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DEVELOPMENT OF A FOOD SAFETY TOOLKIT FOR DRY COMMON BEANS (*PHASEOLUS VULGARIS* L.) IN UGANDA USING A HAZARD ANALYSIS AND CRITICAL CONTROL POINT (HACCP) APPROACH

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ABSTRACT

Common beans (*Phaseolus vulgaris* L) may be contaminated with heavy metals and aflatoxins. Cooked beans may also be contaminated with micro-organisms due to poor hygiene and sanitation practices. Hazard Analysis and Critical Control Point (HACCP), which is a globally recognised food safety program, was proposed as a suitable program to minimise/eliminate the risk of contamination. Therefore, the objective of this study was to develop a HACCP plan for dry common beans in Uganda and an accompanying food safety toolkit. The seven principles of HACCP as outlined by Codex Alimentarius were followed to develop a HACCP plan for the dry common beans value chain in Uganda. A decision tree diagram was further used to identify each potential hazard at each processing stage and Critical Control Points (CCPs) along the chain. The identification of the CCPs was further supported by an evaluation of the actual risk and severity of the hazard. For the CCP identified, reliable control mechanism and corrective actions were established to fulfill the requirements set by the critical limits to guarantee the safety of the products. Verification and records systems were proposed to determine the effectiveness and traceability of the HACCP plan. For identified CCPs, a co-creation methodology was used to develop the food safety toolkit. This was carried out in four sessions that included a background of the chain actors' ambitions to determine the suitability of the toolkit, assessment of CCPs, expert advice on the CCP and an exercise to develop concepts for each CCP. From the analysis, fourteen processing stages starting from land selection to cooking and serving were identified. Out of these, four stages were CCPs. These were land selection and preparation, storage, post-harvest drying, and cooking and serving. Hazards at the CCPs included heavy metals, mycotoxins, and micro-organisms such as *S. aureus*, *E. coli,* and *Salmonella* spp. A combination of good hygiene and sanitation practices and good agricultural practices were recommended as control measures against the hazards. To further equip the value chain actors with mitigation strategies, a food safety toolkit whose usefulness is to give the actors a systematic means to control identified CCPs was developed. In this regard, the toolkit and HACCP plan will complement each other. From the study results, implementation of the toolkit, followed by an assessment of its uptake and impact on livelihoods and food safety risks is recommended.

Key words: Common beans, food safety toolkit, prerequisite programs, HACCP plan, hazards, Uganda

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INTRODUCTION

Food safety is an essential condition for food quality, which implies the absence or occurrence, within acceptable limits, of hazards that may create risks for human health [1]. Hazards are nonetheless a common occurrence along food value chains that lack effective control measures. The hazards may be inherent in the seed or introduced from other sources as food moves along the supply chain from the farm to fork continuum. Because of this, food safety risks such as food-borne diseases occur frequently. Today, there is an increasing public concern about the negative environmental and health impacts of chemicals (pesticides, growth regulators and mineral fertilisers) used in crop production [2] as well as microbial pathogens and their toxins. There is, therefore, a need to control the occurrence of these hazards through the implementation of effective Food Safety Management Systems (FSMS).

An important tool to assure food safety is the Hazard Analysis and Critical Control Points (HACCP) system, which has been incorporated into the Codex Alimentarius as well as into the national legislation of many countries [3]**.** Among FSMS, HACCP is recognized in the international food safety community as a worldwide guideline for controlling food-borne hazards [4]. The HACCP approach can be applied to all stages of the food process, ranging from production to processing, transportation, retail in commercial establishments and/or direct utilization by the consumer [5].

Two major components of HACCP are hazard analysis and critical control point determination. Hazard analysis is primarily about systematically identifying and assessing the food production process, and selecting any biological, chemical, and physical risks or factors that may render the food unsafe. Critical control is mainly about utilizing the results of hazard analysis, to formulate and manage the controllable points or procedures during the process to minimize the food safety hazard of final products [6]. A HACCP system thus entails a systematic and structured approach to identifying hazards (biological, chemical, and physical), assessing the likelihood of these occurring at any stage of food production from raw materials to the final product, and defining preventive measures for their control to ensure that food safety control is integrated into the design of the process, rather than at testing of the end products [7].

To implement a HACCP system, adequate information on the product and the operational procedures related to its processing is critical, as it allows for identification of the points where contamination is likely to occur, and the setting of most effective preventive measures to ensure food safety [5]. Successful implementation of HACCP is impossible without the prerequisite programmes, such as Good Agricultural Practices (GAP), Good Manufacturing Practices (GMP), Good Hygiene Practices (GHP) and Sanitary Standard Operation Procedures (SOPs) [8]. Implementation of these practices and procedures is a fundamental prerequisite to making implementation of the HACCP system feasible [9]. Therefore, efforts to improve product quality and food safety can only be achieved by a consistent and integrated implementation of these prerequisites during crop production, harvesting, post-harvest storage, food preparation and any other stages along the food value chain.

Even though HACCP has been applied to most foods and food products, not much consideration has been given to the dry common bean, specifically in Uganda and other

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African countries. One of the factors behind this is that beans are dried immediately after harvest. Moisture content and water activity are key factors affecting the storage, shelf life, and safety of foods [9]. The moisture content of the dry common bean is 16–20% but are traded at a moisture content of 16% or less [10]. Dry common beans may thus be regarded as safe because of their low moisture content. Nevertheless, some studies have shown that beans can accumulate heavy metals [11] and can be contaminated with aflatoxins [12]. In addition, street-side vending of cooked beans in some countries such as Uganda is done by vendors who may have poor hygiene practices [13], which are risk factors for microbial contamination of foods.

A possible presence of hazards in the common beans value chain may have important public health implications. This is because the common bean is a key staple food crop and the most widely produced and consumed food legume in Africa [14]. Thus ensuring the food safety and quality of the common bean value chain in compliance with international standards is of crucial importance to both consumers and the legume industry [13]. This can be achieved by implementation of HACCP, which is a globally recognised FSMS. The research reported here was conducted in the context of a product development process for pre-cooked beans for the Ugandan and Kenyan markets. The objective of this study was to develop a HACCP plan for the dry common bean in Uganda and an accompanying food safety toolkit targeting value chain actors. The entire production process of the common bean was evaluated. The potential biological, chemical and physical hazards that may exist in every step of the production process were identified, and the critical control points (CCPs) were determined. The HACCP plan was generated and used to develop a food safety toolkit - a practical guide for mitigating contamination along the dry common bean value chain.

