiencies in the population) may be useful baseline information.

Our method developed an estimation of:

- i) the change in macronutrients: carbohydrates, proteins and lipids, dietary fibre and energy.*
- ii) key changes and shortfalls in the following selected, key micronutrients: iron, zinc and vitamin A. Deficiencies in these often un-monitored micronutrients are prevalent in many developing countries, resulting in hidden hunger and malnutrition (Welch & Graham, 1999).*

It should be considered that nutrients may be differentially affected by nutritional losses (**qualitative nutritional loss**): some nutrients are not very sensitive to degradation (carbohydrates, proteins, and metal ions such as zinc or iron), but others – such as vitamins (A,B,C,D,E) – are easily degraded. For example, carbohydrates and minerals (iron/zinc) are mostly stable, so nutritional loss would equate to weight loss. But selective consumption by pests of the germ portion of grains can result in protein change for example and affects the proportion of other nutrients such as fat and carbohydrate in the grains. Provitamin A carotenoids can be qualitatively degraded by oxidation due to exposure to air (insect damage exposing part of the grains to air; or air oxidation during storage) or by temperature. About 70% of carotenoids (provitamin A) were lost from dried sweet potato after 4 months' storage without any measurable weight loss (Bechoff *et al.*, 2010a; 2011).

Selection of value chain steps

An estimation of the critical steps where physical and quality losses occur along the VC, along with their main causes, should be conducted. The steps of the value chain for the crops of interest have to be identified through literature and interviews with partners in the field. APHLIS has a record of the main value chain steps for cereals such as maize, rice, sorghum, millet, wheat, barley, fonio, oats and teff and is currently developing value chain steps for pulses and roots.

If no robust literature data is available for the crop(s) of interest, a VC approach (Kaplinsky and Morris, 2001) can be used to systematically examine the nature and extent of physical and quality losses from farm to market. The approach focusses on estimating PHLs at all postharvest stages up to the

consumer buying the product in the market (Aulakh & Regmi, 2013). The different value chains-of a single commodity and the proportion of food products that (1) become unfit for human consumption (physical loss); and (2) are affected by different levels of quality degradation (quality loss) at the different steps of the VC, can be recorded.

In the NUTRI-P-LOSS project we were able to use the existing VC steps from APHLIS for cereals and pulses and VC steps in-development for sweet potato: There was one value chain for maize and one for cowpea and two value chains for sweet potato (fresh sweet potato for home consumption or marketing) and dried sweet potato (home storage of dried pieces during the season where no fresh sweet potato is available or when sweet potato is of lesser quality).

- *Maize and cowpea: 1. Harvesting/field drying; 2. Transport from field; 3. Platform/further drying; 4. Threshing and shelling; 5. Winnowing; 6. Farm storage; 7. Packing, sorting, grading 8. Transport to market; 9. Market storage)*

- *Fresh sweet potato: 1. Harvesting and handling; 2. Transport from field; 3. Keeping of raw crop; 4. Transport to market; 5. Market storage*

- *Dried sweet potato: 1. Harvesting and handling; 2. Transport from field; 3. Drying; 4. Farm-level storage after drying; 5. Transport to market; 6. Market storage*

These steps were in accordance with field observations during value chain studies in Uganda and Zimbabwe.

Estimating quantitative nutritional losses

The quantitative loss estimate is based on the conversion of physical losses throughout the value chain into nutrient losses using food composition tables.

Weight loss

Obtaining accurate weight loss at each step of the VC is critical. Weight losses can be obtained from literature or from reported or measured weight loss whilst conducting a VC study in the field.

Average weight losses for maize, cowpea, and sweet potato were obtained from APHLIS. There are two value chains for sweet potato (fresh sweet potato for home consumption or marketing) and dried sweet potato (home storage of dried pieces during the season where no fresh sweet potato is available or when sweet potato is of lesser quality).

