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Journal of Postharvest Technology
2018, **06**(2): 90-103
http://www.jpht.info

RESEARCH ARTICLE

Effect of harvesting time and drying methods on aflatoxin contamination in groundnut in Mozambique

Emmanuel Zuza Jnr[1*], Amade Muitia[2], Manuel. I.V. Amane[3], Rick .L. Brandenburg[4], Andrew Emmott[5] and Ana M. Mondjana[1]

[1]Eduardo Mondlane University, Faculty of Agriculture and Forestry Engineering, Department of Crop Protection, P.O. Box 257, Maputo, Mozambique,
[2]Nampula Research Station, Av. FPLM km 7, Via Corrane, Nampula, Mozambique
[3]Institute of Agriculture Investigation of Mozambique, P.O. Box 3658, Maputo, Mozambique
[4]North Carolina State University, Department of Entomology, Center for Turfgrass Environmental Research and Education, Box 7613, Raleigh, Nc 27605-7613
[5]Twin and Twin Trading Ltd, Third Floor 1, Curtain Road London EC2A 3LT .

Received: 08.01.2018 Accepted: 29.02.2018

ABSTRACT

The production and utilization of groundnut (*Arachis hypogea* L) has increased tremendously across all provinces of Mozambique in recent times. However, the presence of mycotoxins, especially aflatoxins has remained a critical food concern in both the human and livestock diet. In this study, the effect of harvesting time and drying methods on aflatoxin contamination were examined at two locations namely; Nampula Research Station (PAN) and Mapupulo Agricultural Research Center in Nampula and Cabo Delgado provinces respectively. A randomized complete block design in a split-split plot arrangement with four replications was used with three groundnut varieties; (*ICGV-SM-99568*, *ICGV-SM-01514* and *JL-24*) as the main plot and three harvesting dates (10 days before physiological maturity, at physiological maturity and 10 days after physiological maturity) and two drying methods; (A-frame and tarpaulin) as the sub-plots. Groundnut samples were analyzed for aflatoxin contamination using immuno-chromatographic assay strips by the M-reader. In both locations, field observations indicated that on average aflatoxin contamination levels were lower at physiological maturity (H2) (≤ 10 ppb) compared to harvesting 10 days before (H1) (≤ 15 ppb) and 10 days after physiological maturity (H3) (≥ 20 ppb). It was also observed that the two drying methods were effective in prevention of aflatoxin contamination on groundnut kernels to levels lower than 20 ppb. However, aflatoxin contamination levels were significantly lower (≤12 ppb) as a result of the A-frame than the tarpaulin method. The results of this study therefore, have indicated that proper post-harvest management of groundnuts such as harvesting at physiological maturity and improved drying gave lowest aflatoxin contamination levels lower than the FDA/WHO regulatory levels of 20 ppb.

Keywords: Groundnut, harvesting time, aflatoxin contamination, drying methods

Citation: Zuza, E.Jnr., Muitia, A., Amane, M.I.V., Brandenburg, R.L., Emmott, A. and Mondjana, A.M. 2018. Effect of harvesting time and drying methods on aflatoxin contamination in groundnut in Mozambique. *Journal of Postharvest Technology*, **6**(2): 90-103.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is the third most important crop in Mozambique after maize (*Zea mays*) and cassava (*Manihot esculenta*) (Muitia, 2013; Walker et al., 2006). It is a major cash crop and the main source of cooking oil for many Mozambican families (Muitia, 2013; Muitia, 2005). In terms of production, groundnut occupies the largest area among the

* *For correspondence:* E.J. Zuza (*Email:* manzyzuzajnr@gmail.com)

ISSN: 2348-4330

grain legumes in the country (Muitia, 2013; Arias and Libombo, 1994) with the largest concentration in Nampula, Zambezia and Cabo Delgado provinces.

Despite its importance as food, the presence of mycotoxins, especially aflatoxins has the potential to limit its use in both the human and livestock diet (Rahmianna et al., 2007). Furthermore, aflatoxin contamination of agricultural crops, such as; groundnut and cereals, causes annual losses of more than US $750 million in Africa and more than US $100 million per year in USA (Kamika and Takoy, 2011). Poor management practices by farmers and adverse climatic conditions at harvest and post-harvest are some of the prompting factors for post-harvest aflatoxin contamination. The timing of harvesting greatly influences mould production at harvest (Guo et al., 2003). Wright et al. (2005) highlighted that farmers tend to delay in harvesting their crop which results in over maturity leading to mould infections and subsequent aflatoxin contamination.

Correct and proper drying of harvested groundnuts is very essential in prevention of fungal infection of the crop. Additionally, proper drying is critical for maintaining seed quality for consumption and safe storage. However, the traditional groundnut drying techniques in Mozambique, involve field and bare ground drying which rather promote fungal growth and consequent aflatoxin contamination (Jeffrey, 2011). Moreover, these are slow, time consuming and labour intensive, involving lots of crop handling and due to rains that normally persist at harvesting and drying times, it is difficult to achieve the recommended moisture content for safe storage (which is 6-8 %). In addition, the crop is persistently exposed to the soil, which is a major source of contamination by fungi (Okello et al., 2010; Kaaya et al., 2007; Singh et al., 2014).

Ideally, pods should be dried with sufficient air circulation and in the shade (Okello et al., 2010). This is because excessive exposure to the sun can affect the quality of the seed. Two principal methods are used elsewhere in Africa, both of which can produce good quality seed with reduced levels of fungal infection (AICC, 2014). These drying methods are namely; Corks and A-Frame methods. However, the traditional drying techniques in Mozambique involve bare ground drying and are a major source of fungal contamination. Furthermore, some farmers do not dry groundnuts immediately after harvest, due to labour constraints needed for plucking (Jeffrey, 2010). Thus, they heap the nuts either in the field or in houses. These practices, coupled with inefficient and slow drying process under the humid conditions enhance aflatoxin contamination greatly.

Although research on the effect of harvesting time and drying method of groundnut on aflatoxin development, has received increasing consideration worldwide, in Mozambique, research on this matter is still very scarce (Almeida et al., 2013). However, there is evidence to suggest that aflatoxin contamination is a major food-safety concern in Mozambique where the environmental conditions and socio-economic problems are conducive due to poor post-harvest and storage management and subsequent food spoilage and aflatoxin contamination. This is evident by levels of certain types of cancer and the negative correlations between aflatoxin in the diet and development in children and the declining of groundnut exports from Mozambique since 1998 (FAO-STAT, 2015: Almeida et al., 2013).

