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Full Length Research Paper

The quality of maize stored using roof and sack storage methods in Katumba Ward, Rungwe District, Tanzania: Implications on household food security

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The quality of maize stored using sack and roof storage methods was studied by investigating the presence of *Fusarium*, *Aspergillus* and *Penicillium* infections using qualitative methods in 130 maize samples that were randomly collected from the roof and sack storage facilities in Katumba ward, Rungwe district, Tanzania. Levels of fumonisins, aflatoxins, ochratoxins and T-2 toxins were determined using quantitative methods on selected 77 maize samples. It was found that 86% of the selected maize samples were infected by one, two or all of the three pathogenic fungi investigated, whereas 88% were contaminated by one, two or three types of the investigated mycotoxins. The average concentrations of the mycotoxins were as follows: 596.48 ± 38.85 µg/kg of aflatoxins, 745.73 ± 105.57 µg/kg of ochratoxins 87717.95 ± 14984.32 µg/kg (or 87.2 ± 15 mg/kg) of fumonisins, and 1803.77 ± 244.56 µg/kg (or 1.8 ± 0.241 mg/kg) of T-2 toxins. The concentrations of the mycotoxins were a lot higher than the internationally accepted levels. These observations indicated that in Katumba ward, maize stored using roof and sack storage methods was exposed to infection by *Fusarium*, *Aspergillus* and *Penicillium* species, and that the farm households were at risk of ill health due to the mycotoxins.

Key words: Maize, storage, quality, fungi, mycotoxins, food security.

INTRODUCTION

Katumba ward is located in Rungwe district, Mbeya region, Tanzania, between 9° 13´ 60 South and 30° 37´ 0 East (Anon, 2008) and it lies 13490 meters above sea level. Tanzania, the country in which Katumba ward is situated is located in East Africa between longitude 290 and 410 East, Latitude 10 and 120 South (Government of the United Republic of Tanzania, 2005). Furthermore, Rungwe district is characterized by rainfall throughout the year ranging from an average of 900 mm in the lowland zone to 2,700 mm in the highland zone and cool temperatures ranging from 18 to 25°C (Administrator, 2010). As with all other highland areas, in Rungwe district temperature may drop to a minimum of 10°C during the cold season (Anon, 2008). Fog and mist are also common (Government of The United Republic of Tanzania, Office of Prime Minister and Vice President, 1995). Like the rest of Rungwe district, Katumba ward is characterized by rainfall throughout the year and cool temperatures ranging from an estimate of 10°C during

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the night to an estimate of 25°C during the day (Anon, 2008). At the time when this study was conducted the estimated population in Katumba ward was 10,965 and 2649 households.

Farm households in Katumba ward store maize using the roof and sack storage methods, and use an average of 1 kg and a minimum of 500 g of maize flour per meal (Mboya et al., 2011). The farm households prefer maize meals such that two out of three meals that the farm households consume in at least six days per week are made from maize (Mboya et al., 2011). Although maize is such an important staple food crop in Katumba ward, assessment of its quality in terms of pathogenic fungi and mycotoxins has never been studied before in this ward. Reports show that the susceptibility of maize to fungal infection is influenced by favourable conditions such as high humidity, inadequate storage technologies and insect activity in maize (Chelkowski et al., 2006; Tachin, 2008; Weinberg et al., 2008; WHO, 2006; Williams, 2004). Poor storage technologies allow insect infestations to occur, whereas insect activity in stored maize may lead to increase in moisture content of the maize.

In general, the climatic conditions, such as rainfall throughout the year and cool temperatures that characterizes Rungwe district are known to promote fungal infection of maize grain. *Fusarium*, *Penicillium* and *Aspergillus* species have been identified as the most important fungi that attack stored maize, and have been associated with production of mycotoxins that can cause serious health problems to both humans and animals (Sweeney et al., 2000; Montes et al., 2009). Apart from the mycotoxins being also associated with the reduction of the nutrient content of maize (Jood et al., 1992), maize which is infested by fungi becomes at risk of being infested by insect pests as well, due to the attraction of the insect pests to the odour caused by the deterioration of the fungi infested maize (Ako et al. 2003). Thus maize storage methods that allow growth of moulds put stored maize at risk of being infested by insect pests as well. These facts raised questions regarding the quality of maize stored using roof and sack storage methods in Katumba ward in terms of its nutritional value, the degree to which it is safe for consumption and its implications on household food security.

The interest in this study was on moulds that attack stored maize and produce mycotoxins that are harmful to both humans and animals. Thus mycotoxins produced by *Fusarium*, *Aspergillus* and *Penicillium* species were studied in maize grain that was collected from the farm households. The mycotoxins produced by the said types of fungi include fumonisins produced by *Fusarium* species (Cousin et al., 2005; Arora, 2004; Wood et al., 2003), especially *F. verticillioides* (synonym *F. moniliforme*) and *F. proliferatum* (Öhlinger et al., 2004) and aflatoxins mainly produced by *Aspergillus* species: *A. flavus*, *A. parasiticus* (Cousin et al., 2005; Pitt, 2000), *A. nomius* (Sweeney et al., 2000; Wood et al., 2003), *A. ochraceus*, *A. pseudotamari* (Bennet and Klich, 2003) and *A. bomycis* (Peterson et al., 2001). Ochratoxins are mainly produced by *Penicillium* species and some *Aspergillus* species (Wood et al., 2003) such as *A. niger*, *A. carboinarius,* and *A. ochraceous* (Cousin et al., 2005; Bennett and Klich, 2003; Pitt, 2000); whereas T-2 toxins are also produced by *Fusarium* species (Pitt, 2000).

