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Effects of postharvest handling practices on quality of groundnuts and aflatoxin contamination

Dambolachepa, H.B.[1*]; Muthomi, J.W.[1]; Mutitu, E.W.[1]; Njoroge, S.M.[2]

[1]Department of Plant Science and Crop Protection, University of Nairobi, P.O Box 29053-00265, Nairobi, Kenya; [2]ICRISAT-Lilongwe, Chitedze Agricultural Research Station P.O Box 1096 Lilongwe, Malawi

[*]Corresponding author E-mail: dambolachepah@yahoo.com

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Abstract

The increased cases of aflatoxin contamination are exacerbated by poor post-harvest management practices, coupled with adverse climatic conditions at harvest and post-harvest stages. This study therefore was carried out to improve safety and quality of groundnuts from aflatoxin contamination, through use of proper postharvest handling practices. Specifically the study determined the effects of harvesting dates and drying methods on aflatoxin contamination. Field experiments were carried out both at Chitedze and Chitala Agricultural Research Stations in Malawi during 2017/2018 growing season. A randomized complete block design in a split plot arrangement with three harvesting dates as the main plot and four drying methods as the sub-plots replicated three times was used. Groundnut was assessed for kernel infection by *Aspergillus flavus*, and level of aflatoxin contamination. Significantly low levels of about 0.5µg/ Kg of *A. flavus* infection and aflatoxin contamination were observed at 90 days after sowing (DAS). Higher aflatoxin contamination of up to 5µg/ Kg was observed at 80 DAS, and 10 days late after physiological maturity (100 DAS). This study also identified Mandela cock, a-frame drying rack as effective drying method that can reduce aflatoxin contamination in groundnuts by 75 %. Moreover, Mandela cock drying method was shown as the most effective compared to A-frame and drying rack drying method. Current study therefore recommends for adoption of timely harvesting at physiological maturity, and drying using either Mandela cock or A-frame and drying rack. Further studies need to be carried on biological control of aflatoxin contamination.

Keywords: Groundnut, *Aspergillus* spp., Aflatoxin, Harvesting dates, Drying methods

1. Introduction

In recent years continued increase in mycotoxins especially aflatoxin contamination limited the importance of groundnuts. Aflatoxin contamination compromised the potential use of groundnut both in human and livestock diets (Rahmianna *et al*., 2007). The increased cases of aflatoxin contamination are

exacerbated by poor post-harvest management practices by many farmers, coupled with adverse climatic conditions at harvest and post-harvest stages. As reported by Liang, (2006), the problem of aflatoxin contamination can be mitigated through adoption of good post-harvest handling operations such as; proper harvesting, drying, curing, transportation, storage, and marketing. Studies of Wright *et al*., (2005) showed that delayed harvesting of groundnut usually exposed it to moldy infection and aflatoxins as well. Therefore, the aim of this study was to determine the effects of harvesting dates and drying methods on aflatoxin contamination of groundnuts in Malawi.

2. Material and methods

2.1. Experimental design and layout

One susceptible cultivar of groundnut to *Aspergillus* species invasion, JL 24 (Kakoma) was grown, to evaluate effects of harvesting time and drying techniques on; kernel quality, pod yield, moisture content, and aflatoxin contamination according to Waliyar, (2016). Treatment combinations comprised of three harvesting dates (80, 90, and 110 DAS), and four drying techniques; Conventional, Mandela cork, A-frame, and Sun dry on rack.

In the first treatment; groundnuts was harvested at10 days before its maturity (80 DAS), the second treatment was harvested at its maturity date (90 DAS), whereas, the last one was harvested at 10 days later (110 DAS). The four drying techniques evaluated were; conventional drying method, A-frame, Mandela cork, and Sun drying on the rack.

In conventional treatment, groundnuts were lifted and scattered on the ground with pods and haulms facing either way as described by Jnr, (2018). In the second treatment, an A-frame drying method was used in which a tripod type structure (pyramid shaped) was raised with a help of three bamboo poles about 1.5 m length, then the plants were hang pods up. Haulms in the coir rope were arranged around the structure from top to bottom, while maintaining 70 cm between the two loops (AICC. 2014). The third treatment was Mandela cork drying that followed a similar method used by Limbikani *et al*., (2018), in which the plants were raised to one meter high, while arranged in 0.5 radius and the pods outwards. The last treatment was sun drying on the rack; whereby the platform was raised one meter above, covered with mesh, and the groundnuts will be spread on the platform in reference to Jnr, (2018).

The assay used split plot block design with three replications. Thus; the field was demarcated into three blocks wherein every block was then divided into three harvesting date treatment plots, measuring 10 m × 8 m in size. Harvesting date plots were further subdivided into 4 m × 3 m sub-plots of four drying method treatments, to determine interactions between harvesting dates and drying techniques in regard to aflatoxin contamination. In all treatments, groundnuts were dried for a period of two weeks after harvesting.

2.2. Collection of data

Data collected include; weather variables, agronomical parameters (pod yield and shelled yield), moisture content both at harvest and after drying, moldy and shriveled kernels, groundnuts infection by *Aspergillus* sp., as well as aflatoxin contamination.

2.2.1. Determination of weather parameters for 2017/2018 growing season

Weather for 2017/ 2018 growing season which was recorded on daily basis was collected from Chitedze and Chitala meteorological stations, both were in Malawi. Minimum and maximum temperatures and precipitation records were recorded during the study.

2.2.2. Assessment of pod and shelled yield

Groundnut was harvested at different dates; before it reached physiological maturity, at its physiological maturity, and after its physiological maturity, while hand hoes were used to lift the pods from the soil. The lifted groundnut plants were dried using four drying methods namely; mandela cork, conventional, A-

frame, and on the rack. Pod yield was then determined by weighing the pods on an electric scale in Kg/ plot. Harvested groundnut pods were shelled using hand shelling method weighed on an electric scale sensible to 0.1 g. The yield for each plot was later converted in kilogram per hectare (Kg/ ha). The seed size (weight of 1000 seeds) was also recorded in grams per plot (g/ plot).

2.2.3. Determination of kernel moisture content

Moisture content after drying was determined using DMC 500 moisture meter (Seed-buro Equipment Company, USA), whereby 1000 seeds from each replicate sample were poured into this moisture tester. The moisture content readings were then recorded.

2.2.4. Determination of kernel quality and infection with *A. flavus*

To determine moldy and shriveled kernels, 1000 seeds from each replicate were used. The 1000 seeds were physically sub divided into 4 portions, formed of about 250 seeds sub samples from each portion. From these 250 seeds, number of moldy and shriveled kernels were counted and expressed in percentage using the equation of Maina *et al*., (2016) with slight modifications as follows:

$$\%\ \textbf{moldy kernels/shrivelledkernels} = (\text{No. moldy/shrivelled kernels}) / (\text{Total number of kernels}) \times 100$$

Harvested groundnuts pods were thoroughly dried for two weeks. Natural seed infections by *Aspergillus* sp. were ascertained by shelling the pods and selecting 100 seeds from each treatment.

