AFRICA ENVIRONMENTAL REVIEW Journal

ISSN: 1727-8341

AER Journal Volume 5, Issue 1, pp. 111-129, June, 2022

RESEARCH ARTICLE

Available Online at *http://ojs.uoeld.ac.ke/*

Evaluation of the Effectiveness of Drying Groundnuts (*Arachis hypogaea*) on Post-Harvest Losses: A Case Study of Khwisero Sub-County, Kenya

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Abstract

Loss of grains through mould infection is a serious problem for farmers in rural societies. Solar drying of groundnuts offers a huge potential to reduce Aflatoxin contamination. The purpose of this study was to assess the effectiveness of drying groundnuts on post-harvest losses in Kenya. The investigation was guided by the following specific objectives: To characterize the physical characteristics of various groundnut varieties in Khwisero Sub-County, Kenya; to characterize the drying technologies existing in the Sub-County, Kenya and to evaluate the performance of the existing drying technologies in the Sub-County. The study adopted a factorial experimental design. In this study parameters included; temperature, relative humidity, moisture content, drying time, and drying rate. The groundnuts for experimental purposes were acquired through purposive sampling. Data was collected using data loggers, a data sheet, and a household survey. The following physical properties of groundnut grains were evaluated; surface area, bulk density, and porosity. To evaluate the efficiency of the existing dryer designs for effective drying of groundnuts, the effectiveness of each drier was determined the following parameters; drying time, drying rate, moisture content, temperature, and relative humidity. The drying technologies under study were open sun drying, the greenhouse effect, and the modified greenhouse effect. The open sun drying depended on the natural weather while the Greenhouse and the modified greenhouse effect offered the opportunity for the farmers to dry their kernels in any circumstance of weather or duration e.g. sunny, rainy, or cloudy weather, in the day or at night when temperatures are colder with energy reaching the surface of 678 kWh/m^2. It is critical to dry harvested groundnuts correctly, as improper drying can promote fungal growth and reduce kernel quality for consumption and propagation.

Keywords: Drying, Groundnuts *(Arachis hypogaea), Post*-Harvest Losses, Khwisero Sub-County, Kenya

INTRODUCTION

Groundnut production is dominated by small - scale farmers, and the plant is regarded as one of the most vital food crops as well as a cash crop (Tsusaka et al., 2016). The grain is served raw, roasted, boiled, and unshelled. Traditionally, nuts are ground into coarse flour and mixed with leafy greens. It is also used to extract oil and make butter, and the leftover cake is processed into animal feed and human food. Aflatoxin levels found in groundnuts sold in local markets exceed safe levels for human consumption in nearly half (49%) of samples (Emmott & Stephens, 2014). Every year, nearly 1.3 billion tons of food are lost or wasted in the post-harvest chain, accounting for over 30% of global crop production (Gustavsson et al., 2011).

Infested with the carcinogenic fungus Aspergillus flavus, the pod and kernel contain 25% of the world's mycotoxins (Nautiyal, 2012). Post-harvest contamination is more common than pre-harvest contamination. Aflatoxin levels in food rise during storage (Kaaya & Kyamuhangire, 2016). In Sub-Saharan Africa (SSA), annual grain post-harvest losses (PHL) are estimated to be USD 4 billion, which is sufficient to feed 48 million people for an entire year (Affognon et al., 2015; Mlalila et al., 2017). Additionally, the PHL is estimated to be equivalent to between 6% and 10% of human-caused greenhouse gas emissions (Vermeulen et al., 2012). When crop farming accounts for a significant portion of smallholders' household income in Sub-Saharan Africa, reducing post-harvest loss (PHL) at the farm-gate level can immediately increase the real incomes of small-scale producers (Sheahan & Barrett, 2017). As a result of warm, humid garage conditions with an optimal temperature of $25^{0}C$ that encourage fungal growth in various crops, Aflatoxin contamination occurs (Setsetse, 2019). Aside from storage, drying the grain on-site is essential for grain preservation. But inappropriate drying methods can exacerbate Aflatoxin contamination (Hell & Mutegi, 2011).

Aflatoxin mitigation is possible with low-cost drying platforms, drying outside the sector, and drying on mats (Tsusaka et al., 2017). Pratiwi and Rahmianna (2017) found that practices like lifting at the right time, stripping pods quickly after harvest, drying quickly, and ventilation during storage can help reduce Aflatoxin levels. Quantitatively, harvesting and post-harvest (PH) management techniques, along with labor availability, affect PHLs. Pollution with mycotoxin is the leading cause of crop loss (Tefera, 2012). This study anticipated that smallholder farmers' post-harvest losses in groundnuts will be reduced by this innovation and invention. Furthermore, smallholder farmers will benefit from improved groundnut quality free of Aflatoxin, reducing illnesses like cancer. Drying harvested groundnuts correctly is critical to preventing fungus infection. Drying is also important for preserving seed quality for consumption and storage.