Fumonisins are specifically associated with cancer of the oesophagus (Pitt, 2000), T-2 toxins are associated with aleukia, a disease of the alimentary canal (Pitt, 2000), aflatoxins are particularly associated with cancer of the liver (Munkvold et al., 2009; Wood et al., 2003) and ochratoxins are associated with kidney problems (Hayes, 2001). While there are no set acceptable standards for T-2 toxins' levels in maize, the international regulatory limits for fumonisins and aflatoxins are 4 mg/kg (Wu, 2004) and 20 µg kg of produce (Munkvold et al., 2009), respectively. Different countries have different acceptable levels of ochratoxins in cereals, and 50 µg/kg is the highest acceptable level for a number of countries (FAO, 2004). This implies that levels above 50 µg/kg ochratoxins in maize may be harmful to consumers. The main objective of this study was to examine the quality of maize stored using sack and roof storage methods in Katumba ward, Rungwe district, Tanzania, and its implication on household food security. The specific objectives are:

1. To investigate the presence of *Fusarium*, *Penicillium*, and *Aspergillus* species in maize stored using the roof and sack storage methods in Katumba ward, Rungwe district, Tanzania and its implications on the quality of maize, on household food security and on the capacity of the roof and sack storage methods to protect stored maize from fungal infections;
2. To investigate the presence and concentrations of fumonisins, T-2 toxins, ochratoxins, aflatoxins in maize stored using the roof and sack storage methods in Katumba ward, Rungwe district, Tanzania and their implications on the quality of maize and on the consumers' health.

MATERIALS AND METHODS

A qualitative study was carried out on 130 ground maize samples from Katumba ward, Rungwe district Tanzania in order to investigate the presence of *Fusarium, Penicillium and Aspergillus* species in the maize samples, whereas quantitative methods were applied for detecting the related mycotoxins. The maize samples for studying the fungi species were randomly sampled using the procedure described by Pitchler (2006). A total of 87 out of the 130 maize samples were of the improved varieties, 43 were of the indigenous types. Also, a higher proportion of the farm households store maize using the roof storage method compared to the proportion o f farm households that store maize using the sack

storage method (Mboya et al., 2011). Thus a total of 88 out of the 130 maize samples were collected from the roof storage facilities and 42 were collected from the sack storage facilities.

Preparation of the maize samples for mycological analysis

The instruments used in the grinding process were washed thoroughly with dish washing liquid and 3.5% sodium hypochlorite solution, followed by thoroughly rinsing with sterile distilled water and drying using a clean cloth before grinding each of the maize samples. The procedure was repeated between the maize samples in order to minimize chances of cross contamination. Serial dilution series of 10^{-6} were prepared for each maize sample. Three replicate plates of the sample dilutions (10^{-6}) were made by plating 1 ml of each sample dilution separately onto three PDA plates using sterile spread techniques. *Fusarium* selective media originally prescribed by Nash and Snyder (1962) was used to investigate the presence of *Fusarium* species in the maize samples. The plates were incubated at 28°C for 7 days. Fungal colonies were observed under the light microscope using a wet mount for morphological characteristics of *Fusarium, Penicillium* and *Aspergillus* in order to confirm their presence in the maize samples. Further morphological and molecular identification of the fungal species that were found in the maize samples was conducted by the Biosystematics Division, Mycology Unit, Plant Protection Research Institute, Agricultural Research Council (ARC), Pretoria, South Africa for confirmation. Maize samples that formed more colonies and those found to be infested with two or all of the three fungal species of interest in this study were selected for further investigation. Hence the selection of 77 maize samples (68% of the infected maize samples) for this particular study. Twenty one out of the 77 selected maize samples were collected from the sack storage facilities and 56 were from the roof storage facilities. Methanol was used for obtaining sample extracts from the maize samples. More information concerning the number of maize samples that were subjected to the tests is presented in Table 3.

Quantification of fumonisins, aflatoxins, ochratoxins and T-2 toxins

The presence and concentration of mycotoxins were studied using Elisa kits supplied by Neogen Corporation. The procedure followed for analysis and quantification of the mycotoxins was as described by the kits' manufacturer (Neogen Corporation, 2007, 2008, 2009a, 2009b). Some of the maize samples were tested for the presence of more than one type of mycotoxin, thus in general a total number of 154 tests were conducted using the 77 maize samples selected for mycotoxin studies. The reactions between the antibodies and the mycotoxins in the maize sample extracts produced a blue colour, the intensity of which was read using a microplate reader with a 650 nm filter at room temperature. Two strips were used for each mycotoxin test, and the microplate readings for the strips differed significantly, therefore two graphs for each type of mycotoxin tested were plotted. The concentration of aflatoxins, fumonisins, ochratoxins and T-2 toxins in the maize sample extracts was determined using the equations in Table 2, which were obtained through plotting Graphs shown in Figures 1 to 4 using the values for the mycotoxins concentrations in the control samples against the corresponding wavelengths. In order to achieve the highest degree of linearity the graphs for studying the concentration aflatoxins, T-2 and ochratoxins were plotted using values of the concentrations of the mycotoxins concerned in the form of logarithm ($\log_{10}$) followed by converting the $\log_{10}$ values into their respective antilog$_{10}$ values.