By assessing different harvesting times and different drying methods it was hoped that the results would enhance the use of good post-harvest handling practices (drying and harvesting time) that would minimize aflatoxin contamination of groundnuts at farmer level.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted during the 2015/2016 growing season in two locations namely; Nampula Research Station (PAN) and Mapupulo Agricultural Research Center (CIAM), located in Nampula and Cabo Delgado Provinces, respectively. Nampula Research Station (PAN) is located about 7 km east of Nampula city in Northern Mozambique (15° 09' S, 39° 30' E) and is elevated at 432 m above sea level. The soil type is sandy loam and the vegetation is predominantly grassland. The average rainfall is slightly over 1000 mm which starts around November/December up to April/May, with its peak in January. The maximum temperature in the region is about 39 °C and the minimum temperature is 19 °C (Muitia, 2013). Mapupulo Agricultural Research Center (CIAM) is located about 18 km south of Montepuez town about 200 km west of Pemba the capital of the province, which lies at (13° 12' S, 38° 53' E) and is elevated at 476.7 m above sea level. The soils are clay loam and deep brown loam. It receives annual precipitation of 1200 mm on average from November/December to April/May, and the average temperature is between 20 and 25 °C (Muitia, 2013).

Field Establishment

The study was carried out during the 2015/2016 growing season at PAN and CIAM. The test materials were evaluated using a randomized complete block design in a split-split plot arrangement with four replications. The main plot was the variety while harvesting time and drying method were sub-plots. The net plots were 6 rows by 6 m long with one seed per planting station which were spaced at 50 cm apart and the planting stations were spaced at 10 cm. Spanish groundnut varieties (take 90 days to mature) were used for the study namely: *ICGV-SM-99568*, *JL-24* and *ICGV-SM-01514*. The experiments were established on 23rd December and 24th December at CIAM and PAN respectively at the onset of the rains. No fertilizer, pesticides or supplementary water were applied, and no seed treatment before planting was applied.

The assessment of the effect of harvesting time and drying method on aflatoxin contamination among the varieties involved dividing the net plots into three harvesting time treatments: (i) 10 days before physiological maturity indicated as H1; (ii) at physiological maturity indicated as H2 and (iii) 10 days after physiological maturity indicated as H3. The following drying treatments were imposed on the plants from each of the plots: (1) pulling and inverted windrowing of plants for 3 days, followed by further drying of the plants with the pods on constructed "A-Frames" for 4 weeks and (2) pulling and inverted windrowing of plants for 3 days, followed by stripping of the pods and further drying on interlaced tarpaulins mats for 4 weeks. The samples were later subjected to aflatoxin testing using the immune-chromatographic method M-Reader.

Weather Data

Air temperature, relative humidity and rainfall data was collected using weather stations on the research stations.

Determination of Moisture Content

The moisture content of groundnut samples was measured using the Mini GAC moisture meters. These were calibrated to ensure the accuracy. To determine the moisture content, groundnut samples were initially shelled. Later, a total of 50 g was filled in the moisture meter loader: after which the loader was emptied into the analyzer. The results were read using the display window on the moisture meters.

Aflatoxin Analysis

Validation of the M-Reader

To determine the precision and recovery of the immune-chromatographic assay analysis, antigenic standards were used. For high calibration standard procedure, 100 µl of pink antigenic standard was added to 500 µl of sample buffer diluent. Then 100 µl was aliquoted in a separate vial. A reveal Q+ test strip was placed in the vial and was left to develop for 6 minutes. After 6 minutes the strip was placed in the mReader strip holder and aflatoxin levels were read using the mReader. For the low calibration standard procedure, 35 ml of 65 % ethanol solution was added to a 10 g control groundnut sample which was free of aflatoxins. Then, a 100 µl of the pink antigenic standard solution was added to the 30 ml extracts and mixed for 2 minutes. Later, a 100 µl of the mixture was added to 500 µl of sample buffer diluent. A mixture of 100 µl was later aliquoted to a separate vial. Finally, the total aflatoxin in the sample was measured by placing the reveal Q+ test strip in the vial and was left to develop for 6 minutes and aflatoxin reading was done using the mReader.

Sample preparation and aflatoxin determination

Aflatoxin analysis was carried out using immune-chromatographic assay Reveal Q+ mReader according to the manufacturer's recommendation. Prepared groundnut samples (500 g each) were ground finely using the Agri-Grind grinder until fine particles and homogeneity was obtained. Then, a sub-sample of 10 g was obtained from each of the composite samples. The sub-sample was aliquoting in 35 ml of 65 % ethanol, and the contents were mixed gently by shaking the holding tube manually. After filtration of the blended subsample, 100 µl of the filtrate was mixed with 500 µl diluent solution in a dilution vial. After obtaining a fine mixture, a 100 µl extract of the aliquoted mixture was collected and added to a separate vial. Finally, a reveal Q+ test strip was placed in the vial containing the aliquoted mixture and was left to develop for 6 minutes. The test strip was later placed in the mReader holder, and aflatoxin contamination levels of the sample were determined using the mReader based on the chromatographic characteristics of the sample in the strip. The data was statistically analyzed using GenStat Discovery 4. An independent Tukey-test was used to compare the means of the aflatoxin results. The tests for relationships was carried out using the Pearson Correlation Index and the interpretation was performed at two-sided 95 % confidence limit.

RESULTS AND DISCUSSION

A summary of mean air temperature, relative humidity and rainfall during the 2015-2016 growing season at Mapupulo Agricultural Research Center is presented in Table 1.

The mean daily air temperature during the pod-filling period was about 26.3 °C up until H1. Although the mean daily temperature declined to around 24.5 °C by H3. The site received a total rainfall of 684.6 by H1 and 830 mm between H2 and H3 respectively of which 50-65 % fell during the pod-filling period. Additionally, there were also some post-harvest rainfall during the drying period, with 37.2 mm falling between H2 and H3. The average relative humidity was between 80-85 % during the groundnut harvesting and drying periods. However, overall there were generally high temperatures and heavy rainfall during the pod-filling till H2.

