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Improvements within the peanut production chain to minimize aflatoxins contamination: an Ethiopian case study.

Carla Cervini[1]*, Carol Verheecke-Vaessen[1], Tingting He[1], Abdi Mohammed[2], Naresh Magan[1], Angel Medina[1]

[1]Applied Mycology Group, Environment and AgriFood Theme, Cranfield University, Cranfield, UK

[2]Haramaya University, School of Plant Sciences, P.O. Box138, Haramaya, Ethiopia

***Corresponding author:** Carla.Cervini@cranfield.ac.uk

ABSTRACT

Peanuts (*Arachis hypogaea* L.) are a worldwide crop appreciated by consumers and known to have several health benefits (e.g. decreasing risk of cardiovascular diseases, lowering LDL cholesterol). Nonetheless, during the production chain, peanuts can be contaminated by mycotoxigenic fungi, especially *Aspergillus flavus* and *A. parasiticus*, responsible for contamination of this commodity with aflatoxins (AFs). Chronic exposure to these mycotoxins is known to have carcinogenic, teratogenic and immunosuppressive effects, while acute exposure can be fatal.

Peanut-based products are considered the "new-gold" in Lower Middle-Income Countries (LMICs) as they are used to produce therapeutic food to fight malnutrition in children in the form of high energy bars (e.g. Plumpy'Nut®). The present study has been focused on an examination of the existing Ethiopian peanut supply chain to identify components that require improvements during pre-harvest, harvesting and post-harvest where practical and affordable intervention practices can be implemented. The lack of Good Agricultural Practices (GAPs), the use of traditional and rudimentary methods for drying and shelling peanuts, as well as inadequate storage locations are some of the main factors associated with the high contamination of Ethiopian peanuts with AFs. While control of AFs is complex, in-depth examination of existing practices has facilitated an overview of the potential for efficient and low-cost strategies to reduce and minimize these toxin risks in the Ethiopian peanut production chain. This includes the use of Drycard™ as a tool to check moisture content, the creation of homemade solar dryer and wooden nutcrackers, and the use of either the Purdue Improved Crop Storage (PICS) bags or novel bags with slow-release food-grade preservatives. The implementation of some of these approaches should ensure a safer home-grown peanut supply chain that would contribute to the growth of the economy of the country by reducing the high

costs of importing such raw materials and supporting the use of local smallholder farmers peanuts. This would have significant economic benefits in the local peanut production chain.

KEYWORDS: groundnuts, mycotoxins, toxigenic fungi, pre/post-harvest management, developing countries.

1. Introduction

Peanut (*Arachis hypogaea* L.), also known as groundnut, is the worlds' fourth most important source of edible oil and the third most valuable source of vegetable protein (Govindaraj et al., 2009; Upadhyaya et al., 2006).

Apart from being an important cash crop, peanuts are also known to exhibit great beneficial effects by reducing low-density lipoprotein (LDL) levels and decreasing the risk of cardiovascular diseases (Suchoszek-Lukaniuk et al., 2011). They are often used for therapeutic purposes and are considered the "new gold" in many Low- and Middle-Income Countries (LMICs) (Manary, 2006; Santini et al., 2012). Indeed, because of these properties, peanut-based products are used for the production of ready-to-use therapeutic foods (RUTF) for the treatment of nutritionally affected children in developing countries, such as Ethiopia (Mupunga et al., 2017).

In 2019, 157 ktonnes of peanuts were produced in Ethiopia with a 50% increase in production in the last 5 years (FAOSTAT, 2021). Peanut production is concentrated in Oromiya and Benishangul-Gumuz regions, mainly in Eastern Hararghe and Metekel zones, respectively (Mohammed et al., 2014). These areas are characterized by being mostly lowlands (< 1500 m above mean sea level) with sub-humid to humid climate, with an average temperature of approximately 25˚C and average annual rainfall > 500 mm, matching the optimum climatic conditions for peanut production (Nega et al., 2015).

However, episodes of drought stress or intermittent rainfall can predispose the ripening groundnuts to infection by toxigenic xerophilic fungi from the *Aspergillus* section *Flavi* group and result in contamination of the local peanuts with aflatoxins (AFs). Chemically, AFs are a group of structurally related difuranocoumarin derivatives. There are four major ones, aflatoxin B_1, B_2, G_1 and G_2 (Klich, 2007). The most abundant aflatoxin-producing species associated with peanuts are *Aspergillus flavus* and *A. parasiticus*. Generally, *A. flavus* produces mainly aflatoxin B_1 and B_2 (AFB_1, AFB_2) and other toxic compounds, including cyclopiazonic acid (CPA), whereas *A. parasiticus* forms all four aflatoxins, AFB_1, AFB_2, AFG_1, and AFG_2, but no CPA (Frisvad et al., 2019). AFB_1 is the most potent naturally formed carcinogen (Squire, 1981; IARC, 2002).

