Impact of Maize Storage Methods on Aflatoxin Contamination In Eight Districts of Southern Province of Rwanda

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Abstract

Aflatoxin levels were measured in 900 farmer's stores grouped into 18 respective cooperatives throughout the whole parts of the southern region of Rwanda to assess the effects of different approaches of storage on aflatoxin attacks on maize. Questionnaires, maize sampling, and laboratory testing methods were used in this study to find out which storage techniques were linked to greater or lower aflatoxin levels in stored maize in the southern region of Rwanda so that extension services could be recommended on aflatoxin-reducing measures. Farmers were questioned on the structure of their storage, form, period, and pest problems in storage, as well as what they did to battle them and the sample was taken for aflatoxin testing, the presence of aflatoxin in stored corn was negatively associated to pesticide application. Aflatoxin contamination was found to be lower (2.8 parts per billion) when grain was stored in bags with pallets; aflatoxin levels were higher (88.5 parts per billions)in those who stored corn under their roofs. Henceforth, appropriate maize storage, sorting out of damaged cobs, the use of appropriate storage insecticides, storage in well-equipped, hygienic, and aerated stores with pallets, and farmers being aware of the risk that insects and aflatoxins pose to their stored maize, were found to minimize the level of aflatoxin in stored maize.

Key Words: Pallets, roofs, pest, samples, Farmers

Introduction

Maize is the most common crop extensively grown in Rwanda. Due to agricultural intensification measures, rwandan maize production increased by 129 % from 175,000 tons in 2008 to 400,000 tons in 2011. Though Rwanda's maize output has fluctuated greatly in recent years, it has tended to climb from 1971 to 2020, hitting 451,000 tons in 2020 (Pulat *et al.*, 2013). Storage fungus can contaminate maize, and some of them can produce mycotoxins, which are detrimental to animal and human health. Aflatoxins are mycotoxins produced by *Aspergillus flavus* a prevalent postharvest fungus in maize. The level of aflatoxin in a product varies depending on the season, how long it has been stored, and storage variables. Toxin contamination was shown to be higher during the rainy season and increased with storage duration (Abdoulie *et al*, 2021). Aflatoxin contamination in storage is influenced by the storage system. Maize storage procedures differ based on different farmer's habits; some have warehouses with palettes while others are used to store their maize on the ground. Farmers frequently leave their maize cobs on the floor in a corner of the building or the courtyard, exposing them to the soil and increasing the risk of *Aspergillus flavus* development (Philippe, 2014).

Rwandese farmers frequently altered their storage facilities during the storage period, switching maize from less durable home-based drying facilities or temporary storage to more durable contemporary drying shelters. This study evaluates the best storage method which can be adopted to minimize the level of aflatoxin in maize.

Materials and Methods

Perception of the farmers and farmer's cooperatives

Selected maize farmers and cooperatives in seven districts of Southern province of Rwanda were interviewed from March to July 2021 to assess their stores and warehouses status and types of equipment, to monitor the quantity of maize stored in the warehouse, their safety status, storage procedures, pest, and diseases issues (appendix 1).

During the survey, the Southern region of Rwanda was divided into two Agro-ecological zones such as region located near Nyungwe National parks namely Nyamagabe, Nyaruguru Districts where average temperature ranging from 16-19 degrees Celsius per year and average humidity ranging from 61-78% per year and region located far from Nyungwe National parks such as Huye, Nyanza, Gisagara, Muhanga, Ruhango and Kamonyi Districts where average temperature ranging from 22-26 degree Celsius per year and average humidity ranging from 67-72% per year, rainfall ranging from 222.3mm and 128mm per annum (Anon., 2018).

Samples collection for aflatoxin testing

Maize samples were collected from all maize populations following sampling standards where random sampling method was used to ensure that all maize populations are represented, during sampling. Samples were taken for ground-based storage methods, pallets based storage methods, and storage under roofing of the farmer's houses, 19 samples were taken in selected farmers' cooperatives in eight districts of the southern province of Rwanda (appendix 2).