Nampula Research Station received lower rainfall during the 2015-2016 growing season compared to CIAM (Table 2). The site received rainfall of 299.8 mm (for only 11 days) during pod-filling, and the location experienced a mid-season drought (February).

Table 1. Weather data during the 2015-2016 growing season at CIAM

Month	December	January	February	March	April
Average maximum temperature (°C)	34.1	30.5	31.4	31.9	30.8
Average minimum temperature (°C)	21.8	21.6	21.3	22.0	20.3
Cumulative rainfall (mm)	516.6	1300.6	568.7	800.4	859.7
Total number of rainy days	10	20	18	16	22
Relative humidity (%)	68	83	80	81	79

However, significant higher rainfall fell during H1, whilst H2 and H3 experienced a prolonged end of season drought. The mean daily air temperatures during the pod-filling period at PAN were higher ranging from 30 to 35 °C by H1 to H3. Additionally, the location experienced very high relative humidity ranging from 75-85 %.

Table 2. Weather data during the 2015-2016 growing season at PAN

Month	December	January	February	March	April
Average maximum temperature (°C)	35.3	34.8	36.3	35.2	32
Average minimum temperature (°C)	33.2	29.6	32.1	32.2	29.7
Cumulative rainfall (mm)	232.9	496.6	299.8	799.1	43.9
Total number of rainy days	6	12	11	18	4
Relative humidity (%)	83	87.7	76.3	83	85

Postharvest pod handling and kernel moisture content

Moisture content of groundnut kernels greatly influences the growth of toxigenic fungi and subsequent aflatoxin contamination. The study has shown that different drying methods had different influences on the total kernel moisture losses at different experimental sites at different harvesting times. Moisture content of kernels from the A-Frame at both sites decreased from an average of 38 % to 7 %, within a 4 week period (Figure 1). These moisture contents were significantly different at ($P \leq 0.05$) from each other. It was observed that kernel moisture loss was rapid just after harvesting compared to the other following weeks. This was attributed to the high water activity in the seeds just after harvesting than the following weeks, which resulted into increased diffusion rate of water from the seeds to the environment through evapotranspiration and thus leading to rapid loss of water.

Significant differences ($P \leq 0.05$) were also recorded in kernel moisture loss of tarpaulin dried pods. The moisture content decreased from an average of 38 % to 7 %, within a 2 week period (Figure 2). It has been established that, using the tarpaulin drying method kernel moisture loss was more rapid compared to using the A-frame drying method. The reason behind this was that, with tarpaulin drying, pods were exposed to direct sunlight which resulted into rapid losses of kernel moisture within a short period of time, whilst for the A-frame method the kernels took a longer time to dry because the pods were facing inwards and away from the sunlight and soil and were covered by leaves. This ensured a good air circulation and slow but effective drying.

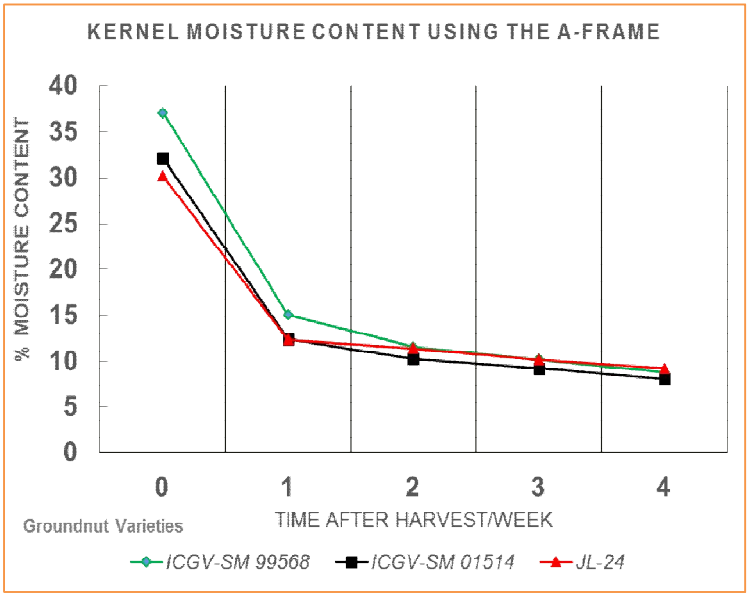

Fig 1. Kernel Moisture Loss when using the A-Frame

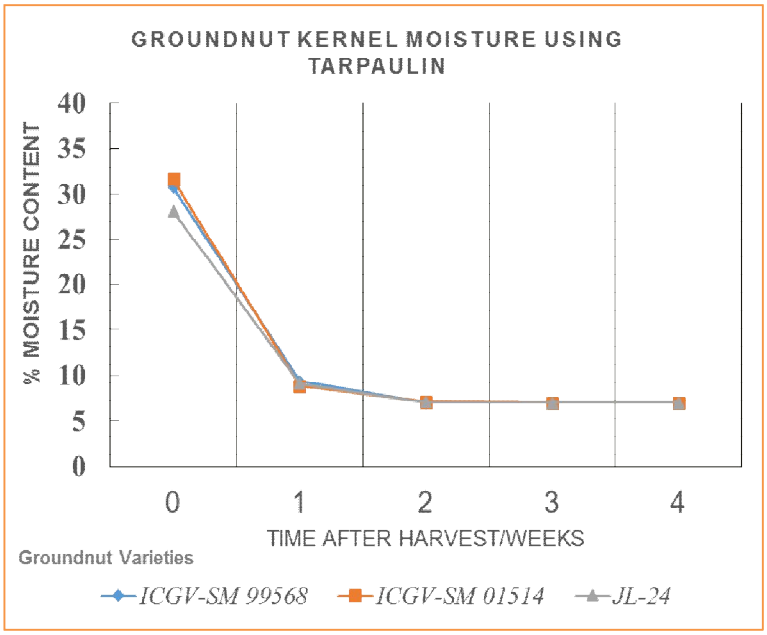

Fig 2. Kernel Moisture Loss when Using Tarpaulins

The study also revealed that the variety *JL-24* took a shorter period of time to dry compared to the other two varieties irrespective of the drying method. This could be attributed to the lower moisture content of the variety and the thinner layer of the shell. The variety *ICGV-SM-01514* took the longest time to dry irrespective of the drying method and this could be attributed to the thicker shell of the variety which led to slower moisture loss.