In the equations in Table 2, 'y' stands for the concentration of either fumonisins; aflatoxins, ochratoxins or T-2 toxins, while *x* stands for the wavelengths corresponding to the concentration of the mycotoxins in the control samples. The estimated quantities of fumonisins, aflatoxins, ochratoxins and T-2 toxins in the maize sample extracts were calculated by replacing '*x*' in the equations with the wavelength value obtained from the microplate reader for each maize sample extract. As indicated, the maize sample extracts for quantifying aflatoxins, fumonisins and T-2 toxins were derived from 3 g of each of the maize samples tested, while the sample extracts for quantifying ochratoxins were derived from 2 g of each of the maize samples tested. Thus the equations were used for calculating the estimated concentrations of fumonisins, aflatoxins and T-2 toxins, respectively, per 3 g of maize, while the estimated concentration of ochratoxins was calculated per 2 g of maize. The values that resulted from the calculations were used to calculate the estimated quantities of the mycotoxins per kg (µg/kg) of each maize sample as shown, where *x* stands for the quantity of mycotoxins:

x = 3 g of maize

x/3 µg = 1 g of maize

x/3 µg × 1000 = 1 g × 1000 =1 kg of maize

Statistical analyses

Statistical Programme for Social Sciences (SPSS) Version 15 was used for frequency counts, percentiles, means, minimum and maximum values. Standard deviations were also obtained for the quantities of maize samples that were infested by *Fusarium*, *Aspergillus* and *Penicillium* species and those which were contaminated by the respective mycotoxins they produce. Cross tabulations and the independent samples t-tests were performed in order to study the performance of the sack and roof storage methods by comparing means for the quantities of mycotoxins in maize samples that were collected from the roof and sack storage facilities. Chi-square test for independence was performed in order to compare the performance of roof and sack storage methods with respect to the ratios of maize samples from each of the storage facilities that were contaminated by mycotoxins.

RESULTS

Types of pathogenic fungi in the maize samples

86.15% of the maize samples were infected by one, two or all of the three types of pathogenic fungi studied (Figure 5), whereas fungi colonies in the infected maize samples ranged from 0 to 99. Further morphological and molecular identification of the fungal species confirmed the presence of the following fungal species in the maize samples:

1. *A. ochraceus* G. Wilh
2. *A. parasiticus* Speare

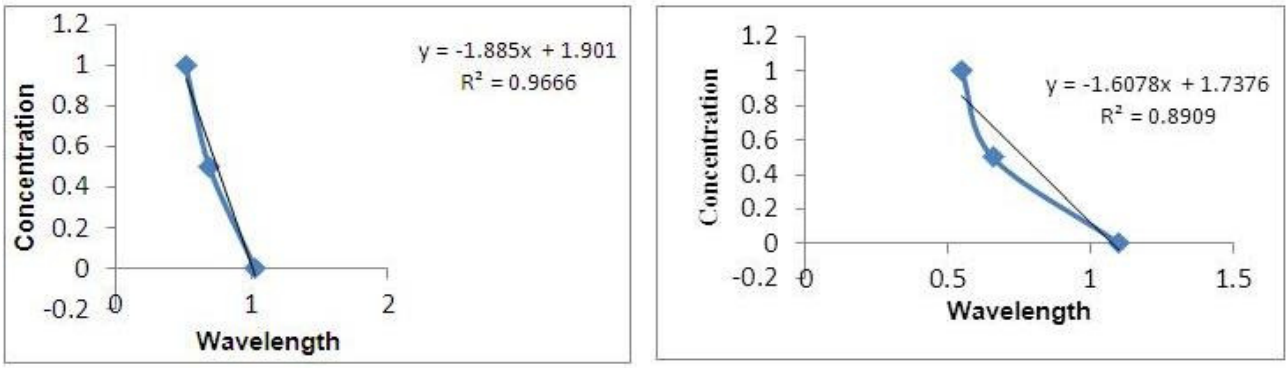
Table 1. Number of the types of fungi in the infested maize samples in relation to the storage facilities from which the maize samples were collected.

Number of types of fungi in the maize samples	Maize samples collected from the roof storage facility	Percent of infected maize samples from the roof storage facilities	Maize samples collected from the sack storage facility	Percent of infected maize samples from the sack storage facilities	Total
One type	18	20.45	13	30.95	31
Two types	30	34.09	8	19.05	38
Three types	28	31.82	15	35.71	43
Total	76	86.36	36	85.71	112

Maize samples from roof storage facilities: n=42; Maize samples from sack storage facilities: n= 88.

Table 2. Equations obtained through plotting graphs of concentration of mycotoxins in the control samples against the corresponding wavelengths.

Type of mycotoxin studied	Equation from the first strip control sample extracts	Equation from the second strip control sample extracts
Fumonisins	$y = -1.885x + 1.901$	$y = -1.6078x + 1.737$
Aflatoxins	$y = -0.907x + 2.01$	$y = -201x + 2.53$
T-2 toxins	$y = -1.880x + 3.608$	$y = -1.73x + 3.679$
Ochratoxins	$y = -1.0561x + 1.959$	$y = -0.648x + 1.829$