Laboratory extraction and calculation of aflatoxin

Separation and purification of aflatoxins by centrifugal partition chromatography was used for extraction and calculation of aflatoxin concentration. The samples were pulverized in a Romer1 Mill, extracted with 60:40 v/v methanol/water, and purified using chloroform. Refrigeration was used to keep the extract fresh (58ºC). The aflatoxin extract was spotted on pre-coated silica gel plates (sigma chemical) and developed in a TLC tank using a chloroform/acetone (96:4, v/v) solvent mixture. The fluorescence of the sample spot was compared to the fluorescence of the aflatoxin standard under long-wave UV light (365 nm) (Gábor *et al.*, 2019).

Analytical statistics

The parameters that influenced aflatoxin development were identified using stepwise linear regression ($P \leq 0.005$). Before analysis, the results of aflatoxin test were log(x+1) transformed to normalize the data. Binomial values were used to represent the answers to yes or no questions. Categorical questions were answered with numbers. Statistical package for the social scientist as the statistical software used (Petros, 2019).

Results and Discussion

Impact of storage structures on aflatoxin contamination

Maize stored under the roof of the home was linked to a higher level of aflatoxin as well as storage maize on the soil (without pallets) is also linked with higher aflatoxin contamination. This storage strategy was only observed in the southern zones, $N^1N^2H^1$ and M^1K^1, where at least part of the harvest may occur during a rainy season due to the bimodal rainfall pattern. When these structures were filled, aeration was insufficient, and maize stored with the husk or not thoroughly dried resulted in increased fungus proliferation. (Maravelakis, P. 2019)

Later in the storage season, storing maize in cleaned bags on pallets was linked to reduced toxin levels. In Rwanda, the shift in storage structure is frequently accompanied by maize processing, which includes dehusking or degrading. At this time, most farmers also sift maize: discolored grains that may have been contaminated with fungi are picked out, lowering the risk of aflatoxin production.

Convection may cause humidity to build up in clay stores, which could explain why aspergillus spores can stay for longer in certain environments, raising the risk of aflatoxin contamination. Farmers have been known to ignite fires beneath storage facilities to reduce humidity and control insects.

Maize was kept in storage for 8 to 10 months. Maize stored in the $N^1N^2H^1$ was more likely to generate aflatoxin. The data from sampling 6 months after harvest revealed a significant positive connection in the $G^1N^1R^1$ and maize aflatoxin levels in a region-wide regression analysis. Farmers who were aware of their storage issues had a lower risk of developing aflatoxin in their maize. Higher levels of aflatoxin were found in $N^1N^2H^1$ maize that was stored on the ground and under the roof of their houses. Cleaning the store before storing the new harvest was linked to lower levels of aflatoxin in the G^1N^1R and M^1K^1. When grain maize was stored on pallets, less aflatoxin development was found. Insect damage to corn stored without the use of storage fumigants was linked to high amounts of aflatoxin especially in $N^1N^2H^1$.

Table 1. Storage factors that are significant when regressed against aflatoxin levels (93=94) (Y) at different storage practices across all districts of southern Districts of Rwanda

Zone	Regression analysis	R^2	n	F-value
$N^1N^2H^1$	$y=0.63+0.71\ x^2$	0.23	130	6.32
$G^1N^1R^1$	$y=0.31+2.13x^8 -0.45x^9 +0.73x^{10}$	0.27	30	4.05
M^1K^1	$y=1.23-63x^2 +1.25x^{13}$	0.2	30	9.4
x1 Maize stored for 3-5 months		t = 2.21*		
x3 Maize store as shelled grain		t = 2.70 *		
x4 Maize stored on ground		t=2.8*		
x5 Maize stored on pallets		t=2.5**		
x6 Maize stored under roof of house		t = 2.24 *		
x7 Use of Aluminium phosphide as storage protectant		t=3.73**		
x8 Use of bags as secondary storage		t = 2.7**		
x9 Maize stored in conical stores		t =4.16**		
x10 Farmers aware of insect damage in store		t = 2.51*		
x11 Maize stored on the roof of the house		t = 2.85*		

