International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 25, No. 3, p. 23-33, 2024

RESEARCH PAPER OPEN ACCESS

The influence of storage practices on aflatoxin contamination of maize in Babati district of Tanzania

Joseph Runyogote, Chacha Nyangi*

Department of Food Science and Technology, College of Agricultural Sciences and Technology Mbeya University of Science and Technology, Mbeya, Tanzania

Article published on September 10, 2024

Key words: Aflatoxin, Maize, Storage practices, Storage structures

Abstract

Aflatoxin levels were determined in a total of 816 stored maize samples throughout two seasons (576 in season 1 and 240 in season 2) from three villages in Babati District, Northern Tanzania. Questionnaires were used at each sampling unit to evaluate maize storage practices, storage structures, pest problems in storage, and farmer's solutions, including chemical treatments, maize storage form, and duration of storage, sorting practices, and source of samples. Quantification for total aflatoxin was done using an Enzyme-Linked immunosorbent assay (ELISA) (Reveal AccuScan® Neogen, USA), and the results were confirmed using a liquid chromatography-tandem mass spectrometer (LC-MS/MS). A total of 38% and 81% of maize samples were positive for aflatoxin from long village in seasons 1 and 2, respectively, while from Sabilo village we had 14% and 89% of positive samples, and from Seloto village 28% and 99% of positive samples from seasons 1 and 2, respectively. Drying maize on a raised platform, sorting out physically damaged and infected grains, storage for 6 months, use of improved bags for maize storage, and application of chemical insecticides during storage were practices found to reduce aflatoxin contamination. The findings from this study suggest that several post-harvest practices can be adopted by farmers to reduce/control aflatoxin development in maize and other crops.

* **Corresponding Author:** Chacha Nyangi ✉ nyangichacha@yahoo.com

Introduction

Mycotoxins are toxic secondary metabolites produced by fungi belonging to genera such as *Aspergillus*, *Penicillium*, *Fusarium*, and *Byssochlamys* in crops, food, and feed products (Aziz *et al.*, 2012; Bosco and Mollea, 2012; Adeyeye *et al.*, 2021). Predominant fungi found in stored maize and maize products are *Aspergillus flavus* and *Aspergillus parasiticus* which produce aflatoxin (Okoth and Kola, 2012; Adeyeye *et al.*, 2021). Aflatoxin causes acute and chronic toxicity, through immunosuppressive, mutagenic, teratogenic, genotoxic, and carcinogenic properties and is widely recognized as a major threat to the public (Villers, 2014; Chhonker *et al.*, 2018).

In the study area maize is generally harvested late and is stored in grain form in wooden granaries, mud silos, or in polypropylene bags. Most of these systems create inadequate storage conditions unfavourable for good drying of maize, particularly in humid and semi-humid zones, subsequently; this promotes fungal infection and production of mycotoxins. The most important mycotoxigenic fungi mostly found associated with stored maize and other products are *Aspergillus flavus* which produces aflatoxins and *Fusarium verticillioides* (previously known as *F. moniliforme*), which produces fumonisins (Okoth and Kola, 2012; Misihairabgwi *et al.*, 2017).

The post-harvest proliferation of aflatoxin can be exacerbated in susceptible commodities under poor storage conditions such as hot and humid storage environment (Njoroge *et al.*, 2019; Muga *et al.*, 2019) If the grain is not properly dried and stored under poor storage conditions (Njoroge *et al.*, 2019); which include high moisture, high air temperature, and high rates of evapotranspiration (Malusha, 2016; Muga *et al.*, 2019) storage time and storage-associated problems such as poor storage, long storage time, high temperature and drought conditions, hygiene and insect infestation (Kahaya and Kyamuhangire, 2006; Sasamalo *et al.*, 2018; Njoroge *et al.*, 2019) as well as the type of storage structure (Maina *et al.*, 2016; Njoroge *et al.*, 2019). All these factors interact and influence fungal infection and proliferation resulting in mycotoxins contamination that is in turn determined by climatic conditions (Fandohan *et al.*, 2005; Milani, 2013; Bereka *et al.*, 2021).

This study aimed to establish the effect of post-harvest storage facilities, storage conditions, and post-harvest practices associated with aflatoxin in stored maize to recommend practices that will reduce contamination levels to smallholder farmers and extension services to improve food safety.