Effect of harvesting time on groundnut aflatoxin contamination

Aflatoxin contamination levels among groundnut varieties at different harvesting times are presented in Figure 3. Significant differences ($P \leq 0.01$) were observed in the mean aflatoxin contamination levels with physiological maturity (H2) having the lowest aflatoxin contamination levels (≤ 10 ppb). The highest aflatoxin contamination levels were recorded when harvesting was executed 10 days after physiological maturity (H3) (≥ 20 ppb) compared to when harvesting was executed 10 days before physiological maturity (H1) (≤ 15), which had considerably lower aflatoxin levels.

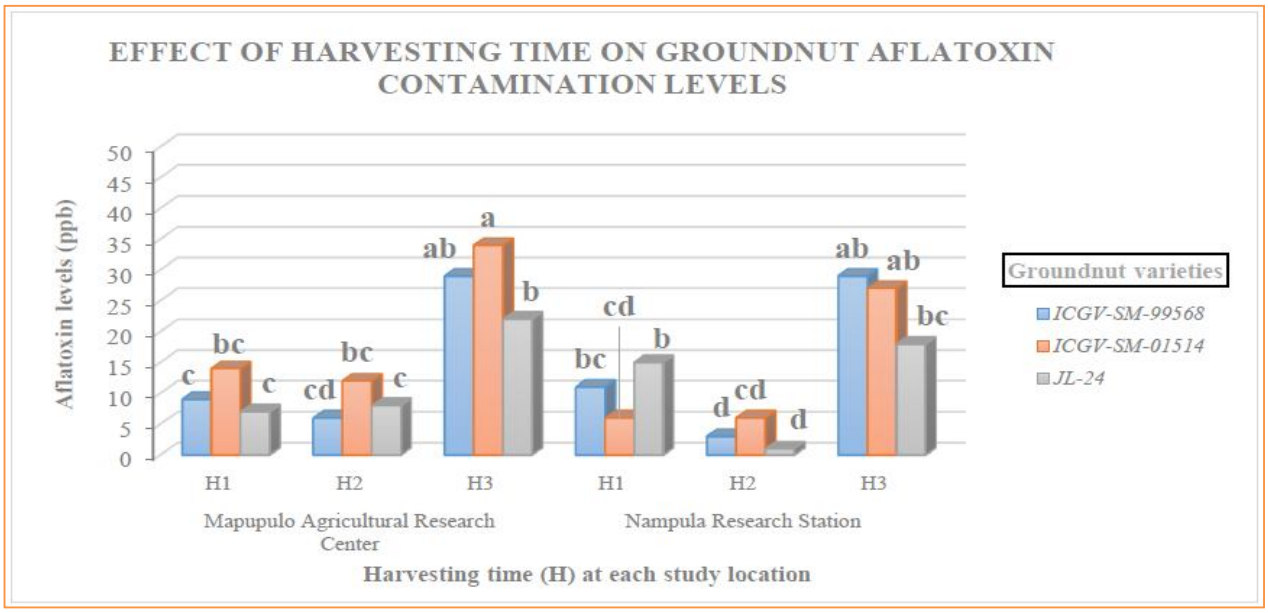

Fig 3. Effect of harvesting time on groundnut aflatoxin contamination levels

The study also revealed significant differences in aflatoxin levels among the three groundnut varieties. The variety *JL-24* had the lowest mean aflatoxin contamination levels compared to the other two varieties. This could be attributed to the lower moisture content of the *JL-24* and the thin shell of the variety which led to rapid drying and minimized fungal invasion and subsequent aflatoxin contamination. Furthermore, it was observed that at CIAM the mean aflatoxin contamination levels of *ICGV-SM-99568* (14.5 ppb) was significantly lower compared to that of *ICGV-SM-01514* (17.9 ppb). A similar trend of results was observed at PAN, however, at this location *ICGV-SM-01514* had the lowest mean aflatoxin contamination levels (12.3 ppb) compared to (14.3 ppb) for the variety *ICGV-SM-99568*.

Effect of drying method on groundnut aflatoxin contamination

Significant differences were observed in aflatoxin contamination levels among the groundnut varieties as a result of drying method. Lower levels of aflatoxin were recorded by the use of the A-Frame compared to the tarpaulin drying method (Figure 4). However, except for the variety *ICGV-SM-01514* (26 ppb) at CIAM, the aflatoxin contamination levels for the groundnut varieties were lower than 20 ppb as a result of both drying methods. Thereby, showing the effectiveness of the two drying methods in prevention of aflatoxin contamination. Significant differences in aflatoxin contamination levels were also observed among the groundnut varieties as a result of the interaction between harvesting time and drying methods at the two study locations (Table 3 and Table 4).