*Significant at <0.05, **significant at< 0.01; $N^1N^2H^1$: Nyamagabe, Nyaruguru, Huye Districts; $G^1N^1R^1$: Gisagara, Nyanza, Ruhango Districts; M^1K^1: Muhanga, Kamonyi District

Effect of storage parameters on aflatoxin levels in maize

Aflatoxin concentrations

At the start of storage, after 4 and 6 months respectively more than 174 maize samples were tested for aflatoxin levels. The majority of samples showed less than 5ppb aflatoxin throughout the whole districts of southern province and sampling occasions. Between 2.2 and 5.8% of the samples had toxin levels of more than 100ppb at the start of storage. Four months later, the percentage of samples with such high levels was between 7.5 and 24 %. There was an increase in aflatoxin levels in samples from the $N^1N^2H^1$ and $G^1N^1R^1$ after 6 months of storage when comparing levels at the start of storage .after 6 months of storage, The fraction of samples with concentrations higher than 30 ppb.

From the commencement of storage until 4 months later, the percentage of samples with high aflatoxin levels increased. At the start of storage, the means of these aflatoxin positive samples were between 22 and 190ppb, and 4 months later, they were between 31 and 221 ppb. As a result, the risk of chronic aflatoxin exposure in the southern region of Rwanda is significant, given that the majority of maize is grown for human consumption, and Rwandese are known to eat maize-based meals up to three times per day,(Anon,2016)[b].

Table 2. Percentage of samples in aflatoxin classes by District at the start of storage

District	<5 ppb	5-10 ppb	10-20 ppb	20-50 ppb	50-100 ppb	>100ppb
Nyamagabe	2.6	0.9	3.6	1.8	2.7	4.5
Nyaruguru	4.8	5	5.8	7.3	7.4	5.8
Huye	80.8	2.5	6.7	3.6	4.5	2.5
Gisagara	4.1	1.1	2.2	4.4	2.2	3.6
Nyanza	6.6	0.9	3.6	1.8	2.7	6.5
Ruhango	4.6	0.9	3.6	1.8	2.7	3.5
Muhanga	5.6	0.9	3.6	1.8	2.7	2.5

Ppb: parts per billions

Table 3. Percentage of samples in aflatoxin classes per district after 4 months of storage

District	< 5 ppb	5-10 ppb	10-20 ppb	20-50 ppb	50-100 ppb	>100ppb
Nyamagabe	85	3.8	2.5	1.3	-	7.5
Nyaruguru	68.4	1.3	7.6	7.6	7.6	-
Huye	71.3	5	-	11.3	5	8.8
Gisagara	67.8	-	4.8	1.6	24.2	-
Nyanza	85	3.8	2.5	1.3	7.5	-
Ruhango	85	-	3.8	2.5	1.3	7.5
Muhanga	85	3.8	2.5	1.3	7.5	-
Kamonyi	85	3.8	2.5	-	1.3	7.5

Ppb: parts per billion

Table 4. Percentage of samples in aflatoxin classes per district after 6 months of storage

District	< 5 ppb	5-10 ppb	10-20 ppb	20-50 ppb	50-100 ppb	>100ppb
Nyamagabe	95	4.8	3.5	2.3	-	8.5
Nyaruguru	78.4	2.3	8.6	8.6	8.6	0
Huye	81.3	6	-	21.3	6	8.8
Gisagara	77.8	-	5.8	2.6	34.2	0
Nyanza	95	4.8	3.5	2.3	8.5	0
Ruhango	95	-	4.8	3.5	2.3	7.5
Muhanga	85	3.8	2.5	1.3	7.5	0
Kamonyi	85	3.8	2.5	-	1.3	7.5

Ppb: parts per billion

Problems with storage

More than 80% of farmers in the eco-region expressed dissatisfaction with their storage facilities. At the start of storage, farmers observed mostly flies and rodents. Insect damage to stored maize was reported by 87 percent of farmers (NNZ), 90 percent (AZ) Lepidopterous pests were reported by 20% of NNZ respondents and 13% of AZ respondents. Fungi were an issue for 17 percent of the AZ in the driest area, whereas fungi were a concern for 6.7 percent of the farmers in the humid zone (NNZ).