The procedure for this analysis used sand witch boxes, which were first sterilized with 99.9% ethanol and allowed to evaporate. 100 seeds from each sample replicated 3 times were surface sterilised by immersing in sodium hypochlorite 2.5 % for 3 min. Seeds were then rinsed in dist. water in three consecutive petri dishes, and thereafter aseptically transferred into sand witch boxes lined inside with moistened 3 double layered absorbent paper towel. These boxes were then covered with lids and incubated for 24 h. To suppress seed germination, the boxes were then placed in deep freezer (-20°C) for 6 h. Later the boxes were incubated at room temperature (25±1°C) for 7 days as described by (Waliyar, 2016). Percentage of seeds infection was assessed using equation of Angeline *et al*., (2016); with slight modifications, while the incidence of each fungal species was calculated as follows:

$$\textbf{Infected kernel}\ \% = \frac{\text{No. of kernels infected by anticipated spp}}{\text{Total number of kernels in each plate}} \times 100$$

Fungal identification was carried based on cultural characteristics such as surface of the colonies, texture, and microscopical characteristics like; conidia head, shape and vesicle in reference to Cotty *et al*., (1994). Fungal growth on the kernels was visualized using stereo-binocular microscope, and identified to genus level as described by Waliyar and Bockelee-Morvan, (1989).

2.2.5. Determination of population of *Aspergillus* spp. in groundnut kernels

Agar plate serial dilution method (ISTA. 1966) was used for isolation of *Aspergillus* spp., whereby groundnuts samples were ground into powder using a blender. Coconut agar was used as a growing medium. Coconut agar medium was prepared by shredding 100 g of coconut pulp homogenized for 5 min. in 200 ml of hot dist. water. The homogenized mixture was then filtered through four layer of cheese cloth, pH adjusted to 7. Agar-gar powder (20 g) was added to the mixture and then autoclaved (Dyer *et al*., 1994). 10 g. of the groundnut powder was suspended in 90 ml of dist. water and shaked for 30 min. using a mechanical shaker. 1ml of this suspension was transferred into 9 ml of dist. water, vortexed and diluted in subsequent 9 ml up to 10-5 dilution. Dilutions of 10-2, 10-3 and 10-4 were plated into selective molten Coconut agar medium, gently swifted; mixed and then incubated at 37°C for 3 days as described by Dyer *et al*., (1994). Each sample was prepared in 3 replicates. Blight-green colonies were counted typical of *Aspergillus* sp. using

stereo dissecting microscope (Jenco, ZM-F502, USA) at 2x-10x magnification (Sibakwe *et al*., 2017).

Colony forming units (CFU) was imputed using the formula of Stefan *et al*., (2003):

$$CFU/g = A*10^{n} /V$$

Where A = Number of colonies

10^{n} = Level of dilution at which counting was carried out

V = Volume of inoculation

2.2.6. Quantification of aflatoxin content in groundnut kernels

One kilogram of groundnut pods from each treatment were shelled, ground into flour and used for aflatoxin estimation in the laboratory on Reveal® Q+ for Aflatoxin using Accuscan Gold Reader according to Odindo *et al*., (2017); Sibakwe *et al*., (2017). In each analysis; unsorted shelled kernels of groundnuts were picked randomly and ground into flour using a Warring commercial blender. 20 g of flour was obtained from each treatment sample; then the flour was sieved using 0.5 mm sieve, and mixed with 50 ml of 65% ethanol in a test tube. This mixture was then transferred into conical flask (250 ml) and shaken at 300 rpm for 5 min. using Gallenkamp orbital shaker. The mixture was filtered through Whatman No. 1 filter paper, and then transferred into a conical flask. 100 µl of this sample filtrate was pipetted into red sample cap; added to 500 µl of diluent, and then mixed by pipetting up and down for five times. Thereafter, 100 µl was pipetted from red cup into transparent sample cap. Neogen test strip was inserted into the transparent sample cap and then left for 6 min. The test strip were finally removed and then placed in strip holder for Aflatoxin readings. The strip holder with test strip was then inserted into Accuscan Gold Reader to obtain the results (Neogen Reveal Q+ for Aflatoxin using Accuscan Gold Reader manual). Levels of Aflatoxin in µg/ Kg were quantified and recorded for each treatment.

2.3. Statistical analysis

Data was subjected to analysis of variance (ANOVA) in GenStat statistical package version 18 package. The analysis used Residual Maximum Likelihood (REML), through which significant variability among the treatments were assessed from standard error of estimation of variance. Means were separated by Fischer's Protected Least Significance Difference (LSD) at the 5 % level of probability (Waliyar *et al*., 2015).

3. Results

3.1. Emergence, stand count and number of days to maturity of groundnut crop among the treatments

Crop phenological parameters that were recorded include; emergence percentage, days to 50 % flowering, and days to physiological maturity of the groundnut crop in all treatments. There were significant differences ($p< 0.05$) in terms of emergence percentage at different harvesting dates for Chitedze trials. Those groundnuts which were to be harvested at 80 days of planting had highest percentage of emergence (84 %), whereas those which were to be harvested at 100 days had the lowest emergence percentage below 70 %.

However, no differences were observed in terms of emergence percentage of different drying methods in both sites. Groundnuts grown at Chitedze showed significant difference ($p\leq 0.01$) in terms of stand count percentage at different harvesting dates. Higher plant stand count was observed at 80 days of harvesting, while lowest mean stand count was observed at 100 days of harvesting (Table 1). No differences in interaction in terms of stand count at different harvesting dates were observed at Chitala.

3.2. Pod yield, shelled yield (Kg/ha) and 1000 seed weight of groundnuts

There was significant difference ($p<.001$) in terms of pod yield after exposing groundnuts to different drying methods at both sites. Higher yields were

recorded for groundnuts which were dried using Mandela cock method of about 12604 Kg/ ha at Chitedze, and 1382 Kg/ha at Chitala. The conventional method recorded lowest yields of about 633Kg/ha at Chitala.