Materials and methods

Study area

The study was conducted in three villages of Long, Sabilo, and Seloto in Babati District, Manyara Region, Tanzania. In the first season, we assessed farmers' maize storage practices and aflatoxin levels in three villages. The villages were purposively selected as they represented different climatic zones. The high altitude high rain zone (Long village) lies between 2150 and 2450 meters above sea level (m.a.s.l), with relatively high annual rainfall of 1200 mm. The mid-altitude low rainfall zone (Sabilo village) lies between 1500 and 1850 m.a.s.l with relatively low rainfall of 900 – 1100 mm, while the mid-altitude high rain zone (Seloto village) lies between 1850 – 2150 m.a.s.l with relatively annual rainfall of 1100 – 1200mm (Fig. 1).

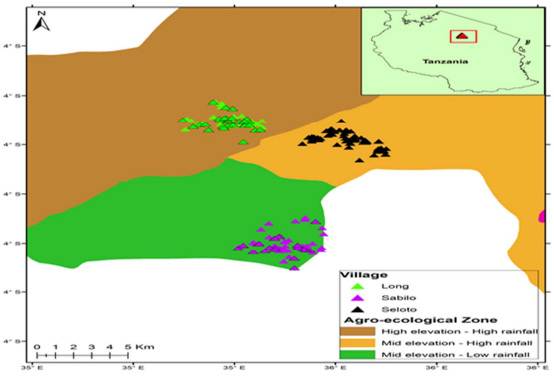

Fig. 1. Location of households where maize samples were collected in three villages in Babati district, Tanzania. They are overlaid on an agro- ecological zone map.

Selection of farmers

Twenty farmers were randomly selected from a list of 150 farmers in each village generated by the

respective village's extension officers and previously used in collecting at-harvest maize samples in season 1 (Nyangi *et al*., 2016). For season 2 only 10 farmers were selected from each village among the twenty farmers who participated in the previous survey, as the previous results indicated low aflatoxin levels and low variation. All farmers agreed to participate in this study after several meetings with the help of the village government and extension officers. Each farmer provided 350 kg of maize to be stored in their household for at least 6 months for both seasons from maize harvested in their respective farms.

Sample collection for aflatoxin analysis

Samples were collected at intervals of 0, 90, and 180 days of storage in both seasons from farmers' traditional storage facilities (i.e., farmers' storage facilities; either granary/cribs or polypropylene bags); improved storage facilities and control (polypropylene bags in which no storage treatment was applied). Farmers were interviewed using a semi-structured questionnaire. Responses were elicited on farmers' storage practices; storage facilities; pests' problem in storage; storage treatment; time/length of storage; source of samples and farmers' solutions to these problems. GPS coordinates and basic demographic details of farmers/producers were also collected.

One sub-sample was drawn from each storage facility, if there was more than one source for the same lot as explained by the interviewee; the sub-samples from each source were mixed to have approximately 1kg of each sample that was representative of the lot. For farmers who sorted their storage lots into suitable for human consumption and bad quality for livestock, two separate samples were taken. The samples were then placed in a clean paper bag (A4 envelope) that was then sealed, labelled and immediately transported to plant pathology laboratory of International Institute for Tropical Agriculture (IITA) in Dar es salaam, Tanzania.

Quantification of total aflatoxin

Aflatoxin was determined in the maize following the method described by Nyangi *et al.* (2016). The samples were ground using a Bunn grinder (Man: Bunn-O-Matic Corporation Springfield, Illinois, U.S.A), homogenized, and subdivided to obtain a representative sub-sample for analysis. A 50 g sub-sample was taken from each of the ground samples and extracted with a 250 mL mixture of ethanol/water (65:35, v/v) and shaken vigorously at 150 revolutions per minute (r/min) for 3 min using a laboratory shaker (IKA® Werke, Germany). Extracts were filtered through Whatman No. 1 filter paper (Whatman International Ltd., Maidstone, UK). Then total aflatoxin (µg/kg) was quantified following the manufacturer's protocol using Reveal AccuScan® III reader (Neogen Corporation, USA), a quantitative ELISA-based analytical test designed specifically for aflatoxin.

The detection limit for total aflatoxin was 2 µg/Kg with a quantitation range of 2 - 150 µg/Kg. The analytical quality of the ELISA methods was assured by the use of certified reference material (CRM), a naturally contaminated maize sample with a certified total aflatoxin content of 18.1 ± 3.6 µg/kg supplied by Neogen, USA (Neogen Corporation, USA). For data analysis, non-detectable levels were based on the detection limits (LOD) of the test method for aflatoxin. Detectable levels were compared to the East African Community (2011) established maximum tolerable limits (MTL) which is similar to that of Tanzania. For technical validation, random subsets of samples were re-analyzed using LC-MS/MS at the Interuniversity Department for Agrobiotechnology (IFA Tulln, Austria).