In Ethiopia, the occurrence of *Aspergillus* section *Flavi* species and AFs contamination in different food products, including peanuts, has been investigated over the last decade. For example, Mohammed et al., 2016 reported AFs levels as high as 3135 µg/kg in peanut seed and 158 µg/kg in peanut cake, locally known as "*Halawa*". Overall, very high contamination levels of total AFs were found in Ethiopian peanuts, e.g., 11900 µg/kg (Chala et al., 2013), significantly above the maximum tolerable level of 15 µg/kg established by FAO/WHO (CAC, 1995) and 4-15 µg/kg according to the EU regulation (EC, 1881/2006). Based on the Ethiopian Standard Authority (ESA) and a recent review by Ayelign & De Saeger, 2020, only a very few commodities are currently regulated for mycotoxins in Ethiopia including peanut kernels and peanut butter where maximum allowable limits have been set at 5 and 4 µg/kg for AFB_1 and 10 µg/kg, for total AFs. Furthermore, regulations are particularly aimed at commodities destined for export and have less relevance for consumption of such products by local consumers via unregulated market stalls, especially in rural villages.

Such scenarios characterised by inadequate mycotoxins legislation and very high levels of AFs contamination in a range of different staple commodities, undermines the food safety in Ethiopia, with negative repercussions on food quality and security.

For peanuts, improvements of the local production and supply chain would significantly help industries to be less dependent on importing raw materials and reduce the associated costs. In addition, this would also support and benefit smallholder farmers' welfare. A focus on increasing the quality and safety of Ethiopian peanuts would also contribute significantly to reduce malnutrition in the country and to reduce exposure of rural and urban consumers to AFs and their associated effects, especially on immunocompromised groups and infants and children (Wild et al., 2015; IARC, 2002).

Thus, this review aims to present recent and efficient strategies to prevent and/or control aflatoxins contamination in the key phases (pre-harvest, harvest and drying, post-harvest) of the Ethiopian peanut production chain.

2. Mitigation strategies of aflatoxins contamination in Ethiopian peanuts

To deeply understand how the application of mitigation strategies can help to contain the aflatoxigenic risk along the Ethiopian peanut production chain, we revised the flow diagram proposed by Pitt et al., 2013 and adapted it to an Ethiopian case study.

A comprehensive version of the graph comprising mitigation strategies vs increased AFs-risk along the entire Ethiopian peanut production chain is reported in the supplementary materials (Figure S1).

The theoretical basis of our graph relies upon the achievement of the Food Safety Objective (FSO) which in the case of mycotoxins is described by the following formula

$$H_0 + \Sigma_I - \Sigma_R = FSO$$

where H_0 is the initial level of contamination, Σ_I is the set of stages where mycotoxins concentration is likely to increase, Σ_R is the set of stages where key actions in reducing the contamination can be applied. For the sake of simplicity, in our study we considered H_0 at the time of pre-harvest, Σ_I is the cumulative effect of critical factors during pre-harvest, harvest and drying, and post-harvest leading to increased AFs concentration if no mitigation strategies are applied, Σ_R is the cumulative effect that visual sorting has in reducing aflatoxins level when applied after harvest and before storage.

The approach taken here is entirely qualitative, no weight has been given to the slopes of the lines in the figure. In practice, increases or decreases in aflatoxin levels reported in the graph, are strongly dependent on the different tools or practices applied.

2.1.Pre-harvest interventions for improvements

AFs contamination of peanuts often occurs in field soil before harvest. Any episodes of drought stress can allow cracking of developing pods and infection by *A. flavus* and/or *A. parasiticus* and associated AFs contamination. As they are heat stable and difficult to eliminate, prevention of their formation would be the best option although the weather conditions play a major role in determining this (Raters & Matissek, 2008).

Peanut cultivation in Ethiopia relies almost completely on the availability of manual labour and the high levels of rainfall occurring in the production regions. The crop planting and agronomy is not mechanised, thus requiring significant manual labour inputs and the plants are usually rainfed to try and avoid drought stress. Drought stress acts by causing a decrease of plants' natural defences including cracking of the pods and pest damage which allows ingress of drought-tolerant xerophilic fungi such as *A. flavus* and *A. parasiticus* (Pitt & Hocking, 2009). Under conditions of adequate rainfall or irrigation, these fungi are less competitive resulting in much lower levels of AFs contamination (Torres et al., 2014). However, globally, peanut crops are often produced in climatic regions where sub-optimal weather conditions, especially drought stress can occur, facilitating colonisation by these *Aspergillus* species and associated AFs (Pitt et al., 2013). Thus, weather conditions during the groundnut-filling period play a key role in determining the relative risks of AFs contamination in the pre-harvest phase and impacts on crop yield and quality.

Pre-harvest aflatoxin management comprises a wide range of strategies in the context of the implementation of GAPs. These include the selection of well-drained sandy loam soil being chosen for peanut cultivation to allow easy seed germination, sprouting, peg penetration and pod formation and avoid drought stress episodes. Different soil types may have significantly different levels of fungal infection because of their relative water retention properties (Magan, 2007). Chala et al., 2014 reported that the major soil type in different Oromiya districts is sandy loam. This favours the rapid proliferation of the fungi under dryer conditions, while heavier soil types with a higher water-holding capacity are less likely to trigger drought stress episodes, which can stimulate *Aspergillus* section *Flavi s*pecies to infect the ripening peanuts.

