Chapter 2

Effect of Harvesting Time and Drying Methods on Aflatoxin Contamination in Groundnut in Mozambique

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Additional information is available at the end of the chapter

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Abstract

The production and utilization of groundnut have increased tremendously across all provinces of Mozambique. However, the presence of aflatoxins has remained a critical food concern in the human diet. In this study, the effect of harvesting time and drying methods on aflatoxin contamination was examined in Northern Mozambique. A randomized complete block design in a split-split plot arrangement with four replications was used with groundnut varieties as the main plot and harvesting dates and drying methods as the subplots. Groundnut samples were analyzed for aflatoxin using the Mreader. In both locations, field observations indicated that on average, aflatoxin contamination levels were lower at physiological maturity (≤10 ppb) compared to harvesting 10 days before (≤15 ppb) and 10 days after physiological maturity (≥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. 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 postharvest management of groundnuts, such as harvesting at physiological maturity and improved drying, gave lowest aflatoxin contamination levels.

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

1. Introduction

Groundnut (*Arachis hypogaea* L.) is the third most important crop in Mozambique after maize (*Zea mays*) and cassava (*Manihot esculenta*) [1, 2]. It is a major cash crop and the main source of

cooking oil for many Mozambican families [1, 3]. In terms of production, groundnut occupies the largest area among the grain legumes in the country [1, 4] 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 [5]. 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 [6]. Poor management practices by farmers and adverse climatic conditions at harvest and postharvest are some of the prompting factors for postharvest aflatoxin contamination. The timing of harvesting greatly influences mold production at harvest [7]. In [8], it is highlighted that farmers tend to delay in harvesting their crops which results in over maturity leading to mold 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 [9]. Moreover, these are slow, time-consuming, and labor-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 [10, 11].

Ideally, pods should be dried with sufficient air circulation and in the shade [10]. 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 [12]. 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 labor constraints needed for plucking [9]. 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 [13]. 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 postharvest and storage management and subsequent food spoilage and aflatoxin contamination. This is evident by the 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 [13, 14].

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

2. Materials and methods

2.1. 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 [1]. 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 [1].

2.2. 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 subplots. The net plots were six 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 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 mreader.

2.3. Weather data

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

2.4. 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.

2.5. Aflatoxin analysis

2.5.1. Validation of the MReader

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 min. After 6 min, the strip was placed in the mreader strip holder, and the 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 min. Later, a 100 µl of the mixture was added to 500 µl of the 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 min, and aflatoxin reading was done using the mreader.

2.5.2. 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 were obtained. Then, a subsample of 10 g was obtained from each of the composite samples. The subsample 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 min. The test strip was later placed in the mreader holder, and the aflatoxin contamination levels of the sample were determined using the mreader based on the chromatographic characteristics of the sample in the strip. The data were statistically analyzed using GenStat Discovery 4. An independent Tukey's test was used to compare the means of

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the aflatoxin results. The tests for relationships were carried out using the Pearson Correlation Index, and the interpretation was performed at two-sided 95% confidence limit.

3. Results

3.1. Weather data at CIAM and PAN during 2015–2016 growing season

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 was also some postharvest rainfall during the drying period, with 37.2 mm falling between H2 and H3. The average relative humidity was between 80 and 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).

Month	December	January	February	March	April
Average max temperature (°C)	34.1	30.5	31.4	31.9	30.8
Average min 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

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

Month	December	January	February	March	April
Average max temperature (°C)	35.3	34.8	36.3	35.2	32
Average min temperature (°C)	33.2	29.6	32.1	32.3	29.7
Cumulative rainfall (mm)	232.9	469.6	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

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

However, significant higher rainfall fell during H1, while 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 to 85%.

3.2. 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 38–7%, 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 38–7%, 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, while 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.

