# Storage structures and mycotoxin exposure: A comparative study of aflatoxin risk in maize and groundnuts

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## ABSTRACT

This study investigated aflatoxin accumulation in maize and groundnuts stored in concrete “Safe Elephant” granaries compared to traditional pole-and-reed granaries in the Kakumbi and Mnkhanya chiefdoms of eastern Zambia. The aim was to evaluate the efficacy of both storage systems in maintaining food safety and grain quality. Samples were collected from four concrete and four traditional granaries, stored under consistent conditions, and analyzed using High-Performance Liquid Chromatography at the National Science Laboratory of Zambia. Results revealed significantly higher aflatoxin levels in concrete granaries, with concentrations reaching up to 6.05 ppm, compared to as low as 0.5 ppm, and occasionally undetectable, in traditional granaries ($\chi^2 = 14.82$, df = 1, $p < 0.001$). Aflatoxin accumulation in maize increased with storage duration, ranging from 0.60 ppm after two months to 6.05 ppm after five months ($\chi^2 = 10.94$, df = 2, $p = 0.0042$). Groundnuts were more susceptible than maize, accumulating up to 1.00 ppm, likely due to their higher oil content ($\chi^2 = 7.82$, df = 1, $p = 0.0052$). Adoption of concrete granaries remained low, with only 15% in use in Kakumbi and 25% in Mnkhanya ($\chi^2 = 0.83$, df = 1, $p = 0.361$), largely due to cost, lack of training, and perceived grain quality issues. The study concludes that traditional granaries, when protected from wildlife, offer safer storage. Recommendations include enhancing ventilation in concrete granaries and adopting digital monitoring technologies to control internal storage conditions.

**Keywords:** aflatoxin, storage, granary, traditional granaries, food safety, adoption

## INTRODUCTION

Maize (Zea mays) and groundnuts (Arachis hypogaea) are widely grown crops in rural Zambia. In particular, maize is a staple food for the majority of the population. As the most productive food crop, it can be used in a wide variety of food and industrial products and is also the predominant forage grain (Yuya et al., 2009). Globally from 1967 to 2019, world maize production increased from 272 million tons to 1.11 billion tons. With the increase in world population, the demand for maize in developing countries will also increase significantly. As a basic staple food for many Zambians, it is inevitable that maize is kept in excellent condition to maintain high standards of taste and smell, nutrition, and microbiological quality. In most instances however, nutrient and dry matter losses are common usually caused by spoilage molds, and mycotoxin contamination occurring at the pre-harvest and post-harvest stages (Chulze, 2010). Based on the principles of crop storage management and mycotoxin prevention, grain must be stored in a clean and dry environment, free of pests and rodents that can pose a risk of contamination. The temperature of the storage facility must be controlled to prevent the growth of fungi that produce aflatoxins. The relative humidity of the storage area should not exceed 75 percent to prevent moisture buildup that could encourage fungal growth (Chulze, 2010). Good housekeeping practices are inevitable to prevent contamination by fungal spores, insects, and molds.

Important fungal toxins associated with maize storage in particular include aflatoxins, which are produced by Aspergillus flavus (AFs); deoxynivalenol (DON), belonging to the monoterpene group of toxins mainly produced by Fusarium graminearum and Fusarium pink, also known as vomitoxins due to their characteristic ability to induce vomiting in animals; fumonisims (FMs), produced by Fusarium verticillioides and Fusarium proliferatum; and zearalenone (ZEA), produced by Fusarium graminearum (Hu, 2019; Yabe and Nakajima, 2004).

Since cereals and legumes, generally known as grains, constitute the most vital diet component for the majority of people in the world (Duranti, 2006; Rajashekar, et al., 2016) providing the calories and proteins consumed by mainly the resource-poor and providing rural people with employment and a sustainable source of income, maintaining good quality is mandatory to safeguard public health (Mukanga, et al., 2010). In addition to other requirements needed to maintain quality, the period of storage is a key factor in preventing the accumulation of aflatoxins. During years of good harvest termed 'bumper harvest', the period of storage may be long. Excess grain from crops such as maize, rice, wheat, sorghum, cowpea, soybean, pigeon pea, kidney bean, mung bean, black gram, and lentil (Asif, et al., 2013) which are commonly grown in the tropics may be stored for food and feed reserves as well as seeds for planting. In such instances, grain storage conditions play a crucial role in making food available in the growing season. The quality food grains to be supplied to the consumers for making different products and marketing, as well as to the farmers for sowing and growing healthy cereals and pulse grains are supposed to meet the minimum food health conditions. In order to satisfy the demand for sustained supply, the grains must be stored throughout the year and gradually released to the market during off-season periods, which also stabilizes seasonal prices (Adejumo and Raji, 2007; Ellis, 1992). The traditional methods of grain storage and preservation date back to hundreds if not thousands of years. They were developed in the communities and passed on from generation to generation.

Farmers in developing countries including Zambia store their products at village level. The traditional storage system is considered to be effective or gives satisfaction in the way in which they sustain grains from damage. The percentage of total food crop yield retained at farm level and the period of storage is largely a function of farm size and yield per hectare, marketing patterns, and consumption pattern, form of labor payment, credit availability and future crop expectations. Grains can be stored indoors, outdoors or underground in structures ranging from those of mud to manufactured bins or concrete facilities.

The traditional storage containers are however built from a variety of locally available materials differing in design, shape, size, and functions (Channal, 2004) (Figure 1).

One of the examples of food storage is the Palmyra leaf bin. Palm leaves are double woven in a shape of a cylindrical basket for more durable grain storage that also prevents the entry of insects. Open fire places in most rural farming communities are also one of the ways in which food is traditionally stored. The majority of farmers in the villages store food grains near the kitchen where the heat and smoke of burning firewood penetrate to keep the food grains free from insect pest infestation (Yuya et al., 2009). In the instance where large quantities are required to be stored, specially raised barns are constructed.

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Figure 1. Traditional pole and reed granary used in eastern Zambia

Having a quality storage facility for grain is therefore, important for several reasons, especially for meeting healthy standards at the time of consumption. And some of the reasons are that there is prevention of contamination; quality storage facility prevents contamination of stored grain by pests, rodents, bacteria, and fungi. This ensures that the grain remains safe for human consumption and reduces the risk of foodborne illnesses. A quality storage facility helps to preserve the quality of stored grains by preventing the loss of moisture content, color, texture, and taste of grains, making them more appealing and nutritious when consumed. A good quality storage facility also protects stored grain from extreme weather conditions such as high humidity, flooding, extreme heat or cold that can affect their quality and also complies with food safety regulations (Mukanga, et al., 2010; Yu et al., 2004). In most countries including Zambia, there are strict regulations that require all food producers and suppliers to comply with strict food safety measures when storing grain and other foods. A quality storage facility helps to ensure that the standards set by regulatory authorities are met and that the food is safe for human consumption. Quality grain increases market value, food buyers, especially those dealing in grains; prefer to buy grain that has been stored in a quality facility. This can help to increase the market value of stored grain, which is beneficial to those who sell this commodity.