NNZ: Near Nyungwe national park zone (Nyamagabe, Nyaruguru, and Huye Districts

AZ: Amayaga Zone (Gisagara, Nyanza, Ruhango, Muhanga, Kamonyi districts)

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Table 5. Farmers' reactions to storage issues at the start of the season (%)

Storage period	$N^1N^2H^1$	$G^1N^1R^1$	M^1K^1
No problem	13.3	18.7	8.8
Molds	5.5	47	7.4
Insects	37.5	18.7	43.6
Rats	18.6	18.6	15
Rats + Termites	0.0	2.4	1.2
Rats+insects	25.4	35.6	26.4

$N^1N^2H^1$: Nyamagabe, Nyaruguru, Huye Districts; $G^1N^1R^1$: Gisagara, Nyanza, Ruhango Districts;
M^1K^1: Muhanga, Kamonyi Districts

Impact of form of storage

A large number of farmers in Rwanda's southern zones preserved maize with the husk. Before storing corn, farmers chose cobs with good husk cover. Insect assault and water seepage are both thwarted by good husk cover. The impact of husk or no husk storage on aflatoxin generation was zone-specific and dependent on the incidence and type of insect pest. There have been reports of greater insect development rates on maize stored in loose grains, which could lead to an increase in aflatoxin levels. In Rwanda, some farmers in the southern agro-ecological zones preferred to store maize with husk for coleoptera protection.

Impact of storage duration

The duration of storage differed per districts ecological -zone. In the $N^1N^2H^1$ and $G^1N^1R^1$, storage for 5 to 12 months as usual. In the M^1K^1, 13.7 percent of maize was held for more than a year, indicating that maize is preserved after the new harvest arrives. The size of corn stockpiles is used to determine the wealth and social status of their owners in this area, and maize can be stored for up to three years. In the M^1K^1, maize was often kept for 3 to 8 months. A storage time of 7-12 months was used in the $N^1N^2H^1$.

Table 6. Farmers' responses to the amount of time they keep their crops in storage (%)

Storage period	$N^1N^2H^1$	$G^1N^1R^1$	M^1K^1
3-5 months	32.1	12.5	11
6-7 months	23.8	10.5	9.8
8-10 months	20.5	83.2	7.8
11-12 months	15.8	11.8	6.8
> 12 months	6.7	0	0

$N^1N^2H^1$: Nyamagabe, Nyaruguru and Huye Districts respectively; $G^1N^1R^1$: Gisagara, Nyanza, Ruhango Districts respectively; M^1K^1: Muhanga, Kamonyi Districts respectively.

Effects of treatments for storage

Farmers' reactions to storage issues were diverse. Approximately half of the farmers polled said they did nothing to address storage issues. Aside from that, storage methods differed from farmer to farmer and within areas. Commercial pesticides, either a specific formulation for stored grains such as aluminum phosphide (58g) and malathion), or insecticides frequently used against maize pests, were utilized by those who treated their maize; rodenticides were utilized by a small number of Rwandese farmers. Another option for dealing with storage issues was to sell the corn. Farmers also employed neem leaves (*Azadirachta indica*), pepper (*Capscicum frutescens*), ash, ash combined with sand, kerosene, smoke, or dry manure as storage protectants. In the AZ, 51% of respondents were satisfied with the efficacy of their storage treatment, whereas, in the NNZ, 49% were satisfied,Only 27.5% of $N^1N^2H^1$ respondents and 30% of $G^1N^2R^1$ respondents thought their control solution solved their storage issues. Before stocking their stores with new corn, farmers usually cleaned them and removed old stock. Maize could germinate in Rwanda under specific conditions, such as high rainfall or poor roofing. In Nyamagabe, Nyaruguru and Huye had an 8.9% level at the start of storage, 21.5 % in Gisagara, Ruhango, and Nyanza, 9.6% in Muhanga and Kamonyi Districts. This limit was surpassed by 7.8% of Nyamagabe, Nyaruguru, and Huye Districts samples, 20.8 % of Gisagara, Nyanza, and Ruhango Districts samples, and 12.8 % of Muhanga and Kamonyi districts of samples four months later as shown in Table 7.