METHODS

Development of a HACCP plan

According to the Codex Alimentarius [15], the seven principles outlined below were followed to develop a HACCP plan for the dry common bean (herein also referred to as beans) in Uganda.

- *Principle 1: Conduct a hazard analysis*
  This involves identifying hazards and assessing the risks associated with them at each step in relation to the end use of a product in the commodity system.
- *Principle 2: Determine the critical control points (CCPs)*
  A CCP is a step at which control (actions/measures) can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level.
- *Principle 3: Establish critical limits for each control point*
  Each control measure associated with a CCP must have an associated critical limit that separates the acceptable from the unacceptable control parameter.
- *Principle 4: Establish a monitoring system*
  Establish monitoring procedures for each critical limit at each CCP. Monitoring helps to assess whether a given parameter is under control, and within the critical limit(s) specified in Principle 3.

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- *Principle 5: Establish a procedure for corrective action, when monitoring at a CCP indicates a deviation from an established critical limit*
  The corrective action is designed to bring the product and the process back under control.
- *Principle 6: Establish record-keeping procedures*
  Establish a record-keeping system that documents that critical limits are not exceeded and if they are exceeded, what corrective actions are taken to bring the system back under control.
- *Principle 7: Establish verification procedures*
  Establish verification procedures to demonstrate that the HACCP plan is functioning as planned. It is also important to ensure that the HACCP system is audited after a predetermined period to guarantee that there is compliance. For the effectiveness of the HACCP system, there should be internal and external audits.

A decision tree diagram and a risk and severity matrix were used to identify each potential hazard at each processing stage, and to determine whether a step was classified as a CCP or not (Figure 1). For the CCP identified, reliable control mechanisms and corrective actions were established to fulfill the requirements set by the critical limits to guarantee the safety of the products. Verification and records systems were proposed to determine the effectiveness and traceability of the HACCP plan. A checklist was used to collect information in the verification process. Ten farmers representing ten farmer groups and five vendors were selected for the verification of the production process. A farmer group comprises 20 to over 100 members. Farmers were selected from the greater Masaka region where the 'pre-cooked beans' project was implemented.

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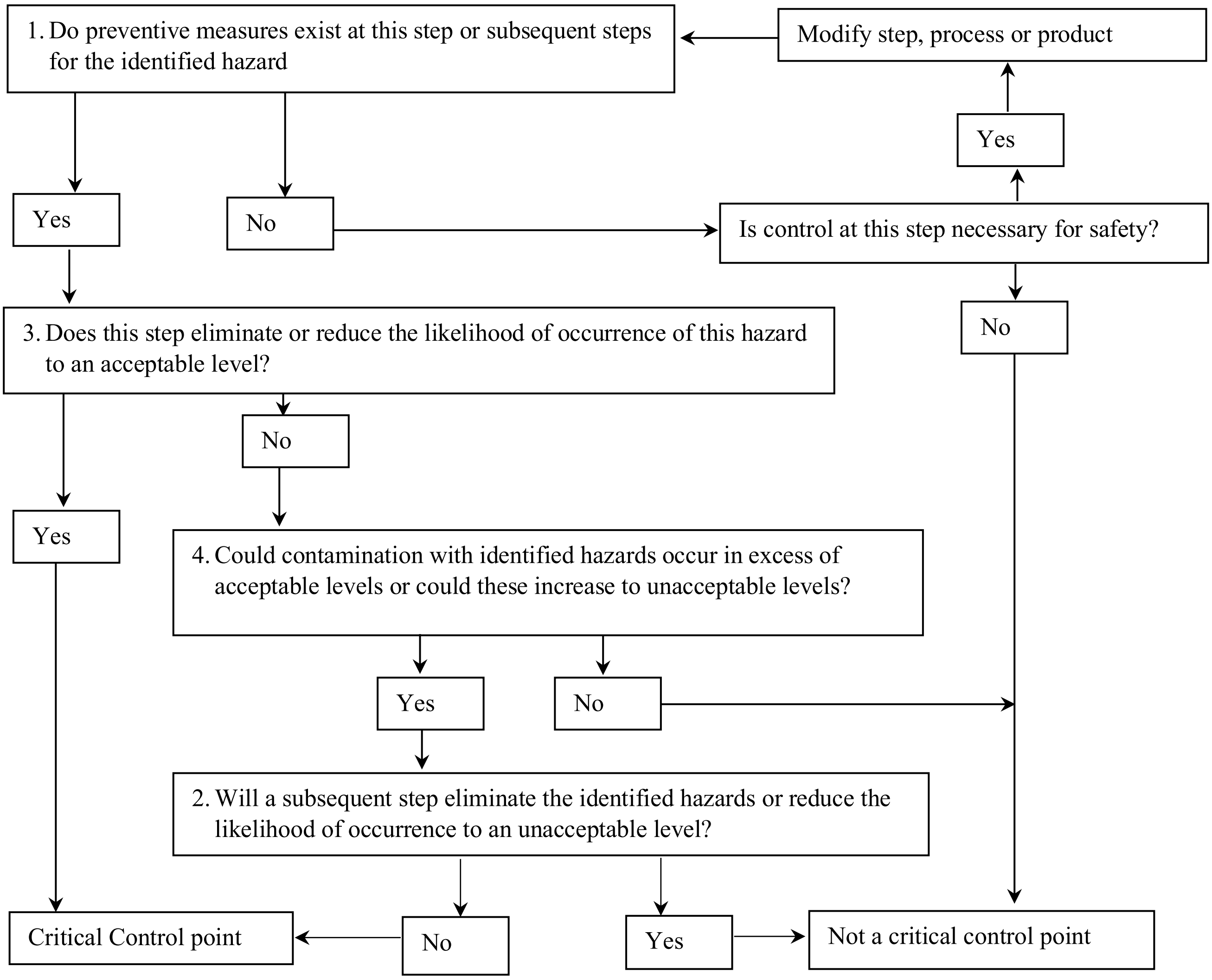

Figure 1: Decision tree diagram for CCP [15]

Development of food safety toolkit

Co-creation is a process that engages users of a product in the innovation process. It allows for the creation of products that are tailor-made to suit the exact needs of the users. It gains the simple yet overlooked insights into user's needs [16]. Developing food safety management systems often requires specialized expertise. Using this method gives the end user of these systems an opportunity to create an ideal system that has the simple attributes they would appreciate in the system concept.

In this case, participants in the co-creation process identified problems and created solutions that informed food safety toolkit innovation. Interaction among various value chain actors allowed them to co-create distinctive practices with food safety experts to achieve the desired level of food safety output for the dry common bean value chain. As stated, this collaboration also allowed the parties involved to unlock new sources of competitive advantage [16]. This is especially important for small-scale farmers who are locked out of prime markets because their produce is linked to numerous safety concerns.