Table 1: Emergence, stand count (%) and number of days to maturity of groundnut crop among all treatments

	Chitedze				Chitala			
	Emergence count (%)							
Drying method	80	90	100	Mean	80	90	100	Mean
A-frame	83.5	75.3	71.5	76.8[a]	85.8	90.0	73.1	82.9[a]
Conventional	90.8	81.3	74.7	82.3[a]	77.1	76.8	82.5	78.8[a]
Drying rack	81.8	67.3	63.8	75.1[a]	84.0	74.2	77.3	78.3[a]
Mandela cock	79.3	74.2	76.2	72.5[a]	88.0	86.8	74.6	83.2[a]
Mean	83.9[b]	74.6[a]	71.5[a]		83.6[a]	82.1[a]	76.8[a]	
CV%	12.6				9.8			
$LSD_{0.05}$	D=9.4	H= 8.1	D*H 16.3		D=7.8	H=12.3	D*H=15.1	
F pr.	D= 0.200	H=0.013	D*H= 0.734		D=0.447	H=0.375	D*H=0.145	
	Stand count							
A-frame	83.1	75.1	66.0	74.7[a]	77.3	80.5	73.1	76.9[a]
Conventional	76.8	74.5	78.4	75.3[a]	70.5	77.1	76.8	74.8[a]
Drying rack	80.5	67.4	66.8	71.5[a]	71.5	74.6	77.8	74.7[a]
Mandela cock	78.6	72.5	63.1	71.4[a]	82.0	87.1	75.1	82.4[a]
Mean	79.8[b]	72.3[a]	76.6[a]		75.3[a]	79.8[a]	75.7[a]	
CV%	12.0				12.5			
$LSD_{0.05}$	D=8.6	H=8.8	D*H=8.0		D=9.5	H=12.8	H*D=17.2	
F pr.	D= 0.690	H=0.009	D*H=0.735		D=0.447	H=0.375	H*D=0.145	
	Days to maturity							
A-frame	86.3	91.7	89.7	89.2[a]	84.3	91.7	89.7	89.2[a]
Conventional	89.0	88.7	88.7	88.8[a]	89.0	88.7	88.7	88.8[a]
Drying rack	90.0	92.5	89.6	90.7[a]	90.0	92.3	89.7	90.7[a]
Mandela cock	87.0	89.7	88.3	88.3[a]	87.0	89.7	88.3	88.5[a]
Mean	88.1[a]	90.6[a]	89.1[a]		88.1[a]	90.6[a]	89.1[a]	
CV%	3.4				2.4			
$LSD_{0.05}$	D=2.9	H=2.6	D*H=5.2		D=2.1	H=6.3	H*D=6.3	
F pr.	D=0.418	H=0.155	D*H=0.788		D=0.158	H=0.580	H*D=0.436	

-Means were separated by Fischer's Protected Least Significance Difference (LSD) at p=≤0.05. Means followed by same letter(s) within columns and rows are not significantly different, CV % is the Coefficient of Variation, and Fpr. is F probability value (p< 0.05). Key: D= Mean value for Drying method, H= Mean value for Harvesting dates, H*D=Mean value for Harvesting date*drying method, DAS=Mean values for Days after sowing.

High significant difference (p< 001) was also observed for different harvesting dates at both sites of Chitedze and Chitala. Those groundnuts harvested at 90 DAS had higher yields than those harvested at 100 DAS in all the sites (Table 2). There was an interaction (p< 0.05) among the treatments at Chitedze and Chitala sites. High yields were observed when groundnut was harvested after 90 days, and dried using Mandela cock method. Groundnut shelled yields from Chitala did not differ among harvesting dates and drying methods treatments. However, significant difference (p< 0.05) was observed for shelled weight at Chitedze. Groundnuts dried using Mandela cock resulted into shelled yields of 950Kg/ ha, which was more than those dried using conventional method (300Kg/ ha). Significant difference (p< 001) was also observed for shelled yield at different harvesting dates in Chitedze. Groundnuts harvested after 90 days had higher shelled yield (1200Kg/ ha), than those harvested at 100 days after planting (300Kg/ha). There was significant difference (p< 0.05) in terms of 1000 seed weight for groundnuts dried using different methods at Chitala. Harvesting dates and drying methods for groundnuts at Chitedze did not record any difference in terms weight (Kg/ ha) for 1000 kernels.

Table 2: Pod yield, shelled yield, 1000 kernel weight (Kg/ ha) for groundnuts at Chitedze and Chitala during 2017/2018 growing season

	Chitedze				Chitala			
				Pod yield				
Drying method	80DAS	90DAS	100DAS	Mean	80DAS	90DAS	100DAS	Mean
A-frame	1258.3	1838.9	591.7	1229.6^{b}	1350.0	1838.9	408.3	1199.1^{b}
Conventional	330.6	1047.2	691.7	1147.2^{b}	347.2	958.3	594.4	1264^{b}
Drying rack	1041.7	1911.7	422.2	689.8a	1175.0	1911.7	311.1	633.3^{a}
Mandela cock	1172.2	1977.8	697.2	1260.4^{b}	1536.1	2308.3	191.7	1381.7^{b}
Mean	950.7^{a}	1693.9^{b}	600.7^{a}		1102.1^{b}	1754.3^{c}	502.8^{a}	
CV%			22.6				24.6	
LSD	D=239.4	H=207.3	D*H=414.6		D=273.1	H=150.1	H*D=421.6	
Significance	D=<.001	H=<.001	D*H=0.005		D=<.001	H=<.001	H*D=0.002	
				Shelled yield				
A-frame	977.8	1297.2	291.7	855.6^{b}	558.6	288.9	404.7	417.3^{a}
Conventional	163.9	592.5	281.1	345.8^{a}	464.7	336.1	360.0	386.9^{a}
Drying rack	611.9	1169.4	269.4	683.6^{ab}	499.4	333.9	326.4	386.6^{a}
Mandela cock	801.7	1708.7	318.1	942.7^{b}	520.6	408.9	318.1	415.9^{a}
Mean	638.8^{b}	1191.8^{c}	290.1^{a}		510.7^{a}	342.0^{a}	352.3^{a}	
CV%			20.4				22.1	
LSD	D348.2	H=301.6	D*H=603.1		D=242.5	H=127.8	H*D=271.2	
Significance	D=0.009	H=<.001	D*H=0.224		D=0.922	H=0.212	H*D=0.857	

1000 seed weight								
A-frame	263	241	272	259[a]	340	208	272	273[b]
Conventional	195	206	236	212[a]	217	89	139	149[a]
Drying rack	306	225	258	263[a]	233	153	258	216[ab]
Mandela cock	305	328	260	298[a]	338	246	260	281[b]
Mean	267[a]	257[a]	257[a]		283[a]	174[a]	232[a]	
CV%			23.7				18.8	
LSD	D=84.9	H=73.5	D*H=147.0		D=87.1	H=165.5	H*D=185.0	
Significance	D=0.252	H=0.88	D*H=0.846		D=0.017	H=0.295	H*D=0.939	

-Means were separated by Fischer's Protected Least Significance Difference (LSD) at p=≤0.05. Means followed by same letter(s) within columns and rows are not significantly different, CV % is the Coefficient of Variation and Fpr. is F probability value (p< 0.05). Key: D=Mean value for Drying method, H=Mean value for Harvesting dates, H*D=Mean value for Harvesting date*drying method, DAS=Mean values for Days after sowing.