Moreover, deep ploughing of the land is important to clear weeds and ensure a well-prepared seedbed for proper water penetration and retention reducing the risk of aflatoxins occurrence and contributing to better yields (CAC, 2004). In Ethiopia, fields for peanut cultivation are prepared from one year to the next by ploughing them once or twice before the next peanut sowing season.

Pre-planting tillage is usually done using either oxen or tractors depending on the facilities farmers can access. Weed control is carried out manually using a hoe during the entire planting season.

The sowing of peanut seeds usually occurs from mid-April to the end of May when Ethiopia is about to enter its long rainy season, the so-called "*Kiremt"* (Ethiomet.gov.et, 2020).

The seed cultivars (cvs) for cultivation should be purchased from a certified seller, with the emphasis on choosing at least partially *A. flavus* resistant cultivars. Different cvs of groundnut seeds with improved characteristics have been focused on days of maturity, disease resistance, yield and final oil content in Ethiopia (Nega et al., 2015). However, breeding peanuts with resistance to fungal spoilage and AFs contamination is still challenging due to the lack of identified resistance genes and high G x E interaction. Recently, Haramaya University released a new groundnut cv, namely ICGV-95469, which has foliar resistance to diseases, a shorter period to maturity and high yields, which are thus suitable for rainy areas, such as the Oromiya region. Such improvements play a key role in indirectly increasing resistance to *A. flavus* and/or *A. parasiticus* spoilage and thus, AFs accumulation.

Most of the Ethiopian farmers often exchange seeds amongst themselves, and seldom trust recommended improved varieties. There are no private sector or governmental peanut seed enterprises providing certified peanut seeds (Abady et al., 2019). Therefore, the seed used and their susceptibility to *Aspergillus* section *Flavi* species and associated mycotoxins can rarely be guaranteed.

To favour adequate crop development and limit the build-up of aflatoxin-producing fungi and associated mycotoxin occurrence, it is also recommended to maintain ad row and intra-plant spacing to avoid overcrowding of plants and prevent conducive microclimate from developing during peanut growth as well as practising appropriate crop rotation from one year to the next (CAC, 2004).

It is very common in Ethiopia to intercrop peanuts with sorghum and/or maize. Multiple cropping systems, in which two or more crops are planted in the same field, are major components of African agriculture resulting in crop intensification in time and space (Kebede et al., 2020). However, intercropping with *Aspergillus* section *Flavi* susceptible crops such as maize and/or sorghum favours the distribution and build-up of inoculum of these toxigenic species, especially via crop debris, either on the soil surface or incorporated into the soil from one crop to another, and from year to year. The reason for the widespread use of intercropping is to avoid the potential for complete crop failure in a mono-cropping system, and an attempt to reduce disease and pest pressures, as well as the shortage of arable land (Berhanu, 2017).

No chemical fertilizers are applied directly to peanut plants, although some livestock manure is often used as an alternative to more natural fertilizer. Fertilizers such as urea, diammonium phosphate (DAP), Nitrogen-Phosphorus-Sulfur (N-P-S) are applied to maize and/or sorghum, and peanut crops are thus able to benefit from these nutrients by extraction from the soil, especially microelements such as phosphorous (P) and zinc (Zn). Interestingly, in these inter-cropping systems, groundnuts showed better yield to fertilizer residues left from the other crops than to fertilizers applied directly to the peanut crop (GRDC, 2017).

No evidence is currently available in the literature on the effect of fertilizer on aflatoxins contamination in Ethiopian peanuts. However, several authors already reported how their application influenced AFs accumulation levels in peanuts, suggesting that the use of calcium-based fertilizer (e.g. gypsum) might be effective in reducing the risk of AFs (Waliyar et al., 2008; Eche et al., 2017) while farmyard manure application has been often linked with increased AFs concentrations in peanuts (Nakhro and Dkhar, 2010; Kumar et al., 2010).

Biocontrol has been considered amongst the most efficient technologies for the reduction of AFs contamination pre-harvest (Torres et al., 2014; Bandyopadhyay et al., 2016). It broadly refers to the use of natural non-toxigenic fungi applied to reduce the incidence of pests, diseases, or toxins (Pitt and Hocking, 2006). A promising strategy for biocontrol of AFs in Ethiopian peanuts is represented by the application of atoxigenic strains of *A. flavus* to compete with the toxigenic ones by displacing them and reduce the levels of AFs contamination.