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Co-creation had been employed highly in business markets to create value for both suppliers and customers [17]. Most importantly, it is a good model to bridge the knowledge gap between science and society [18]. Some of the concepts applied in food safety management systems may be too complicated for farmers who have limited formal education. For this reason, it is ideal to bridge the gap between the food safety requirements and the value chain actors through participatory models. We, therefore, adopted co-creation as an appropriate model to diffuse food safety knowledge to value chain actors in a manner that would ensure that the information was both understandable and practical for them.

In the model, the users were value chain actors and the innovation was the HACCP food safety toolkit for the actors. A co-creation methodology (2-hour session with 8 participants) was employed to facilitate discussion amongst the value chain actors (farmers, processor and food vendors) in the dry common bean value chain. The co-creation process was carried out in four sessions that included a background of the chain actors' ambitions to determine the suitability of the toolkit, assessment of CCPs, expert advice on the CCPs, and an exercise to develop concepts for each CCP. The toolkit developed as a result of this co-creation process is presented at the end of this paper. The aim of the toolkit was to generate a thorough framework for food chain assessment with a focus on the economic, social and cultural factors that influence food safety, as well as how knowledge, attitudes, and practices of value chain actors, including consumers, can contribute to risky food practices.

There are twelve tasks required to develop a HACCP plan and these are designed to ensure that the seven principles are applied correctly [15]. The twelve tasks were applied to develop the HACCP plan for the common dry bean value chain and are discussed in subsequent sub-sections.

Task 1: ***The HACCP team***

The HACCP team was composed of experts and individuals representing: a HACCP specialist, a food scientist, a microbiologist, a representative of the common bean growers, a food quality control specialist from the common bean processing industry, a public health specialist, and a quality control and safety specialist from the Uganda Bureau of Standards.

Tasks 2 and 3: ***Product description and intended use***

The product description and intended use is given in Table 1.

Tasks 4 and 5: ***Verified flow diagram of the dry common bean value chain***

The verified flow diagram (VFD) of the dry common bean value chain was established by means of observation and using information provided by the HACCP team members, farmers, processors, and other dry common bean value chain actors. The flow diagram was verified by visiting major dry common bean growers, trading centers, bean processing industries, and street food vendors. The VFD is shown in Figure 2.

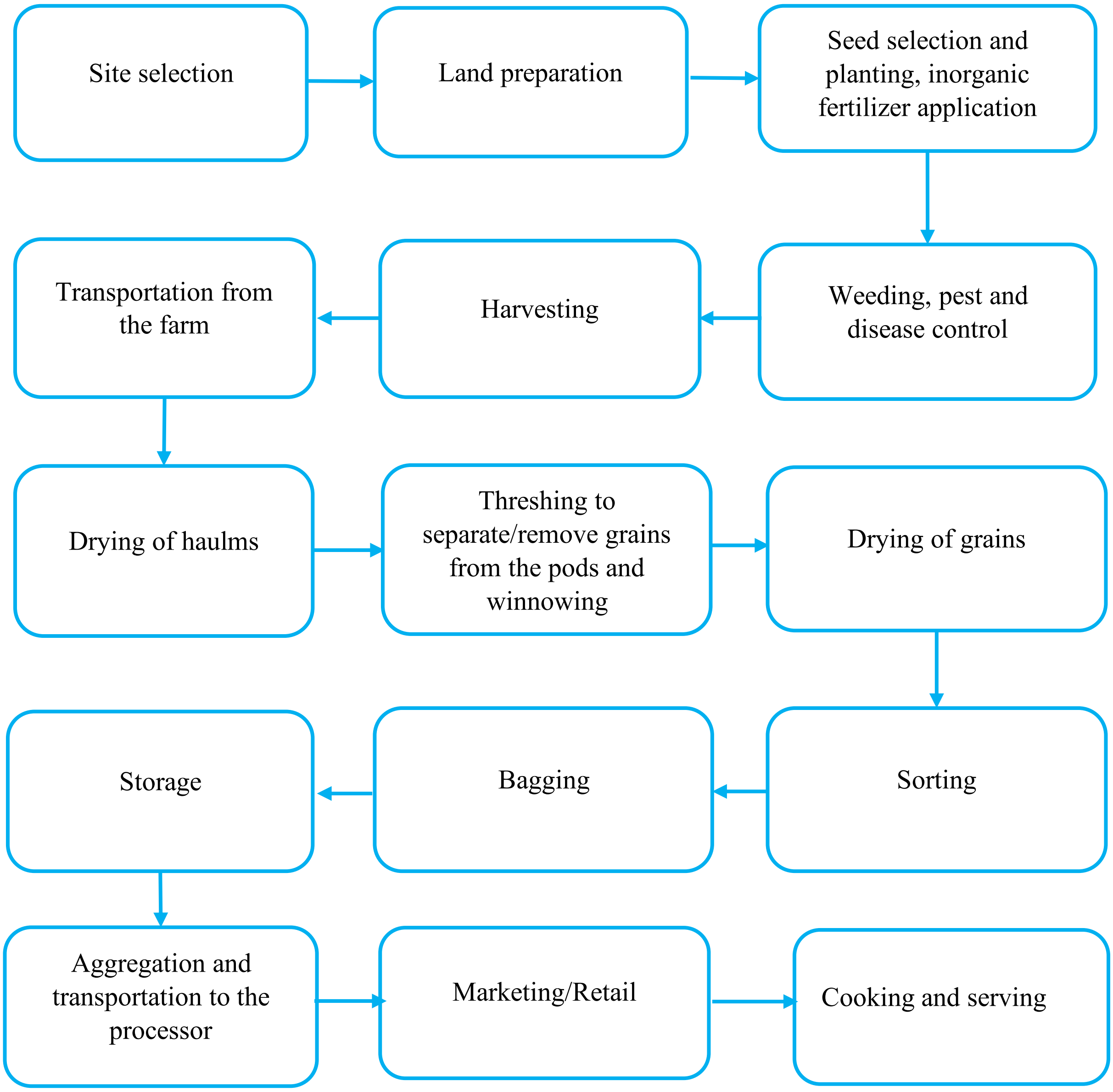

Figure 2: Verified flow diagram of the dry common bean value chain that includes 15 steps from 'farm to fork'

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RESULTS AND DISCUSSION

The HACCP Process: Principle 1 – Principle 5

Task 6: *Hazard analysis and identification of possible control measures*

Task 6 of the HACCP plan included a listing of all potential hazards according to the VFD, conducting a hazard analysis and identifying control measures.

a) Identification of hazards

The dry common bean value chain is susceptible to many hazards. A list of all potential biological, chemical, or physical hazards that may be introduced, increased, or controlled from 'farm to fork' was therefore generated by the HACCP team. These included mycotoxins, *Salmonella* spp., *Escherichia coli (E. coli)*, *Staphylococcus aureus* (*S. aureus)*, insects, chemical residues such as pesticides, and heavy metals.

b) Identification of steps in the verified flow diagram where contamination is most likely to occur

At each step of the verified flow diagram, the HACCP team identified all possible hazards and determined the likelihood of the beans being contaminated with these hazards.