Graph 1a: 1st strip

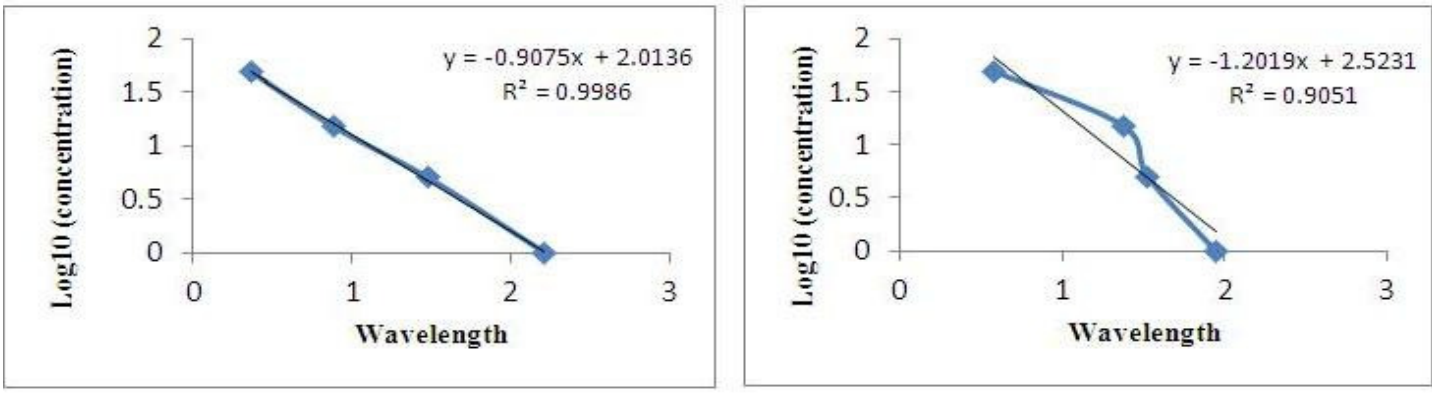
Graph 1b: 2nd strip

Figure 1. Fumonisins concentration in the control samples.

4. *Penicillium oxalicum* Currie & Thom
5. *Penicillium decumbens* Thom
5. *Penicillium raistikii* G. Sm
6. *Penicillium verruculosum* Peyronel
7. F. verticillioides (sacc)
8. *Fusarium subglutinans* (Wollenweber. and Reinking) P.E. Nelson, Toussoun and Marasas

A total of 86.36% of the maize samples that were collected from the roof storage facilities were infected by the pathogenic fungi of interest to this study, whereas a total of 85.71% of the maize samples that were collected from the sack storage facilities were also infected by the fungi. Also, 31.82% of the maize samples from the roof storage facilities were infected by all of the three types of the pathogenic fungi studied as opposed to 35.71% of the

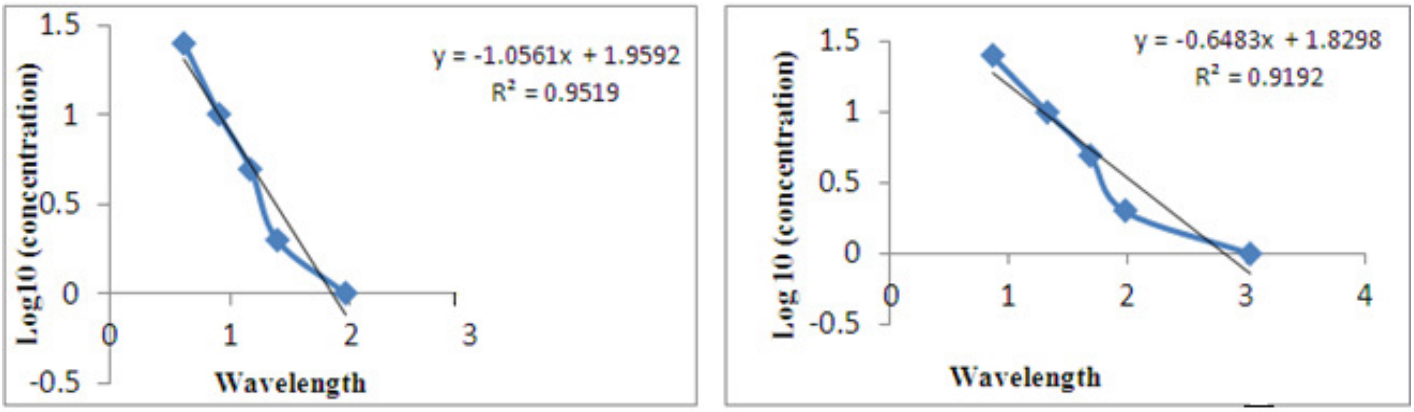
maize samples from the sack storage facilities which were also infected by all of the three types of fungi (Table 1). It was found that 97.67% of the maize samples of the indigenous types were infected by the pathogenic fungi and 90.7% of the maize samples of the improved varieties were also infected by the fungi.



Graph 2a: 1st strip

Graph 2b: 2nd strip

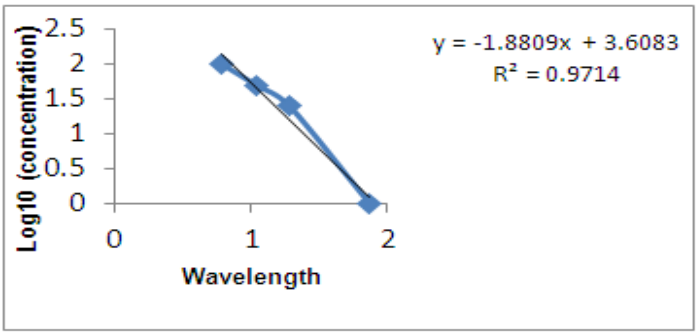
Figure 2. Aflatoxins concentration in the control samples.