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

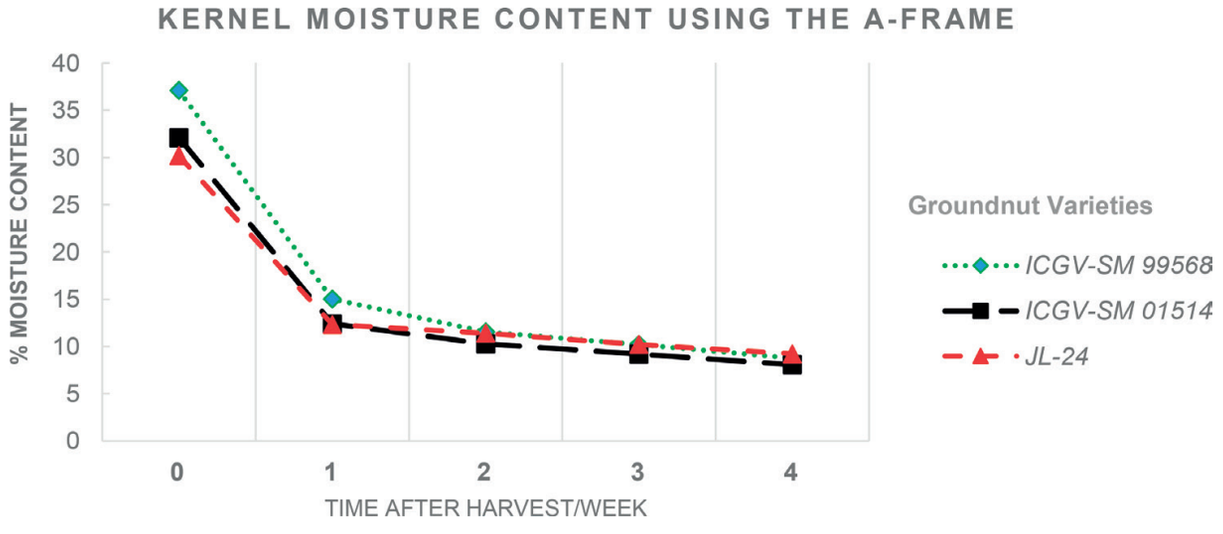

Figure 1. Kernel moisture loss when using the A-Frame.

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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.

3.3. 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

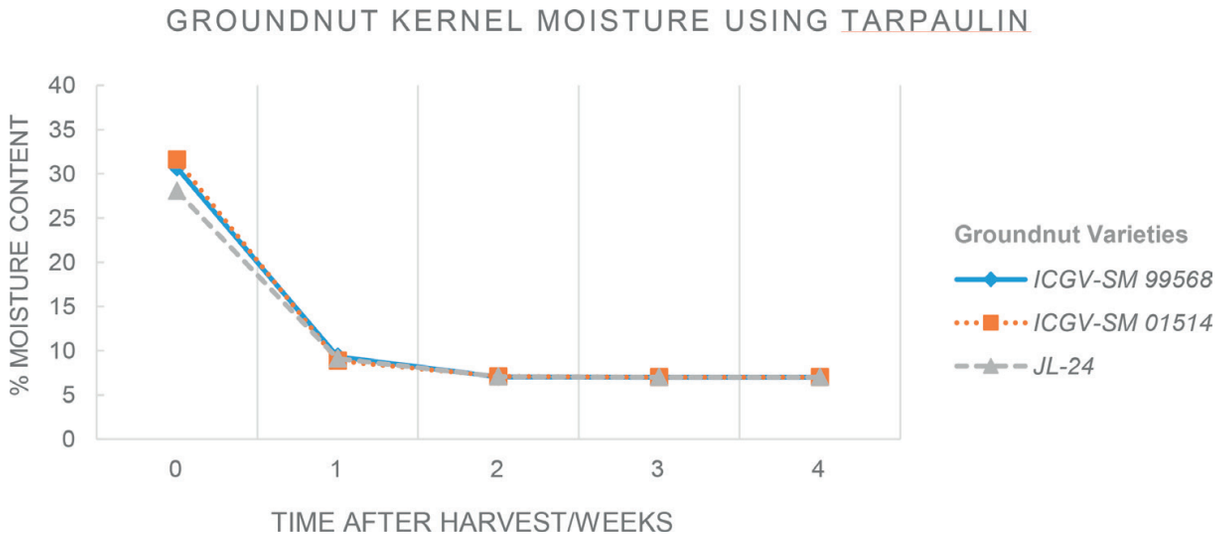

Figure 2. Kernel moisture loss when using tarpaulins.