Physical losses are best reported as [cumulative losses](#). The sum of the losses is not the individual losses because losses are cumulative (definition of cumulative weight loss: “A loss value not from a single measurement but from multiple measurements, where at each measurement the previous loss has been considered. The most common example is where losses from production are estimated. With each subsequent loss the remaining production is smaller, consequently even if relative (%) weight losses remain the same the absolute losses (tonnages) diminish. A special case of this is farm storage losses where farmers are consuming grain during the season. Losses become greater with time so that each lot of grain that is consumed will have been subject to a different degree of loss. The cumulative storage loss is the weighted average of each loss measure not just the loss observed in the grain that remains at the end of the storage season.” (Hodges *et al.* 2014).

The steps of the value chain where potential nutritional qualitative losses can happen, in addition to quantitative losses, should be identified at this stage.

Selection of the nutritional composition of crops

Selecting the appropriate nutritional composition for each of the crops is important as this would have implications on the predicted amounts of the different nutrients lost.

Food nutritional composition is generally presented for 100g of product and in this type of format:

Table. [USDA food composition for white maize](#)

Try FoodData Central **Basic Report: 20314, Corn grain, white**

[Return to Search Results](#)
[Full Report \(All Nutrients\)](#)
[Statistics Report](#)
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Nutrient values and weights are for edible portion.

Search nutrient table:

Nutrient	Unit	1 Value per 100 g
Proximates		
Water	g	10.37
Energy	kcal	365
Protein	g	9.42
Total lipid (fat)	g	4.74
Carbohydrate, by difference	g	74.26
Minerals		
Calcium, Ca	mg	7
Iron, Fe	mg	2.71
Magnesium, Mg	mg	127

Showing 26 nutrients

To make our estimate relevant to the country of interest, in our study, rather than using food composition from literature (nutrient databases), we sent samples collected in the field for nutritional analysis to a laboratory. We compared our data to USDA data and existing literature on food composition of African crops, to verify that it was of a similar order.

We selected the data that was analysed by the laboratory in-country (CIP-Kenya or Zimbabwe laboratories) for the samples of white maize, orange maize, cowpea, white fleshed and orange fleshed sweet potato, because data from Ugandan and Zimbabwean samples is better for a model using sub-Saharan African crops and destined for African farmers. In our opinion, selecting this data is more relevant because context-specific. We selected samples at harvest (baseline) and compared the nutritional composition of the same samples analysed by the in-country laboratory and a second laboratory (cross-check analysis). Nutritional composition of the dried sweet potato value chain was calculated on a dry weight basis (from fresh sweet potato to the dried product), in order to account for postharvest losses, independently of the change in dry matter

Conversion of weight loss into nutritional loss

The cumulative nutrient loss at each of the steps of the value chain can then be calculated for 100g of the crop, using the assumption that the nutritional composition does not vary at the different steps (pure quantitative loss) and therefore the weight loss in the product will be translated into a similar proportion of each nutrient loss.

Estimating qualitative nutritional losses

The qualitative loss estimate is based on predicting the changes in nutrients in crops. The nutrient changes may be exclusively qualitative (for example at the storage step if there is no material lost) or quantitative and qualitative at the same time (for example there may be material lost at the storage step as well as nutritional changes in the crop if stored for a certain amount of time).

Predictive equations

The predictive equations can be generated using a multiple linear regression model. Based on the storage conditions provided from the field and laboratory data, factors including storage time, level of infestation, temperature and % damaged grain introduced separately and as an interaction were considered as factors that could potentially contribute to changes in macronutrient and micronutrient content.

An example of predictive equations developed as linear regressions is as follows: $y = a + bx_1 + cx_2 + d x_1x_2$ where x_1 =storage time; x_2 =% damage grain and $x_1 x_2$ =interaction term. a,b,c,d are constants.

In addition to the predictive equations, the significance of each factor incorporated into the model on target nutrient levels was assessed using analysis of variance (ANOVA) ($p < 0.05$).