The release of the first biocontrol products, AF36 and Afla-guard®, used in cotton and maize and maize/groundnuts, respectively, in the USA, has encouraged the International Institute of Tropical Agriculture (IITA) and USDA-ARS to develop a similar bio-pesticide Aflasafe®, which is adapted and improved for use in African agroecosystems (Bandyopadhyay et al., 2016). This biocontrol product is based on a mixture of four atoxigenic fungal strains belonging to distinct Vegetative Compatibility Groups (VCGs) of *A. flavus*, native to the target country where control is required. Such a multi-genotype strategy is meant to provide a better adaptation to different crops, environments, and agricultural practices (Bandyopadhyay et al., 2016; Probst et al., 2011). In a study conducted in Ghana, it was shown that the application of Aflasafe® 35-40 days after planting, resulted in a significant reduction of AFs content (< 99%) in 800 peanut and maize farmers' fields (Agbetiameh et al., 2019). In Africa, there are 14 atoxigenic biocontrol products registered under the tradename Aflasafe® for use in maize; 13 of those products are also registered for use in peanuts and two of those are registered for use in sorghum (Bandyopadhyay et al., 2016; Schreurs et al., 2019). Numerous African countries have registration for the use of Aflasafe® products while in Ethiopia, biocontrol products are in development within the NutriNuts project currently ongoing at Cranfield University (UKRI, 2019). The estimated cost for 10 kg of Aflasafe® product to treat one hectare of production, ranges from US$12 (526.30 Birr) to US$ 18.75 (822.35 Birr) which makes the application of biocontrol agents a feasible solution for Ethiopian farmers that often have areas of only 0.125 to 2 ha of land for peanut cultivation (Chala et al., 2014; Bandyopadhyay et al., 2016).

Overall, the implementation of both GAPs, including field and crop management practices, and the use of BCAs would synergistically limit the risk of AFs occurrence during the pre-harvest phase in the Ethiopian peanut production chain. This is provided that drought stress episodes are avoided where possible.

The effect of proposed mitigation strategies on aflatoxins formation in Ethiopian peanuts during pre-harvest is reported in Figure 1.

2.2.Harvest and drying interventions for improvements

Peanuts' harvest involves different practices that, when applied, may help farmers deliver safe peanuts to the consumers. In the Eastern areas of Ethiopia, peanuts are harvested in October or later when the dry season "*Bega*" starts (Ethiomet.gov.et, 2020). Adherence to GAPs would certainly contribute to mitigating the risk of AFs in Ethiopian peanuts at the harvesting stage.

Timely harvesting of peanuts is necessary as excessive numbers of overmature or very immature pods at harvest can be reflected in high levels of AFs in the final product (CAC, 2004). The harvesting time of Ethiopian peanuts is based on the physiological maturity of the crop. This is usually when the colour of the leave changes from green to yellow and start to become detached; the ripening internal pods also change colour during this period to dark grey.

It is important to avoid mechanical damage during the harvesting process and subsequent threshing as this can lead to damage to the protective shell allowing the rapid invasion of the pods by *A. flavus* and *A. parasiticus*. Peanuts should be handled as gently as possible, with every effort being made to minimize physical damage during this phase (CAC, 2004). If peanuts cannot be immediately transported they should be stored for the shortest time possible in a way that will keep them dry and protected from rain, insects, rodents, birds and drainage of water (CAC, 2004) by the use of appropriate protective covers or appropriate locally available storage systems.

In Ethiopia, peanuts plants are manually pulled from the soil with the help of a hoe or shovel, arranged in piles and left in the field for 1-2 days to allow some moisture evaporation to avoid seed shrivelling. It is important that the surfaces where this is done must be cleared of any crop debris or decaying plant material to minimise colonisation from such inoculum sources where *A. flavus* and/or *A. parasiticus* might reside (CAC, 2004). Once collected, peanuts should be sorted to remove damaged or rotten nuts and any foreign materials and transported as soon as possible to the processing facility. The lack of effective sorting procedures to separate damaged seeds from intact ones also contributes to the spread of aflatoxin producing fungi in the Ethiopian production chain.

After harvest, this drying phase should be done evenly to avoid pockets of high moisture pods and dried to reach a moisture content (m.c.) < 7.5-8 % than those required to favour mould growth during storage. Generally, >10% m.c. (=0.82 water activity) after harvesting predisposes peanuts to colonisation by aflatoxigenic species and AFs contamination (Garcia-Cela et al., 2020). Several studies have shown a positive correlation between high m.c. (>10-15%), the rate of infection and AFs production in lipid-rich commodities (Mora and Lacey, 1997; Houssou et al., 2009; Hell et al., 2000), including peanuts (Kaaya et al., 2006).

In Ethiopia, the drying process used for shelled nuts is a passive one lasting for about one week and is entirely done by placing the harvested peanuts in piles in the field on the ground under natural sunlight and manually turning these from time to time to facilitate relatively even drying. This practise is discouraged because the direct contact with the soil exposes the peanuts to being damaged and eaten by rodents, birds and insect pests allowing further ingress and colonization by aflatoxigenic fungi. In addition, the piles of groundnuts are not covered allowing rewetting to occur during rainfall episodes resulting in colonised nuts being further contaminated with AFs as the conditions are conducive for growth and toxin synthesis on the lipid-rich nuts (Alonge, 2015; Zuza Jnr et al., 2018).

In Ethiopia no direct moisture content measurements are made periodically to check the rate of drying and the timing of reaching a safe level. The final moisture content is evaluated in a rudimentary way by a rough verification based on visual inspection and pressing the nuts with fingers to gauge whether an appropriate moisture content has been reached.