3.3. Percentage of shriveled groundnut kernels and moisture content at harvest and after drying from Chitala and Chitedze

Moisture contents at harvest and after drying were the two assessed categories of moisture levels. The first level of moisture was assessed at harvest ranged from 19% -21 at Chitedze, while 19% -20% at Chitala. The second category of moisture was assessed after exposing the groundnuts to different drying methods. Different drying methods caused reduction of moisture levels to 6% -9% for Chitedze, and 5% - 9% at Chitala (Table 3) There was percentage of variation (p< 0.05) in terms of shriveled groundnut kernels at Chitedze recorded using different drying methods. Groundnut dried using conventional method had highest percentage of 43% of shriveled kernels, compared to drying on the rack (18%). In addition, significant difference (p< 0.05) of percentage of shriveled kernels was also observed using different drying methods at Chitala.

Groundnut harvested at different dates showed significant difference (p≤ 0.05) in terms of percentage of shriveled kernels at Chitedze and Chitala. In both sites groundnuts harvested at 90 days showed lowest percentage of shriveled kernels. There was no any significant difference observed at both sites in terms of groundnut moisture content at harvest, after exposing these kernels to different drying methods and different harvesting dates. Moisture contents of groundnuts after drying at Chitedze showed high significant difference (p< 001) on using different drying methods. Low mean level of moisture content (6 %) was observed in groundnut dried using Mandela cock, whereas higher level (11 %) was recorded after drying using conventional method. Similarly, moisture content of groundnuts exposed to different drying methods at Chitala differed significantly (p< 0.05). Mandela cock caused the lowest level of moisture (5 %), while drying rack presented high (9 %) moisture level. Different dates of harvesting groundnuts at Chitedze caused difference (p< 0.05) in moisture content. Lowest mean level (6%) of moisture content was observed on kernels harvested 100 days after sowing, whereas highest level (9 %) was observed at 80 days of harvest. However, no significant difference in moisture level was observed for groundnuts harvested at different dates at Chitala.

3.4. Percentage of moldy kernels and number of CFU by *Aspergillus* spp.

Identification of colony forming units (cfu) showed highly significant difference (p< 001) in terms of number of cfu produced by *A. flavus* from groundnuts exposed to different drying methods at Chitala. The least mean number of cfu (256) was observed in groundnuts which were dried on A-frame, while the

Table 3: Percentage of shriveled kernels, moisture content at harvest and after drying

	Chitedze				Chitala			
	Shriveled kernels							
Drying method	80DAS	90DAS	100DAS	Mean	80DAS	90DAS	100DAS	Mean
A-frame	35.3	8.3	24.1	22.6[a]	34.5	4.4	23.6	20.8[a]
Conventional	56.6	27.5	44.7	42.9[b]	55.6	27.5	47.8	43.6[b]
Drying rack	25.6	10.9	18.5	18.3[a]	23.8	10.9	16.6	17.1a
Mandela cork	32.4	4.9	21.2	19.5[a]	32.4	32.4	4.9	19.5[a]
Mean	37.5[c]	12.9[a]	27.1[b]		36.6[c]	12.0[a]	27.3b[c]	
CV%			27.3				23.1	
LSD	D=14.5	H=12.4	D*H=25.1		D=13.8	H=15.8	H*D=21.9	
F pr.	D=0.006	H=0.002	D*H=0.96		D=0.019	H=0.008	H*D=0.966	
	Moisture Content at harvest							
A-frame	20.7	21.8	18.7	20.2[a]	20.7	21.8	18.7	20.4[a]
Conventional	22.4	18.5	21.4	20.8[a]	20.0	18.7	21.4	20.3[a]
Drying rack	20.2	17.9	19.2	19.1[a]	20.2	17.9	19.2	19.1[a]
Mandela cork	16.6	20.6	19.9	20.1[a]	21.0	18.6	19.4	19.8[a]
Mean	20.6[a]	19.6[a]	19.8[a]		20.18[a]	19.7[a]	19.8[a]	
CV%			10.6				10.8	
LSD	D=2.1	H=1.8	D*H=3.6		D=2.1	H=1.4	H*D=3.3	
F pr.	D=0.4	H=0.5	D*H=0.2		D=0.548	H=0.699	H*D=0.232	
	Moisture Content after drying							
A-frame	9.2	7.8	5.9	7.7[a]	7.5	9.6	9.7	8.8[b]
Conventional	13.3	10.3	9.8	11.1[b]	9.3	5.7	8.9	9.2[b]
Drying rack	7.3	7.3	6.6	7.1[a]	9.4	9.5	8.6	7.9[b]
Mandela cork	7.6	5.7	4.9	6.1[a]	6.5	6.0	6.0	5.6[a]
Mean	9.3[b]	7.8[a]	6.8[a]		8.2[a]	7.3[a]	8.2[a]	
CV%			21.9				24.2	
LSD	D=1.7	H=1.5	D*H=2.9		D=1.9	H=1.6	H*D=3.0	
F pr.	D=<.001	H=0.008	D*H=0.786		D=0.004	H=0.316	H*D=0.216	

-Means were separated by Fischer's Protected Least Significance Difference (LSD) at p=≤0.05. Means followed by same letter(s) within columns and rows are not significantly different, CV % is the Coefficient of Variation and Fpr. is F probability value (p< 0.05). Key: D=Mean value for Drying method, H=Mean value for Harvesting dates, H*D=Mean value for Harvesting date*drying method, DAS=Mean values for Days after sowing.

highest number (3322) was observed on using the conventional method. Similarly, significant difference (p≤ 0.05) in terms of number of cfu was also observed from groundnut kernels grown at Chitedze. However, there was no significant difference (p= 0.090) and (p= 0.081) in terms of number cfu formed by *A. flavus* at different harvesting dates at Chitedze and Chitala, respectively. At both sides there was no significant difference (p> 0.05) for the groundnuts exposed to

different harvesting dates and drying methods in terms of cfu by *A. niger*. On the contrary, there was significant difference ($p< 0.05$) in number of cfu formed by *A. parasticus* from groundnuts kernels exposed to different drying methods at Chitedze and Chitala. Groundnuts dried on the rack at Chitedze had lower number of cfu (167), compared to those from conventional drying method (1178). Significant difference ($p\leq 0.01$) was observed in number of cfu by *A. parasticus* recovered from groundnuts kernels harvested at different dates at Chitedze. No significant difference ($p= 0.087$) in the number of cfu produced by A. *parasticus* from kernels harvested at different dates at Chitala (Table 4).