Example of statistical inputs used to design the predictive model with factors influencing nutritional losses: example of all grains from lab data (predictive models were produced by Hawi Debelo & Mario Ferruzzi, North Carolina State & Purdue University)

Crop	Target nutrient		Predictive factors	Predictive factors with interaction terms
White maize	<u>Macronutrients:</u> Energy, Moisture, Protein, Nitrogen, Fat, Total Carbs, Dietary Fibre	<u>Micronutrients:</u> Total Ash, Iron, Zinc	Storage time (weeks), Level of grain damage (%) (related to level of infestation)	Storage time (weeks) X Level of grain damage (%) (related to level of infestation)
Cowpea				
Orange maize		<u>Micronutrients:</u> Total Ash, Iron, Zinc, Carotenoids		
Dried sweet potato				

Conversion of nutritional loss into nutritional requirement lost at the country level and estimated number of people affected

Nutrient loss per 100g can be translated into nutrient loss at the country level (national production per year) or regional level (regional annual production). National production data can be found on the APHLIS website (<https://www.aphlis.net/>) or FAOStat website (<http://www.fao.org/faostat/>) and through country-partners who have information from the Ministry of Agriculture, for example.

A challenge was to obtain reliable data for country production: national production data per annum for cowpea, sweet potato, and maize was obtained either from the APHLIS+ website, FAOStat, or the Ministry of Agriculture (through NUTRI-P-LOSS partners). The total production was estimated to be after exportation. Orange fleshed sweet potato production in Uganda was estimated to be 10% of the total sweet potato production and the proportion of sweet potato being dried estimated to be 15%, based on information from the International Potato Center (CIP) (Mayanja Sarah, and Robert Mwangi (World Food Prize 2016), Personal Comm.). National Orange maize production in Zimbabwe was estimated from a newspaper article from the [Zimbabwean Farmers Association](#).

To further understand how nutrient loss at the country level can impact individuals, NPHL loss can be converted into lost nutritional requirements. The number of people who could have lost their daily nutritional requirement can be calculated.

There are various measures of nutritional requirements as described by the [Nutrient Reference Values for Australia and New Zealand](#) :

- Estimated average requirement (EAR): A daily nutrient level estimated to meet the requirements of 50% of the population (healthy individuals)
- Recommended Dietary Intake (RDI): The average daily dietary intake level that is sufficient to meet the nutrient requirements of nearly all (97.5% of the population) (healthy individuals)
- Adequate Intake (AI): the average daily nutrient intake level based on observed or experimentally determined approximations or estimate of nutrient intake by a group of healthy people that are assumed to be adequate
- Estimated Energy Requirement (EER): the average energy intake that is predicted to maintain energy balance in a healthy adult of defined age, gender, weight, height and level of physical

activity, consistent with good health. In children and pregnant/lactating women, the EER includes those needs associated with the deposition of tissues or secretion of milk

- Upper level of intake (UL): the highest average daily nutrient intake level likely to pose no adverse health effect to almost all individuals in the population. As intake becomes higher than the UL, the potential risk of adverse effects increases

The project had to decide which measurement of nutritional requirements would be the most suitable. EAR was selected because there were less risks of over-estimating the nutritional requirements than when using RDI (Recommended Dietary Intake). EAR for an average individual in the country was calculated after categorising the population into various age groups including nutritionally vulnerable groups.

The conversion of nutritional losses into nutritional requirements lost by different life-stage groups and selection of EARs was initially discussed by experts including Dr Tanya Stathers, Anne Bush, Dr Julia de Bruyn, and Dr Mario Ferruzzi under the APHLIS+ project in 2018.

Example of categories of population:

- Children < 5 years
- Children 5-15
- Adolescent boys 15-19
- Adolescent girls 15-19
- Adolescent girls 15-19 pregnant
- Adolescent girls 15-19 lactating
- Men 20-49
- Women 20-49 not pregnant/lactating
- Women 20-49 pregnant
- Women 20-49 lactating
- Men 50-70
- Women 50-70
- Men 70+
- Women 70+

In addition, the population can be further divided into specific groups of interest, for example, children under 1 year, HIV-infected population etc. A challenge with very specific groups is to find ample robust data to estimate the proportion of those groups in the total population.