From the commencement of storage until 6 months later, the percentage of samples with high aflatoxin levels increased. At the start of storage, the means of these aflatoxin positive samples were between 22 and 190 ppb, and 6 months later, they were between 31 and 221 ppb. As a result, the risk of chronic aflatoxin exposure in Rwanda is significant, given that the majority of maize is grown for human use, and Rwandese are known to eat maize-based meals up to three times per day. The information gathered during this investigation backs up prior findings of how *A. flavus* interacts with storage variables. Aflatoxin was previously linked to storage structure, according to research (Niyibituronsa *et al.*, 2021).

Table 7. Farmers' reactions to storage treatments (%).

Storage Conditions	N1N2H1	G1N2R1	M1K1
No treatment	50	63.8	43.8
Storage insecticides	18.7	26.3	26.3
Rodenticides	7.5	2.5	2.5
Traditional means	21.3	28.8	21.3
Sale	25	20	21.3
Sorting	22.5	50	55.3
Mechanical means	30.8	36.3	46.3

N1N2H1: Nyamagabe,Nyaruguru, Huye Districts respectively;G1N2R1: Gisagara, Nyanza, Ruhango Districts respectively, M1K1: Muhanga, Kamonyi Districts respectively,**Whereas: N1** stands for Nyamagabe District; **N2** stands for Nyanza District; **G1** stands for Gisagara District; **R1** stands for Ruhango District; **M1** stands for Muhanga District; **K1** stands for Kamonyi District; **H1** stands for Huye District.

Structure of storage

A higher aflatoxin level was connected with maize stored under the roof of a house in Rwanda. This storage strategy was only observed in the southern zones, where the bimodal rainfall distribution means that at least part of the harvest may take place during a rainy time (Ankwasa *et al*..2021). Bringing partially dried maize ears into a dark location away from any sunlight or air movement would not be a desirable practice because *Aspergillus flavus* does not show protracted growth below the aw of 0.85 or 17 percent grain moisture. High temperatures, which are known to be beneficial to *Aspergillus flavus* and aflatoxin formation, could also be a predisposing factor impacting maize below metal sheeting (Benkerroum, 2020).

Storage period

In this investigation, it was discovered that there was a regional difference in the length of storage in Rwanda's southern region. People in southern regions probably preserved their maize for lengthy periods for sociological reasons, as vast and many maize stores confer social esteem on their owners. In general, however, storage times in the south were shorter since farmers were not required to store maize for as long as they were in the north because the second season crop was harvested in January. Farmers in the south farmed more maize land and typically utilized superior kinds, resulting in more corn per hectare that lasted for longer periods.(Nabwire *et al*,2020)

Only during a storage length of 3-5 months did the effect of storage time on aflatoxin content become apparent, resulting in a greater aflatoxin level in the preserved maize samples. Farmers who keep maize for a short time appear to take fewer measures and are careless than those who store maize for a long time. Farmers who expected to sell maize after a longer storage period were more likely to dry meticulously, sort out broken cobs, and use insecticides, whereas the former consumed the maize as rapidly as possible . (Masomo. 2020)

Form of storage

A large number of farmers in Rwanda's southern zones preserved maize with the husk. Before storing corn, farmers chose cobs with good husk cover. Insect assault and water seepage are both thwarted by good husk cover. Aflatoxin levels were lower in maize with high husk cover in India. They discovered decreased aflatoxin contamination in maize types with a tight husk cover in two out of three years. In Rwanda, the impact of husk or no husk storage on aflatoxin generation was zone specific and dependent on the incidence and type of insect pest. There have been reports of greater insect development rates on maize stored as loose grains, which could lead to an increase in aflatoxin levels (Wenndt *et al*,2020).