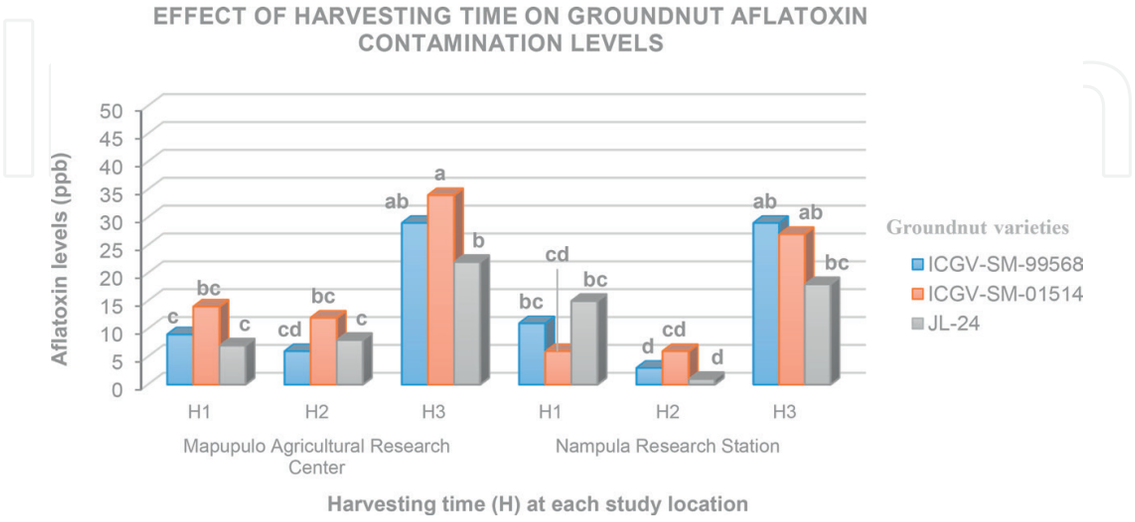

Figure 3. Aflatoxin levels in groundnuts as affected by harvesting time.

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.

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.

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3.4. 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 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, and 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

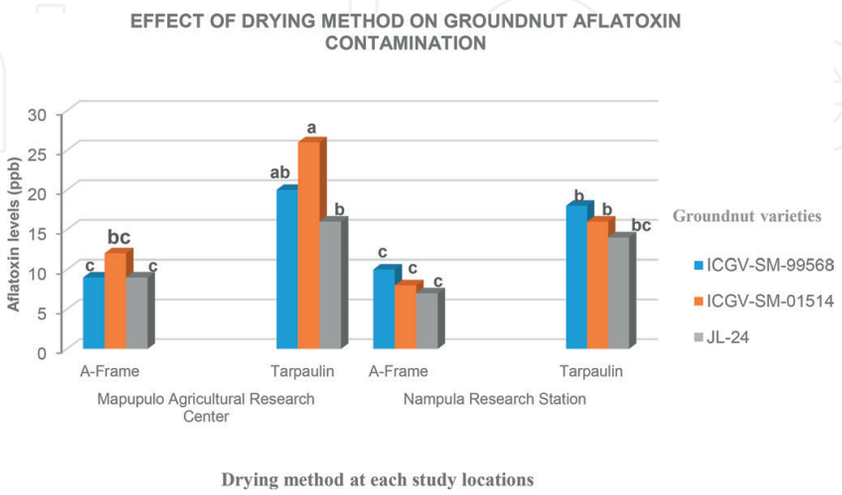

Figure 4. Effect of drying method on groundnut aflatoxin contamination.

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at the two study locations (**Tables 3** and **4**). 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 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.

Drying method	Variety	Harvest timing		
		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 within a column followed by the same letter are not significantly different based on Tukey's test (**P < 0.01**).