Thus, the use of an appropriate low-cost and re-usable moisture content indicator for this important phase of the peanut chain might be an effective solution. For example, the relatively simple and inexpensive DryCard™ developed by the US Agency for International Development (USAID) and the University of California Davis (UC Davis) would be very beneficial for monitoring the kinetics of naturally dried peanuts in Ethiopia. It is a simple device to determine relative humidity around dried stored products (Thompson et al., 2017) that does not require any skills for its use. It is colour indicative as the strip of cobalt chloride ($CoCl_2$) is light blue and would turn to purple and pink when the equilibrium relative humidity (ERH) is high (Zambrano et al., 2019). For its use, the DryCard™ and the commodity sample are placed together in an airtight container. Within 20-30 minutes, an initial indicative value will be obtained, with a very accurate and reliable result obtained in 2 hours (UC Davis, 2017).

When the ERH value is <65% (=0.65 a_w), the sample is considered to be dry enough to prevent any fungal growth and risks of mycotoxin production during this phase (Thompson et al., 2017).

The DryCard™ can be reused indefinitely for a period of up to 3 years and it is suitable for any type of dried product (UC Davis, 2019). The cost for its manufacturing is low (for 100 cards, US$4 for cobalt chloride strips and US$2.4 for plastic lamination) (UC Davis, 2017).

In addition, drying the peanuts on tarpaulins rather than directly on soil was found to be an improved practice that resulted in lower AFs contamination. This may also be due to reducing the inoculum potential from spores from the soil being transferred to the drying pods, especially during turning. In addition, a tarpaulin can be used to completely cover the drying peanuts during rain episodes (Jordan et al., 2020).

Alternatively, instead of using natural sun drying, active drying approaches could also be implemented. For example, the Collapsible Dryer Case™ from GrainPro Inc can be adapted to be an affordable drying solution. It consists of a lightweight woven coated polyethylene case that is portable and easy to relocate with simple installation through air inflation (GrainPro, 2020). It can be easily reclosed on itself creating a rainproof cover (Villers, 2014). This allows farmers to act rapidly in case of sudden changes in the prevailing weather conditions. The package comes with a foot pump that does not require electricity and a repair kit. Moreover, GrainPro Inc ultimately has been requesting organizations in Ethiopia to be their distributors (GrainPro, 2020), which would ease the delivery of both information and their products, hence to better provide alternative active drying solutions for farmers.

The build-up of a passive solar dryer would represent another possible efficient strategy to improve the drying of peanuts in Ethiopia, as they use natural air circulation without the need for energy supply and it is simple and cheaper to construct (Ekechukwu & Norton, 1999). A typical solar dryer consists of mainly two parts, the heat collector covered by glass and the drying chamber. As sunlight reflects on the glass, the glass becomes hot and the heat is transferred to the drying chamber through the absorber, which is made of high thermal efficient material such as galvanized iron sheet (Hegde et al., 2015). Air flows in via the lower inlet, it gets heated, goes towards the drying chamber passing through the trays of placement, and eventually flows out loaded with moisture evaporated from the drying products.

Today there are opportunities to also exploit both passive and active solar drying approaches. A passive solar dryer can be constructed with locally available cheap materials or even refuse/waste. For instance, aluminium tins can be used as heat absorbers. For example, Kumar et al., 2015 compared the performance of three different absorber plates, which sowed that plates made of aluminium fins had the highest thermal efficiency, allowing the drying chamber to reach an average temperature of 73.2ºC when the ambient temperature was around 39.5ºC. Tins painted in black can further increase the absorption of heat.

Another option for peanuts drying in Ethiopia is the use of desiccants that can adsorb water and bind it strongly (Bradford et al., 2018). The use of forced-air driers based on silica gel has been successfully demonstrated in different countries (Bradford et al., 2016; Kunusoth et al., 2012). This system is cost-effective on quantities up to approximately 100 L volume at a time, making it suitable for smallholders' farmers (Timsina et al., 2018).

An integrated approach consisting of combining adherence to GAPs and the use of improved drying tools would certainly help Ethiopian farmers to tackle the current poor AFs management practices and also provide benefits of increased crop yield and quality.

The effect of suggested mitigation strategies on AFs accumulation in Ethiopian peanuts during harvest and drying is shown in figure 2.

2.3. Post-harvest interventions for improvements

After drying, peanuts are collected in polyethylene bags and transported home within the same day as most of the fields are close to the farmers' houses. These bags are reusable but rarely cleaned, representing a critical factor for post-harvest contamination with spoilage and mycotoxigenic fungi. Transportation is mostly done by loading the bags on women' heads or by stacking the bags on top of each other on conventional trucks simply covered with tarpaulin sheets for protection from rainfall episodes.

According to the Codex recommendations, prevention of an increase in AFs during transportation and storage depends on adherence to GAPs which includes maintaining a safe m.c. ($a_w \leq 0.70$; ERH≤70%), low environmental temperature (0-10°C) and appropriate hygienic conditions (CAC, 2006).