In order to calculate the EAR of an average individual, the population age pyramid of the country(ies) and the proportion of groups of interest in the country(ies) has to be calculated. The population age pyramid can be found for a number of countries on the following website:

<https://www.populationpyramid.net/>

In our project, we selected different groups of nutritional interest based on the DHS (Demographic Health Survey) for Zimbabwe and Uganda. The age categories 50+ were selected because there were fewer older people (the age pyramids are a triangular shape: most of the population is young). The proportion of those different groups of nutritional interest related to the total population of the country was calculated. The number of pregnant women was calculated from the percentage of pregnant women given by the DHS for Zimbabwe and Uganda (respectively 6.3% and 10% of women 15-49-year-old). The number of lactating women was calculated from the birth rate (34.2 and 42.9 live birth per

1000 people in Zimbabwe and Uganda, respectively) (Index Mundi) minus the infant death rate (36 and 35 infant mortality per 1000 live birth in Zimbabwe and Uganda, respectively) (UNICEF <https://data.unicef.org/country/zwe/> and <https://data.unicef.org/country/uga/>). Number of live infants was equated to the number of women giving birth and having a live infant (we ignored twin, triplet births). Out of this, the number of lactating women was calculated using the proportion of women breastfeeding from the DHS (98% and 97% in Zimbabwe and Uganda, respectively). The average weight gain of pregnant women was indicated to be on average 7.5kg over the pregnancy period (Nutrient Reference Values from Australia and New Zealand page 196). For each nutrient we calculated the average additional requirement of pregnant women over the pregnancy period (9 months). Some nutritional requirements do not change in the first trimester of pregnancy (e.g. energy, protein, carbohydrate) whilst others are higher throughout the pregnancy period (fibre, iron, zinc, vitamin A). The average weight of lactating women was estimated to have returned back to their initial weight before pregnancy. The nutritional requirements of lactating women was estimated to be for exclusive breastfeeding over the first 6 months and thereafter partial breastfeeding (Nutrient Reference Values from Australia and New Zealand; <http://www.fao.org/3/y5686e/y5686e0b.htm>) up to 12 months.

An estimate of energy requirement is based on the Physical Activity Level (PAL) as indicated: <http://www.fao.org/3/y5686e/y5686e07.htm>):

- Sedentary or light activity lifestyle: PAL \approx 1.5
- Active or moderately active lifestyle: PAL \approx 1.8
- Vigorous or vigorously active lifestyle PAL \approx 2.2

Estimated energy requirements were based on a physical activity level (PAL) = 1.8- moderate for all the groups because we hypothesised that manual jobs are common in Zimbabwe and Uganda and the population pyramids indicate a young population. The physical activity level may differ between cities (where some people who work in offices and drive their car would have a more sedentary activity (PAL=1.4-1.5, whilst others would be outside working in markets and businesses) and rural areas (where farmers whose job is physical would be the major part of the population PAL=2.0-2.2). Nutritional requirements for carbohydrate were not indicated in Nutrient Reference Values from Australia and New Zealand for individuals older than 1-year-old therefore we used the USDA standard. Total fat requirements were also only indicated up to 1-year-old, therefore we used 20 g/100g thereafter. For orange maize and orange fleshed sweet potato the conversion factors from provitamin A carotenoids to retinol were 4:1 and 12:1, respectively (Bechoff and Dhuique-Mayer 2017).

The number of people having lost their daily nutritional requirement can be calculated by first dividing the nutrient lost at the country level (per annum) by 365 days. This daily quantity is then divided by the daily nutritional requirement of an average individual. This calculation gave the estimated number of average individuals in the country that would have lost 100% of their nutritional requirement (EAR) as a result of the crop postharvest loss. This was calculated as a proportion of the total population of the country.

Challenges and lessons learned

Firstly, considering the successes, this project has successfully delivered an approach that other practitioners, interested in measuring nutrition losses, can successfully replicate. This approach has been developed as a collective effort between international and local partners in the UK, Africa and USA. An original methodology has been tested that can achieve the following:

- determining nutritional postharvest loss (NPHL) estimates in various crops and commodities at each step of the value chain
- determining the potential impact of those nutritional losses on the nutritional requirements of people at the population level

As in any new approach, there were a number of challenges and new lessons to be learned. Those from NUTRI-P-LOSS can give some useful insight for future projects that will look into the development of NPHL estimates. We have segmented those challenges into 5 types: those related to 1) literature collection, 2) laboratory analysis, 3) controlled experiments, 4) field work, and 5) the development of the model.