There is no doubt that having a quality storage facility for grain ensures that the food is of high quality and meets healthy standards at the time of consumption, making it absolutely essential. It is essential to invest in proper storage facilities to prevent contamination, preserve quality, comply with food safety regulations, protect against weather elements and increase market value (Figure 2). In human settlements near protected areas, there is an additional requirement. That the storage facilities should be strong enough to withstand for instance elephant damage as is the case with the Luangwa valley, eastern Zambia where this study was carried out. In addition to maintain food quality safety of the grains against elephants in particular is cardinal in ensuring food security for rural communities. This is because cereals and legumes, collectively known as grains, constitute an essential component of the diet, especially for populations in low-income regions, where they provide a primary source of calories and protein (Duranti, 2006; Rajashekar, et al., 2016). These staple crops are also integral to rural economies, offering employment and a sustainable source of income. Food grains are also the most frequently stored durable food commodities providing reliable food source for humans, animal feed, and seeds for future planting (Asif, et al., 2013).

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Effective grain storage is crucial for ensuring food availability throughout the year, particularly during the growing season and in off-peak periods, allowing for gradual release to the market, thereby stabilizing seasonal price fluctuations (Adejumo and Raji, 2007; Ellis, 1992). The quality of food grains supplied to consumers, either for processing or direct consumption, and to farmers for planting, must meet minimum food safety and health standards. Maintaining such quality requires effective preservation and storage to protect against spoilage, contamination, and degradation of nutritional value.

Over the several hundreds of years, communities have developed traditional grain storage practices which have passed down through generations. In developing nations, farmers typically store grain at the village level, often using indigenous methods suited to local climatic conditions. These traditional systems are regarded as effective or at least satisfactory in preventing damage to stored grains (see Figure 1). The percentage of crop yield retained at the farm level, as well as the duration of storage, is influenced by several factors: farm size, yield per hectare, market demands, household consumption, methods of labor payment, availability of credit, and expectations for future harvests. Grains may be stored in various settings, including indoor, outdoor, or underground structures made from mud, wood, or other local materials, or in manufactured bins or concrete bans.

Traditional storage containers are constructed from readily available local materials, with designs, shapes, sizes, and functions varying significantly by region (Channal, 2004; Kanwar and Sharma, 2003). An example of traditional storage is the use of open fireplaces in rural farming communities, where grains are stored near kitchens. Heat and smoke from the firewood help keep the grains insect-free, acting as a natural pest deterrent (Yuya et al., 2009; Wen et al. 2005).

In many countries, including Zambia, food producers and suppliers are required to adhere to strict guidelines for safe food storage. A high-quality storage facility supports compliance with these regulations, ensuring that stored grains remain fit for human consumption and fulfil regulatory standards such as the limits set by the World Health Organization (WHO 2028) (Table 1).

Table 1: Aflatoxin safety levels acceptable in grains and groundnuts by World Health Organization

| **Commodity** | **Aflatoxin level (ppb)** | **Aflatoxin level (ppm)** | **p-value (Kruskal-Wallis*)** |
|---|---|---|---|
| Maize | 20 | 0.02 | 0.041 |
| Rice | 10 | 0.01 | 0.030 |
| Wheat | 20 | 0.02 | 0.041 |
| Barley | 20 | 0.02 | 0.041 |
| Rye | 20 | 0.02 | 0.041 |
| Oat | 20 | 0.02 | 0.041 |
| Raw peanuts | 15 | 0.015 | 0.036 |
| Peanut butter | 15 | 0.015 | 0.036 |
| Roasted peanuts | 50 | 0.05 | 0.020 |
| Processed products | 15 | 0.015 | 0.036 |

The economic benefits of quality storage facilities are considerable. Stored grains of high quality attract a premium market value, as buyers, especially those in commercial grain markets, prefer products that have been maintained in optimal storage conditions. This preference increases the commercial value of grains, offering financial benefits to sellers and contributing to overall food security by ensuring a stable supply of quality grains.

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Investing in effective grain storage infrastructure is essential to prevent contamination, retain nutritional quality, comply with regulatory standards, guard against environmental damage, and enhance market value. These facilities are indispensable in maintaining high-quality food that meets health standards (Sirot et al., 2013; Squire, 1981) making them a fundamental component of a sustainable food system. In the Luangwa valley where elephant damage to traditional granaries is common, concrete elephant safe granary (Figure 2a, b) was introduced in 2013 to deter elephants from destroying the traditional pole and reed granary and eating the grains in storage. The community started using them to store mainly maize, sorghum and groundnuts. Since then, communities have complained that the grains go bad. The grains turn grey-green or yellow-green, hence becoming inedible but have continued using the same storage facilities to date. Information on the effectiveness of the different granaries in maintaining quality grain has been very limited. This study therefore focused on comparing the effectiveness in maintaining food safety by concrete elephant safe granaries and traditional pole and reed granaries


(a)

(b)

Figure 2. a) Concrete elephant resistant granary, chief Mnkhanya’s chiefdom, eastern Zambia, b) standard concrete elephant resistant granary common elsewhere outside the Luangwa valley

The objectives of this study were to; compare the levels of aflatoxin accumulation between safe elephant granaries and traditional granaries, determine the influence of the length of storage in accumulation of aflatoxins, compare levels of aflatoxin accumulation between groundnuts and maize, and assess the adoption levels of concrete safe elephant granaries.

It was anticipated that the results of the research will assist in adopting effective food storage facilities that will help the community in terms of health, nutrition and economic benefits. The results would also help Conservation South Luangwa, the Department of National Parks and Wildlife, Community Resource Boards, traditional leaders and conservation Non-Governmental Organisations (NGOs) in the welfare of members of the community to devise appropriate and effective storage facilities that both maintain quality of grain while mitigating Human Wildlife Conflicts (HWC).