Table 3. Groundnut aflatoxin levels as affected by the interaction of harvesting time and drying method at CIAM.

Drying method	Variety	Harvest timing		
		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^{bc}	1^{c}	12^{b}
Tarpaulin	ICGV-SM-99568	18^{b}	4^{c}	32^{a}
	ICGV-SM-01514	8^{bc}	8^{bc}	33^{a}
	JL-24	19^{b}	2^{c}	22^{ab}
Mean ± SE A-Frame 9 ± 4.03		Tarpaulin 16.5 ± 5.6		

Means within a column followed by the same letter are not significantly different based on Tukey's test (**P < 0.01**).

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

4. Discussion

A number of studies have shown that weather directly influences host susceptibility to aflatoxin contamination [15]. 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, and 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 to 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 [16]. In addition, studies have shown that the optimal temperature range for production of aflatoxin is approximately 25–30°C agreeing with the current study [17].

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. This was consistent with the findings of Hell and Mutegi [18] 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.

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 the 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. [1] who reported that harvesting groundnuts too early or when the pods are immature result in high aflatoxin levels in the kernels. The findings were also consistent with the findings by Hell et al. [19] 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 coincided with some postharvest 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 Mphande et al. [20] who reported that postharvest contamination with aflatoxin in groundnut increased when harvesting was executed 5 days

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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 [21]. 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 the ready entry of fungi including *Aspergillus* species and consequently aflatoxin contamination. Kombiok et al. [22] 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 the ready entry of the fungus, and thereby increasing the chances of aflatoxin contamination. Furthermore, 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 [23].

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 et al. [18] 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, the 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 [24].

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 [15] 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.

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 [25]. This agrees with the current study and furthermore, the drying method greatly influences the resistance of groundnuts to fungal attack. It has been established from the results of this study that both the A-Frame and tarpaulin drying methods were effective in reducing the moisture content of groundnut to the recommended level of ≤7%, and thereby reduced the chances of heavy aflatoxin contamination on the kernels. However, the tarpaulin drying method was more rapid in reducing kernel

moisture levels compared to the 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 were 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 the 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 that if drying is too rapid, there are alterations in the seed coat that favor fungal infection [26].

High aflatoxin contamination levels with the tarpaulin drying method could also be as a result of weather conditions. Postharvest 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. This was not the case with the A-frame since the pods were covered with leaves and thereby preventing water from reaching the pods and ensuring exposure to air circulation all the time. One of the disadvantages of drying groundnuts on tarpaulins is the time and effort required to gather the pods together and cover them during rain showers and respreading the pods as soon as possible in order to continue drying; this is difficult and the adverse moist conditions as a result of 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.

5. Conclusions and recommendations

The results of the assessment of different harvesting times and different drying methods are rather obvious (and confirm previous studies), namely (a) harvesting 10 days after physiological maturity (H3) results into the highest levels of aflatoxin, (b) harvesting groundnuts too early or when the pods are immature results in high aflatoxin levels in the kernels, (c) physical damage of pods as a result of digging using hoes (there is not much of an alternative when harvesting during dry weather), (d) insects influence the levels of aflatoxin contamination, and (e) A-frame and the tarpaulin drying are more effective in reducing aflatoxin contamination of groundnuts. However, the implementation of those good postharvest handling practices (drying and harvesting time) requires a close monitoring at the farmer level.

It may be interesting to research the constraints by adopting such practices (when farmers are knowledgeable about the problem). Besides, it is difficult to avoid in the studied areas of Mozambique the ideal situation of an optimal temperature range for production of aflatoxin (between 25 and 30°C). Wet and more humid conditions quite evidently aggravate aflatoxin levels. Scenarios may be useful to better understand the necessary trade-offs to be made by the farmer to optimize harvesting times and drying method depending on the local context (availability of tarpaulin, A-frames, or Mandela Cork dying methods) and weather forecasts. An assessment of the conditions under which [waiting for] physiological maturity is difficult to respect would have been useful and the reasons why damage to the pods cannot be avoided.

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Conflict of interest

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.

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