Step 1 On-farm during site selection

Heavy metals are ubiquitous in the environment, because of both natural and anthropogenic activities, and humans are exposed to them through various pathways [19]. Consuming food crops grown in contaminated soils results in ingestion of significant amounts of the metals [20]. Other possible contaminants include mycotoxins. Some fungi such as *Fusarium* spp. are present in the soil [21] presenting a risk of mycotoxin contamination. Therefore, it was concluded that contamination with heavy metals, chemical residues, and mycotoxins was likely at this step.

Steps 2 to 8 Land preparation to the removal of pods from the stalk and winnowing

During land preparation, farmers use organic fertilizers. Some of these, especially manure, harbor a significant number of micro-organisms such as *Salmonella* spp. and *E. coli*. Although it has been argued that the application of such fertilizers may act as a pathway for microbial hazards into humans, these are most likely in vegetables and fruits [22]. These find their way through water that is splashed during rain downpours or irrigation. Beans, on the other hand, are protected within the pod hence may not be subjected to such contaminants. However, some heavy metals such as cadmium and lead are very similar to micronutrients, and thus can be absorbed by plants hence posing a risk to the consumers [23]. Farmers also tend to apply chemicals to control weeds, pests, and diseases. Application of these chemicals, especially the pesticides that are applied in mixtures, exhibits undesirable harmful effects on humans [24]. However, humans are not affected by low doses of such chemicals apart from cases of long-term exposure. During harvesting and threshing poor practices, which may include placing the crop on bare soil, exposes the crop to mycotoxins and micro-organisms, which may be present in the soil. The same may occur during drying, threshing, removal of pods from the stalk, and sorting if the crop is exposed to the soil. Drying the beans on bare soil exposes them to other hazards such as microorganisms from fecal material of free-range poultry and other

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animals within the vicinity. Although these hazards were identified at these steps, it was concluded that the contamination with these hazards is low.

Step 9 Postharvest drying
Farmers air-dry their beans in the open. At this step, the crop has been threshed hence the grains are exposed to the environment. Improper drying can lead to the growth of mold, which may lead to contamination with mycotoxins. Furthermore, exposure of the grains to the soil may lead to further mycotoxins contamination as well as microorganisms such as *E. coli* that are present in the soil. Contamination at this point was concluded to be very likely.

Step 10 Sorting
During manual sorting by farmers, poor hygiene practices may result in contamination with *S. aureus*, which is naturally present on human skin. Presence of *S. aureus* in foods is among the leading causes of food-borne bacterial intoxications worldwide [25].

This is attributed to enterotoxins (SEs) produced by enterotoxigenic strains [26]. Although the micro-organism itself is destroyed by heat, the toxins survive to cause illness. Given that most farms have limited access to portable water for hand washing, it was concluded that contamination with *S. aureus* is very likely at this step.

Step 11 Bagging
At this step, frequent re-use of gunny bags may be a source of microbial cross-contamination. However, it was concluded that the likelihood for contamination at this level was low.

Step 12 Storage
At this step, poorly ventilated stores can cause an increase in humidity. The once dry grain may take up moisture and become prone to contamination with mold and fungi. Furthermore, the temperature may increase inside the stores to optimal ranges for microbial growth. It is also at this step where farmers may apply chemical grain preservatives. Uncontrolled application of these chemicals in high amounts or wrong concentrations may leave residues on the grain, which may be harmful to consumers. In addition, the grains may be infested with insects and rodents that may be a source of microbial cross-contamination. It was therefore concluded that contamination at this step was very likely.

Step 13 Transport to the market
At this step, transport with other non-food grade materials may result in cross-contamination. Cross-contamination may also occur when bags or vehicles used are not clean. In addition, use of open trucks may expose the beans to the external environment, which can be a source of physical contamination such as dirt, dust, chaff, and stones. However, it was concluded that contamination at this level was low.

Step 14 Marketing/retailing
At this step, the level of hygiene and sanitation in the market or retail shops may have an impact on the overall food safety of the beans. Food handlers may be a source of

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foodborne pathogens and disregard of good hygiene practices especially in small food establishments can result in cross-contamination of foods [27]. On the other hand, food contact surfaces also harbor microorganisms that can also be transferred to food. These microorganisms include *Salmonella* spp., *S. aureus*, and *E. coli* [28]. Although these microorganisms may be present, growth on dry beans is highly unlikely because of the low moisture content of the grain.

Step 15 Cooking and serving
At this step, foreign matter such as stones, wood splinters, and husks may be introduced due to inadequate sorting and washing. In addition, heavy metals and chlorine may be introduced from polluted water and from covering the boiling beans with a plastic material such as polythene. Use of such water may also introduce pathogens such as *E. coli*. It was concluded that contamination at this stage is highly likely.

c) Possible control measures of identified hazards
The most effective way to control contaminants at the initial step of the value chain includes selecting sites that are not waterlogged. Some metal oxides become associated to iron and manganese and become soluble under waterlogged reduced conditions [29]. This may increase uptake of the metals by the plant. In the case of mycotoxins, it is important to limit inter-cropping with crops such as cereals that are susceptible to mycotoxins.

During land preparation, organic fertilizers can be disinfected to eliminate the threat of microbes. When using herbicides, directions of use must be strictly followed to prevent chemical residue accumulation in the soils. During planting, only herbicides recommended by the national standards organizations should be used. In addition, inter-cropping with mycotoxins susceptible crops should be limited. A crop rotation system aimed at phytoremediation (phytoextraction) should also be practiced to enable recovery of soils from any heavy metal contamination and breaking the cycle of microbial toxin contamination. While applying mineral fertilizers, controlling pests, weeds, and diseases, it is important to follow the manufacturer's instructions when applying various chemicals. In addition, these chemicals should be applied at the right time to allow for a safe withdrawal period.