Table 4: Number of colony forming units (CFU) produced by *Aspergillus* species recovered from groundnut kernels

	Chitedze				Chitala			
	Colony forming units for *A. flavus*							
Drying method	80DAS	90DAS	100DAS	Mean	80DAS	90DAS	100DAS	Mean
A-frame	0	0	733	244[a]	33	0	733	256[a]
Conventional	2700	833	467	1333[b]	3233	800	5933	3322[b]
Drying rack	67	100	1900	689[a]	100	33	1500	544[a]
Mandela cork	43	0	933	933[a]	400	100	1033	511[a]
Mean	800[a]	233[a]	1008[a]		917[a]	258[a]	2300[a]	
CV%			74.5				49.4	
LSD	D=828.2	H=717.3	D*H=1434.5		D=1349.1	H=1821.2	H*D=2434.1	
F pr.	D =0.065	H=0.090	D*H=0.021		D=<.001	H=0.081	H*D=0.156	
	Colony forming units for *A .niger*							
A-frame	33	67	800	300[a]	300	33	2367	900[a]
Conventional	300	1400	300	667[a]	1467	567	2533	1522[a]
Drying rack	200	67	133	133[a]	100	167	2033	767[a]
Mandela cork	533	33	367	311[a]	500	67	567	378[a]
Mean	267[a]	367[a]	400[a]		367[a]	433[a]	1875[a]	
CV%			60.4				49.9	
LSD	D=640.3	H =554.5	D*H=1109.0		D=970.9	H=1644.8	H*D=1934.4	
F pr.	D=0.387	H=0.856	D*H=0.228		D=0.134	H=0.106	H*D=0.448	

Colony forming units for *A. parasticus*								
A-frame	100	33	400	178a	100	33	2167	767[a]
Conventional	2467	867	200	1178b	7467	1167	7467	3700[b]
Drying rack	267	33	200	167a	167	233	1167	522[a]
Mandela cork	600	33	467	367a	433	133	2333	967[a]
Mean	858[b]	242[a]	317[a]		792[a]	392[a]	3283[a]	
CV%			24.1				24.0	
LSD	D=462.1	H=400.2	D*H=800.5		D=2064.2	H=2812.2	H*D=3736.9	
F pr.	D=<.001	H=0.008	D*H=0.003		D=0.015	H=0.087	H*D=0.441	

-Means were separated by Fischer's Protected Least Significance Difference (LSD) at p=≤0.05. Means followed by same letter(s) within columns and rows are not significantly different, CV % is the Coefficient of Variation and Fpr. is F probability value (p< 0.05). Key: D=Mean value for Drying method, H=Mean value for Harvesting dates, H*D=Mean value for Harvesting date*drying method, DAS=Mean values for Days after sowing.

There was significant difference (p≤ 0.01) in number of cfu by other fungal species such as *Fusarium* and *Penicilium* from groundnuts at Chitedze and Chitala on using different drying methods. Lowest number of cfu (689) was observed on using drying rack at Chitedze, and (1167) on using A-frame at Chitala. There was significant difference (p< 0.05) in terms of number of cfu by other fungal species such as *Fusarium* and *Penicilium* at different harvesting dates of Chitedze and Chitala.

Groundnuts at Chitedze showed no significant variations in terms of total number of cfu by different fungal spp. at different drying methods and different harvesting dates. Conversely, groundnuts kernels from Chitala exposed to different drying methods showed significant difference (p< 001) in total number of cfu (Table 5).

Significant difference (p< 001) in percentages of mouldy kernels was observed on using different drying methods at both Chitala and Chitedze. There was significant difference (p≤ 0.05) in terms of mouldy kernels with different harvesting dates at Chitedze, however no significant difference (p=0.122) was observed for Chitala kernels.

3.5. Percentage of kernel infection by A. flavus and aflatoxin B1 contamination (µg/ Kg)

Kernel infection by various fungal spp. was almost similar across both sites. There was significant difference (p≤ 0.01) in percentages of kernels infection by *A. flavus*, mainly those exposed to different drying methods at both sites. Mandela cock drying method at Chitedze presented the lowest percentage as 2 % of infected kernels; whereas, at Chitala A-frame had the lowest percentage of about 0.7%. Noticeable difference (p< 0.01) of kernel infection by *A. flavus* at different harvesting dates was realized at Chitedze. Groundnut harvested at 90 days had the lowest percentage of kernel infection by *A. flavus* (3%), compared to highest level of infection of (12%) for groundnut kernels harvests at 100 days.

No significant difference (p= 0.161) was observed for kernel infection by *A. flavus* at Chitala using different drying methods. However, there was highly significant difference (p< 001) for kernel infection by *A. niger* using drying methods at Chitedze. In contrast, no noticeable difference (p= 0.152) of kernel infection by *A. niger* using different drying methods at Chitala. Significant differences (p< 0.05) and (p=≤ 0.01) in terms of kernels infection by *A. niger* at different harvesting dates were observed at Chitedze and Chitala, respectively. Groundnut kernels from Chitedze were infected significantly (p< 0.05) by *A. parasticus* on using different drying methods, whereas no significant difference (p= 0.128) were detected for kernel infection by *A. parasticus* at Chitala.

Table 5: Total number of CFU by different fungal spp. and percentage of moldy kernels