Treatments for storage

Insecticides are widely used on stored grains in Rwanda, which is one of the difficulties with pesticide use. Up to 18.3 percent of farmers in this study utilized aluminum phosphide (58g) to safeguard their stored wheat. Pesticides are distributed by agro-dealers through the state extension office in Rwanda, and they are more widely available than recommended. Insecticides have higher toxicity and durability, posing a risk to consumers, particularly when consumed immediately after treatment. The misuse of very hazardous pesticides for the control of storage pests is a recurring issue in developing countries (Zikankuba *et al.* 2019).

Insect damage is frequently followed by mold growth because insects create a micro-environment conducive to the growth of storage fungi. Actellic was found to have no direct influence on *Aspergillus flavus* formation in maize grains in research, leading to the conclusion that the aflatoxin-reducing effect of insecticides is a secondary effect through the reduction of insect infestation. Aflatoxin concerns were less common among farmers who used insecticides to safeguard their stored corn.

The use of local plant substances to protect against storage insects increased aflatoxin levels in stored maize samples in this study. Many studies have shown that plant compounds can be employed in vitro to limit the growth of *Aspergillus flavus*. It appears that achieving the in vitro impact by applying plant components directly to the preserved cobs is not always possible. Many of the plant ingredients utilized in the store are also used in traditional medicine (Anon, 2016)[a].

As a result, mixing plant chemicals with preserved corn cobs may increase the risk of aflatoxin formation rather than reducing it. Plant elements, such as leaves, can also raise the relative humidity inside the grain store. Farmers in Rwanda consistently evaluated indigenous solutions as less effective than commercially available items, but they employed these substances because they did not have access to or could not afford chemical products (Yaolei *et al.*2020).

Conclusion

This study was conducted in eight districts of the southern province of Rwanda to assess the impact of maize storage methods on aflatoxin contamination, different methods were used to reach the study objectives such as interviews with the farmers, sample collection for aflatoxin testing, laboratory analysis of aflatoxin**.** The current study identified several storage factors that may help to reduce aflatoxin levels in stored maize in Rwanda, including storage insect control through the sorting out of damaged cobs, the use of appropriate storage insecticides, storage in well-equipped, hygienic, and aerated stores with pallets and farmers aware of the risk that insects and aflatoxins pose to their stored maize. The recommendation drawn from this research is that toxin levels can also be controlled by using a storage container that is appropriate, hygienic, and not storing maize on the ground but pallets. Further research is needed to determine how storage methods affect aflatoxin levels in Rwanda's various agro-ecological zones.

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References

Abdoulie J, Huali X, Xiaoqian T, Zhang Q, Peiwu Li. 2021. Worldwide aflatoxin contamination of agricultural products and foods: From occurrence to control. Comprehensive Reviews in Food Science and Food Safety published by Wiley Periodicals LLC on behalf of Institute of Food Technologists 20 (3): 2332-2381. doi:10.1111/1541-4337.12734

Ankwasa E M, Francis I, Ahmad T. 2021. Update on mycotoxin contamination of maize and peanuts in East African Community Countries. Journal of Food Sciences Nutrition 7 (1): 001-010. doi:10.17352/jfsnt.000026

Anonymous 2016a. Rwanda agriculture and animal resources development board annual report 2016-2017.Kigali-Rwanda

Anonymous 2016b. Handbook on pesticidal plants optimization of pesticidal plants: technology, innovation, outreach & networks (OPTIONs). University of Greenwich natural resource institute.

Anonymous 2018. Catalog of meteorology Rwanda existing weather and climate information and its data policy.