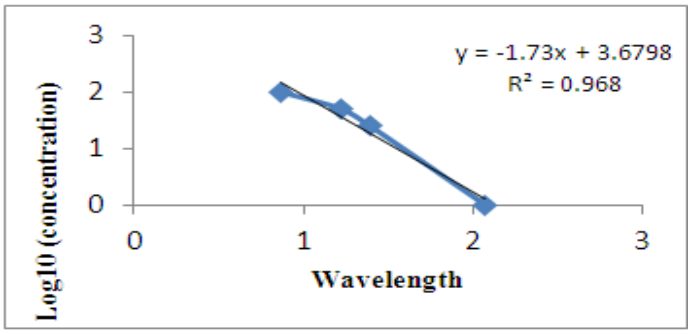
Graph 3a: 1st strip

Graph 3b: 2nd strip

Figure 3. Ochratoxins concentration in the control samples.



Graph 4a: 1st strip



Graph 4b: 2nd strip

Figure 4. T-2 concentration in the control samples.

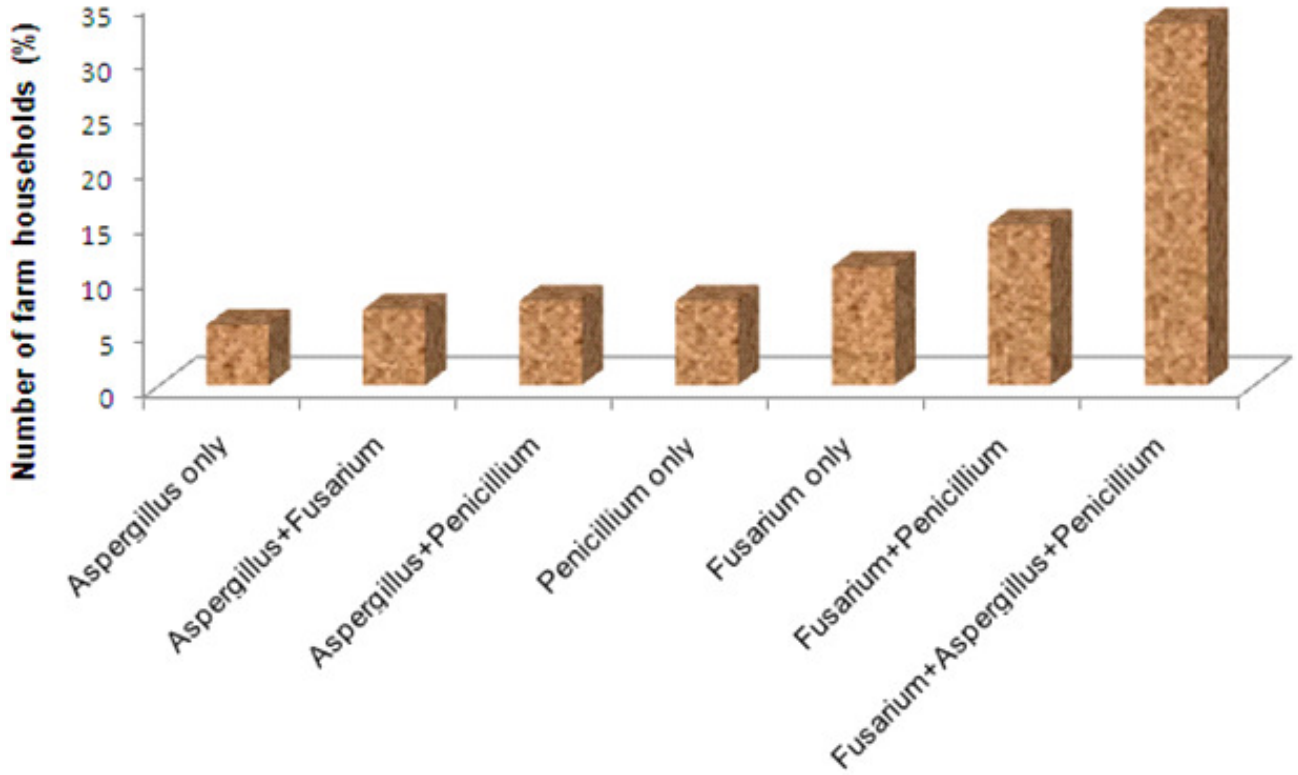


Figure 5. Types of pathogenic fungi per maize sample.

The incidence of contamination of maize by fumonisins, aflatoxins, ochratoxins and T-2 toxins

A total of 88.31% of the maize samples studied for mycotoxins were contaminated with one, two, or three of the mycotoxins investigated. The results also showed that 68.42% of the maize sample extracts that were studied for the presence of fumonisin were contaminated by this particular mycotoxin and 55% of the maize samples that were studied for the presence of aflatoxins were contaminated by the specific mycotoxin. Furthermore, 76.32% of the maize samples that were studied for the presence of ochratoxins were found to be contaminated by the mycotoxin and 94.74% of the maize samples that were studied for the presence of T-2 toxins were found to be contaminated by the mycotoxin.

The presence of mycotoxins was detected in 83.9% of the sub-samples of maize that had been collected from the roof storage facilities, whereas all of the selected maize samples that were collected from the sack storage facilities for mycotoxins studies were contaminated with the mycotoxins investigated. Table 3 shows highest level

of contamination of the maize samples with T-2 toxins and fumonisins followed by ochratoxins for both; maize samples from the roof and from sack storage facilities. Likewise, Table 4 reveal that percentage of maize samples that were concurrently contaminated with two types of mycotoxins was the highest for both, maize samples from the roof and from the sack storage facilities.