Statistical analysis

Data were analyzed using SAS 9.4, SAS Institute, Cary NC. Four models were built; one for all villages, and one for each village. A stepwise linear regression in a Generalised linear model (HPGENSELECT) was used to identify factors that significantly affected the contamination of maize with aflatoxin. Aflatoxin levels were log (x + 1) transformed to normalize data before analysis. The answers to "yes or no" answers were entered as binomial values and answers to categorical questions were entered as numbers.

Results

Farmer's storage practices

Farmer storage practices across all three villages and the proportion of farmers associated with each practice, including the number of maize samples collected are presented in Table 1.

Table 1. Storage practices and demographic characteristics of farmers across three village

Practices	Season 1	Season 2
	Total samples n = 576 (%)	Total samples n = 240 (%)
Storage structures		
Improved bags	179 (31)	77 (32)
Polypropylene (POP) bags	167 (30)	102 (43)
Granaries/Cribs	54 (9)	61 (25)
Control (POP) with no treatment	176 (30)	*N/A
Storage length/time		
Day 180	174 (30)	90 (37)
Day 90	342 (59)	90 (37)
Day 0	60 (11)	60 (26)
Storage pests		
Insects	92 (16)	22 (9)
Insects and rodents	79 (14)	145 (60)
No pests	405 (70)	73 (31)
Remove previous crop residue from stores		
Yes	573 (99)	239 (99)
No	3 (1)	1 (1)
Storage of maize with other crops		
Yes	270 (47)	127 (53)
No	306 (53)	113 (47)
Stores treatment		
Chemical pesticides	93 (16)	78 (32)
Natural protectants	40 (7)	45 (19)
No stores treatment	443 (77)	117 (49)
Grain treatment		
Chemical pesticides	74 (13)	108 (45)
Natural protectants	39 (7)	2 (1)
No use of pesticides	463 (80)	130 (54)
Drying method		
On ground	568 (99)	186(77)
On platform	8 (1)	54 (23)
Sorting		
Yes	501 (87)	240 (100)
No	75 (13)	0 (0)
Storage form		
Grain	576 (100)	240 (100)
Cobs	0 (0)	0 (0)

n = Number of samples collected, (%) = percentage of farmers responded.

Prevalence and mean total aflatoxin levels in maize

Fig. 2 represents different aflatoxin contamination from the three villages in season 1, season 2, and both seasons. Table 2 shows the difference in aflatoxin prevalence and mean concentration in two consecutive seasons and post-harvest practices in the study area. Practices that led to low aflatoxin levels were sorting, grain treatment with chemical pesticides, storage for 180 days, and the use of improved storage bags. The highest aflatoxin levels were related to maize collected from Seloto village, drying of maize on bare ground, maize storage with other crops, and farmers who didn't sort maize.

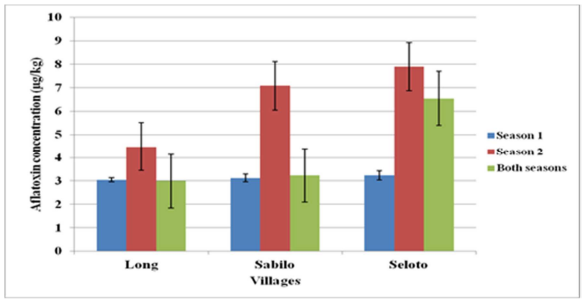

Fig. 2. Mean total aflatoxin levels with their corresponding standard error from three villages in seasons 1, 2, and in both seasons

Table 2. Prevalence and mean aflatoxin levels in maize for each applied post-harvest practice

Variables	Season 1		Season 2	
	Total number of samples (%)	Mean(µg/kg)	Total number of samples (%)	Mean µg/kg)
Storage structures				
Improved storage bags	179 (43)	3.06	77 (81)	4.42
Polypropylene bags (POP)	167 (15)	2.95	102 (91)	7.35
Granaries/Cribs	54 (15)	3.19	61 (98)	7.58
POP bags without any treatment applied (Control)	176 (28)	3.30	*N/A	*N/A
Storage length in days				
0 days	60 (13)	4.95	60(98)	7.59
90 days	342 (22)	2.99	90 (90)	6.67
180 days	170 (43)	3.06	90 (83)	5.54
Villages				