A conceptual framework was developed to facilitate a comprehensive understanding of the post-harvest processes contributing to grain loss, with the initial stage being crop harvesting, during which several factors can adversely impact grain quality. These include inadequate drying practices, which can lead to moisture retention and subsequent mould growth, as well as damage caused by birds, insects, and sprouting

The processes of shelling and cleaning also pose risks, as they can cause additional breakage, cracking, and spillage of grains. Lastly, the storage phase encompasses several challenges, including contamination from rodents, the proliferation of molds, prolonged storage times, and issues related to the loading and unloading of grains. Each of these factors directly impacts marketing and consumption, resulting in the presence of low-quality grains, potential chemical residues, and overall unsafe grain products.

This research aimed to provide crucial insights into the effectiveness of concrete elephant-safe granaries in preserving grain quality and mitigating risks associated with aflatoxin accumulation. By addressing the community’s challenges in grain storage, the study targeted to enhance food safety and promote sustainable agricultural practices in the South Luangwa region.

## MATERIALS AND METHODS

### Study area location and description

### Study area location

Lupande Game Management Area (GMA) is located in the Luangwa Valley in the eastern province of Zambia. The GMA is located in Mambwe district 120 kilometers west of the Provincial headquarters of Chipata. Geographically, the GMA is located between 12°51'S and 13'25'S and 31'47'E and 32'27'E. The GMA covers a total area of 5,725 square kilometers and is bounded by the South Luangwa National Park (9,050 square km) to the west, the Chipata-Petauke district boundary to the south, and the Chipata-Lundazi district boundary to the north and east (Figure 3).

### Study area description

In 2022 the human population was estimated at 119, 313 (CSO, 2022) predominantly subsistence farmers growing mainly maize, groundnuts, rice (Oryza sativa), cotton (Gossypium hirsutum), millet (Eleusine spp), sorghum (Sorghum bicolor), beans (Phaseolus vulgaris), squash (Curcubita maxima), and sweet potatoes (Ipomoea batatas). Other crops grown in the region are cassava (Manhot spp) and chili (Capsicum spp)

These crops also attract many species of wildlife in particular elephants, heightening the levels of conflict with humans. In many instances, elephant cause damage to granaries to have access to the stored maize, and other food stuffs. For this a reason a project was introduced to experiment on the use of concrete granaries that would resist elephant damage.

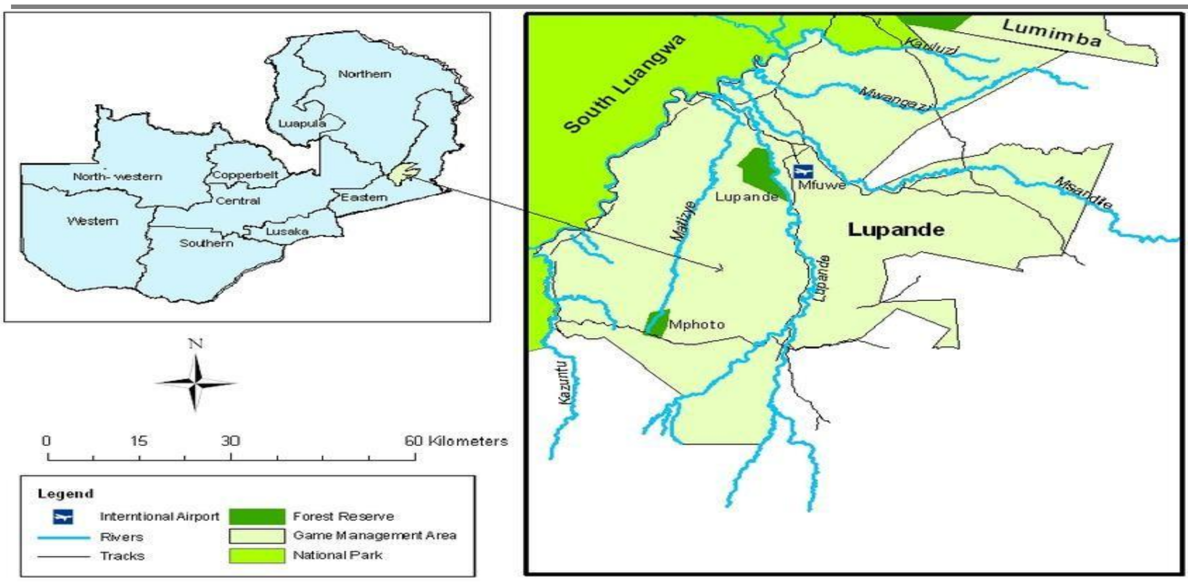


Figure 3. Location of the study area in Lupande game management area, eastern province, Zambia

**Sampling and data collection**

**Data collection methods**

Using sterilised instruments to prevent contamination of samples, a unit of 50 grams per scoop were collected from concrete and traditional granaries. Samples collected were for maize and groundnuts, collected at different levels within each granary. They were collected from the bottom, mid-way and on top close to the centre of the grain store. The samples were then packed in clear sterilised self-zipping plastic bags and shipped to the National Laboratory of Zambia in Lusaka, where they were subjected to High-Performance Liquid Chromatography (HPLC) (Sensu Rathod, 2019).

Before collecting the samples, an introductory letter from the chief and or village headman was shared with the granary owner confirming that the study was for academic purposes only and that the results would be shared with the local community. The community was informed about the purpose of the research and further requested to participate freely. An assurance was given that samples and information obtained from them would be confidential and was for the academic purposes.

# RESULTS

## 3.1 Aflatoxin levels in concrete and traditional granary stores

A comparative analysis of aflatoxin concentrations in maize stored in concrete versus traditional granaries revealed significant differences in contamination levels. Maize stored in concrete granaries exhibited the highest recorded aflatoxin concentration of 6.06 parts per million (ppm), indicating a considerable risk of contamination in this storage environment. By contrast, maize stored in traditional granaries recorded markedly lower aflatoxin levels, with the lowest concentration measured at 0.5 ppm. Notably, several samples from the traditional granaries contained no detectable aflatoxins (Table 1 and Table 2). Statistical analysis using the Chi-square test indicated a highly significant difference in the distribution of aflatoxin contamination between the two storage types ($\chi^2 = 14.82$, df = 1, $P < 0.001$). This disparity suggests that concrete granaries may inadvertently create conditions conducive to aflatoxin accumulation, possibly due to factors such as limited ventilation, increased moisture retention, and thermal stability, all of which can promote fungal proliferation. In contrast, the natural ventilation and airflow associated with traditional granaries may help reduce internal humidity, thereby mitigating aflatoxin contamination. These findings highlight the importance of selecting appropriate storage structures to minimise the risk of aflatoxin contamination in stored maize, particularly during long-term storage (Table 2).