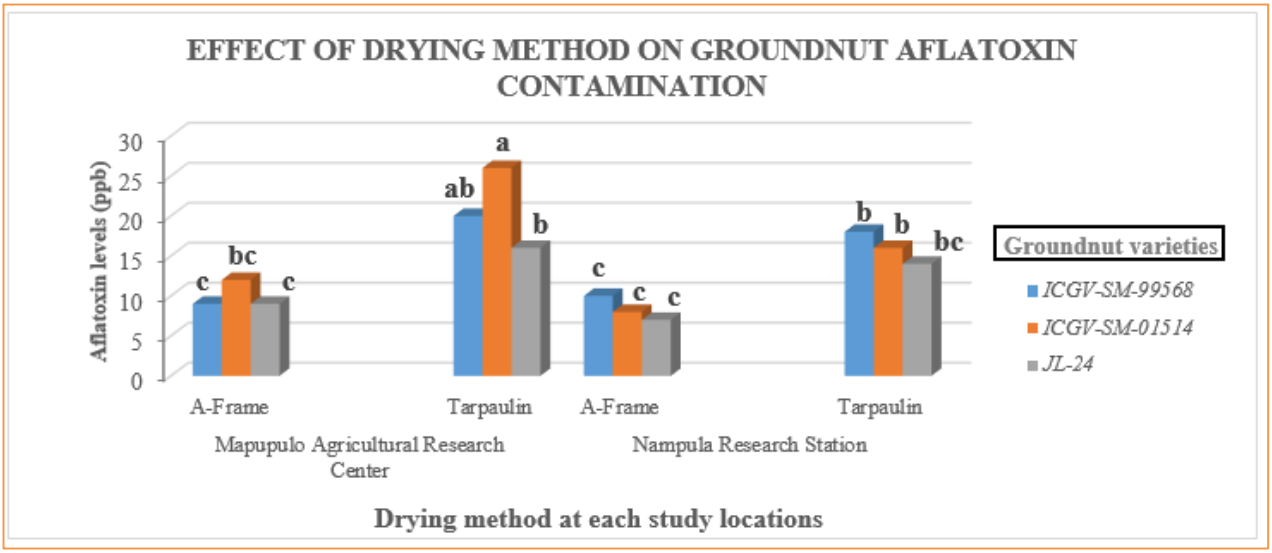

Fig 4. Effect of drying method on groundnut aflatoxin contamination

The results showed that aflatoxin contamination of the nuts started at H1 and significantly increased with delayed harvesting time (H3). At Mapupulo Agricultural Research Center the lowest aflatoxin contamination levels were found to be 3 ppb and 4 ppb for the A-frame and tarpaulin drying methods respectively harvested at physiological maturity. For Nampula Research Station the lowest levels of aflatoxin contamination were found to be 2 ppb for both drying methods harvested at physiological maturity. Higher aflatoxin levels (≥ 25 ppb) were recorded when harvesting was executed 10 days after physiological maturity (H3) with respect to the drying methods. In summary, it has been established that the interaction of delayed harvesting and tarpaulin drying method resulted in higher aflatoxin contamination among the groundnut varieties than the interaction of delayed harvesting and A-frame drying method. Overall, the interaction of harvesting time and A-frame drying method resulted into lower aflatoxin contamination levels than the interaction of harvesting time and tarpaulin drying method.

Table 3. Groundnut aflatoxin levels as affected by the interaction of harvesting time and drying method at Mapupulo Agricultural Research Center

Drying Method	Variety	Harvesting Time		
		H1	H2	H3
A-Frame	ICGV-SM-99568	3^{c}	7^{bc}	17^{b}
	ICGV-SM-01514	10^{bc}	3^{c}	25^{a}
	JL-24	4^{c}	4^{c}	19^{ab}
Tarpaulin	ICGV-SM-99568	16^{bc}	4^{d}	40^{ab}
	ICGV-SM-01514	17^{bc}	10^{cd}	42^{a}
	JL-24	9^{cd}	13^{c}	25^{b}
Mean±SE	**A-Frame 10±3.77**		**Tarpaulin 21±5.17**	

Means followed by the same letters within a column do not differ significantly according to Tukey's honestly significant difference test (P ≤ 0.01).

Table 4. Groundnut aflatoxin levels as affected by the interaction of harvesting time and drying method at Nampula Research Station

Drying Method	Variety	Harvesting Time		
		H1	H2	H3
A-Frame	ICGV-SM-99568	3^{c}	2^{c}	27^{a}
	ICGV-SM-01514	2^{c}	2^{c}	21^{ab}
	JL-24	10^{c}	1^{c}	12^{b}
Tarpaulin	ICGV-SM-99568	18^{bc}	4^{c}	32^{a}
	ICGV-SM-01514	8^{bc}	8^{bc}	22^{ab}
	JL-24	19^{b}	2^{c}	25^{b}
Mean±SE	**A-Frame 9±4.03**		**Tarpaulin 16.5±5.6**	

DISCUSSION

A number of studies have shown that weather directly influences host susceptibility to aflatoxin contamination (Cotty, 2007). The differences in the intensity of aflatoxin contamination between CIAM and PAN could be attributed to the variability in intensity and duration of rainfall, temperature as well as relative humidity between the two locations. In general, CIAM had significantly higher aflatoxin contamination levels compared to PAN. This was attributed to higher than normal temperatures (≥ 30 °C) and late season rainfall which created warm, moist conditions suitable for fungal growth and subsequent higher aflatoxin contamination levels on the kernels. These outcomes are similar with earlier accounts that wetter and more humid conditions tend to aggravate aflatoxin levels as it enhances the growth of *Aspergillus* species and production of aflatoxins in groundnuts compared to drier climatic conditions (Menza et al., 2015). Widstrom et al. (2003) indicated that the optimal temperature range for production of aflatoxin is approximately 25-30 °C agreeing with the current study.

The study also recorded higher aflatoxin contamination levels in the groundnut kernels above the recommended 20 ppb (US standards) at both CIAM and PAN. This could be as a result higher air temperatures (≥ 30 °C) along with elevated relative humidity (≥ 70 %) which provided optimum conditions for fungal invasion especially for the *Aspergillus* section *Flavi* and later production of aflatoxins. The was consistent with the findings of Hell and Mutegi (2011) who reported that environmental conditions that favor *Aspergillus* group of fungi included high soil or air temperature (25-30 °C), high relative humidity (70-85 %) and drought stress. Al- Shikli et al. (2010) and Sugri et al. (2015) found out that the optimum temperature range for aflatoxin production is 25-35 °C, although production can occur over a wide range of temperatures (10-40 °C). Additionally, research results by Kusumaningrum et al. (2010) exhibited that relative humidity above 70 % were optimal for growth of *A. flavus* and subsequent aflatoxin contamination. The current study has therefore shown significant positive correlations between local weather conditions and aflatoxin contamination levels, where, high temperature (≥ 25 °C) and high relative humidity (≥ 70 %) favored growth of *Aspergillus* species and increased the rate of aflatoxin production.

Field observations have shown that on average aflatoxin contamination levels were lower at physiological maturity (H2) compared to harvesting at 10 days after physiological maturity (H3). Furthermore, harvesting the crop at H1 had significantly higher aflatoxin contamination levels than harvesting at H2, with some exceptions. The high aflatoxin levels at H1 were attributed to immaturity of pods, higher pod and kernel moisture content and adverse conditions of wet and humid weather, which provided conducive conditions for fungal invasion and consequently aflatoxin production. Additionally, most of the pods were small and shriveled, which provided direct access to entry of microorganisms including fungi into the pods and

consequently attacking the kernels and later contaminating the crop with aflatoxins. This confirmed the findings of Okello et al. (2010) who reported that harvesting groundnuts too early or when the pods are immature results in high aflatoxin levels in the kernels. The findings were also consistent with the findings by Cotty and Jaime-Gracia (2007) who found that aflatoxin contamination was positively correlated with wet weather during harvest (rainfall). It has also been shown that as a result of early harvesting, drying concided with some post-harvest rainfall which led into high aflatoxin contamination of the crop since there was excess moisture which provided suitable conditions for fungal growth and development and production of aflatoxins.