The estimated quantities of aflatoxins, fumonisins, T-2 toxins and ochratoxins per kg of ground maize are shown in Table 5. Details concerning the percentages of contaminated maize samples and the average amounts of mycotoxins in maize samples from the roof and sack storage methods are indicated in Tables 3 and 6. A chi-square test ($\alpha > 0.05$) revealed that there was no significant difference between the proportions of the infected maize samples to the uninfected ones for the maize samples collected from the roof and sack storage facilities.

Quantities of mycotoxins that each of the farm households could consume per meal

In Katumba ward a farm household consumed an average of 1kg and a minimum of 0.5 kg or 500 g of maize meal per meal, thus the estimated amounts of mycotoxins that a farm household could consume per meal are equivalent to the amounts of mycotoxins that were detected per kg of maize flour shown in Table 5.

Table 3. Number of maize samples from the roof and sack storage facilities that were tested for mycotoxin contamination.

Contaminated maize samples	Fumonisins	Ochratoxins	Aflatoxins	T-2 toxins
Number of maize samples studied	38	38	40	38
Number of maize samples collected from roof facilities for the test	25	30	32	25
Number of maize samples collected from sack facilities for the test	13	8	8	13
Percent of contaminated maize samples from roof storage facilities	96	73.3	50	96
Percent of contaminated maize samples from sack storage facilities	92.3	87.5	96	93.3

Table 4. Number and types of mycotoxins in each of the maize sample.

Types of mycotoxins	Percent of maize samples that were contaminated with the mycotoxins	Percent of contaminated maize samples from the roof storage facilities	Percent of contaminated maize samples from the sack storage facilities
One type	41.5	42.90	38.10
Two types	37.7	32.10	47.62
Three types	7.8	7.10	14.28
Four types	1.3	1.80	0.00
Total	88.3	83.90	100.00

Maize samples from the roof storage facilities: n = 56; Maize samples from the sack storage facilities: n = 21.

The t-test results (Table 6) for each of the storage methods revealed that there were no significant differences between the means for the quantity of each of the mycotoxin that was studied.

DISCUSSION

The fact that that more than half of the maize samples that were studied were infested with pathogenic fungi implies that in Katumba ward more than half of the households experienced pathogenic fungi in stored

maize. Furthermore, as shown in Figure 5, more than 50% of the maize samples that were infected by the pathogenic fungi studied had more than one type of the fungi, which also implies that for at least half of the 130 farm households from which the maize samples were collected, stored maize was infected by more than one type of the pathogenic fungi.

The *A. ochraceus* and *A. parasiticus* confirmed to be present in the maize samples are associated with the production of ochratoxins and aflatoxins (Pitt, 2000), respectively, whereas *P. verrucosum* and *P. nordicum* are said to be the main *Penicillium* species that produce ochratoxins (Cabañes et al., 2010). The presence of pathogenic fungi in the maize samples imply that the quality of maize in Katumba ward was poor and that the farm households in Katumba ward were exposed to pathogenic fungi through maize consumption. This would possibly not only have a negative effect on the palatability of the maize meals made from this maize, but would also put stored maize at risk of being infested by insect pests (Ako et al., 2003), which can lead to losses of maize grain by weight as a result of the insects feeding on the maize. In turn this would compromise the food security of the maize consumers. Both the indigenous and the improved varieties of maize stored using roof and sack storage methods in Katumba ward were equally affected by the pathogenic fungi, hence the poor quality of stored maize. This implies that both the sack and roof storage technologies in Katumba ward were not adequate for protecting stored maize against fungal infection. The fact

Table 5. The estimated quantities of mycotoxins per kilogram of maize.

ID	Aflatoxins (µg/kg)	ID	Ochratoxins (µg/kg)	ID	Fumonisins (µg(/kg)	ID	T-2 toxins (µg/kg)
1	342.00	1	936.00	2	-	2	892.00
5	-	5	-	5	10666.67	5	850.00
8	-	15	-	6	-	6	467.00
9	561.33	16	-	7	-	7	743.67
10	454.67	18	440.00	10	-	10	686.33
12	388.00	22	568.00	12	52000.00	12	2149.33
15	408.67	23	448.00	13	96666.67	13	502.67
16	367.00	24	499.00	15	23333.33	15	704.33
18	664.33	29	608.50	19	16000.00	19	-
21	460.67	31	449.00	23	-	23	681.33
22	496.67	33	-	24	2000.00	24	1007.67
23	929.67	35	404.50	26	-	26	1485.67
25	432.33	36	-	27	7000.00	27	1979.67
28	-	37	3617.00	29	-	29	2368.33
30	420.00	38	-	32	-	32	971.67
31	387.67	39	-	36	-	36	-
32	-	42	-	38	-	38	467.00
33	421.67	43	-	44	32000.00	44	2111.67
38	565.00	46	-	48	15666.67	48	1473.33
41	455.33	47	-	50	-	50	1519.00
42	1301.33	51	-	51	45666.67	51	1229.33
45	774.00	55	604.00	54	133666.67	54	1057.67
47	-	64	-	55	84666.67	55	1414.00
49	-	65	756.50	65	141000.00	65	861.00
50	-	72	-	66	197333.33	66	783.67
51	-	74	587.00	68	88666.67	68	853.33
54	-	80	399.00	70	27333.33	70	1152.33
58	-	84	540.00	81	161333.33	81	2274.33
72	632.33	90	561.50	85	141000.00	85	3738.67
75	751.00	97	482.50	95	336333.33	95	1285.67
79	912.67	99	407.00	97	17666.67	97	1330.00
80	-	101	433.00	99	354000.00	99	708.33
84	996.67	105	635.00	105	68333.33	105	3015.33
89	-	106	1358.50	108	89666.67	108	3880.00