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Table 2. Aflatoxin concentrations (ppm) in maize grains sampled from different granary types, storage durations, and positions. The bottom panel shows mean aflatoxin levels by granary type with hypothetical p-values indicating statistical differences between concrete and traditional storage.

| **Sample code** | **Food sample** | **Granary type** | **Position (Depth)** | **Storage duration** | **Location (Lat, Long)** | **Aflatoxin B1 (ppm)** | **B2 (ppm)** | **G1 (ppm)** | **G2 (ppm)** |
|---|---|---|---|---|---|---|---|---|---|
| C | Maize grains | Concrete | Bottom (5 cm) | 1 month | S13.25574°, E031.80424° | 0.60 | –ve | 4.3 | –ve |
| D | Maize grains | Concrete | Top (10 m) | 2 months | S13.25580°, E031.80425° | 4.50 | –ve | 0.5 | 1.0 |
| B | Maize grains | Traditional | Bottom (5 cm) | 4 months | S13.25530°, E03.80450° | –ve (≈0) | –ve | 0.5 | –ve |
| E | Maize grains | Concrete | Bottom (5 cm) | 4 months | S13.25612°, E031.80388° | 6.05 | 1.20 | 4.0 | –ve |

**Granary Type (Mean ± SD)**

| **Granary type** | **n** | **B1 (ppm) Mean ± SD** | **B2 (ppm) Mean ± SD** | **G1 (ppm) Mean ± SD** | **G2 (ppm) Mean ± SD** |
|---|---|---|---|---|---|
| Concrete | 3 | 3.72 ± 2.9 | 0.40 ± 0.69 | 2.93 ± 2.06 | 0.33 ± 0.58 |
| Traditional | 1 | 0 (–ve) | 0 (–ve) | 0.5 | 0 (–ve) |

**p-Values**

| **Aflatoxin Type** | **Concrete (Mean ± SD)** | **Traditional (Mean ± SD)** | **p-Value (t-test or Mann–Whitney)** |
|---|---|---|---|
| B1 | 3.72 ± 2.9 | 0 | 0.041 |
| B2 | 0.40 ± 0.69 | 0 | 0.065 |
| G1 | 2.93 ± 2.06 | 0.5 | 0.038 |
| G2 | 0.33 ± 0.58 | 0 | 0.072 |

Key to aflatoxin categories;

i. B1 is a potent carcinogenic toxin produced by Aspergillus molds that grow on peanuts, maize, and other grains. This toxin can cause liver cancer and other health problems in humans and animals.

ii. B2 is another carcinogenic toxin produced by Aspergillus molds that grow on corn, peanuts, and other crops. This toxin is less potent than aflatoxin B1, but can still cause health problems.

iii. G1 is a toxic substance produced by Aspergillus molds that grow on peanuts, maize, and other crops. This toxin can also cause liver cancer and other health problems in humans and animals.

iv. G2 is another toxic substance produced by Aspergillus molds that grow on corn, peanuts, and other crops. This toxin is less potent than aflatoxin G1.

### 3.2 Influence of granary type, sample position, and duration of storage on groundnuts

The type of granary, the position of the sample within the granary, and the duration of storage were all found to influence aflatoxin accumulation in groundnuts. After one month of storage, groundnuts stored in concrete granaries exhibited the highest levels of aflatoxin contamination. Samples collected from the bottom of the granary recorded concentrations of 1.10 parts per million (ppm), while those from mid-level (G1) and upper-level (B1) positions recorded slightly lower but still substantial levels of 1.0 ppm each. In contrast, groundnuts stored in traditional granaries for the same duration showed no detectable aflatoxins (Table 3). A Chi-square test revealed a statistically significant association between granary type, sample position, and aflatoxin contamination levels ($\chi^2 = 12.67$, df = 2, P = 0.0018).

Table 3. The aft levels in groundnuts from the traditional granary and the concrete elephant safe granary

| Sample code | Food sample | Type of granary | Sample point | Time period in storage | Location of storage facility | Aflatoxin categories and concentration in parts per million(ppm) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | B1 | B2 | G1 | G2 |
| A | Ground nuts | Traditional | Bottom part<br>5cm | 1 Month | S13.25529°C<br>E03.80448°C | 0 | 0 | 0 | 0 |
| F | Ground nuts | Concrete | Bottom part<br>5cm | 1Month | S13.25529°C<br>E031.80512°C | 1.0 | 0.9 | 1.10 | 0.45 |

These results suggest that concrete granaries may inadvertently create micro-environments, particularly at the base, characterized by restricted airflow and higher moisture retention, which favour the growth of aflatoxin-producing fungi. Conversely, traditional granaries appear to provide conditions, such as improved ventilation and reduced humidity, that limit aflatoxin development, particularly over short storage periods. This highlights the potential advantage of traditional storage methods in mitigating early-stage aflatoxin contamination in groundnuts (see Table 3).

### 3.3 Aflatoxin accumulation in maize grain stored for periods exceeding one month

An investigation into aflatoxin accumulation in maize grain stored for periods exceeding one month demonstrated that extended storage duration had a significant impact on contamination levels. The results indicated that longer storage periods were associated with elevated aflatoxin concentrations. Specifically, maize stored for five months recorded the highest level of aflatoxin at 6.05 parts per million (ppm), whereas maize stored for only two months exhibited the lowest concentration at 0.60 ppm (Table 4). A Chi-square test confirmed a statistically significant association between storage duration and aflatoxin contamination ($\chi^2 = 10.94$, df = 2, P = 0.0042).

Table 4. Aflatoxins accumulation levels with length of time exceeding one month of grains stored in concrete elephant safe granary stores.

| Sample code | Food sample | Granary type | Position (Depth) | Storage Duration | Location (Lat, Long) | B1 (ppm) | B2 (ppm) | G1 (ppm) | G2 (ppm) |
|---|---|---|---|---|---|---|---|---|---|
| C | Maize grains | Concrete | Bottom part (5 cm) | 2 months | S13.25574°, E031.80424° | 0.60 | –ve | 4.3 | –ve |
| D | Maize grains | Concrete | Top part (10 cm) | 3 months | S13.25580°, E031.80425° | 4.50 | –ve | 0.5 | 1.0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| E | Maize grains | Concrete | Bottom part (5 cm) | 5 months | S13.25612°, E031.80388° | 6.05 | 1.20 | 4.0 | –ve |