Long	197 (38)	3.04	80 (81)	4.48
Sabilo	194 (14)	3.12	80 (89)	7.09
Seloto	186 (28)	3.24	80 (99)	7.90
Storage pest				
Insects	92 (46)	3.02	22 (68)	3.24
Insects and rodents	79 (39)	3.11	145 (88)	6.57
None	405 (20)	3.18	73 (99)	7.27
Storing maize with other crops				
Yes	306 (24)	3.27	113 (96	7.26
No	270 (30)	3.00	127 (83)	5.85
Stores treatment				
Chemical pesticides	93 (46)	3.05	78 (81)	4.45
Traditional pesticides	40 (58)	3.20	45 (87)	8.19
No pesticides	443 (20)	3.14	117 (97)	7.19
Grain treatment				
1= Chemical pesticides	74 (26)	2.89	108 (83)	5.53
2 = Traditional pesticides	39 (07)	3.13	2 (100)	5.60
3 = No pesticides	463 (29)	3.16	130 (94)	7.34
Drying method				
1 = On bare ground	568 (27)	3.13	186 (87)	7.53
2 = On raised platform	8 (13)	2.40	54 (98)	6.25
Sorting				
1 = Yes	501 (27)	3.02	240 (90)	6.57
2 = No	75 (24)	3.95	N/A	00

n = Number of samples collected, (%) = Percentage of positive samples.

Table 3. Storage factors that are significantly associated with aflatoxin contamination in maize (Y) across and within three villages in the first season

Variables	Regression analysis	Estimate	P-value
Across villages	$Y = 0.30 - 0.10X_1 - 0.06X_2 - 0.08X_3 - 0.19X_4 + 0.03X_5$	0.3021	<.0001*
Long village	$Y = 0.41 - 0.08X_6 - 0.08X_7 - 0.17X_8$	0.4118	<.0001*
Sabilo village	$Y = 0.43 - 0.12X_9 - 0.09X_{10} - 0.18X_{11}$	0.4320	0.0002*
Seloto village	$Y = 0.41 - 0.28X_{12} + 0.16X_{13}$	0.4062	<.0001*
X_1 Maize stored in improved bags		-0.1012	<.0001*
X_2 Maize stored in Polypropylene bags		-0.0551	0.0247*
X_3 Maize stored in cribs/granaries		-0.0766	0.0282*
X_4 Maize stored for 6 months		-0.1924	<.0001*
X_5 Maize stored with other crops		0.0322	0.0461*
X_6 Maize stored in improved bags		-0.0829	0.0070*
X_7 Maize stored in Polypropylene bags		-0.0760	0.0152*
X_8 Maize stored for 6 months		-0.1681	0.0004*
X_9 Maize stored in improved bags		-0.1194	0.0002*
X_{10} Maize stored in cribs/granaries		-0.0905	0.0346*
X_{11} Maize stored for 6 months		-0.1829	0.0004*
X_{12} Maize stored in improved bags		-0.2781	<.0001*
X_{13} Farmers used chemical insecticides to protect stored maize		0.1628	<.0001*

Y = dependent variable - aflatoxin levels (µg/kg), X = independent variables (practices), * = statistically significant at $P < 0.05$.

High aflatoxin levels were only associated with the storage of maize crops. Maize stored in Improved and polypropylene bags from Long Village had a low risk of aflatoxin development. From Seloto village, treatment of stored maize with chemical pesticides did not reduce the risk of aflatoxin development, while maize stored in improved bags had low aflatoxin levels compared to other storage facilities (Table 3).

Surveys in the second season

Across three villages, the aflatoxin development in stored maize was not reduced through store treatment with both chemical and traditional (natural plants) insecticides and storage of maize with other crops. Low aflatoxin levels were related to storage of maize for 6 months (Table 4). Aflatoxin risk increased when maize was stored with other crops in Long Village. In Sabilo village,

the storage of maize for 6 months was related to a decrease in aflatoxin development. In Seloto village, maize stored for 6 months was related to low levels of aflatoxin development and storage problems caused by insects and rodents increasing the risk of aflatoxin contamination (Table 4).

Table 4. Storage factors that are significantly associated with aflatoxin contamination in maize (Y) across and within three villages in the second season

Variables	Regression analysis	Estimate	P-value
Across villages	$Y = 0.64 - 0.39X_1 + 0.08X_2 + 0.20X_3$	0.4003	<.0001*
Long village	$Y = 0.32 + 0.27X_4 + 0.18X_5$	0.5533	0.0002*
Sabilo village	$Y = 0.96 - 0.58X_6 + 0.31X_7$	0.4320	<.0001*
Seloto village	$Y = 0.60 - 0.44X_8 + 0.28X_9$	0.0583	0.0001*
X_1 Maize stored for 6 months		-0.3876	<.0001*
X_2 Use of chemical insecticides to treat stores before storing maize		0.0842	0.0074*
X_3 Use of the traditional plant to treat stores before storing maize		0.2016	<.0001*
X_4 Maize stored with other crops		0.2662	<.0001*
X_5 Use of chemical insecticides to treat stores before storing maize		0.1773	<.0001*
X_6 Maize stored for 6 months		-0.5774	<.0001*
X_7 Use of chemical insecticides to treat stores before storing maize		0.3078	0.0002*
X_8 Maize stored for 6 months		-0.4434	<.0001*
X_9 Insects and rodents problems in store		0.2860	0.0005*