Benkerroum 2020. Aflatoxins: Producing-molds, structure, health issues and incidence in Southeast Asian and Sub-Saharan African countries. International Journal of Environmental Research and Public Health 17 (4):1215-1232. doi:10.3390/ijerph17041215

Gábor E, Zsófia H, Adiyadolgor T, Biljana Š, Csaba V, András S. 2019. Separation and purification of aflatoxins by centrifugal partition chromatography. Toxins (basel) medical and pharmaceutical drug innovation.11 (6): 309. doi:10.3390/toxins11060309

Maravelakis, P. 2019. The use of statistics in social sciences. Journal of Humanities and Applied Social Sciences 1 (2):87-97. doi:10.1108/JHASS-08-2019-0038

Nabwire R.,Wangia D., Trang Quach H.T, Xiao S., James O., Githanga D.P, Omu A., Anzala Jia Sheng W.2020. Determinants of aflatoxin exposures in Kenyan School-aged children. International Journal of Environmental Health Research 30:1-9. doi:10.1080/09603123.2020.1854192

Nishimwe K., Erin L B, Ayabagabo J.D, Habimana R. 2019. Assessment of aflatoxin and fumonisin contamination and associated risk factors in feed and feed ingredients in Rwanda. Toxins medical and pharmaceutical drug innovation 11(5):270 doi:10.3390/toxins11050270

Niyibituronsa M, Mukantwali C, Nzamwita M, Hagenimana G, Niyoyita S, Niyonshima A, Hakizimana C, Ndilu L, Nyirahanganyamunsi G, Nkurunziza E.et al..,2021. Assessment of aflatoxin and fumonisin contamination levels in maize and mycotoxins awareness and risk factors in Rwanda. African Journal of Food Agriculture Nutrition and Development 20 (5): 16420-16446. doi:10.18697/ajfand.93.19460.

Petros Maravelakis .2019. The use of statistics in social sciences. Journal of Humanities and Applied Social Sciences. 1(2):87-97. DOI 10.1108/JHASS-08-2019-0038

Philippe V. 2014. Aflatoxin and safe storage. Frontier in microbiology 5:2-8 doi:10.3389/fmicb.2014.00158

Pulat B, Tae YK, Rezvan M, Ryung S, Jen S, Matt S, Freda Y. 2013. Maize in Rwanda: a value chain analysis, Columbia University for the east-west management institute &Unido.Onlineavailable at https://open.unido.org/api/documents/5328232/download/Maize%20in%20Rwanda%20-%20A%20Value%20Chain%20Analysis visited on 21 September, 2021.

Said M.S., Masomo. 2020. Aspergillus flavus and aflatoxin contamination in the maize value chain and what needs to be done in Tanzania. Scientific African. 10:13 doi:10.1016/j.sciaf.2020.e00606

Timothy O., Ambrose K.K, Phanice W., Alex P.W, Sarah K., Papias Nt., Mark P.O, Caroline K.N, Samuel B.O. 2021. The scourge of aflatoxins in Kenya: A 60-Year Review (1960 to 2020)". Journal of Food Quality, pp31 .doi:10.1155/2021/8899839

Wenndt A, Sudini HK, Pingali P, Nelson R. 2020. Exploring aflatoxin contamination and household-level exposure risk in diverse Indian food systems 15(10):2-19 doi:10.1371/journal.pone.0240565

Yaolei Z, Mengmeng L, Yuanxiao L, Erqi G, Ke B. 2020. Reduction of aflatoxin B1 in Corn by water-assisted microwaves treatment and its effects on corn quality. Toxins (basel) medical and pharmaceutical drug innovation 12(9):605 . doi:10.3390/toxins12090605

Zikankuba L, Mwanyika G, Ntwenya JE, Armachius J, Fatih Y. 2019. Pesticide regulations and their malpractice implications on food and environment safety. Cogent Food & Agriculture. Cogent food&Agriculture 5(1):18-25. doi:10.1080/23311932.2019.1601544