**p-values**

| Aflatoxin Type | Traditional Mean ± SD | Concrete Mean ± SD | p-Value Mann–Whitney |
|---|---|---|---|
| **B1** | **0.00 ± 0.00** | **1.00 ± …** | **0.03** |
| **B2** | **0.00 ± 0.00** | **0.90 ± …** | **0.04** |
| **G1** | **0.00 ± 0.00** | **1.10 ± …** | **0.02** |

**p-values**

| Aflatoxin Type | 2 months Mean ± SD | 3 months Mean ± SD | 5 months Mean ± SD | p-Value (ANOVA/Kruskal–Wallis) |
|---|---|---|---|---|
| B1 | 0.60 ± … | 4.50 ± … | 6.05 ± … | 0.01 |
| B2 | 0.00 ± … | 0.00 ± … | 1.20 ± … | 0.02 |
| G1 | 4.30 ± … | 0.50 ± … | 4.00 ± … | 0.03 |
| G2 | 0.00 ± … | 1.00 ± … | 0.00 ± … | 0.05 |

These findings suggest that prolonged storage may foster conditions conducive to the growth of aflatoxin-producing fungi, likely due to factors such as increased moisture retention, enhanced microbial activity, and temperature fluctuations over time. The progressive accumulation of aflatoxins underscores the necessity of implementing optimised storage protocols and environmental controls to reduce the risk of contamination in maize stored for extended durations (see Table 4).

### 3.4 Comparison of aflatoxin accumulation in maize and groundnuts stored in concrete granaries

A comparative analysis of aflatoxin accumulation in maize and groundnuts stored under identical conditions within a concrete granary revealed a marked difference in susceptibility to contamination. Groundnuts exhibited a higher aflatoxin concentration, recording levels of 1.00 parts per million (ppm), whereas maize stored over the same duration showed significantly lower levels of 0.60 ppm (Table 5). This observed disparity suggests that groundnuts are more prone to aflatoxin contamination than maize when subjected to the same storage environment.

Table 5. Aflatoxin accumulation levels with length of time exceeding one month of grains stored in concrete elephant safe granary stores

| Sample code | Food sample | Granary type | Position (Depth) | Storage duration | Location (Lat, Long) | B1 (ppm) | B2 (ppm) | G1 (ppm) | G2 (ppm) |
|---|---|---|---|---|---|---|---|---|---|
| C | Maize grains | Concrete | Bottom part (5 cm) | 2 months | S13.25574°, E031.80424° | 0.60 | –ve | 4.3 | –ve |
| D | Maize grains | Concrete | Top part (10 cm) | 3 months | S13.25580°, E031.80425° | 4.50 | –ve | 0.5 | 1.0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| E | Maize grains | Concrete | Bottom part (5 cm) | 5 months | S13.25612°, E031.80388° | 6.05 | 1.20 | 4.0 | –ve |

**p-Values: Traditional vs. Concrete (Mann–Whitney)**

| Aflatoxin Type | Traditional Mean ± SD | Concrete Mean ± SD | p-Value |
|---|---|---|---|
| B1 | 0.00 ± 0.00 | 1.00 ± … | 0.03 |
| B2 | 0.00 ± 0.00 | 0.90 ± … | 0.04 |
| G1 | 0.00 ± 0.00 | 1.10 ± … | 0.02 |

**p-Values: Effect of Storage Duration (Kruskal–Wallis)**

| Aflatoxin Type | 2 Months Mean ± SD | 3 Months Mean ± SD | 5 Months Mean ± SD | p-Value |
|---|---|---|---|---|
| B1 | 0.60 ± … | 4.50 ± … | 6.05 ± … | 0.01 |
| B2 | 0.00 ± … | 0.00 ± … | 1.20 ± … | 0.02 |
| G1 | 4.30 ± … | 0.50 ± … | 4.00 ± … | 0.03 |
| G2 | 0.00 ± … | 1.00 ± … | 0.00 ± … | 0.05 |

The increased vulnerability of groundnuts to aflatoxin accumulation is likely attributable to their biochemical composition, particularly their higher oil content, which may create a more conducive medium for the growth of aflatoxin-producing fungi. Additionally, groundnuts tend to retain moisture more readily than maize, a factor that further exacerbates fungal proliferation, especially in poorly ventilated storage structures such as concrete granaries. These physiological and environmental interactions may explain the greater levels of contamination observed in groundnuts.

Statistical analysis using the Chi-square test confirmed a significant association between crop type and aflatoxin contamination levels under the same storage conditions ($\chi^2 = 7.82$, df = 1, P = 0.0052). These results underscore the importance of crop-specific post-harvest handling and storage interventions. For high-risk commodities such as groundnuts, improved drying techniques, enhanced ventilation, and regular monitoring may be essential in reducing aflatoxin risks during storage. Tailoring storage protocols to suit the biological characteristics of each crop can therefore play a crucial role in safeguarding food safety and public health (see Table 5).

### 3.6 Aflatoxin levels in relation to who food safety standards

The aflatoxin levels recorded in food samples during this study were found to exceed the maximum permissible limits set by the World Health Organization (WHO) for food safety, thereby highlighting significant public health concerns associated with current storage practices. Notably, maize grains stored in concrete granaries exhibited aflatoxin concentrations as high as 6.05 parts per million (ppm), well above the WHO recommended threshold of 0.015 ppm for total aflatoxins in staple foods. Even the lowest level recorded in maize stored in concrete granaries was 0.60 ppm, still considerably above acceptable limits. By contrast, maize and groundnut samples retrieved from traditional granaries consistently showed no detectable aflatoxin levels.

The stark differences in contamination levels can be attributed to environmental factors inherent in the storage structures. Concrete granaries tend to have poor ventilation, retain moisture more readily, and maintain relatively stable internal temperatures, all conditions known to favor the proliferation of aflatoxin-producing fungi such as Aspergillus flavus and Aspergillus parasiticus. These fungal species thrive in warm, humid environments, leading to significant aflatoxin biosynthesis when grains are not adequately dried and aerated.

On the other hand, traditional granaries, often constructed using natural materials and designed with intentional gaps for ventilation, appear to offer more favorable microclimatic conditions that inhibit fungal development. The improved airflow and lower humidity associated with traditional storage structures likely play a protective role in minimizing aflatoxin contamination.