1. Literature

- Lack of adequate data: The information reported in the literature referred mainly to physical losses and little was reported in relation to qualitative nutritional losses that could be applied to our model. This gap was particularly relevant for postharvest loss for sweet potato. There was also a lack of consistency in the data (for example FAO figures that have been used in previous work on nutritional postharvest losses ([Glopan 2018](#)) often present very high physical postharvest losses. Sometimes, the way the information was reported meant that it was not specific enough for the type of work that we were planning to do (for example other nutrients were presented than those that we were planning to include in the model or other conditions of storage, environment *etc.*).

The gaps in knowledge included for example:

- Information about the type and extend of nutrition losses
- Information about the relationship between nutrition losses and insect, mould, or other pest damage
- Information about how nutrition loss relates to the transformation of the product – for example for a fresh product with a low dry matter content to a dried one with a high dry matter content and the method used to achieve this (chip size, duration and method of drying etc)

This absence of literature data or consistency in reporting meant that it was important to conduct laboratory and field trials to ‘fill the gaps’ in knowledge. In our experience, for common crops and commodities, quantitative nutritional losses could be estimated from literature but qualitative nutritional losses (changes) would require actual experiments.

2. Laboratory analysis of nutrients

- In-country laboratory selection and inter-laboratory quality check: One of the critical tasks of the project was to identify laboratories that could accurately analyse the nutritional composition of our samples (maize, cowpea, sweet potato).

Samples produced in Zimbabwe were analysed by the University of Zimbabwe, and samples from Uganda were analysed at CIP-Kenya, at the [Beca Laboratory](#) (an international recognised laboratory platform for East Africa). Samples from the UK experiment under controlled conditions were sent to the KSS laboratory in Kent. We conducted interlaboratory cross check between the UK-Kenya laboratories and UK-Zimbabwe laboratories. We encountered problems with all the 2 out of the 3 laboratories: the UK laboratory gave inconsistent results on the first two batches we sent and then over-estimated the dietary fibre content in cowpea from Zimbabwe. The Kenyan laboratory gave values out of range for iron content after drying and this may be because there was soil contamination. In summary, inter-laboratory analysis gave consistent values for macronutrients but there were more discrepancies with regards to minerals and dietary fibre. We were able to solve those discrepancies by selecting the Zimbabwean laboratory, since it gave values in accordance with the literature for fibre content and also selected values for the samples at harvest stage for sweet potato in the field.

- Sample transportation: another challenge was logistics for the transportation of samples.

For example, samples of maize and cowpea for the storage experiment in the UK that were shipped from Zimbabwe were held in customs for 1 month and arrived in the UK with insect infestation, which led to a significant delay due to extra work removing the damaged grain. Samples of maize and sweet potato from Uganda had to be transported by road from Uganda to Kenya (Beca laboratory in Nairobi) and this required extra logistics. Other samples of dried sweet potato were air-freighted to the UK.

- Cost of laboratory analysis: The cost of nutritional analysis is a major constraint to the number of samples that can be collected. The cost per analysis was high, up to about £130 in the UK and cheaper in other countries, but cross-check analyses had to be performed to ensure that the results were of sufficient quality.

3. Experiment in controlled conditions in laboratory

In order to produce a predictive model, we conducted experiments of artificial infestation and storage under controlled conditions of temperature/humidity.

- Obtaining sufficient data from a controlled laboratory experiment to develop a predictive model: one of the challenges of laboratory data was that it was very labour-intensive (measuring grain damage etc.) in order to produce enough data points for the model. Despite this, the number of data points that were generated were still limited because the experiment was conducted at one temperature/humidity and therefore the conditions were different from the field. These were? approximate, sometimes far from the reality, but necessary if we want to develop a predictive model.

4. Field experiments

These are complementary to the laboratory experiment under controlled conditions and field work is necessary to understand and describe the actual conditions of the crop from harvest to market. However, field work has a number of challenges

- Which samples to collect: one of the challenges in the field is to decide which samples to collect for laboratory analysis. Because of the logistics of transportation and cost, a rigorous experimental design prior to starting the field work is needed, which determines the ideal samples for collection and the associated cost for transportation and analysis.
- Where and how to analyse samples for food analysis composition: the most suitable laboratory(ies) to analyse the samples must be identified. In our study, we analysed field samples in-country due to

the lower cost and for logistical reasons. A cross-check analysis is necessary to check the laboratory's reliability.