Harvesting 10 days after physiological maturity (H3) resulted into highest levels of aflatoxin contamination compared to H1 and H2 among the groundnut varieties in both study locations. Confirming the study findings by Hell et al. (2003) who reported that post-harvest contamination with aflatoxin in groundnut increased when harvesting was executed 5 days after physiological maturity. Additionally, the study has shown that delayed harvesting resulted into higher aflatoxin contamination levels greater than the FDA/WHO regulatory levels of 20 ppb (Mphande et al., 2004). The high aflatoxin contamination levels at H3 were as a result of heavy damage of pods by insects especially termites (*Odontotermes badius* and *Odontotermes latericus*) which provided ready entry of fungi including *Aspergillus* species and consequently aflatoxin contamination. This confirmed the findings of Dowd (2003) who reported that insects influence the levels of aflatoxin contamination in commodities such as; maize and groundnut by carrying fungal inoculum and causing damage that provide ready entry of the fungus and thereby increasing the chances of aflatoxin contamination. Moreover, Kombiok et al. (2012) indicated that insects such as termites cause scarification of pods, which weakens the shells and makes them liable to crack during harvesting leading to further insect, microbial and disease infestations.

High aflatoxin contamination levels at H3 could also be attributed to physical damage of pods as a result of digging using hoes. Harvesting groundnut 10 days after physiological maturity coincided with dry weather making it difficult to harvest the groundnuts by hand pulling which led to digging the nuts out of the soil using hand hoes. Similar to the effect of insect damage to pods, physical damage to pods tended to increase with delay in harvesting perhaps due to the dryness of the soil which made pulling and digging out of pods very difficult. As a result many pods of the groundnut varieties got damaged which favored the entry and invasion of the nuts by *Aspergillus* Section *Flavi* that later produced aflatoxins as a result of respiration. These findings are concurrent with the findings of Hell and Mutegi (2011) who indicated that some factors that influence the incidence of fungal infection and subsequent toxin development include: invertebrate vectors (insects), grain damage, inoculum load, substrate composition, fungal infection levels, prevalence of toxigenic strains and microbiological interactions. Moreover, Horn (2005) reported that highest levels of *A. flavus* and *A. parasiticus* infection and aflatoxin contamination are associated with seed damage caused by either insects or physical damage of pods.

It has also been observed that delayed harvesting coincided with high relative humidity (≥ 75 %) and higher air/soil temperatures (30-35 °C) which provided hot and moist conditions for fungal growth and subsequent aflatoxin contamination. This phenomenal confirmed the findings of Cotty and Jaime-Garcia (2007) who stated that influences of delayed harvesting on aflatoxin contamination are most severe when crops are caught by higher than normal temperatures (25-30 °C) and high relative humidity just prior to or during harvest (≥ 70 %). Additionally, harvesting groundnut 10 days after physiological maturity coincided with high populations of *Aspergillus* species in the soil which led to high aflatoxin contamination. Vijayasamundeeswari et al. (2010) reported that populations of *A. flavus* were significantly higher in the pod-zone than in the field soil and increased with maturation of the crop.

The correct drying of harvested groundnuts is very important, as inappropriate drying can help induce fungal growth and reduce kernel quality for consumption and germination for the following season. At harvest groundnut fruits have a higher

moisture content (38-40 %) and must be dried to (7-8 %) to prevent growth of fungi (Waliyar et al., 2015) agreeing with the findings of this study. Moreover, drying method greatly influences the resistance of groundnuts to fungal attack (Rahmianna et al., 2007). It has been established from the results of this study that both the A-frame and tarpaulin drying methods were effective in reducing moisture content of groundnut to the recommended level of ≤ 7 % and thereby reduced the chances of heavy aflatoxin contamination on the kernels. However, tarpaulin drying method was more rapid in reducing kernel moisture levels compared to A-frame dying method. This was attributed to the direct exposure of the pods to sunlight compared to the shading of pods with leaves when on the A-frame.

Nevertheless, significant differences were observed in aflatoxin contamination levels between A-frame and tarpaulin drying methods. Lower aflatoxin contamination levels were observed when using the A-frame (≤ 10 ppb) compared to tarpaulin drying (≤ 20 ppb) which had to some extent higher aflatoxin contamination levels. The high aflatoxin contamination levels when using the tarpaulin method was attributed to alterations of the pod and seed coat as a result of direct exposure to sunlight which resulted into creation of microscopic poles and cracks that provided ready entry of fungi and later aflatoxin production. The advantage of the A-frame drying method over tarpaulin drying was that it prevented direct exposure of the pods to sunlight and provided increased air circulation as a result of the pods being on a raised platform which led to efficient and effective drying resulting into lower fungal invasion. This confirmed the findings of Fernandez et al. (1997) who reported that if drying is too rapid there are alterations in the seed coat that favor fungal infection. Furthermore, Nautiyal (2002), reported that tarpaulin drying results into restricted air movement within the nuts and thereby providing inefficiency in reducing moisture and providing conditions for fungal growth and consequently aflatoxin contamination. The current study findings are in accordance to the study conducted by Hell et al. (2008) who found that drying maize using platforms (A-Frames) reduced contamination of the crop by toxigenic fungi than using tarpaulins.

High aflatoxin contamination levels with the tarpaulin drying method could also be as a result of weather conditions. Post-harvest abrupt rainfall during the drying period resulted into wetting of pods and prevented drying of the pods to the open sun on some days when it rained all day which resulted into creation of moist conditions conducive for aflatoxin production by the fungi. While as for the A-frame this was not the case since the pods were covered with leaves and thereby preventing water from reaching the pods and ensuring exposure to air circulation all the time. Nautiyal (2002) reported that one of the disadvantages of drying groundnuts on tarpaulins was the time and effort required to gather the pods together and cover them during rain showers and re-spreading the pods as soon as possible in-order to continue drying, this was difficult and the adverse moist conditions as result of the rain provided optimum conditions for fungal invasion and aflatoxin production.