Discussion

Post-harvest practices' including storage is a critical stage where infection and mycotoxin accumulation occur. Care must be taken to store grains that are wholesome and healthy; various post-harvest practices were studied over two consecutive seasons. The data from this study support the results from previous studies that reported how the proliferation of aflatoxin interacts with storage factors. It was previously reported that aflatoxin contamination was related to storage length/time (Maina *et al.*, 2016; Ng'ang'a *et al.*, 2016; Nyangi *et al.*, 2016; Sasamalo *et al.*, 2018; Likhayo *et al.*, 2018) storage structures (Maina *et al.*, 2016; Ng'ang'a *et al.*, 2016; Nyangi *et al.*, 2016; Sasamalo *et al.*, 2018; Bereka *et al.*, 2021), and insect infestation (Fandohan *et al.*, 2005; Hell *et al.*, 2003; Nyangi *et al.*, 2016; Sasamalo *et al.*, 2018; Bitu and Gemta, 2022).

The length of storage emerged as the most significant variable explaining the aflatoxin contamination in stored maize in both growing seasons. There was a remarkable decrease in aflatoxin levels from the beginning of storage (day 0) to the end of storage (day 180). The decreasing trend was most consistent during the first growing season, this may be attributed to farmers' practices of periodical taking their maize out of storage facilities, then sundry and repacking into storage bags, and this was usually done monthly and may play a part in control of insect infestation. The higher aflatoxin contamination observed at time zero (0 storage day) reveals that the grains were exposed to aflatoxin during pre-storage; this concurs with a study on aflatoxin contamination during harvesting of maize grains in the study area (Nyangi *et al.*, 2016; Sasamalo *et al.*, 2018). The finding from this study also agrees with those reported by Hell *et al.* (2000) in Benin, Ng'ang'a *et al.* (2016) in Kenya, and Sasamalo *et al.* (2018) in Tanzania, that higher aflatoxin levels were associated with short storage period (3 – 5 months) and lower levels in longer storage duration (8 - 10 months). However, our results contrast with Hell *et al.* (2003) and Likhayo *et al.* (2018) who stated a higher incidence of aflatoxin contamination in maize stored for 6 months compared to the freshly harvested maize (0 months of storage) in Benin. Moreover, the results from this study also disagree with previous findings by Liu *et al.* (2006) in China, Fandohan *et al.* (2005) from Benin, and Likhayo *et al.* (2018) from Kenya who reported an increase in aflatoxin levels in storage systems throughout the storage period.

The decreasing trend of aflatoxin levels with the length of storage suggests that the treatment methods applied by farmers were partly effective in reducing the mycotoxin prevalence in stored maize. Post-harvest practices such as the application of chemical

pesticides had a considerable effect on reducing aflatoxin prevalence, common insecticides used were Actellic® (pirimiphos-methyl) and Bami force® (Permethrin and Malathion) and natural plant protectants. The results are comparable to Sasamalo *et al.* (2018) and Kebede *et al.* (2020), who reported that the application of chemical pesticides has a direct effect on reducing aflatoxin contamination in maize grains and the conclusion was that aflatoxin–reducing effect of insecticides has an indirect effect through the reduction of insect infestation that is known to increases susceptibility to invasion by mycotoxin forming fungi. Berega *et al.* (2021) also reported that grains damaged by insects are susceptible to mould infection and mycotoxin development, as insect infestation produces a microclimate propitious for the development of storage fungi.

Aflatoxin levels in both seasons were lower in Long village which was located in a high-altitude and higher rainfall zone and higher in Seloto village located in a mid-altitude high rain zone (section 2.1). The climatic condition was the major factor for this trend in results observed from this study, as the optimum conditions for aflatoxin production is a temperature of 33°C and water activity of 0.99 while that for growth is 35°C and water activity of 0.95 (Bereka *et al*., 2021). Therefore, *Aspergillus flavus* and aflatoxin are more likely in maize and crops grown in the heat and drought stress associated with warmer climates (Likhayo *et al*., 2018; Benkerroum, 2020; Biru and Gemta, 2022) and storage environment which is humid and warm for the contamination of stored products (Okoth and Kola, 2012; Likhayo *et al*., 2018). The previously recorded temperature in the study area was found to range from 12˚C in Long village to above 25˚C in Seloto village. Aflatoxin contamination levels were significantly higher in season 2 which was generally humid and warmer compared to season 1.