The Purdue Improved Crop Storage (PICS, 2015) bags, a hermetic storage technology that has been used in Africa, could be a solution for short and medium-term use. These bags consist of two inner layers of 80-µm high-density polyethylene protected by an outer layer of woven polypropylene bag. Due to the low permeability, the inner layers act as oxygen barriers once packed. These are sealed allowing the increase in CO_2 from the respiration of the commodity and the associated mycobiota and the decrease in O_2 level inside the bag. This prevents any insect proliferation and has been shown to reduce AFs contamination (Murdock & Baoua, 2014). Such hermetic storage conditions provided by PICS bags can inhibit or minimise AFs contamination during storage (USAID, 2015).

Studies have demonstrated that no weight loss and increase in pest population was observed on both shelled and unshelled peanuts stored in PICS bags for up to 6-months (Baributsa et al., 2017). Sudini et al., 2015 found that peanuts stored for 4 months in PICS bags had retained seed vitality and oil content. Comparison of cloth bags with the PICS bags with peanuts inoculated with *A. flavus* showed AFs contamination levels of 63.7 µg/kg and 33.5 µg/kg, respectively. Thus, PICS bags could be a cost-effective solution for the home storage of peanuts. The price per unit is between US$2.00 and $3.00 (100kg capacity), with a durability of up to 3 years (Murdock & Baoua, 2014).

Albeit Agricultural Input Supply NGOs like CRS (Catholic Relief Services), ICRS (International Committee of the Red Cross) supply PICS bags for free to the farmers. However, the lack of awareness of the advantages in reducing AFs contamination have limited their use by Ethiopian rural farmers communities.

Ethiopian peanuts are usually home-shelled after laying them on bags, the same ones used for transport or storage, which have often been in direct contact with the ground. The process usually takes place when farmers need to sell, plant or eat peanuts and it consists of beating the nuts with a wood stick or using teeth, after soaking the peanuts with water to soften the pods. Hand shelling is time-consuming and labour-intensive, leading to sore thumb syndrome or painful wounds on fingers, and is done predominantly by women and children, who account for around 70% of this activity (Abady et al,. 2019). Moreover, breaking pods using teeth involves the risk of aflatoxin contamination and ingestion, if individual peanuts are heavily infected. After shelling, the pods will be used for cooking or as firewood. A medium-term exposure of the peanuts to ground dust, air and insect damage before being sold represents another critical point where AFs contamination in the Ethiopian peanut production chain can occur. As peanuts are lipid-rich, they can adsorb water very quickly in damp humid environments which allows AFs to be synthesised during this phase.

To address these problems at a farmer level, a simple shelling tool that is easy to construct with locally readily available materials could be helpful. A simple nutcracker can be made by tying two sticks together using a rubber band and keeping them separated using a piece of folded cardboard.

For larger-scale operations, different motorized shelling machinery has been developed with good overall performance (Adedeji and Danladi, 2016; Muhammad and Isiaka, 2019; Nagesh et al., 2018). However, considering the possible energy constraint in Ethiopia, the hand-operated type is recommended to minimise energy requirements, as manpower is the only necessary power source.

The first hand-operated sheller was the Universal nut sheller which was invented in Mali and is now developed by a non-profit international organization called the Fully Belly Project for developing countries (TheFullBellyProject, 2006). It can shell the peanuts by spinning the hand crank that unites the rotor and rotates it continuously. The rotor's movement allows peanuts to fall into the clearance between the rotor and the outer stator, and to be cracked by friction. This device requires on-site assembly, as the main body is made of concrete and it takes around 6 days to dry. Then the metal components can be installed. Other than peanuts, it is also capable of shelling a variety of nuts such as shea nuts and dried coffee (TheFullBellyProject, 2006).

Another hand-operated decorticator is built of a handle mounted in a semi-circular metal hopper with a perforated bottom. When rocking the handle, peanuts will be pressed and broken thanks to the cast iron pegs assembled on the oscillating sector. The kernels and the shell will then fall through the bottom. The clearance between the concave form bottom and the oscillating sector is adjustable, the bottom is also replaceable to suit different sizes of peanuts (Ansari et al., 2015; Kulbhushan et al,. 2017).

Before collecting all the shelled peanuts together for storage, physical separation through discarding the defective and shrivelled ones can be an important but simple step to help improve the safety and the quality of the harvest. On the one hand, clean and whole kernels would add value to the peanuts for selling to the wholesale traders; on the other hand, the removal of altered kernels also helps to reduce the risk of AFs, as a fungal infection is more likely to occur in damaged and shrivelled kernels (Lavkor and Var, 2017), and contaminated peanut kernels are often discoloured (Dorner, 2008).

Studies have also shown that hand sorting as an intervention can reduce up to 42.9% of AFs in peanuts (Xu et al., 2017). Standards on the hand sorting procedure can be taught to farmers through extensive training. By providing training materials, showing both samples of good-featured peanuts and altered kernels, organising practical sorting sessions, and explaining the reason behind these, farmers could better understand the beneficial consequences of sorting and also improve the skill sets.

Ethiopian peanuts are usually stored in re-used polyethylene bags, piled directly on the ground and in house, where space is often shared with other crops and livestock. This is a critical factor increasing the risk of contamination of peanuts by *Aspergillus* spp. and AFs. The use of PICS bags or novel bags with slow release of food-grade preservatives would represent valuable solutions for the long-term storage of peanuts in Ethiopia. The use of antimicrobial packages is a promising path to control bacterial and fungal growth leading to safe food products (Irkin & Esmer, 2015; Motelica et al., 2020). However, this kind of novel bag is currently commercialized only in the USA and Japan (Motelica et al., 2020). Thus, one of the main challenges would be for industries to promote their use, especially in developing countries by considering cost-effectiveness and raising awareness among farmers.