During harvesting, it is important that the crop is harvested on a dry day where exposure to moisture is minimum, to avoid soiling the beans. In this case, harvesting should be carried out in late morning hours or early evening hours when there is less dew. In addition, harvesting should not be carried out when it has just rained. In case the harvested beans are soiled, pods should be allowed to sun-dry on a raised tarpaulin platform. Once dried, the crop should be threshed in hessian bags to avoid soil contamination and grain loss. After threshing, the beans then undergo post-harvest drying to bring the grain moisture to less than 14 percent. This moisture content can be achieved easily by air drying [30]. Once dried, an adequate number of workers should be employed to ensure thorough sorting to remove physically damaged, shriveled, rotten, as well as grains with signs of pest infestation and disease.

After sorting, new and clean bags should be used to package the grain. In case old bags are re-used, they should be washed, disinfected, and thoroughly sun-dried. During storage, a number of measures should be carried out to preserve the safety and quality of the stored beans. The bags should be placed on wooden pallets to avoid direct contact with the floor. Also, where applicable recommended storage pesticides should be used at recommended rates. These chemicals should also be applied at the right time to avoid exposing consumers to chemical residues. In addition, the "first in, first out" principle should be followed. In this instance, beans that came in first should be used or sold first. The dry beans should be stored away from other crops that are prone to fungal contamination and growth.

The grain store should have sufficient ventilation. The roof and walls of the storage facility should be free from leaks to prevent the bagged grain from regaining moisture in storage. To prevent vermin infestation, the storage facility should be vermin proof by ensuring that cracks and crevices are sealed off. In addition, a clearance of at least five-meters that is void of trash, piles of debris, or heavy foliage should be maintained around the storage facility to prevent vermin and insect infestation. Traps can also be used inside the storage building to control vermin and insects.

During transportation, avoid transporting grain in non-food grade materials; and carrying them together with other commodities that pause a risk of contamination such as maize grains and agro-inputs. The transportation vehicles should also be cleaned and disinfected before loading beans. The loaded beans should be covered with a tarpaulin to avoid dampening, especially during rainy seasons. During marketing/retailing the beans should be packaged in dry gunny bags or containers to maintain their low moisture content. In addition, they should not be placed on the bare ground.

During cooking, which is the final step, potable water should be used. In situations where pesticides have been used in storage, beans should be washed at least three times prior to cooking. In addition, non-reactive materials such as polythene should not be used to cover food during cooking. In addition, the personnel handling food should maintain a very high level of personal and environmental hygiene and avoid non-food grade additives during cooking.

Tasks 7 to 10: *Development of a HACCP plan for the verified flow diagram (VFD) of the dry common bean value chain*

A worksheet summarizing the HACCP plan for the dry common bean value chain is given in Table 2. The development of the plan at each step in the VFD is given below. National and regional standards bodies were consulted to advise on the critical limits recommended herein. In the plan, each step was classified as either CCP, GAP, or good post-harvest practice (GPP). CCPs were determined using the decision tree in Figure 1. GAP and GPP, which are practices that prevent contamination of the beans on the farm and after harvest, were determined in consultation with the HACCP team.

Step 1: Site selection – CCP1

This step was identified as a CCP with site selection, crop rotation and limited inter-cropping with mycotoxin susceptible crops as the control measures. This CCP will

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reduce the exposure of beans to heavy metals, chemical residues, and mycotoxins, hence reducing the levels of any of these contaminants in harvested grain. An appropriate critical control limit could be to avoid selecting planting sited that show traces of heavy metals and chemical residues. Trained agronomists and soil scientists could best monitor this CCP.

Step 2: Land preparation – GAP

Disinfecting organic fertilizers and correct use of herbicides can reduce contaminants at this step. Contaminated fertilizers can contaminate beans with *Salmonella spp*. and *E. coli*, while misuse of chemical residues can result in these residues in the grain.

Step 3: Seed selection and planting – GAP

During planting, the plants can be contaminated with herbicides used in land preparation or mycotoxins from other crops from inter-cropping. However, this can be controlled by use of recommended herbicides and crop rotation. Limiting inter-cropping can also be used as a control measure. Furthermore, the use of adulterated herbicides and other chemicals has a negative impact on human health. Such chemicals have less than the recommended concentration of the active ingredients hence farmers apply more chemicals than recommended to achieve the same level of efficiency with chemicals that are not adulterated. The resulting level of chemical residues on crops is therefore high. Proper regulation of these chemicals is thus essential. In addition, farmers apply mineral fertilizers before or after planting. Indiscriminate use of these fertilizers may negatively affect human health.

Step 4: Weeding, pest and disease control - GAP

This is an important step in crop management. Without it, grain yields can be very low. However, it also represents a step where misuse of chemicals can result in chemical residues, which can affect human health negatively. Therefore, it is imperative that manufacturers' instructions and specifications are adhered to strictly. In addition, time of application is important. Timely application of chemicals can, therefore, reduce incidences of chemical residues on the crop.

Step 5: Harvesting – GPP

During harvesting, timing is important. Exposure of harvested crop to moisture significantly increases the moisture content of the crop and can result in soiling. Harvesting in the late morning and early evening hours can prevent exposure of the crop to dew, while harvesting in sunny weather can reduce soiling. This can also reduce the spread of the common bean diseases especially anthracnose and ultimately limiting the damage to the grains. Such damages would otherwise be easy entry points of infection by other pathogens that produce mycotoxins. Also, timely harvesting reduces the risk of increased weevil attack that may lead to infection by fungal and bacterial pathogens during drying and storage.

Step 6: Transportation from the farm – GPP

During transport, the condition of the mode of transportation is important. Dirty containers or trucks can potentially contaminate the harvest; and this is also true where beans are transported together with other commodities such as maize and groundnuts.

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Step 7: Drying – GPP
Inappropriate drying of beans - for example on bare ground - can result in microbial contamination. This also exposes the beans to physical hazards such as stones, wood splinters, fecal matter from birds, and other domestic animals, and broken glass. To reduce microbial contamination, the beans could be dried on a raised platform to less than 14 percent moisture content.

Step 8: Threshing to remove pods from the stalk and winnowing – GPP
Threshing beans in hessian bags could avoid contamination with stones, wood splinters, and micro-organisms from the soil. Correct removal of pods from the stalk ensures little contamination of the beans. This and winnowing should be done on the tarpaulin to prevent contact with the soil that may harbor microorganisms such as *E. coli*, spore formers such as *Bacillus* spp. and fungi.

Step 9: Postharvest drying – CCP2
This was identified as a CCP with one possible control measure. The beans could be dried to 14 percent moisture content on a tarpaulin or raised platform prior to storage. Molds and fungi should be maintained at less than 10^4 colony forming units per gram (cfu/g) in maize [31]. This criterion can also be applied for beans. Critical limits, other than these, can be set in terms of sun-drying time, which will result in the required final moisture content.