All farmers visited during this study were found to store their maize in grain form with the majority of farmers sorting their maize before storage. This could also be a reason for low aflatoxin levels as reported by Malusha (2016), Kumar & Kalita (2017), and Bereka *et al.* (2021), and that storage of maize in grain form should be encouraged owing to the prevention of contaminants especially when sorting is done and the outer covering is removed. Almost all farmers in the study area cleaned their stores and removed the residue from the previous harvest before loading the new harvest. This might also help in the control of mycotoxins. Aflatoxin contamination was higher in maize stored with other crops in both seasons; the most common crops that are usually stored alongside maize were beans, wheat, sunflower and pigeon pea. These other crops may become infected with *A. flavus* in the field and lead to aflatoxin development during storage (Nyangi *et al*., 2016; Sasamalo *et al*., 2018).

Drying maize on bare ground was found to have higher levels of aflatoxin contamination compared to drying on top of platforms/mats. This finding is comparable with other studies that reported on the relationship of drying maize on bare ground with aflatoxin contamination (Kaaya and Kyamuhangire, 2006; Bereka *et al*., 2021). Atukwase *et al.* (2009) reported that drying maize on bare ground was found to be positively associated with mycotoxin contamination; this may be attributed to drying harvested maize without husks.

This practice brings maize grains into direct contact with soil which is a primary source of mould *spores*, in addition, drying maize on the bare ground may cause an increase in the water activity of the grains due to the absorption of moisture from the soil and re-wetting by rain (Kaaya *et al*., 2006; Kinyungu *et al.,* 2019), which lead to high water activity that creates a favourable condition for fungal growth and aflatoxin production. Maize cobs that are dried on bare ground are therefore vulnerable to fungal infection and subsequent contamination with mycotoxins (Atukwase *et al*., 2009; Kinyungu *et al.,* 2019). It is therefore suggested that farmers should quickly dry their maize to a moisture content that is unfavourable for fungal growth and avoid drying maize on bare ground. This reduces the free water

required for fungal development and aflatoxin production (Lanyasunya *et al*., 2005; Likhayo *et al*., 2018). Aflatoxin contamination was found to increase 10-fold in a day, especially when field-harvested maize is stored with high moisture content (Hell *et al*., 2005; Likhayo *et al*., 2018). Thus, proper dying technology should be developed and adopted by farmers.

Sorting out physically damaged and infected grains (based on their colouration, odd shapes, shrivelled, and reduced size) from the intact commodity was found to reduce aflatoxin levels in season 1. The results are comparable to Kumar and Kalita (2017) who reported that sorting alone reduces aflatoxin levels by 40-80%. Nji *et al.* (2022) found that stored unshelled peanuts were found with reduced levels of aflatoxin contamination compared with stored shelled peanuts. Physical methods can also involve basic sanitation measures such as removal and destruction of debris from previous harvests both in the field and store which would help in minimizing infection and infestation of produce both in the field and storage (Hell *et al*., 2005; Nji *et al*., 2022). All farmers (100%) in the study area cleaned their stores and 99% of farmers removed the residue from the previous harvest before loading the new harvest, this practice can reduce dirty and other contaminants from getting to maize and creating an unfavourable storage environment for mould growth and aflatoxin contamination. This practice helps in the management of aflatoxin as the crop residue from the previous harvest may harbour fungi that can contaminate newly stored crops and produce aflatoxin (Summer and Lee, 2009; Nji *et al*., 2022).

Conclusion

Several post-harvest practices that may help to reduce aflatoxin levels in stored maize were identified in this study: control of storage insects that increase susceptibility to invasion of grains by mycotoxins-producing fungi, sorting to remove fungi-infested and damaged cobs/grains, use of improved bags, and removal of previous year's residues as well as cleaning of stores. Moreover, the application of genetic recombination in *A. flavus* and other species is being investigated for its potential to mitigate aflatoxins to ensure the safety and quality of food. Further research is required to show how shelling, drying, insect infestation, storage form, awareness, and storage structures influence aflatoxin levels in different agro-ecological zones in Tanzania and intervention strategies to mitigate mycotoxins.

Acknowledgements

We appreciate the support of Grace Michael, Simoni Boni, and Emmanuel Koyano of IITA Tanzania; Sylvester Temba, Lydia Munuo, Siha Koka, and Samson Lyimo of Nelson Mandela African Institute of Science and Technology (NM-AIST) Arusha, Tanzania for their concerted efforts during the surveys. And to farmers and extension officers who cooperated during the surveys.