Another critical factor for AFs formation at this stage is represented by inadequate storage facilities in Ethiopia. Sometimes, storages houses are covered using black plastic sheets, which may absorb high temperatures and create a conducive environment for storage moulds development and insect pests. Bankole & Adebanjo, 2003 reported that traditional storage structures used for crops in Nigeria included containers made of plant materials (woods and bamboo). Adequate storage facilities with proper ventilation, good roof and concrete floor are required to prevent rewetting of peanuts and limit their susceptibility to post-harvest AFs contamination (CAC, 2006).

A comprehensive approach, including the adoption of GAPs, the use of improved tools/devices and the delivery of training sessions and informative campaigns addressed to Ethiopian farmers would help improve the management of AFs risks in peanuts during post-harvest. Figure 3 shows the effect of proposed controlling strategies on AFs accumulation in Ethiopian peanuts during post-harvest (transport-shelling-storage).

3. Conclusions

This review presented an overview of the possible improvements within the Ethiopian peanuts production chain to mitigate the risk of AFs contamination.

A holistic approach including adherence to GAPs and the use of specific tools in the different phases would help Ethiopian farmers address AFs occurrence in locally grown peanuts. The improved mitigation strategies proposed are simple and relatively easy to apply. They do not require many professional skills. In addition, the equipment involved is easy to operate, do not require extra energy supplies and utilise readily available local materials. However, every solution comes with some costs and it might be challenging to educate farmers about why these investments would be important in the long term, considering farmers low-income levels (< US$ 3.40/day).

Therefore, inclusive informative sessions to educate farmers on the impacts of AFs on this economically important commodity, the benefits of reducing exposure on human health at a local level are critical. This would provide benefits in improved management of the home-grown peanut chain. This would provide benefits due to the increased use of Ethiopian peanuts to produce therapeutic foods and reduce the reliance on imported peanuts.

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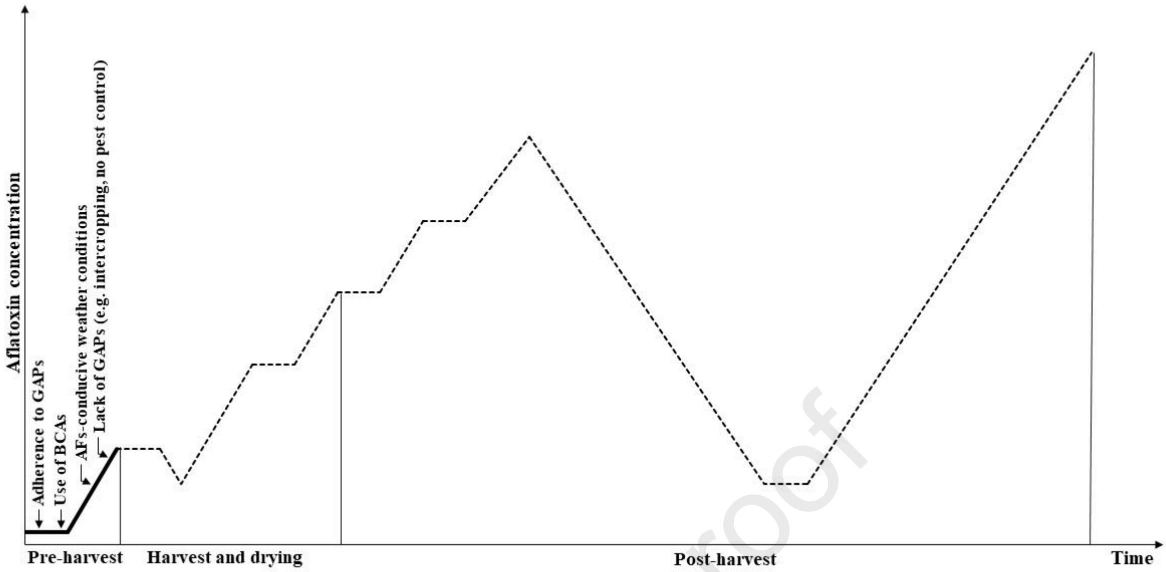
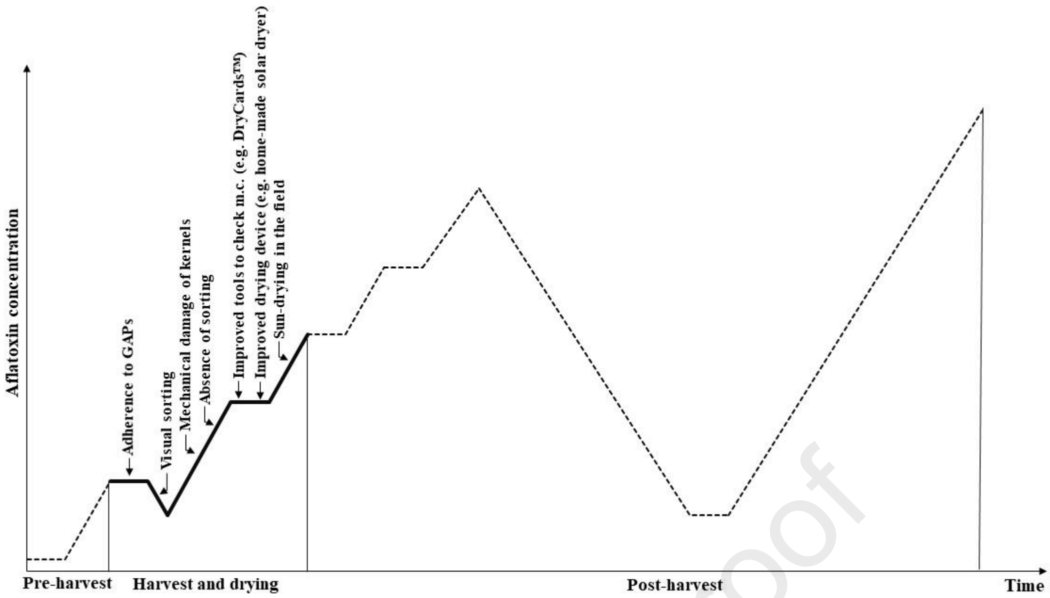
Figure 1: Time course of aflatoxin formation in relation to proposed mitigation strategies in Ethiopian peanuts during pre-harvest.