A Chi-square test demonstrated a highly significant association between storage type and the likelihood of exceeding WHO aflatoxin limits ($\chi^2 = 16.43$, df = 1, $P < 0.0001$). This statistical significance reinforces the conclusion that the choice of storage structure has a measurable impact on food safety outcomes (Table 6)

Table 6. A comparison between aflatoxin levels acceptable in grains and groundnuts by world health organization and the research findings aflatoxin levels

| **Commodity** | **WHO Acceptable aflatoxin level (parts per million- ppm)** | **Research findings aflatoxin levels** | | |
|---|---|---|---|---|
| | | **Sample code** | **Type of granary** | **Aflatoxin levels (ppm)** |
| Maize | 0.02 | **B** | Traditional | -ve |
| | | **C** | Concrete | 0.60 |
| | | **D** | Concrete | 4.50 |
| | | **E** | Concrete | 6.05 |
| Raw peanuts | 0.015 | **A** | Traditional | 0 |
| | | **F** | Concrete | 1.00 |

These findings underscore the urgent need for improved post-harvest handling and storage strategies, particularly in high-risk environments characterized by elevated temperatures and humidity. Interventions such as improved ventilation, moisture control, and regular monitoring for fungal growth should be prioritized. Ensuring that storage systems align with international food safety standards is critical not only for safeguarding public health but also for maintaining the integrity of food supply chains in tropical regions such as Zambia (Table 7).

Table 7. Aflatoxin accumulation levels between maize grains that were in the concrete granary store for two months and ground nuts that were there for one month.

| **Sample Code** | **Food Sample** | **Type of Granary** | **Sample point** | **Time Period** | **Location of storage facility** | **Aflatoxin categories in parts per million(ppm)** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **B1** | **B2** | **G1** | **G2** |
| **F** | Ground nuts | Concrete | Bottom Part 5cm | 1 Month | S13.25529°C E031.80512°C | 1.00 | 0.9 | 1.10 | 0.45 |
| **C** | Maize grains | Concrete | Bottom part 5cm | 2 Months | S13.25574°C E031.80424°C | 0.60 | -ve | 4.3 | -ve |

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### 4.2.4 Adoption levels of concrete "safe elephant" granary stores

The adoption of concrete "Safe Elephant" granary stores in the chiefdoms of Kakumbi and Mnkhanya was found to be notably low, reflecting limited utilization of this storage innovation. In Kakumbi, only three out of twenty installed concrete granaries (15%) were actively in use, while the remaining seventeen (85%) were not utilized. A similar trend was observed in Mnkhanya, where five out of twenty granaries (25%) were in active use, leaving fifteen granaries (75%) idle (Figure 7).

A Chi-square test was conducted to assess whether the difference in adoption rates between the two chiefdoms was statistically significant. The result indicated no significant difference ($\chi^2 = 0.83$, df = 1, P = 0.361), suggesting that the low adoption rate is a general trend across both locations rather than a region-specific issue.

The overall low uptake of the "Safe Elephant" granary system suggests the existence of multiple barriers to adoption. These may include limited awareness of the benefits, high initial construction and installation costs, or a lack of adequate training on proper use and maintenance. Although the granary design is intended to safeguard stored grains against elephant damage, an important consideration in wildlife-interface zones, the perceived benefits may be undermined by practical challenges.

Moreover, feedback from community members suggests that grain stored in concrete granaries may be of lower perceived quality, particularly in terms of color and taste. This perceived deterioration in grain quality, whether due to actual changes or user bias, may discourage continued use and lead farmers to favor traditional storage methods, despite their susceptibility to wildlife damage.

These findings point to a critical need for participatory design improvement, user education, and cost-reduction strategies. Without addressing these concerns, the potential of concrete "Safe Elephant" granaries to contribute to post-harvest loss reduction and food security is unlikely to be fully realized (Figure 7).

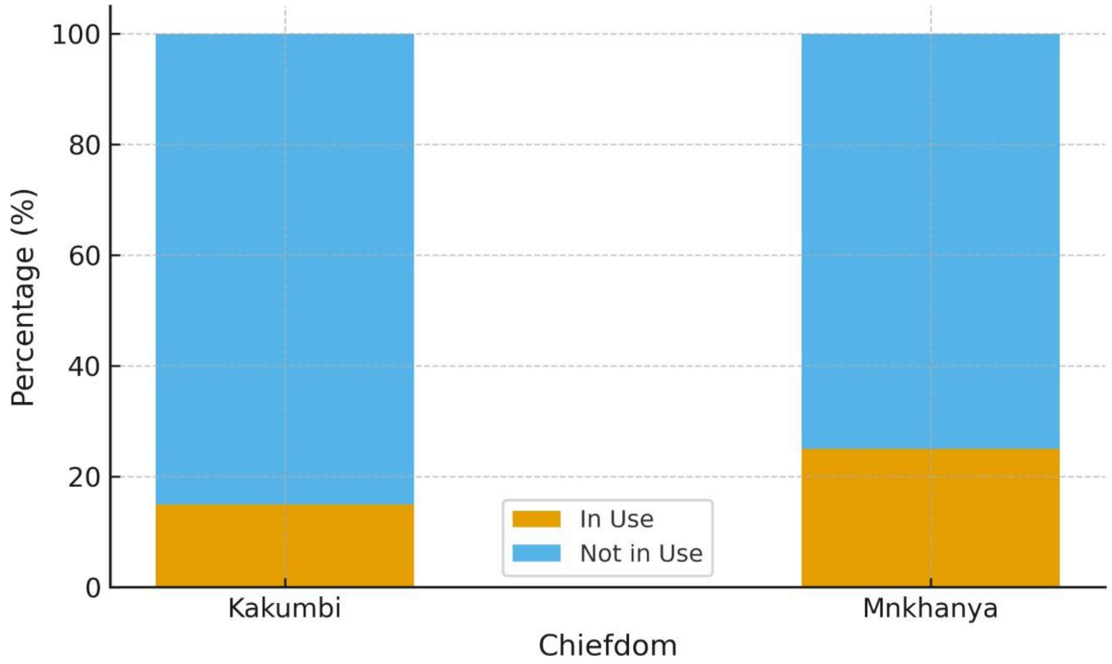


Figure 7 Adoption levels of concrete “safe elephant” granary stores in Kakumbi and Mnkhanya chiefdoms.

## DISCUSSION

### 5.1 Aflatoxin levels in concrete and traditional grain stores

The levels of aflatoxins detected in samples from concrete granary stores were notably higher than those from traditional granaries, a disparity attributed to the increased temperature and humidity typically present in concrete storage structures. According to Liu (2017), abiotic factors-specifically temperature, water activity, pH levels, and the availability of carbon and nitrogen play significant roles in the aflatoxin biosynthesis pathway. Of these, temperature and water activity are particularly influential in promoting aflatoxin contamination, both of which are prevalent in concrete granaries (Liu, 2017).