References

Adeyeye SAO, Ashaolu TJ, Idowu-Adebayo F. 2021. Mycotoxins: Food safety, consumer health, and Africa's food security. Polycyclic Aromatic Compounds. https://doi.org/10.1080/10406638.2021.1957952

Atukwase A, Kaaya AN, Muyanja C. 2009. Factors associated with fumonisin contamination of maize in Uganda. Journal of Science Food and Agriculture **89**, 2393-2398. https://doi.org/10.1002/jsfa.3734

Azizi IG, Ghadi H, Azarmi M. 2012. Determination of aflatoxin B1 levels of the feedstuffs in traditional and semi-industrial cattle farms in Amol, Northern Iran. Asian Journal of Animal and Veterinary Advances **75**, 528-534. https://doi.org/10.3923/ajava.2012.528.534

Bereka TY, Kuyu CG, Tolera KD, Addis EM. 2021. Current postharvest practices and aflatoxin contamination awareness amongst maize producers in Jimma Zone, Southwest of Ethiopia. World Mycotoxin Journal **15**(1), 35-43. https://doi.org/10.3920/WMJ2020.2642

Biru TM, Gemta BG. 2022. Knowledge, attitude, and management practices of stakeholders towards fungal invasion and mycotoxin contamination of wheat and maize in Ethiopia. East African Journal of Science **16**(2), 171-186.

Bosco F, Mollea C. 2012. Mycotoxins in food. In: Food Industrial Processes—Methods and Equipment. (Edited by Valdez B.) InTech Janeza Trdine, 9, 51000 Rijeka, Croatia, 169-200.

Chhonker S, Rawat D, Naik R, Koiri R. 2018. An overview of mycotoxins in human health with emphasis on development and progression of liver cancer. Clinical Oncology **3**, 1408-2018. http://doi.org/10.3389/fmicb.2014.00158

East African Community. 2011. East African standards maize grains - EAS 2/2011 of 2011. Available at: [https://law.resource.org/pub/eac/ibr/eas.2.2011.html] site visited on 20th March 2024.

El-Kady IA, El-Maraghy SSM, Abdel-Mallek AY, Hasan HAH. 1993. Effect of four pesticides on aflatoxin production by *Aspergillus flavus* IMI 89717. Zentralblatt für Mikrobiologie **148**(8), 549-557. https://doi.org/10.1016/S0232-4393(11)80219-2

Fandohan P, Ahouansou R, Houssou P, Hell K, Marasas WFO, Wingfield MJ. 2005. Impact of mechanical shelling and dehulling on *Fusarium* infection and fumonisin contamination in maize. Food Additives and Contaminants **23**, 451-421. https://doi.org/10.1080/02652030500442516

Hell K, Cardwell KF, Poehling HM. 2003. Distribution of fungal species and aflatoxin contamination in stored maize in four climatic zones of Benin, West Africa. Journal of Phytopathology **151**, 690-698. https://doi.org/10.1046/j.1439-0434.2003.00792.x

Hell K, Cardwell KF, Setamou M, Poehling HM. 2000. The influence of storage practices on aflatoxin contamination in maize in four climatic zones of Benin, West Africa. Journal of Stored Products Research **36**, 365-382.

Hell K, Fandohan P, Bandyopadhyay R, Kiewnick S, Sikora R, Cotty PJ. 2005. Pre- and post-harvest management of aflatoxin in maize: An African perspective. In: Mycotoxins: Detection Methods, Management, Public Health and Agricultural Trade. (Edited by Leslie JF, Bandyopadhyay R, and Visconti A.), Cromwell Press, Townbridge, UK. pp. 219-229.

Hettiarachchi GHCM, Gooneratne J, Hirimburegama WK. 2001. Effect of initial moisture content and relative humidity on the accumulation of aflatoxin in maize grains (*Zea mays*) during storage. Journal of the National Science Foundation of Sri Lanka **29**(1&2), 29-34.

Kaaya AN, Kyamuhangire W, Kyamanywa S. 2006. Factors affecting aflatoxin contamination of harvested maize in the three climatic zones of Uganda. Journal of Applied Sciences **11**, 2401-2407.

Kaaya AN, Kyamuhangire W. 2006. The effect of storage time and climatic zone on mould incidence and aflatoxin contamination of maize from traders in Uganda. International Journal of Food Microbiology **110**, 217-223.