Step 10: Sorting – GPP
This was identified as a GPP with two possible control measures. Potable water and gloves can be supplied to the sorters to reduce the prevalence of *S. aureus* on sorted beans. The critical limit of *S. aureus* on the hands of the sorters at this step is 10^2 cfu/cm^2 [32].

Step 11: Bagging – GPP
Correct packaging of farm produce is recognized as a good agricultural practice. An effective packaging material acts as a barrier against contaminants and external factors such as sunlight and moisture. Re-use of packaging bags results in cross-contamination from previously contaminated bags. Insects and micro-organisms can also accumulate if the storage conditions such as heat and moisture favor their growth. These can, however, be reduced by use of new bags or disinfection of previously used bags.

Step 12: Storage – CCP3
With high yields, and other factors such anticipation of better market prices or predicted famine farmers may opt to store their harvest long-term. Beans can be stored for up to two years. This was therefore identified as CCP with several control options. Proper ventilation could prevent the buildup of temperature and humidity in the storage facility. Storing on wooden pallets reduces microorganisms attack to the grains. Setting up traps, clearing bushes around storage facilities and sealing cracks and crevices can prevent entry of vermin and insects. Application of first-in-first-out method can prevent accumulation of contaminants on old grain, which may, in turn, contaminate more recent harvests. Use of recommended chemicals will reduce the harmful effects of chemical residues. Critical limits of the grains can be set at 14 percent moisture content while the temperature within the storage shelter can be set and maintained at 25°C.

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Step 13: Transportation to the market – GPP
During transportation, beans are prone to poor handling that can lead to microbial contamination. However, transportation of beans in food grade materials can prevent the contamination. The transport vehicle and/or vessels can be disinfected before loading beans. Furthermore, beans can be covered with tarpaulin to avoid dampening especially in the rainy seasons. In addition, beans should not be transported together with other items such as groundnuts and maize grains that are highly susceptible to *Aspergillus* spp. that produce aflatoxins among other mycotoxins.

Step 14: Marketing/retailing – GPP
At this step, exposure of the dry beans to moisture can lead to the growth of fungi and mold hence the risk of mycotoxins. In addition, the handlers must adhere to strict hygiene and sanitation practices to prevent cross-contamination with hazards. Furthermore, at this step, the retailers may apply pesticide to prevent insect pest-induced loss of the beans by storage pests such as weevils. These chemicals must be applied as instructed to safeguard consumers from the harmful effects of chemical residue.

Step 15: Cooking – CCP4
This is the last step in the value chain and it was also identified as a CCP. Use of potable water can prevent microbial contamination while the use of non-reactive materials during cooking will reduce monomer migration. Good personal and environmental hygiene and sanitation can also lower microbial contamination. In addition, non-food grade additives can be avoided during cooking. The critical limits that can be set include cooking at 90–120 °C for 1–3 hours depending on how long the beans take to soften [33]. *S. aureus*, *E. coli,* and *Salmonella* spp. must not be detected [34]. The limit of yeasts and molds is set at 10^4 cfu/g [31], and pesticide, heavy chemicals, and other chemical residues should be absent.

Task 11: *Establish verification procedures*
Validation procedures will be established for each of the CCPs and overall verification will be provided by the fully quantitative results on representative samples of the soil, batches of harvested beans and food handlers' hands. The bean processors, government institutions such as Uganda Bureau of Standards and National Crops Resources Research Institute or research organization such as International Center for Tropical Agriculture may carry out sample analysis. The HACCP Plan will be audited quarterly and amended as necessary.

Task 12: *Establish documentation and record keeping*
The HACCP Plan will be fully documented, with appropriate record keeping by all actors at each step.

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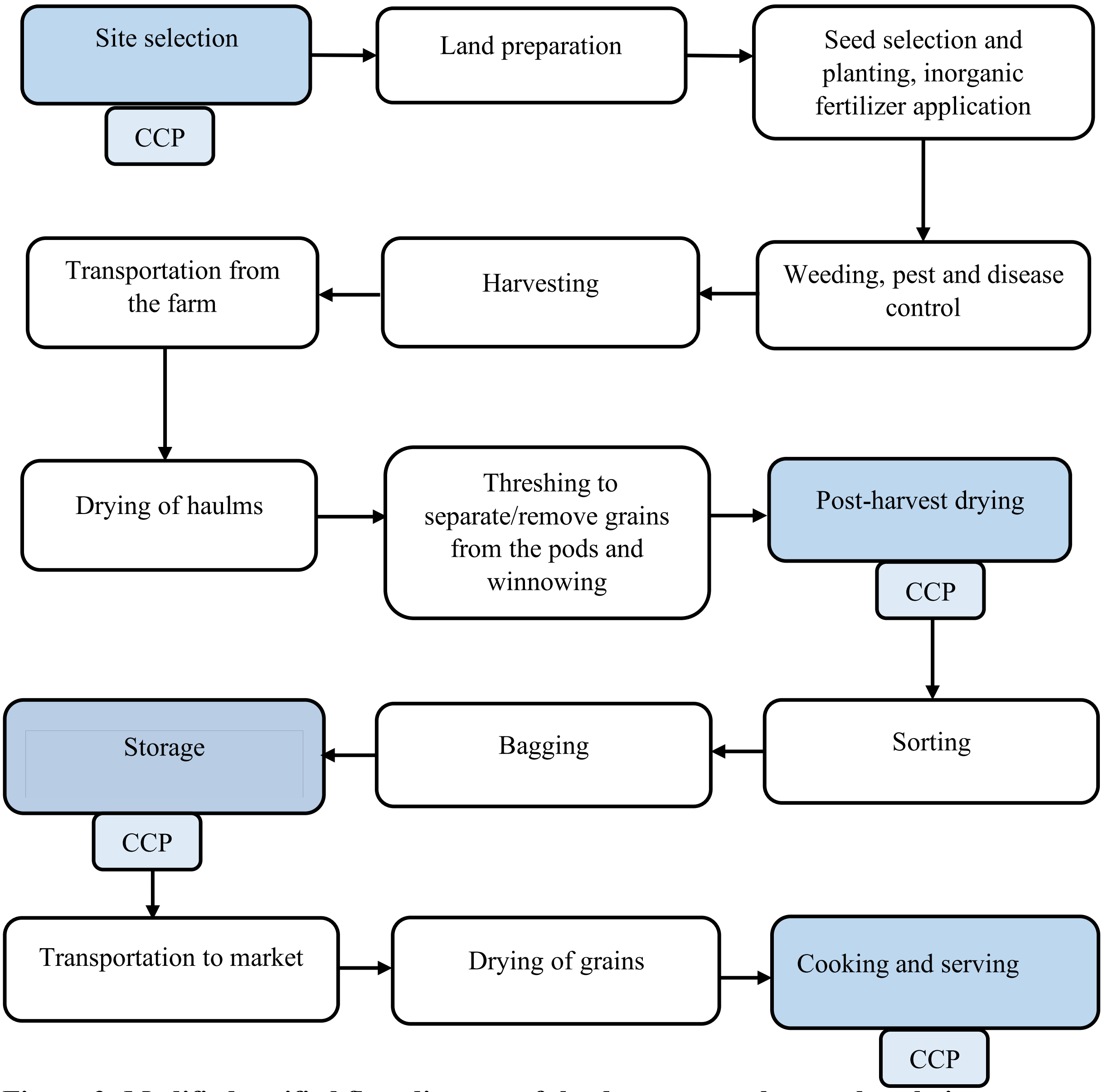