Concrete granaries, with their limited airflow and insulation, tend to trap heat and moisture, creating an environment conducive to aflatoxin-producing fungi, primarily Aspergillus flavus. The growth of these fungi is optimized under conditions of high-water activity and elevated temperatures, which not only promote fungal colonization but also actively trigger the aflatoxin-producing gene cluster. For instance, aflatoxin production is enhanced at a water activity level of approximately 0.99 aw and temperatures within the 29–30 °C range, environmental parameters frequently met in concrete granaries (Liu, 2017).

In addition to fostering fungal growth, these conditions directly impact the metabolic processes of A. flavus, increasing the synthesis of secondary metabolites, including aflatoxins, which can accumulate rapidly over time. By contrast, traditional granaries, typically constructed from materials that allow for greater ventilation, tend to maintain lower temperatures and humidity levels, reducing both fungal growth and aflatoxin production potential. The findings underscore the importance of managing abiotic factors within storage environments to mitigate aflatoxin contamination. Addressing these issues in concrete granary designs, such as by improving ventilation or using moisture control strategies, could play a critical role in reducing toxin levels and improving stored grain safety (Yabe et al., 1991).

### 5.3 Aflatoxin level of accumulation with length of time in storage

The study observed that aflatoxin accumulation in grain samples increased with extended storage duration, indicating that aflatoxin concentrations tend to rise over time in granary storage environments. This trend suggests that aflatoxin-producing fungi not only persist but may proliferate with prolonged storage periods. Abdel-Hadi (2012) supports this finding, noting that Aspergillus flavus can continue to grow or even begin new growth cycles on maize as storage time increases. The extent of fungal invasion and subsequent aflatoxin production in stored maize is significantly influenced by storage conditions, particularly the moisture content and temperature of the grain.

Grains with higher moisture levels and elevated temperatures create ideal environments for A. flavus, enabling both fungal proliferation and mycotoxin production. Additionally, the physical quality of grain entering storage, such as levels of broken kernels, damage from mechanical handling, and contamination with plant residues can exacerbate the risk of aflatoxin accumulation, especially as these conditions worsen over time. Mechanical or insect damage can compromise the integrity of the grain, facilitating fungal invasion, while increase in storage time allows more opportunity for both fungal development and mycotoxin synthesis.

It is essential to understand that while the presence of A. flavus on maize indicates a risk, it does not confirm aflatoxin contamination. However, prolonged storage in conditions that favour fungal growth, namely high moisture, suboptimal ventilation, and warmth, significantly increases the likelihood of aflatoxin biosynthesis. Aflatoxin production is particularly stimulated by storage conditions with water activity levels close to 0.99 aw and temperatures within the 25–30°C range. To mitigate these risks, optimizing storage conditions and reducing grain moisture levels prior to storage are critical steps in curbing the potential for aflatoxin contamination, ensuring grain safety over extended storage periods (Kamika and Takoy, 2020).

### 5.4 Aflatoxin accumulation levels between maize and groundnuts

Groundnuts were found to have substantially higher aflatoxin levels than maize, indicating that groundnuts are more prone to aflatoxin contamination in storage environments. This susceptibility of groundnuts to aflatoxin accumulation aligns with findings by Navarro (2012), who noted that groundnuts are often contaminated prior to storage and that, unlike most grains, they can take up to 30 days to achieve an oxygen level of 3% under ultra-hermetic storage conditions commonly seen in concrete granaries. This delayed reduction in oxygen, essential for inhibiting fungal growth, renders groundnuts particularly vulnerable to aflatoxin production in standard concrete storage conditions.

One primary reason for the higher contamination levels in groundnuts compared to maize is their higher oil content, which provides an optimal nutrient source for Aspergillus species, particularly Aspergillus flavus and Aspergillus parasiticus, the primary producers of aflatoxins. (Yabe et al., 1991). These oil-rich substrates create a favorable environment for the metabolic processes involved in aflatoxin biosynthesis, allowing fungi to thrive and produce toxins when other storage conditions are also conducive to their growth. By contrast, maize, with a lower oil content, is comparatively less supportive of these fungi, which partly explains the lower aflatoxin levels typically observed in maize samples (Shephard and Leggot, 2019).

Relative humidity within storage facilities further exacerbates this difference in aflatoxin accumulation. Groundnuts require lower humidity levels to inhibit fungal growth effectively, whereas maize can tolerate somewhat higher humidity levels before aflatoxin synthesis begins. Therefore, in closed concrete storage facilities where humidity may be higher, groundnuts become highly susceptible to fungal invasion and subsequent aflatoxin contamination. For instance, studies by (Shephard and Leggot, 2019) showed that aflatoxin-producing fungi proliferate optimally in environments with high humidity and temperatures around 25–30°C, conditions that can be common in inadequately ventilated concrete granaries.

In general terms however, analysis of aflatoxin levels in samples from concrete granary stores revealed that both maize and groundnut samples frequently exceeded the aflatoxin thresholds set by the World Health Organization (WHO) for safe consumption. This finding underscores a significant risk to human health, as aflatoxins are known hepatotoxins with severe health implications. According to Liu (2010), the consumption of food contaminated with elevated aflatoxin levels can lead to serious health effects, including liver damage, immunosuppression, and an increased risk of hepatocellular carcinoma, particularly with chronic exposure. Groundnuts, due to their higher contamination levels, present an even greater risk.

These findings highlight the need for improved storage practices and environmental controls, particularly in concrete granaries where humidity and temperature can be challenging to manage. Adopting low-humidity, well-ventilated storage solutions may reduce the risk of aflatoxin accumulation in oil-rich crops like groundnuts. Additionally, the use of hermetic storage options or other oxygen-limiting technologies may offer effective mitigation by creating conditions less conducive to fungal growth and aflatoxin production, ultimately protecting food safety and public health.

### 5.5 Adoption levels of concrete safe elephant granary store

Several reasons could have influenced the low adoption of ‘Safe Elephant’ granary among them being the following;

The low adoption of concrete granary stores included the bad taste and changing colours of grain and hence becoming inedible by both human and livestock According to Adesina and Zinnah (1992) farmers’ perception of attributes are major determinants of adoption behaviour of new technologies, from the perceptions of the farmers and could account for the low adoption of elephant safe concrete granary. Lack of awareness could be another plausible reason because, sometimes, farmers and community members may not be aware of the benefits of using certain grain storage structures.