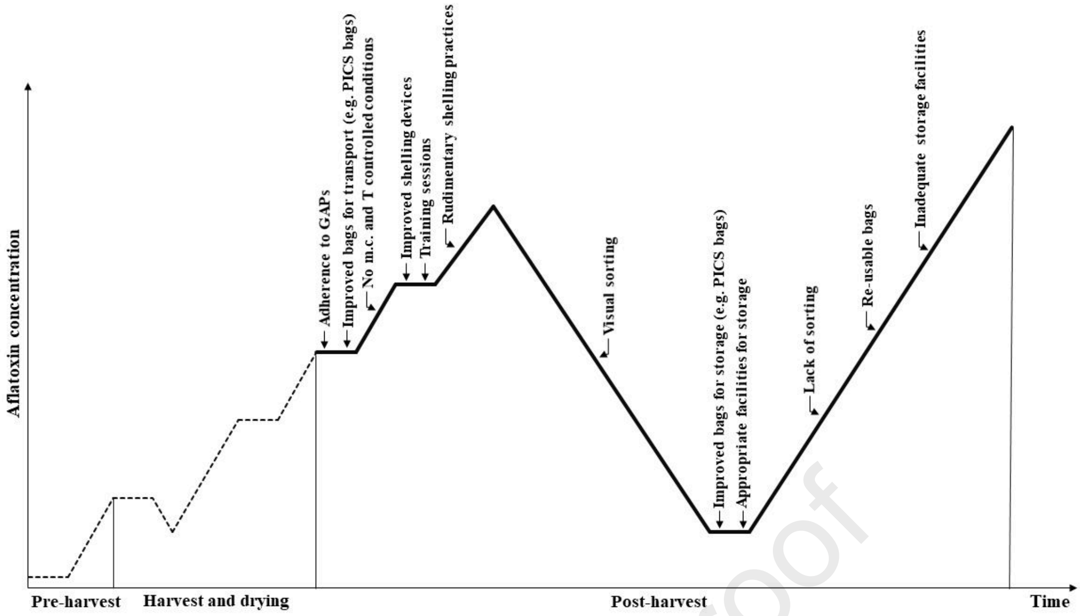
Figure 2: Time course of aflatoxin formation in relation to proposed mitigation strategies in Ethiopian peanuts during harvest and drying.

Figure 3: Time course of aflatoxin formation in relation to proposed mitigation strategies in Ethiopian peanuts during post-harvest (transport-shelling-storage).



Aflatoxin concentration
Adherence to GAPs
Use of BCAs
AFs-conducive weather conditions
Lack of GAPs (e.g. intercropping, no pest control)
Pre-harvest
Harvest and drying
Post-harvest
Time


Aflatoxin concentration
Adherence to GAPs
Visual sorting
Mechanical damage of kernels
Absence of sorting
Improved tools to check m.c. (e.g. DryCards™)
Improved drying device (e.g. home-made solar dryer)
Sun-drying in the field
Pre-harvest
Harvest and drying
Post-harvest
Time



Aflatoxin concentration
Adherence to GAPs
Improved bags for transport (e.g. PICS bags)
No m.c. and T controlled conditions
Improved shelling devices
Training sessions
Rudimentary shelling practices
Visual sorting
Improved bags for storage (e.g. PICS bags)
Appropriate facilities for storage
Lack of sorting
Re-usable bags
Inadequate storage facilities
Pre-harvest
Harvest and drying
Post-harvest
Time

Declaration of competing interest

The authors declare no conflict of interest.

Improvements within the peanut production chain to minimize aflatoxins contamination: an Ethiopian case study

Cervini, Carla

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