	Chitedze				Chitala			
	CFU recorded by other fungal species (*Fusarium and Penicilium)*							
Drying method	80DAS	90DAS	100DAS	Mean	80DAS	90DAS	100DAS	Mean
A-frame	400	167	1833	800a	567	100	2833	1167[a]
Conventional	4300	1633	1000	2056b	5067	0	15300	6789[b]
Drying rack	700	367	233	689a	1667	67	3333	1689[a]
Mandela cork	1033	200	1167	800a	1500	100	2800	1467[a]
Mean	1608c	592a	1058b		2200b	67a	6067c	
CV%			24.8				59.1	
LSD	D=906.2	H=784.8	D*H=1569.6		D=1626.5	H=2554.4	H*D=3123.1	
Significance	D=0.014	H=0.044	D*H=0.002		D=< 001	H=0.007	H*D=<.001	
	Total CFU recorded by different fungal species (*Fusarium and Penicilium*)							
A-frame	267	67	3767	1367[a]	967	200	8100	3089[a]
Conventional	8400	4400	1200	4667[a]	10933	3433	31500	15289[b]
Drying rack	433	567	12633	4544[a]	1967	567	8367	3633[a]
Mandela cork	2000	133	3667	1933[a]	2833	400	6733	3322[a]
Mean	1292[a]	1292[a]	5317[a]		4175b	1156a	13675c	
CV%			32.8				18.2	
LSD	D=4879.5	H=4225.8	D*H=8451.5		D=1138.7	H=2060.9	H*D=2351.2	
Significance	D=0.381	H=0.160	D*H=0.091		D=<.001	H=<.001	H*D=<.001	
	Percentages of moldy kernels							
A-frame	10.3	7.8	11.6	9.9a	9.8	5.8	11.6	9.9[a]
Conventional	38.9	27.3	40.5	35.6b	17.0	8.2	34.8	20.0[b]
Drying rack	8.1	5.4	21.1	11.5a	8.7	3.3	9.1	7.0[a]
Mandela cork	14.0	4.9	14.8	11.3a	9.2	5.9	11.4	8.8[a]
Mean	17.8b	11.3a	22.0b		11.2[a]	5.8[a]	16.7[a]	
CV%			28.3				23.6	
LSD	D=9.7	H=8.5	D*H=16.9		D=5.7	H=11.1	H*D=12.3	
F pr.	D=<.001	H=0.049	D*H=0.862		D=<.001	H=0.122	H*D=0.044	

-Means were separated by Fischer's Protected Least Significance Difference (LSD) at p=≤0.05. Means followed by same letter(s) within columns and rows are not significantly different, CV % is the Coefficient of Variation and Fpr. is F probability value (p< 0.05). Key: D= Mean value for Drying method, H=Mean value for Harvesting dates, H*D=Mean value for Harvesting date*drying method, DAS=Mean values for Days after sowing.

Significant difference ($p \leq 0.05$) were observed (Table 6) in terms of groundnut kernels infection by A. parasticus at different harvesting dates for Chitedze and Chitala. For groundnuts at Chitedze; lowest level of infection by *A. parasticus* was observed at 90 days (0.2%), whereas, lowest level (2%) was detected at 100 days for Chitala.

Table 6: Percentage of seed infection by *Aspergillus* species

	Chitedze				Chitala			
	Infected kernels by *A. flavus*							
Drying method	80DAS	90DAS	100DAS	Mean	80DAS	90DAS	100DAS	Mean
A-frame	5	0.3	13.3	6.2^{a}	0.0	2.0	0.0	0.7^{a}
Conventional	11.7	10	5.0	8.9^{bc}	11.7	0.67	3.7	5.3^{b}
Drying rack	32.3	1.0	8.0	13.8^{c}	4.0	1.0	0.3	1.8_{a}
Mandela cork	2.3	0.0	4.7	2.3^{a}	5.0	2.0	0.7	2.6^{a}
Mean	12.8^{b}	2.8^{a}	7.8^{b}		5.17^{a}	1.42^{a}	1.2^{a}	
CV%			20.8				31.8	
LSD	D=6.1	H =5.2	D*H =10.8		D=5.1	H=2.3	H*D=5.4	
Significance	D=0.007	H=0.003	D*H=<.001		D=0.004	H=0.161	H*D=0.011	
	Infected kernel by *A. niger*							
A-frame	0.0	0.0	5.7	1.9^{a}	0.0	0.0	6.3	2.1^{a}
Conventional	24.7	3.0	5.0	10.9^{b}	5.3	3.7	25.3	11.4^{b}
Drying rack	11.3	4.7	3.7	17.7^{b}	12.3	5.0	38.0	18.4^{b}
Mandela cork	0.7	0.0	1.0	0.6^{a}	1.0	0.0	1.0	0.7^{a}
Mean	9.2^{b}	1.9^{a}	12.2^{b}		9.7^{b}	2.2^{a}	12.7^{b}	
CV%			110.6				48.1	
LSD	D=8.3	H=7.6	D*H=14.5		D=12.0	H=7.9	H*D=14.8	
Significance	D=<.001	H=0.022	D*H=0.004		D=0.152	H=<.001	H*D=0.003	
	Infected kernel by *A. parasticus*							
A-frame	0.0	0.0	0.7	0.2^{a}	4.0	1.3	0.3	1.9^{a}
Conventional	17.0	0.0	0.0	5.7^{ab}	6.3	3.0	1.9	9.4^{a}
Drying rack	2.7	1.0	20.7	8.1^{b}	10.7	1.7	1.7	4.7^{a}
Mandela cork	2.7	0.6	1.0	1.4^{a}	5.3	21.3	1.5	7.6^{a}
Mean	5.6^{b}	0.2^{a}	5.7^{b}		6.6^{b}	9.3^{b}	1.8^{a}	
CV%			38.7				18.6	
LSD	D=5.6	H=4.4	D*H=9.7		D=39.1	H=6.8	H*D=5.2	
Significance	D=0.028	H=0.050	D*H=0.001		D=0.138	H=0.040	H*D=0.138	

-Means were separated by Fischer's Protected Least Significance Difference (LSD) at $p=\leq 0.05$. Means followed by same letter(s) within columns and rows are not significantly different, CV % is the Coefficient of Variation and Fpr. is F probability value ($p< 0.05$). Key: D=Mean value for Drying method, H=Mean value for Harvesting dates, H*D=Mean value for Harvesting date*drying method, DAS=Mean values for Days after sowing.

Groundnut kernels infection by other fungal spp. did not differ significantly among different drying methods and harvesting dates at both sites of Chitala and Chitedze (Table 7). However; there was noticeable difference ($p \leq 0.01$) with regard to total number of infected kernels by various fungal spp., with different drying methods at both at sites. Appreciable differences ($p \leq 0.001$), ($p<0.01$) were recorded for kernels infection by various fungal spp. at different harvesting dates for Chitedze, Chitala sites, respectively. Levels of aflatoxin B1 contamination was significantly different ($p< 001$) for kernels exposed to different drying methods at both sites of Chitala and Chitedze. A-frame drying methods had the lowest level of aflatoxin (0.5 µg/ Kg), compared to conventional method which had high level of 4.3µg/ Kg at Chitedze. The same A-frame at Chitala resulted in lowest level of about 0.8 µg/ Kg, whereas conventional method recorded 4.9 µg/ Kg. Appreciable differences of ($p< 0.01$), ($p< 0.05$) in aflatoxin B1 contamination was detected in groundnuts samples from Chitedze and Chitala, harvested at different dates, respectively. Highest levels of aflatoxin contamination were observed in kernels harvested after 100 days of sowing at both sites.