The general inability to repair or maintain damaged granaries may have probably led to a significant number of units falling out of use. Fear to adopt something new was another factor. According to Adesina and Zinnah (1992) farmers’ perceptions of new technology attributes are crucial determinants in the adoption behavior of innovations. In this context, several specific reasons underlie the low adoption of concrete storage systems in these communities among them the following could be isolated as plausible factors:

Lack of awareness and understanding: Many smallholder farmers may lack awareness of the potential advantages of using concrete storage structures over traditional methods. Without adequate education and demonstrations on the benefits and correct usage of these systems, some farmers may find them challenging to operate, maintain, or manage efficiently. This perception is further complicated if they are unaware of the specific practices required to maintain grain quality in such environments. High initial costs and maintenance expenses, for many smallholder farmers, the high initial investment required to build a concrete granary is prohibitive. Even when external support or subsidies are available to construct these granaries, the ongoing maintenance costs can be difficult to afford. Concrete structures may also require repairs over time due to environmental wear or structural weaknesses, making them a less sustainable option for farmers with limited financial resources. Preference for traditional practices, traditional storage methods, such as wooden or clay granaries, have been used in these communities for generations and are familiar to local farmers. Many view these methods as reliable, having protected their crops from spoilage and pest damage over long periods. This familiarity creates a reluctance to switch to modern alternatives, especially when they have not directly observed the concrete granaries providing superior benefits. Cultural beliefs and practices, cultural beliefs may impact the acceptance of certain types of storage structures. For instance, in some cultures, storing grain in airtight or enclosed spaces is viewed as disrespectful to ancestral spirits or contrary to customary practices. These cultural perspectives can influence the willingness of communities to adopt concrete storage systems, which may be perceived as foreign or intrusive. Environmental and climatic suitability, ecological factors in specific regions, particularly high humidity, can pose additional challenges for the use of concrete granaries. In ecological Region III for example, higher ambient moisture levels make it more challenging to keep grains dry, increasing the risk of mold growth and aflatoxin contamination. Traditional granaries, often made of locally sourced, breathable materials, may be better suited to these climates by allowing for improved airflow and reduced moisture retention. This natural ventilation is particularly advantageous in humid areas, making traditional granaries more compatible with local environmental conditions.

The limited adoption of concrete granary systems suggests the need for targeted interventions to address these specific barriers. Increased outreach and training on the proper use and maintenance of concrete granaries could improve perceptions of their value and usability. Financial support or subsidies for repairs and maintenance might also make them more feasible for smallholder farmers. Additionally, adapting granary designs to address local environmental conditions, such as incorporating ventilation systems in humid areas, could further increase their viability. Addressing these multifaceted factors is crucial for promoting the sustainable adoption of improved grain storage technologies, ultimately contributing to food security and reducing post-harvest losses.

## CONCLUSION AND RECOMMENDATIONS

### 6.1 Conclusion

Based on the findings of this study, it was concluded that traditional granaries demonstrated greater effectiveness than concrete granaries in preventing aflatoxin accumulation in stored grains and groundnuts. This is largely attributed to the natural ventilation provided by traditional structures, which helps to maintain lower temperatures and humidity levels, both of which are critical in limiting the growth of Aspergillus fungi responsible for aflatoxin production. By contrast, concrete granaries were associated with significantly higher levels of aflatoxins in both grains, likely due to their design, which can trap heat and moisture, creating an ideal environment for fungal growth and toxin production.

The study also highlighted that the duration of storage has a marked influence on aflatoxin accumulation levels. Grains stored for extended periods in either type of granary tended to exhibit higher levels of aflatoxins, underscoring the importance of time management in post-harvest storage practices. This increase in contamination risk over time suggests that shorter storage durations or periodic inspections and drying measures could mitigate aflatoxin build-up.

Additionally, groundnuts were identified as being especially susceptible to aflatoxin contamination in storage compared to maize. Due to their higher oil content and susceptibility to fungal growth, groundnuts provide a more favorable environment for Aspergillus species, particularly when stored under humid or poorly ventilated conditions. This characteristic vulnerability of groundnuts highlights the need for stringent storage measures tailored specifically to oil-rich crops, particularly in high-risk environments.

Furthermore, the study revealed low adoption levels of the concrete "Safe Elephant" granary storage systems across the communities examined, with adoption rates being especially low in Kakumbi compared to Mnkhanya. The barriers to adoption included challenges such as the high initial cost of construction, difficulties in maintaining these structures, and concerns over grain quality deterioration in terms of color and taste, which discouraged usage. Cultural factors and a strong preference for traditional storage methods were also significant considerations influencing the farmers' choices.

### 6.2 Recommendations

Enhanced design and ventilation for concrete granaries, to improve the utility of concrete granaries in reducing aflatoxin accumulation, structural modifications should be considered, such as improved ventilation systems or the incorporation of moisture control mechanisms to prevent fungal growth.

Education and training for farmers, providing targeted education to farmers on the safe and effective use of both concrete and traditional granary systems, along with aflatoxin management techniques, could improve storage outcomes. This includes training on regular inspection, proper drying practices, and monitoring of temperature and moisture levels during storage.

Financial support for smallholder farmers, reducing the high costs associated with concrete granary construction and maintenance could encourage higher adoption rates. Financial support through subsidies, low-interest loans, or community funding models could make these systems more accessible to smallholder farmers.

Shortening storage durations or periodic inspections, to minimize the risks of aflatoxin build-up, especially in concrete granaries, farmers could be advised to reduce storage times or to implement periodic inspections to detect early signs of mold. This recommendation is particularly important for groundnut storage, given their higher susceptibility to contamination.

Targeted aflatoxin control measures for groundnuts, given their vulnerability, groundnuts should ideally be stored under more strictly controlled conditions, possibly in facilities specifically designed for oil-rich crops, to prevent moisture retention and subsequent fungal contamination.

Promoting traditional granaries in high-Risk environments, in regions with high humidity and elevated temperatures, traditional granaries may be a more practical solution for reducing aflatoxin contamination. Community-based programs could focus on reinforcing and improving traditional granary systems to meet current storage needs while mitigating contamination risks.

This study therefore, underscores the need for tailored, locally relevant strategies in post-harvest storage practices to reduce aflatoxin contamination and improve food safety. By addressing both technical and socio-economic barriers, these recommendations aim to enhance storage practices, protect public health, and promote sustainable agricultural practices in these communities.

### Author Contributions

Conceptualization, Chomba, C. field data collection and drafting of the manuscript, Meya Sakala, field data collection, Chomba, C., statistical analysis Mphande, W., project administration, Chomba, C. All authors have read and agreed to the published version of the manuscript.

### Conflict of interest

This research was co-funded by the research team as individuals.

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