- Obtaining sufficient data from field work to develop a predictive model from field data:

In Zimbabwe we were able to obtain sufficient data to develop predictive equations from field data. In Uganda however we collected samples along the value chain for sweet potato, but there were not enough data points to develop a model.

Developing a predictive model from field data, where temperature/humidity and other environmental factors vary, can be a challenge.

- Qualitative research vs. quantitative research in the field: we spent time collecting qualitative research information in the field by conducting key-informant interviews and? focus groups. Although the data was useful to advise on mitigation strategies to reduce postharvest losses, it was not directly useful to the model. We feel that quantitative data collection (for example measuring physical losses throughout the value chain) rather than in-depth qualitative surveys (getting information about levels of physical losses from informants) would have given more robust data to the model.

5. Predictive Model

- Making choices and assumptions: the predictive model is based on the available data and thus is limited in its predictive capability. A model is a 'simplified vision of the reality' of nutritional postharvest losses. Hence, there is a need to make choices or assumptions in order to produce a model. For example, we assumed that the storage stage was where most qualitative nutritional changes occur that whilst such changes may have occurred at other stages, these were negligible compared with the storage stage.
- The challenge of estimating nutritional postharvest losses: We also had to make an assumption for physical quantitative losses that the nutritional composition would not vary at the different steps of the VC. If we want to translate NPHLs into nutritional requirements lost, we also must make a number of assumptions about the different groups of population, effect of processing, bioavailability of the nutrients *etc.*
- The model does not include details of some nutrients: we have measured selected nutrients but have not selected others. For example, amino-acids, simple sugars and other vitamins or minerals of nutritional importance could have been included but were not because of the limited scope of the project.
- Variability of model prediction: Finally, the variability of the data in terms of nutritional composition, physical losses and nutritional qualitative changes in the product could have added a much more rigorous understanding of NPHLs (for example giving minimum and maximal NPHLs in the model) but this would have required additional time for prediction modelling.

6. Lessons learned

Several lessons have been learned from the NUTRI-P-LOSS project:

✓ There is a lack of published information on nutrition losses in the postharvest value chain. Hence there is a need for new knowledge in this area so that we can better reduce the burden of malnutrition. To acquire this new knowledge, it is important to undertake laboratory and field studies in order to obtain reliable and high-quality data that is usable for the model.

✓ Access to reliable and cost-effective laboratory analysis in LMICs is important for logistical reasons and for overall cost-effectiveness of the project.

- ✓ A challenge was identifying reliable laboratories to conduct nutrient analyses in LMICs. The cost of the analyses is a constraint and must be considered when applying for funds.
- ✓ Obtaining robust laboratory analysis and field data is critical and requires experienced staff in order to collect adequate and reliable information.
- ✓ A multi-disciplinary approach is critical for such studies. For example, a good understanding of the value chain in the field is key to making the right assumptions for the model prediction and this requires access to specialists in this area.
- ✓ Ideally, we should estimate the variability (standard error or minimum/maximum) of the model prediction, as this will make the prediction more robust.

Conclusions

The methods and metrics developed in the NUTRI-P-LOSS project were applied to a root crop (sweet potato), a legume (cowpea) and a cereal (maize) in two countries in Africa (Zimbabwe and Uganda). To our knowledge this is the first time that a predictive model is being developed to estimate nutritional postharvest losses of crops throughout the crop value chain.

In this document, we have developed guidelines to extend the NUTRI-P-LOSS approach to other commodities and different country settings. We have explained the different steps of this methodology and how it could be generalised. Therefore, researchers external to NUTRI-P-LOSS will be able to apply the same methodology to estimate nutritional losses for a different setting and target commodity.

An important benefit of this tool is that the identification of the main nutritional losses can result in an understanding of the nature of postharvest losses at various postharvest VC steps and therefore how these losses have an impact on food security. It can also help identify cost effective targeted solutions that can be supported by policy makers and practitioners. Hence, this tool can potentially impact agricultural policies and help agri-businesses, agricultural practitioners, and nutritionists mitigate nutritional losses.

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