Table 7: Percentage of kernels infected by other fungal spp., and aflatoxin B1 contamination levels (µg/ Kg)

	Chitedze				Chitala			
	Infected kernels by other fungal species (*Fusarium and Penicilium*)							
Drying method	80DAS	90DAS	100DAS	Mean	80DAS	90DAS	100DAS	Mean
A-frame	12.0	2.0	17.7	10.6[a]	0.0	0.0	11.3	3.8[a]
Conventional	24.3	13.3	39.7	25.8[a]	4.0	2.3	3.3	3.2[a]
Drying rack	52.0	6.3	8.3	22.2[a]	1.0	2.7	12.0	5.2[a]
Mandela cork	9.7	2.3	14.7	8.9[a]	6.7	0.0	6.3	4.3[a]
Mean	24.5[a]	6.0[a]	20.1[a]		2.9[a]	1.3[a]	8.2[a]	
CV%			44.5				54.1	
LSD	D=23.8	H=20.6	D*H=41.2		D=6.8	H=12.8	H*D=14.37	
F pr.	D=0.382	H=0.175	D*H=0.475		D=0.936	H=0.376	H*D=0.562	
	Total infected kernel by various fungal spp.							
A-frame	17.0	2.3	38.0	19.1[a]	18.3	2.3	40.1	20.2[a]
Conventional	77.7	26.3	50.3	51.4[b]	71.0	26.3	50.7	49.3[b]
Drying rack	101.6	13.3	62.3	59.1[b]	106.0	17.0	65.7	62.9[b]
Mandela cork	15.3	3.0	21.7	13.3[a]	14.7	4.3	24.0	14.3[a]
Mean	32.9[a]	11.3[a]	43.1[b]		52.5[b]	12.5[a]	45.1[b]	
CV%			34.7				26.0	
LSD	D=22.6	H=26.1	D*H=45.1		D=17.2	H=27.6	H*D=20.8	
F pr.	D=0.002	H=0.002	D*H=0.196		D=0.004	H=0.006	H*D=0.250	

	Aflatoxin B_1 contamination levels							
A-frame	0.1	0.2	1.2	0.5[a]	1.0	0.1	1.5	0.8[a]
Conventional	5.7	2.5	5.8	4.3[b]	6.4	1.5	6.7	4.9[b]
Drying rack	0.1	1.5	1.4	1.3[a]	1.4	0.6	2.4	1.5[a]
Mandela cork	0.2	0.1	1.8	0.7[a]	1.9	0.0	1.9	0.9[a]
Mean	1.2[a]	1.1[a]	2.5[b]		2.4[a]	0.6[a]	3.1[b]	
CV%			21.2				30.9	
LSD	D=1.2	H=1.0	D*H=2.1		D=1.0	H=1.6	H*D=1.9	
F pr.	D=<.001	H=0.002	D*H=0.005		D=<.001	H=0.021	H*D=0.028	

-Means were separated by Fischer's Protected Least Significance Difference (LSD) at p=≤0.05. Means followed by same letter(s) within columns and rows are not significantly different, CV % is the Coefficient of Variation and Fpr. is F probability value (p< 0.05). Key: D=Mean value for Drying method, H=Mean value for Harvesting dates, H*D=Mean value for Harvesting date*drying method, DAS=Mean values for Days after sowing.

4. Discussion

Findings of the current study showed that in all treatments combinations of groundnuts such as; harvesting dates and drying methods, these kernels had the same emergence, stand count, in addition to similar number of days to reach maturity in each plot. Moreover, they were expected to be harvested on different dates and dried using different methods at both sites. This was because these kernels were of one variety, of the same genetic traits, and they were subjected to the same environmental conditions at each site.

Currently we found out that groundnuts which were harvested at 90 days after planting which is at its physiological maturity; and dried on Mandela cock, recorded highest pod and shelled yield, as well as weight (Kg/ ha) of 1000 seeds at both sites. In contrast groundnut harvested either at 80 days or after 100 days and then dried using conventional methods resulted in lowest yields. A-frame and drying on rack methods used in kernels harvested at 90 days of planting resulted in moderately higher yields. These findings also showed significant variations among the treatments, whereby groundnut harvested at 90 days and dried on Mandela cock reached pod yield of above 1500 Kg/ ha. Significant difference however was observed only at Chitedze, whereby groundnut harvested at 90 days and dried on Mandela cock resulted in shelled yield of up to 1200 Kg/ ha. The study also showed that 1000 seed weight did not significantly vary in almost all treatments at both Chitedze and Chitala.

Present findings agree with previous reports of Okello *et al*., (2010) which reported that Mandela cock was one of the recommended drying methods of groundnuts, commonly used by many farmers in most parts of Sub-Saharan Africa. This technique has been recently introduced in many countries in southern Africa region and commonly used, due to its ability to minimize moisture content, yield losses, and the risk of aflatoxin contamination (Matumba *et al*., 2018). According to AICC. (2014), Mandela cock was a well-ventilated stacking method which was considered as a modern way of curing groundnuts. At present study, groundnuts harvested at 90 days had more yields than those harvested too early\ or very late. This agrees to what AICC. (2014) reported that timely harvesting of groundnuts was essential as it avoided bleaching and discoloration of nuts, sprouted pods remained in the ground, aflatoxin contamination and yields were increased. Proper drying methods; together with timely harvesting, have the greatest influence on groundnuts quality, quantity and marketing (Okello *et al*., 2010).

High yields of groundnut harvested at 90 days could be attributed to that fact that groundnuts had reached its optimal physiological maturity, hence no late moldy contamination, no shriveled kernels, and

insect damages were greatly reduced. Previous research of Okello *et al*., (2010) proved that timely harvesting of groundnuts gives the farmer the maximum yield and grade. As reported by Okello *et al*., (2013) yield losses greater than 300-400 kg/ ha may occur as a result of delayed harvesting. Late harvesting also reduces yield; because the pegs become weaker with age, and the pods break off and remain in the ground (Okello *et al*., 2010). Moreover, this study suggested that groundnut harvested at 80 days had many immature and shriveled pods, and were prone to moldy and aflatoxin contamination, hence reduced yields. Rachaputi *et al*., (2002) pointed out that early harvesting and threshing of groundnuts is also recommended to increase yield, and to reduce aflatoxin levels. These findings were also in consistence with that of Okello *et al*., (2013).

Groundnut kernels which were dried on Mandela cock had the highest yields among all the four drying methods. These findings could be attributed to fact that Mandela cock has good air ventilation, dries the pods quickly to it's the required moisture content, and prevents pod mold contamination. The other two drying methods of A-frame and drying rack when incorporated to timely harvesting can also result in high yields and reduced aflatoxin contamination. According to AICC. (2014), A-frame has excellent air circulation; dries groundnuts within the pods, and if properly constructed, the drying foliage of the plants protects the pods from rainfall. However; conventional drying method resulted in high chances of pod contamination with molds, as well as pod damage by insects' pests, thus reduce quality and yields. This finding is in consistent to previous reports of AICC. (2014); Okello *et al*., (2010). Generally high yields and reduction in aflatoxin contamination can be achieved by adopting proper practices such as; harvesting at right crop maturity stage followed by recommended drying methods, cleaning of any extraneous matter including damaged pods after harvest prior to storage (Rahmianna *et al*., 2007).