Kamala A, Kimanya M, Haesaert G, Tiisekwa B, Madege R, Degraeve S, Cyprian C, De Meulenaer B. 2016. Local post-harvest practices associated with aflatoxin and fumonisin contamination of maize in three agro-ecological zones of Tanzania. Food Additives and Contaminants, Part A. https://doi.org/10.1080/19440049.2016.1138546

Kebede H, Liu X, Jin J, Xing F. 2020. Current status of major mycotoxins contamination in food and feed in Africa. Food Control **110**, 106975. https://doi.org/10.1016/j.foodcont.2019.106975

Kinyungu S, Isakeit T, Ojiambo PS, Woloshuk CP. 2019. Spread of *Aspergillus flavus* and aflatoxin accumulation in post-harvested maize treated with biocontrol products. Journal of Stored Products Research **84**, 101519. https://doi.org/10.1016/j.jspr.2019.101519

Kumar D, Kalita P. 2017. Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. Foods **6**(1), 8. https://doi.org/10.3390/foods6010008

Lanyasunya TP, Wamae LW, Musa HH, Olowofeso O, Lokwaleput IK. 2005. The risk of mycotoxin contamination of dairy feed and milk on smallholder dairy farms in Kenya. Pakistan Journal of Nutrition **4**, 162-169.

Likhayo P, Bruce AY, Tefera T, Jones Mueke J. 2018. Maize grain stored in hermetic bags: Effect of moisture and pest infestation on grain quality. Journal of Food Quality, Article ID 2515698, 9 pages. https://doi.org/10.1155/2018/2515698

Liu Z, Gao J, Yu J. 2006. Aflatoxins in stored maize and rice grains in Liaoning Province, China. Journal of Stored Products Research **42**(4), 468-479. https://doi.org/10.1016/j.jspr.2005.09.003

Malusha JM. 2016. Influence of different altitudes, maize harvest seasons and storage and pre-storage practices on aflatoxin occurrence among households in Makueni County, Kenya. PhD Dissertation, Jomo Kenyatta University of Agriculture and Technology. [http://ir.jkuat.ac.ke/bitstream/handle/123456789/2024/Mulusha,%20James%20M.%20PHD%20medical%20Health%202016?sequence=1&isAllowed=y] site visited on 18 January 2024.

Mboya R, Pangirai T, Kwasi SY, Derera J, Maxwell M, Langyintuo A. 2011. The quality of maize stored using the roof and sack storage methods in Katumba Ward, Rungwe District, Tanzania: Implications on household food security. Journal of Stored Products and Postharvest Research **2**(9), 89-199.

Milani JM. 2013. Ecological conditions affecting mycotoxin production in cereals: A review. Veterinary Medicine **58**(8), 405-411.

Misihairabgwi J, Ezekiel C, Sulyok M, Shephard G, Krska R. 2017. Mycotoxin contamination of foods in Southern Africa: A 10-year review (2007–2016). Critical Reviews in Food Science and Nutrition **59**(1), 43-58. https://doi.org/10.1080/10408398.2017.1357003

Muga. 2019. Effect of temperature, relative humidity, and moisture on aflatoxin contamination of stored maize kernels. Bulgarian Journal of Agricultural Science **25**(2), 271-277.

Ng'ang'a. 2016. Effect of triple-layer hermetic bagging on mould infection and aflatoxin contamination of maize during multi-month on-farm storage in Kenya. Journal of Stored Products Research **69**, 119-128. http://dx.doi.org/10.1016/j.jspr.2016.07.005

Njoroge AW, Baoua I, Baributsa D. 2019. Postharvest management practices of grains in the Eastern region of Kenya. Journal of Agricultural Science **11**(3), 33-44. https://doi.org/10.5539/jas.v11n3p33

Nyangi C, Beed F, Mugula JK, Boni S, Koyano E, Mahuku G, Sulyok M, Mateete B. 2016. Assessment of pre-harvest aflatoxin and fumonisin contamination of maize in Babati District, Tanzania. African Journal of Food Agriculture Nutrition and Development **16**(3), 11039-11053. https://doi.org/10.24940/ijird/2018/v7/i6/JUN18005

Okoth SA, Kola MA. 2012. Market samples as a source of chronic aflatoxin exposure in Kenya. African Journal of Health Sciences **20**, 56-61.

Sasamalo MM, Mugula JK, Nyangi CJ. 2018. Aflatoxins contamination of maize at harvest and during storage in Dodoma, Tanzania. International Journal of Innovative Research and Development **7**(6), 11-15. https://doi.org/10.24940/ijird/2018/v7/i6/JUN18005

Shetty PH, Bhat RV. 1999. A physical method for segregation of fumonisin-contaminated maize. Food Chemistry **66**(3), 371-374. https://doi.org/10.1016/S0308-8146(99)00052-7

Summer EP, Lee D. 2009. Reducing aflatoxin in corn during harvest and storage. Learning for Life Bulletin **1231**, 4-12.

Udoh JM, Cardwell KF, Ikotun T. 2000. Storage structures and aflatoxin content of maize in five climatic zones of Nigeria. Journal of Stored Products Research **36**(2), 187-201.

Villers P. 2014. Aflatoxins and safe storage. Frontiers in Microbiology **5**, 158.