Figure 3: Modified verified flow diagram of the dry common bean value chain that includes 15 steps from 'farm to fork' with four identified CCPs highlighted

Co-creation of the food safety toolkit

Session 1: Ambitions of value chain actors

In this session, the value chain actors were probed on their ambitions in order to determine their priorities, and how the toolkit will aid and contribute in fulfilling their goals as actors in the bean value chain. Farmers' ambitions were centered on increasing production by purchasing more land and enhancing productivity per acre of land by improving their farming practices. The other ambition involved increasing community education in food safety as some of them were civic educators. On the other hand, the vendors desired to expand their businesses by increasing their staff and having better

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operations systems (such as running water and sewer systems) to improve their business turnover.

Session 2: Assessing the Critical Control Points

This session explored the current practices of the value chain actors across the critical control points identified earlier. Participants were engaged through a series of questions to gather insights around the four critical control points: plot selection, drying of the beans, storage, and cooking and serving.

CCP1: Plot selection

The farmers were probed on various factors that determine which plot they select. They based their criteria on; the plot's closeness to a water source, soil fertility and availability of a drainage system. They stated that they used sites on the edge of their plots to give their beans maximum exposure to sunlight. They also indicated that land preparation was mainly determined by income from their farm produce from the previous harvest. However, the farmers understood that land preparation affects production in terms of quality, safety, and quantity.

On waste disposal after harvest, the farmers reported that they used the waste from the beans (husks) as manure in their field, and feed for domestic animals such as cows. On crop rotation, the farmers highlighted that they rotated their beans with other crops such as maize every planting season.

On fertilizer/ herbicides application, it was noted that as part of plot preparation, most farmers used manure in their farms. It was also noted that farmers were aware of hazards associated with herbicides. On the matter of who makes the decisions on plot selection, the respondents acknowledged that both men and women were involved in discussions on plot selection. However, women were mostly involved in the final decision on plot selection.

CCP2: Drying after threshing

On the second CCP, which was drying after threshing, the farmers were probed on their current processes of drying beans after harvest. The harvest time of dry beans was when beans are mature on the farm. However, the farmers did not have a specific area in the compound for drying the beans but instead used any location that had direct exposure to the wind and the sun. Some highlighted that they used a room in their homes for drying especially during the rainy season.

The farmers were further probed on methods they use to determine whether the grain had adequately dried. They responded that they have indigenous knowledge on this; for example, a handful of beans are held in a tin and shaken. If they are sufficiently dry, the grains will produce a high pitch sound. Some farmers bite into a few samples of the beans. If they are dry, the grains are hard and don't easily break into smaller pieces.
Finally, the farmers listed destruction from animals such as cows, theft, and unexpected rain as some of the risks associated with drying beans.

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CCP3: Storage
On the third CCP, the respondents were probed on their beans storage practices. The farmers highlighted that they package their beans in gunny bags (either sisal or nylon) or in the Purdue Improved Cowpea Storage (PICS) bags, or plastic buckets or drums. It was noted that some farmers stored their maize together with beans. However, they separated them in the storage facility because this made it easier for them to access the commodity. Some of the farmers adhere to the first in first out principle by consuming the oldest stock first while others just simply select the bags closest to the granary entrance for consumption. The respondents were also probed on the factors they considered whilst constructing a storage facility. Some of the factors mentioned were land size, where a large piece of land would facilitate a bigger storage facility.

Usability and accessibility of the stored items were also listed. On risks associated with beans storage, theft and infestation by insects were considered the most important threats. Therefore, farmers have reinforced entrances to their storage facilities, and in the case of frequent insect infestation, farmers have two granaries to transfer produce if one granary is attacked by insects.

CCP4: Cooking and serving
Food handling and serving by vendors: From the discussion, it was noted that all the food vendors sourced their beans from trusted suppliers, whom they chose based on their value-added services such as sorting of beans and consistent quality of the beans to ensure they are fit for human consumption. Suppliers, therefore, play a key role in the value chain as they determine the quality of beans available to the vendors.

Source of water and sanitation facilities: The vendors stated that they sourced their cooking water from government suppliers who provide portable water at community shared water points. The alternative source of water is independent suppliers who own boreholes.

Licenses to handle food: The respondents revealed that they do not have medical licenses for food handling but pay a one-off fee per week to the authorities to run their food vending businesses. One of the participants who owned a hotel mentioned that it is a requirement by the Ministry of Health for staff handling food to get medical clearance to work. Personal and environmental hygiene were also important to the food vendors as they ensure that they have hand-washing water and communal toilet (pit latrine or a WC) close to their business premises.

Stock depletion: The respondents said that they ensure that the cooked beans are sold out on a daily basis to avoid contamination, which would result from storing cooked beans for a long time. Beans that are left unsold are usually taken home for household consumption.

Session 3: Expert advice on the CCPs
In the first CCP, the experts advised the participants to clear the land/plot properly. When using herbicides, user directions should be followed to prevent residue accumulation in the soils. Also, manure should be treated by air-drying. Air-drying is a cost-effective

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method of reducing microbial load in the manure. The recommended time for drying cattle manure is three months [35]. Use of inorganic fertilizers requires that the farmers use the recommended doses. Growers were also advised to avoid plots that are waterlogged and to use preventive water logging practices such as control of canal seepage and groundwater inflows.

In the second CCP, the farmers were advised to dry their beans on raised platforms, rails and cemented floors, mats made of papyrus or tarpaulins to avoid contact with the soil. The moisture content in the beans should be below 14 percent. During the rainy season, the beans should be dried inside indoors on rails.