However, in general it has been observed that both the A-frame and the tarpaulin drying methods were effective in prevention of aflatoxin contamination of the groundnut crop than would traditional methods of drying which involve field and bare ground drying. Furthermore, the A-frame and tarpaulin drying methods ensured that the groundnut crop attained the recommended moisture content (≤ 7 %) and ensured that the crop was not in direct contact with the soil thereby preventing easy access of fungi to the pods and thus ensuring minimum fungal invasion. This is similar to the findings of Kaaya et al. (2005) who reported that, field and bare drying of maize by traditional methods falls short of attaining moisture levels that are safe for storage; in addition, bare ground drying leads to long-term exposure of the crop to infestation and damage by insects, birds, rodents, wild animals and fungi.

CONCLUSION

All The results of the current study have shown that proper post-harvest management of groundnut such as; harvesting at

physiological maturity gave the lowest aflatoxin contamination levels, lower than the FDA/WHO regulatory levels of 20 ppb than harvesting either too early or too late. Additionally, the study has demonstrated that drying groundnut using the A-frame and tarpaulin methods was effective in ensuring lower aflatoxin contamination levels of kernels. However, the A-frame was more effective compared to the tarpaulin drying method. It is therefore recommended that farmers harvest their groundnut crop at physiological maturity and be encouraged to adopt the use of A-frames in drying their groundnut in order to reduce higher aflatoxin contamination of the crop.

ACKNOWLEDGEMENT

This publication was made possible through support provided by the Office of Agriculture, Research and Policy, Bureau of Food Security, U.S. Agency for International Development, under the terms of Award No. AID-ECG-A-00-07-0001 to The University of Georgia as management entity for the U.S. Feed the Future Innovation Lab on Peanut Productivity and Mycotoxin Control. The opinions expressed herein are those of the author(s) and do not necessarily reflect the views of the U.S. Agency for International Development. The authors are also very grateful to, Eduardo Mondlane University and the Institute of Agriculture Investigation of Mozambique for providing the resources and time in support of the study.

REFERENCES

AICC, (African Institute of Corporate Citizenship). (2014). Harmonized Groundnut Production Manual for Malawi. Lilongwe: Business Support Technology.

Al-Shikli, R.A., Abdulrasool, A.A. and Al-Hiti, M.M. (2010). "Effect of some storage condition upon the survival of some fungal spores." *Iraqi Journal of Pharmaceutical Sciences* 19 (2): 1-10.

Almeida, Z. and Nicolas, R. (2013). Mitigation of aflatoxin in maize and groundnuts in Mozambique. Mozambique: USAID.

Arias, F.J. and Libombo, M.L. (1994). Groundnut Evaluation in Mozambique : Preliminary Results from the 1993/94 Season in Maputo Province. In: Ndunguru, B.J. *et al*., (Eds.). Sustainable Groundnut Production in South and Eastern Africa. Swaziland, Mbabane: International Crops Research Institute for the Semi-Arid Tropics.

Augusto, A. (2004). Development of a Screening Method For determining Aflatoxins. PhD Thesis, Athen, Georgia: University of Georgia.

Cole, R.J., Hill, R.A., Blankenship, P.D., Sanders, T.H. and Garren, K.H. (1982). "Influence of irrigation and drought stress on invasion by Aspergillus flavus of corn kernels and peanut pods." *Developments in Industrial Microbiology* 23: 229-236.

Cotty, P.J. and Jaime-Gracia, R. (2007). "Influence of climate on aflatoxin producing fungi and aflatoxin contamination." *International Journal of Food microbiology* 119: 109-115.

Cotty, P.J. and Lee, L.S. (1991). "Position and aflatoxin levels of toxin positive bolls on cotton plants. Proceedings of the Beltwide Cotton Production and." National Cotton Council of America. Las Vegas, Nevada. pp. 34-36.

Dickens, J.W. (1974). "Selective harvesting may help segregation-3 peanuts." *South-Eastern Peanut Farmer* 12 (3): 100-105.

Dowd, P.F. (2003). "Insect Management to Facilitate Preharvest Mycotoxin Management." *Journal of Toxicology* (Toxin Reviews) 22 (2 & 3): 327-350.

FAO-STAT. (2015). "Country Profile: Mozambique. Groundnut production Trends."

Fernandez, E.M., Rosolem, C.M., Maringoni, A.C. and Oliveira, D.M.T. (1997). "Fungus incidence on peanut grains as affected by drying method and Ca nutrition." *Field Crops Research* 52: 9-15.

Guo, B.Z., Sobolev, V., Holbrook, C.C. and Lynch, R.E. (2003). "Impact of phytoalexins and lesser cornstalk borer damage on resistance to aflatoxin contamination." *Phytopathology* 93: S31.

Hell, K., Cardwell, K.F. and Poehling, H.M. (2003). "Relationship between management practices, fungal infection and aflatoxin for stored groundnuts in Benin". *J. Phytopatol*. 151: 690-698.

Hell, K., Fandohan, P., Bandyopadhyay, R., Kiewnick, S., Sikora, R. and Cotty, P.J. (2008). "Pre-and Postharvest Management of Aflatoxin in Maize: An African Perspective. "Mycotoxins: *Detection methods, management, public health and agricultural trade*. pp. 219-229.

Hell, K. and Mutegi, C. (2011)."Aflatoxin control and prevention strategies in key crops of sub-Saharan Africa." *African Journal of Microbiology Research* 5 (5): 459-466.

Horn, B.W. (2005). "Colonization of wounded peanut seeds by soil fungi: selectivity for species from *Aspergillus* section Flavi." *Mycologia* 97 (1): 202-217.

Jeffrey E.E. (2011). Groundnut Grower's Guide for Mozambique:Production, Harvesting and Post-harvest Handling. Mozambique: CNFA.

Kaaya, A.N., Kyamuhangire, W., and Kyamanywa, S. (2007). "Factors Affecting Aflatoxin Contamination of Harvested Maize in the Three Agroecological Zones of Uganda." *Journal of Applied Sciences* 6: 2401-2407.

Kaaya, A.N., Warren, H.L., Kyamanywa, S. and Kyamuhangire, W. (2005). "The effect of delayed harvest on moisture content, insect damage, moulds and aflatoxin contamination of maize in Mayuge district of Uganda." *J Sci Food Agric* 85: 2595-2599.

Kaaya, N.A. and Warren, H.L. (2005). "A review of past and present research on aflatoxin in Uganda." *African Journal of Food Agriculture and Nutritional Development* 5: 1-17.