Present study demonstrated that percentage of shriveled kernels and moisture content after drying significantly varied from one treatment to the other for all kernels harvested from both sites. Groundnut harvested at 90 days and dried using Mandela cock and drying rack, resulted into low percentage of shriveled kernels (12 %) at both sites. In contrast; conventional drying method in combination with either harvesting earlier before physiological maturity\ or late after maturity resulted in high levels of shriveled kernels (40 %). The same case was with moisture content after drying; current study findings showed low moisture contents about 6% in groundnut harvested at 90 days, and subjected to Mandela cock and drying rack methods. Use of A-frame drying method resulted in moderately low percentage of moisture levels; while conventional method had the highest moisture levels of 10%, especially when groundnuts kernels were harvested at 80 days after planting.

The present findings were in consistence with the previous study of Hell and Mutegi, (2011), who pointed out that moisture and temperature were the main factors that influence post-harvest contamination of stored commodities by *A. flavus*. According to Okello *et al*., (2010) drying aimed at reducing pods moisture content to 6-8 % which was suitable for storage. This agrees with the previous report of AICC. (2014) that the drying process of groundnut using Mandela cock took two to three weeks to reach the recommended moisture content of 6-8 %. Awuah and Ellis, (2002) also substantiated that groundnuts dried to 6.6 % moisture levels were free of fungi for 6 months regardless of the storage protectant used, and these safe moisture levels were ideal to both unshelled and shelled groundnuts. Some of the factors affecting aflatoxin contamination in food grains were; harvesting, drying, storage methods, moisture content, insect damage, and physical damage (Kaaya and Warren, 2005; Waliyar *et al*., 2008). According to Matumba *et al*., (2018); timely drying of groundnuts

by solar drying as is the case with Mandela cock, A-frame and drying rack was important after harvest, since it practically achieved the required moisture content in most parts of sub-Saharan Africa.

In this study, combination of harvesting at 90 and proper drying using Mandela cock resulted into ideal moisture content of about 6 %. These findings could be attributed to the fact that at 90 days the pods were fully matured, and by exposing these pods to well ventilated solar drying methods such as Mandela cock and drying rack, the desired moisture was achieved. This finding was in agreement with previous findings of Zuza, (2017) and Page *et al*., (2002) that Mandela cock has excellent air circulation, and if constructed properly, the drying foliage of the plants protects the pods from rainfall. Current study therefore concluded that it is advisable for farmers to dry groundnuts using these low cost technologies such as Mandela cock, A-frame and drying rack in order to achieve safe moisture content for groundnuts on storage. Furthermore, through this research it was observed that timely harvesting at 90 days resulted in lower percentage of shriveled kernels. This agrees with previous study of Okello *et al*., (2010) who reported that when harvesting is done too early, the seeds will shrink upon drying which lowers their yield, oil content and quality.

Identification of cfu showed significant difference ($p< 0.05$) in terms of number of moldy kernels, and cfu produced by *A. flavus*, *A. parasticus* and other fungal spp. from groundnuts kernels exposed to different drying methods at both Chitala and Chitedze. Generally; there were low levels of *A. flavus* as well as *A. parasticus* cfu of about 200 in all groundnut plots harvested at 90 days, and dried using A-frame method across both sites. In terms of number of moldy kernels; there was very low number of kernels in groundnuts harvested at 90 days, and then dried using A-frame and drying rack methods. This was in the contrary to high contamination of up to 3000 *A. flavus* cfu, recorded in groundnuts harvested at 100 days, and subjected to conventional drying method.

These findings translated that harvesting groundnuts at physiological maturity time and dry using recommended methods reduce groundnut contamination from *Aspergillus* spp. that were responsible for aflatoxin contamination. In a similar study, Chimbaza *et al*., (2017) concluded that stripped nuts dry faster than groundnuts dried as a whole plant. In addition, Mandela cock system and A-frame pole has a potential for reducing fungal contamination and aflatoxins in groundnuts. These findings were also in agreement with Rahmianna *et al*., (2007), who reported that reduction of pod contamination from *Aspergillus* spp. can be achieved by adopting proper practices such as; harvesting at right crop maturity stage, followed by use of recommended rapid drying methods, and removal of any extraneous matters including damaged pods prior to storage. As reported by Jnr *et al*., (2018) delayed harvesting can result into higher levels of molds and aflatoxin contamination compared to timely harvesting. This was attributed to heavy damage of pods by insects especially termites, which provided ready entry of *Aspergillus* spp. and subsequent aflatoxin contamination.

In all treatments, both Chitala and Chitedze were found to differ in terms of percentage level of Aspergilli and other fungal spp. *Aspergillus* spp. that were isolated from the kernels includes; *A. flavus*, *A. niger* and *A. parasticus*, which were also associated with aflatoxin contamination. Percentage of kernel infection by *A. flavus* in groundnut harvested at 80 days after planting was 12 % of the total kernels. On the contrary, those groundnuts harvested at 90 days resulted in lowest percentage of infection by various fungal species.

The current study reported that groundnuts harvested at 90 days and dried using A-frame drying method had the lowest level of aflatoxin contamination (0.5µg/ Kg) compared those harvested at 100 days and dried using conventional method (5µg/ Kg).

Moreover, the present study found out that harvesting groundnut at 90 days after planting resulted in lowest percentage levels of kernel infection by

various fungi species. These findings are in agreement with Jnr *et al*., (2018), that it was advisable to harvest at physiological maturity to reduce *Aspergillus* infection, and contamination of groundnuts.

Conclusion

The present study demonstrated that use of appropriate post-harvest management operations of groundnut such as; harvesting at physiological maturity coupled with proper drying methods like Mandela cork, A-frame, and drying rack gave the lowest *A. flavus* infection and aflatoxin contamination levels of 0.5µg/ Kg, lower than the EU maximum permissible level of 10 µg/ Kg.

Findings of this study showed that groundnut yields tend to decrease while the fungal infection and aflatoxin contamination increases once groundnut is harvested too early before it reaches its physiological maturity, or when harvested ten days late. Drying groundnut using Mandela cock, A-frame and drying rack methods was more effective in achieving lower *A. flavus* infection and aflatoxin contamination levels of kernels. Mandela cock drying method was the most effective compared to the other methods used.

Conflict of interests

The authors declare no conflict of interests.

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