In the third CCP, the farmers were advised to adhere to the principle of first-in-first-out, use new sisal or polybags to store the beans, clear rubbish around the storage facility, properly seal wall gaps or openings in the storage facility and have consistent moisture checks. Prior to storage, the farmers were to ensure that the beans were properly dried to safe storage moisture content, preferably below 14 percent. Occasional re-drying of the beans was also recommended.

In the final CCP, the water quality should be of a high standard. The beans should be cooked at the right temperature and time (between 2 to 3 hours) and served while hot (above 50°C). Vendors were to ensure that individuals handling the food should not handle money at the same time. Utensils used to handle food should be rinsed with clean water.

The farmers and food vendors were receptive of the experts' feedback with the first in first out principle generating the most interest.
Session 4: Co-creation exercise

Participants were divided into four groups consisting of an expert, a farmer and food vendors, each tasked with coming up with a toolkit concept for a particular critical control point, based on the corrective action advised by the technical expert. The groups then presented their toolkit concepts in a plenary session.

For the first CCP, the group recommended that the tool should be designed like a book and should contain less text, more pictures, use simple language, be translated into local languages, and have large font size for easy reading. On the content, they recommended that the toolkit should contain a guide on how to properly plough using oxen, advantages of proper land clearing, proper crop rotation practices, timings of land preparation, and how to prevent water logging, proper use of fertilizer and manure treatment, and soil analysis.

For the second CCP, the group recommended that the toolkit should contain short and precise explanations. On the content, they recommended the toolkit should contain illustrations of the bean drying process, for example, illustrations on how to place the beans on a raised platform or on rails during the rainy season, and illustrations of moisture content testing tools and methods.

For the third CCP, the group recommended that the toolkit should contain pictorials depicting the critical points and elements such as the construction of a storage facility, information on moisture content and its testing, fumigation, and hygiene. On the content, they recommended that the toolkit should contain explanations on reducing rat and insect infestation, moisture testing methods such as heat testing, the right chemicals, and quantity to use for fumigation and proper hygiene and sanitation practices for the stores.

On the fourth CCP, the group recommended that the toolkit should have posters and manuals that can be displayed at food vending premises. This should be followed up with workshops/training sessions on cooking and serving best practices. On the content, they recommended the toolkit should contain a source of quality water, a bean sorting process, hygiene practices during food handling and details on the right temperature for cooking and serving the beans.

CONCLUSION

Four CCPs were identified in the dry common bean value chain. These are land selection and preparation, storage, post-harvest drying, and cooking. In addition, hazards at these points were also identified. The hazards included heavy metals, mycotoxins, and micro-organisms. Basic conditions that maintain food hygiene practices and good agriculture practices may be effective control measures against the hazards. Training of personnel in the four CCPs shown in Figure 3 is also important to ensure that the hazards are kept below the critical limits. A real-life video depicting the 15 steps from 'farm to fork' in the dry common bean value chain in Uganda can be found at
https://www.youtube.com/watch?v=dBRVLrh1U_8&feature=youtu.be

Beyond the training needs identified, a toolkit was developed whose purpose is to equip stakeholders across the food value chain with a cost-effective system for ensuring of food quality and safety from farm to fork. This tool also aids reducing of food loss and waste. The toolkit created through a co-creation process provides information to value chain actors about hazards along the chain and recommended control and assurance activities in a simplified version suitable for most actors. The toolkit is a user-friendly guide that empowers value chain to do their part in systematically controlling hazards in the identified CCPs along the dry common bean value chain. It is available at
https://cgspace.cgiar.org/handle/10568/91932

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Table 1: Description of the dry common bean sold on the local market

Name of product	Dry common bean for human consumption
Description	Dry beans with moisture content between 12 percent and 14 percent, which should be stored in a cool, dry place in bags or sacks on wooden pallets. Prone to insect damage especially by weevils, therefore, preventive and control measures are important for long-term storage
Customer specification	Graded for fair to average quality, 1 percent discoloration, 1 percent foreign matter, 5.5 percent defective grains
Conditions of storage	Bulked in silos Bagged and stacked on pallets Bulked in drums/baskets/buckets
Shelf life	1 month if moisture content is above 16 percent 3 years if moisture content is between 12 percent and 14 percent
Intended use	Boiled, milled for flour (baking, porridge, composite flours), extruded or malted to make therapeutic foods
Packaging	Bags, hessian or polypropylene or bulk
Target consumer	Domestic market and export market

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Table 2: Hazard description and HACCP plan for the dry common bean value chain

	Hazard description and HACCP plan		
CCP	Critical limits	Monitoring	Corrective actions
CCP1: **Site selection**	No waterlogged sites Minimal traces of heavy metals	Check farmer records to establish if the site has been rotated and trash from the previous crop has been well managed. Evaluate history of the previous crop, waterlogging history, metal deposits and waste disposal methods. Observe the site to identify any dumping activity.	Train farmers on the use of waste/trash management, the importance of crop rotation, and dangers of waterlogged areas.
CCP 2: **Postharvest drying**	Moisture content less than 14 percent Yeasts and molds should not exceed 10^4 cfu/g	Check records on the drying techniques used. Use clean drying materials Evaluate the history of drying regime and the weather conditions. Check the moisture content of the beans.	Training on determination of moisture content. Providing moisture meters and other traditional methods which are cheap and easy to use to determine the moisture. Construct improved drying structures such as dryers and drying yards.
CCP 3: **Storage**	Moisture content less than 14 percent Room temp (25-27°C)	Check records on the type and condition of the storage structures used, check also the records on the previous usage of the storage facility. Evaluate the effectiveness of the storage structure to protect the produce from weather conditions as well as fungal, insect and rodent attack.	Do not store beans with moisture content above 14 percent. Training on the use of clean storage structures that protect the produce from weather conditions, fungal, insect and rodent attack. Use recommended storage structure standards. Use different storage facilities for food and non-food stuff.
CCP 4: **Cooking**	Cook at 90–120 °C for 1–3 hours. *Staphylococcus* spp., *E. coli* and *Salmonella* spp. must not be detectable. Yeasts and molds of 10^4 cfu/g. No pesticides or heavy metals.	Ensure that beans are cooked for the right length of time. Check the hygiene of the serving dishes Ensure that the beans are served at hot temp (60 °C) and avoid serving at warm temperatures which favor microbial growth	Wash dishes and sanitize them before serving the beans. Sensitize the families on good hygiene practices and proper cooking methods at the right time. Develop easy to use safety tools such as books and distribute to mothers through health care centers and churches.

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