95	-	108	677.50	118	-	118	5228.67
97	-	115	715.00	120	37666.67	120	2863.00
99	-	116	833.00	122	68333.33	122	5999.00
100	-	121	938.00	127	32666.67	127	6200.67
103	-						
121	-						
Mean	596.50		745.73		87717.95		1803.77
Std Dev	245.72		650.75		92369.53		1486.49
St Error	38.85		105.57		14984.32		244.56
Maximum	1301.33		3617.00		354000.00		6200.67

that both the landraces and the improved varieties of maize were infected by the pathogenic fungi also implies that the maize varieties' lack of resistance to the infections also played a role on the levels of infections in

Table 6. Comparing the difference between the mean scores for the quantities of mycotoxins per kg of maize stored using the roof and the sack storage methods.

Mycotoxins	Storage method	No. of samples tested	Mean µg/kg	Mean difference	t	Sig. (2-tailed)	Level of significance
Fumonisins	Roof	25	58419.62	6634.55	0.222	0.825	ns (α>0.05)
	Sack	13	65054.17				
T-2 toxins	Roof	25	1795.27	252.70	0.489	0.634	ns (α>0.05)
	Sack	13	1542.57				
Aflatoxins	Roof	32	334.33	28.57	0.197	0.845	ns (α>0.05)
	Sack	8	305.76				
Ochratoxins	Roof	30	568.48	28.60	0.117	0.907	ns (α>0.05)
	Sack	8	539.87				

ns= "Not significant".

the stored maize.

Furthermore, wetness and high humidity that characterizes the climatic conditions in Katumba ward (Anon, 2008) create conditions that favour the growth of fungi in stored maize. This, together with the factors pointed out imply that sack and roof storage technologies in Katumba ward are not adequate for protecting stored maize against the climatic conditions indicated above and against fungal infections. The 68 maize samples that were found to be contaminated by the mycotoxins are equivalent to 52.3% of the 130 maize samples that were subjected to mycological analysis. Thus it is estimated that half of the farm households that participated in this study experienced contamination of stored maize by aflatoxins, fumonisins, ochratoxins or T-2 toxins. Since the presence of *A. parasiticus* and *A. ochraceus* were confirmed in the maize samples, the aflatoxins in the maize must have been produced by these particular species. Also *P. verrucosum and P. nordicum* have been reported to be the main *Penicillium* species that produce ochratoxin A. The former produces ochratoxin A in cereals and the latter produces ochratoxin A in meats (El Khoury and Atoui, 2010). However, *P. verrucosum* was identified as one of the fungal species in the maize samples. Hence the ochratoxin detected in the maize samples must have been produced by *A. Ochraceus* which is known to produce ochratoxin A in maize (El Khoury and Atoui, 2010). *F. verticillioides* (sacc), also known as *F. moniliforme* is one of the main producers of fumonisins (Pitt, 2000). Thus fumonisins that were detected in the maize samples must have been produced by *F. verticillioides* (sacc) which was confirmed to be present in the maize samples.

Furthermore, T-2 toxin is known to be produced by several *Fusarium* species, such as *F. tricinctum*, *F. equiseti, F. sporotrichioides* (Ohlinger et al., 2004) and *F. poae* (Bennet and Klich, 2004). Thus the T-2 toxins detected in the maize samples were possibly produced by the *Fusarium* species mentioned earlier, which were not studied. Furthermore, as shown in Table 4, 41.1% of the maize samples were contaminated by only one type of mycotoxin as opposed to 46.8% of the maize samples

that were contaminated by more than one type of mycotoxin. This implies that at least one third of the farm households in Katumba ward were exposed to more than one type of mycotoxin per maize meal. The occurrence of two or more mycotoxins per maize sample raises questions concerning the effects that the interaction between the mycotoxins may have on the stored maize and on the health of the consumers. As indicated, aflatoxins, fumonisins, ochratoxins and T-2 toxins are also known to reduce the nutritional content of maize. Thus the presence of these mycotoxins in stored maize in Katumba ward compromises the nutritional value of the maize, which in turn compromises the farm households' food security.

The average concentrations of the mycotoxins in the maize (Table 5) were as follows: 596.48 ± 38.85 µg/kg of aflatoxins, 745.73 ± 105.57 µg/kg of ochratoxins, 87717.95 ± 14984.32 µg/kg (or 87.2 ± 15 mg/kg) of fumonisins and 1803.77 ± 1803.77 µg/kg (or 1.8 ± 0.241 mg/kg) of T-2 toxins. The amounts of mycotoxins that were detected per kg of maize in Katumba ward are far above the international regulatory standards even for households that utilize only 500 g of maize flour per meal. However, higher quantities of up to 212000 µg/kg (or 212 mg/kg) of aflatoxins have earlier been reported in maize in Kenya (Probst, 2007) and up to 300 mg/kg (or 300000 µg/kg) were reported in Italy (Rittieni et al., 1997). Reports of amounts higher than the maximum amounts of 3617 µg/kg (or 361.7 mg/kg) of ochratoxins and 6200.67 µg (or 620 mg/kg) of T-2 toxins in food or feed were not