Kaba, J.S., Ofori, K. and Kumaga, F.K. (2014). "Inter-Relationships of Yield and Components of Yield at Different Stages of Maturity in Three Groundnuts (Arachis hypogaea L) Varieties." *International Journal of Life Sciences Research* 2: 43-48.

Kamika, I. and Takoy, L.L. (2011). "Natural occurrence of aflatoxin B1 in peanut collected from kinshasa, democratic republic of Congo." *Food Contam* 22: 1760-1764.

Kimatu, J.N., McConchie, R., Xie, X. and Nguluu, S.N. (2012). "The Significant Role of Post-Harvest Management in Farm Management, Aflatoxin Mitigation and Food Security in Sub-Saharan Africa." *Greener Journal of Agricultural Sciences* 2 (6): 279-288.

Kombiok, J.M., Buah1, S. S. J., Dzomeku, I. K and Abdulai, H. (2012). "Sources of Pod Yield Losses in Groundnut in the Northern Savanna Zone of Ghana." *West African Journal of Applied Ecology* 20 (2): 53-63.

Kusumaningrum, H. D., Suliantari, Toha, A. D., Putra, S. H., and Utami, A. S. (2010). "Contamination of Aspergillus flavus and aflatoxin at distribution chain of maize based food product and its influencing factors." *Jurnal Teknologi dan Industri Pangan* 21(2): 171-176.

Lamboni, Y., and Hell, K. (2009). "Propagation of mycotoxigenic fungi in maize stores by post-harvest insects." *Int. J. Food Microbiol* 29: 31-39.

Menza, N.C., Muturi, W. M. and Kamau M. L. (2015). "Incidence, Types and Levels of Aflatoxin in Different Peanuts Varieties Produced in Busia and Kisii Central Districts, Kenya". *Open Journal of Medical Microbiology* 5: 209-221.

Mphande, F.A., Siame, B.A., and Taylor, J.E. (2004). "Fungi, Aflatoxins and cyclopiazonic acid associated with peanut retailing in Botswana." *J. Food Prot* 67: 96-102 .

Muitia, A. (2005). Combination of Root-Knot Nematodes (Meloidogyne spp.) Resistance and Edible Seed Quality for Peanut (*Arachis hypogaea* L.) Production in Mozambique and in the U.S. Lubbock, Texas. MSc Theses. Plant and Soil Science, Texas Tech University.

Muitia, A. (2013). Farmer perceptions and genetic studies of rosette disease in groundnut (*Arachis hypogaea* L.) in northern Mozambique. PhD Thesis, KwaZulu-Natal: African Centre for Crop Improvement.

Nautiyal, P.C. (2002). Groundnut post harvest operations, Post harvest compendium. Rome: Food and Agriculture Organization of the United Nations.

Okello K.D., Archileo, N.K., Jenipher, B., Moreen, W. and Herbert, K.O. (2010). Management of Aflatoxins in Groundnuts; A manual for Farmers, Processors, Traders and Consumers in Uganda. Entebbe: National Agricultural Research Organisation.

Okello, K.D., Biruma, M. and Deom, C.M. (2010). "Overview of groundnuts research in Uganda: Past, present and future." *African Journal of Biotechnology* 9: 6448-6459.

Pande, S., and Rao, N.J. (2001). "Resistance of wild Arachis species to late leaf spot and rust in greenhouse trials." *Plant Disease* 85: 851-885.

Rahmianna, A.A., Taufiq, A. and Yusnawan, E. (2007). "Effect of harvest timing and postharvest storage conditions on aflatoxin contamination in groundnuts harvested from the Wonogiri regency in Indonesia." *SAT eJournal* 5: 1-3.

Rachaputi, N., Wright, G.C. and Krosch, S. (2002). "Management practices to minimise pre-harvest aflatoxin contamination in Australian peanuts."*Australian Journal of Experimental Agriculture* 42: 595-605.

Singh,V., Hedayetullah, Md. Zaman,P., Meher, J. 2014. Postharvest Technology of Fruits and Vegetables: An Overview. Journal of Postharvest Technology, 2(2): 124-135.

Sugri, I., Osiru, M., Larbi, A., Buah, S.S.J., Nutsugah, S.K., Asieku, Y. and Lamini, S. (2015). "Aflatoxin management in Northern Ghana: Current prevalence and priority strategies in maize (Zea mays L)." *J. Stored Prod. Postharvest Res.* 6 (6): 48-55.

Turner, P., Sylla, A., Gong, Y., Diallo, M., Sutcliffe, A., Hall, A. and Wild, C. (2005). "Reduction of exposure to carcinogenic aflatoxins by postharvest intervention measures in West Africa: a community-based study." *Lancet* 365: 1950-1959.

Upadhyaya. H. D., MallikarjunaSwamy .B.P. and Kenchana Gouda R.P.V. (2006). "Characterization of Asian core-collection of groundnut for morphological traits." *Indian Journal. Crop Science*: 129-134.

Vishwanath, V., Sulyok, M., Labuda, R., Bicker, W. and Krska, R. (2009). "Simultaneous determination of 186 fungal and bacterial metabolites in indoor matrices by liquid chromatography/tandem mass spectrometry". *Analytical and Bioanalytical Chemistry* 395:1355-1372.

Waliyar, F., Osiru, M., Ntare, B.R., Vijay Krishna Kumar, K., Sudini, H., Traore, A. and Diarra, B. (2015). "Post-harvest management of aflatoxin contamination in groundnut." *World Mycotoxin Journal* 8 (2): 245-252.

Walker, T., Pitoro, R., Tomo, A., Sitoe, I., Salencia, C., Mahanzule, R., Donovan, C. and Mazuze, F. (2006). Priority Setting for Public-Sector Agricultural Research in Mozambique with the National Agricultural Survey Data. Maputo, Mozambique: IIAM.

Widstrom, N.W., Butron, A., Guo, B.Z., Wilson, D.M., Snook, M.E., Cleveland, T.E. and Lynch, R.E. (2003). "Control of pre-harvest aflatoxin contamination in maize by pyramiding QTL involved in resistance to ear-feeding insects and invasion by Aspergillus spp."*European journal of Agronomy* 19 (4): 563-572.

Wright, G., Rachaputi, N., Chauhan, Y. and Robson, A. (2005). "Increasing productivity and quality of peanuts using novel crop modeling and remote sensing technologies." International Peanut Conference. Bangkok, Thailand: Kasetsart University. pp. 9-12.