Appendixes

Appendix 1. Perceptions of farmers on corn storage procedure

I. METHODS OF STORAGE	
Questions	Areas
When the maize is harvested stored	Selected maize cooperatives/All districts
Why do you store maize ahead of time?	Selected maize cooperatives/All districts
Where do you keep your maize grains before storage	Selected maize cooperatives/All districts
How long do you keep your maize?	Selected maize cooperatives/All districts
What method of storage do you employ during storage	Selected maize cooperatives/All districts
What is the location of your storage facility?	Selected maize cooperatives/All districts
What kind of building materials did you use?	Selected maize cooperatives/All districts
How many seasons have you used pallets in the stores	Selected maize cooperatives/All districts
How many seasons have you stored on the ground?	Selected maize cooperatives/All districts
Do you keep maize in the store all year?	Selected maize cooperatives/All districts
What is the location of your storage facility?	Selected maize cooperatives/All districts
II.PROBLEMS WITH STORAGE	
Do you have a storage issue? No-yes	Selected maize cooperatives/All districts
Which of the storage issues is the most critical?	Selected maize cooperatives/All districts
Insects- Rodents- Birds- Mould · After a few months · When the storage period is over	Selected maize cooperatives/All districts
What steps did you take to resolve this issue?	Selected maize cooperatives/All districts
Is it true that the grain germinates in stores yes or no	Selected maize cooperatives/All districts
Do you sanitize the storage facility before putting it away? No or Yes	Selected maize cooperatives/All districts
What else did you do to get the store clean before putting it away? List	Selected maize cooperatives/All districts
What measures did you employ to treat the store room before storing it? Ash or Sand	Selected maize cooperatives/All districts
Insecticides (specify): Smoke -Manure -Neem?	Selected maize cooperatives/All districts
What nature did you use to keep your maize? In the husk ,as grain, dehusked	Selected maize cooperatives/All districts
Were pesticides used during storage? If yes, please provide its name	Selected maize cooperatives/All districts
Have you taken any additional precautions? List	Selected maize cooperatives/All districts

Appendix 2. Samples collected from the southern province of Rwanda

No	Dıstrıct Name	Cooperatıve Names	Maize Population Size (Kgs)	Sample Sıze(Kgs)	Storage Status	Sample Collected
1	Kamonyı	Coamaleka	50000	2	Ground-Based Storage	Sample Was Taken
		Kabıyakı	40000	2	Ground-Based Storage	Sample Was Taken
		Kabıyakı	45000	2	Ground-Based Storage	Sample Was Taken
2	Muhanga	Tuzamurane	25000	2	Pallets Based Storage	Sample Was Taken
		Dufatanye	40000	2	Ground-Based Storage	Sample Was Taken
		Kokarı	40000	2	Ground-Based Storage	Sample Was Taken
3	Ruhango	Abıyunze	27000	2	Pallets Based Storage	Sample Was Taken
4	Nyanza	Abahujıntego	40000	2	Ground-Based Storage	Sample Was Taken
		Duhujımbaraga	27000	2	Ground-Based Storage	Sample Was Taken
		Abahujıntego	20000	2	Ground-Based Storage	Sample Was Taken
5	Huye	Kopııaka	8000	1	Ground-Based Storage	Sample Was Taken
6	Gısagara	Koabıdu	11000	1	Ground-Based Storage	Sample Was Taken
		Korwamukı	5000	1	Ground-Based Storage	Sample Was Taken
		Coopagka	60000	2	Ground-Based Storage	Sample Was Taken
7	Nyaruguru	Jyamberemuhinzi	10000	1	Ground-Based Storage	Sample Was Taken
		Abesamıhıgo	600	1	Ground-Based Storage	Sample Was Taken
		Abishyizehamwe	30000	2	Ground-Based Storage	Sample Was Taken
8	Nyamagabe	Jyamberemuhinzi	40000	2	Ground-Based Storage	Sample Was Taken