found, thus perhaps this was the first time such high amounts of ochratoxins and T-2 toxins were detected in stored maize. The high quantities of mycotoxins that individuals in the farm households could be exposed to through consumption of contaminated maize meals are very high such that accumulation of the mycotoxins in the bodies of the consumers could lead to a combination of health problems. These include: interference with neurones function, interference with protein synthesis, mutagenesis, suppression of the immune system, and retarded growth. Furthermore, the large quantities of mycotoxins also put the maize meal consumers at risk of being vulnerable to attack by other diseases such as malaria and HIV due to the possible suppression of the immune system caused by the mycotoxins. In the light of the above discussion, maize consumers in Katumba ward are food insecure and they may be suffering or dying unnoticed from consuming maize meals that are contaminated with the above indicated mycotoxins, especially since no investigations have been carried out in this ward in relation to the points raised here. The facts that all of the maize samples that were collected from the sack storage facilities and that 83% of the maize samples collected from the roof storage facilities for the test were contaminated with the mycotoxins show poor performance of the two storage methods with respect to preventing fungal contaminations from occurring. Moreover, the fact that maize samples from both roof and sack storage facilities were contaminated by one or more than one type of mycotoxins (Table 4) indicate that both of the storage methods allowed the production of mycotoxins in the stored maize. Also a highest percentage of the maize samples that were contaminated by T-2 toxins and fumonisins had been collected from the roof storage facilities (Table 3). This implies that for a large number of the farm households in Katumba ward the capacity of maize to be contaminated by T-2 toxins and fumonisins was highest where maize was stored using the roof storage method. However, for the maize samples that were collected from the sack storage facilities the number of maize samples that were contaminated by the T-2 toxins (93.3%) was equally very high, which imply that both roof and sack storage methods were not effective in preventing the production of T-2 toxins in stored maize. Also, the lack of significant differences between the means for the quantity of each of the mycotoxin that was studied revealed by the t-tests imply that there was no difference between the capacity of the roof and sack storage method concerning preventing the production of mycotoxins in stored maize.

Lastly, the high quantities of mycotoxins in the maize samples from roof and sack storage facilities could only be produced in the presence of moisture and right temperatures. At 15 to 37°C the production of ochratoxins A, the type of ochratoxins, which is mostly found in food occurs (FAO, 2004), whereas at 25 to 30°C and 15 to 43°C fumonisins and aflatoxins, respectively are produced (Marin et al., 1995; FAO, 2001). Thus since the quantities of aflatoxins, ochratoxins, fumonisins and T-2 toxins in the maize samples that were collected from the roof and sack storage methods alike were high, it is argued that the temperatures in the storage facilities from which the maize samples were taken were also favourable for the production of the mycotoxins studied.

Rapid drying (Reed et al., 2007), cooling followed by treating the maize with antifungal chemicals (Weinberg et al., 2008) are recommended for preventing growth and development of fungi in maize. The latter is usually recommended for maize seeds used for planting. However, due to the wetness and high humidity that characterizes the climatic conditions in Katumba ward maize which is thoroughly dried can still take in moisture from the surroundings. Therefore apart from ensuring that maize is dry enough prior to storage, there is a need for roof and sack storage technologies in Katumba ward to be improved so that they can prevent stored maize from taking in moisture from the surroundings.

CONCLUSIONS AND RECOMMENDATIONS

For the majority of farm households in Katumba ward, the quality of maize stored using roof and sack storage methods is low due to the infections by *Fusarium*, *Aspergillus* and *Penicillium* species which are pathogenic in nature. The presence of the pathogenic fungi in maize in Katumba ward would in turn render maize meals probably not only unpalatable, but it could also lead to the infestation of the maize by insect pests. Furthermore, while the pathogenic fungi could also lead to reduction of the nutritional value of the maize and, they also put the farm households in this ward at risk of ill health or even premature death due to daily exposure to high levels of the mycotoxins that the pathogenic fungi produce. The mycotoxins include fumonisins and T-2 toxins, aflatoxins, and ochratoxins, respectively. In general, the mycotoxins would impact negatively on the farm households' food security. It is recommended that more research be done in Katumba ward and other parts of Rungwe district in order to find out if there are diseases or deaths that can be linked to the contamination of maize meals by the afore-mentioned indicated mycotoxins. Sack and roof storage methods, which are the only storage methods that are used in Katumba ward for long term storage of maize inadequately, protect stored maize from fungal infection. Thus ways of ensuring that maize stored using roof and sack storage methods is protected from infections by fungi should be implemented in this ward. These should include encouraging the farm households to ensure that storage facilities are clean prior to use, that none of the maize is infected by moulds prior to storage, that maize is dry enough prior to storage and that maize is dried within 48 h prior to storage.

Farmers should also be encouraged to grow maize varieties that are particularly resistant to infection by moulds and insect pests in order to reduce chances of maize grain to be infected during storage. Above all, it is highly recommended that the Tanzanian government should encourage agricultural engineers to design driers such as bio-fuel driers that farm households in humid places such as Katumba ward can use for rapid drying of maize and other food crops prior to storage Additionally, the maize breeding program in Tanzania should emphasize development of maize varieties which are resistant to fungal infections so that contamination of stored maize by mycotoxins can be avoided.

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