Problem Statement

Loss of grains through mould infection is a serious problem for farmers in rural societies. Aflatoxin contamination on groundnut grains causes a lot of economic losses to farmers as well as loss of lives to the consumers of groundnut products. Knowledge of kernel moisture content during peanut drying is important to ensure that the bed of peanuts is dried appropriately. However, the limited availability of commercial and industry-accepted solution for real-time kernel moisture content determination during peanut drying makes its detection cumbersome and laborious. Groundnut farming contributes a significant proportion to smallholders' household income in sub-Saharan Africa; reduction in post-harvest loss especially up to farm-gate level can directly increase the real incomes of small-scale producers (World Bank, 2011). How to attain effective and economical drying of groundnuts in rural societies is a hurdle that farmers need to overcome. Recently in Kenyan shops, maize flours and groundnut butter were withdrawn from shelves due to Aflatoxin contamination (Kuhumba, Simonne, & Mugula, 2018). Approximately half (49%) of groundnut sold at local markets is found to have Aflatoxin levels exceeding those considered safe for human consumption (Emmott & Stephens, 2014). Solar drying technologies exist, but there is a lack of evidence-based information on their performance to encourage the farmer to adopt the technology hence exacerbating huge postharvest losses. Solar drying is a key element in powering agriculture through the reduction of postharvest losses and preparing agricultural products for secondary processing (Desa et al., 2019; Wakjira, 2010). The study sought to evaluate the effectiveness of solar drying groundnuts, by characterizing the physical characteristics of various groundnut varieties in Khwisero Sub-County, Kenya.

Overall Objective
The overall objective of this study is to assess and evaluate the effectiveness of drying groundnuts on post-harvest losses among smallholder farmers in Khwisero Sub-County, Kenya.

Specific Objectives
The study's objectives were as follows:

i. To characterize the physical characteristics of various groundnut varieties in Khwisero Sub-County, Kenya
ii. To characterize the drying technologies existing in Khwisero Sub-County, Kenya.
iii. To evaluate the performance of the existing drying technologies in Khwisero Sub-County, Kenya.

Conceptual Framework

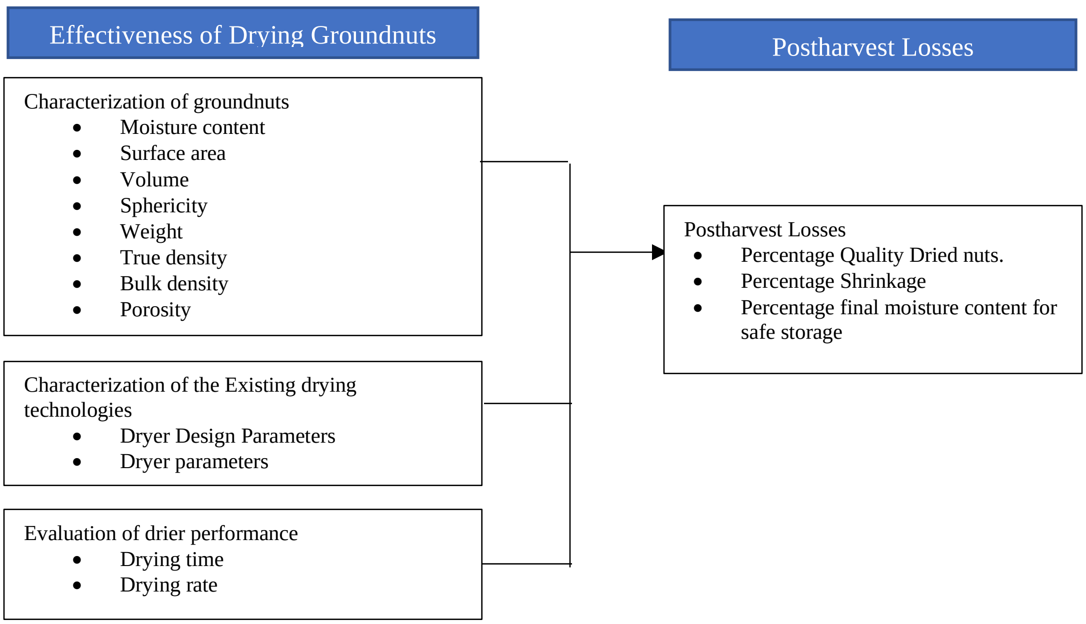


Figure 1: Conceptual Framework.

MATERIALS AND METHODS
Research Design
The study adopted a factorial experimental research design. The research design was appropriate as it enabled the researcher manipulates one variable, and control/randomizes the rest of the variables.

Study Area
The study was conducted in Kakamega's Khwisero Sub-County. Kakamega County is one of Kenya's 47 counties, covering 4,267.1 km2 on the north eastern shores of Lake Victoria, in western Kenya. Trans Nzoia County borders the north, Kisumu County borders the south, Bungoma County borders the west. The County lies between latitude 00 28' and latitude 10 30' North of the Equator, and longitude 340 20' East and 350 15' East of the Greenwich Meridian. The county had 1,663,794 residents in 2019, with 406,255 households, with females making up 52% and males 48%. Groundnuts were grown in lower midland zones 4 (LM4) and 3 (LM3) (Ministry of Agriculture, 2017). The county's mean annual temperatures range from 17.1°C to 34.8°C, with annual rainfall

between 400mm and 1,800mm. Farming is the main source of income at (52 percent).

Household Survey to Determine the Agronomic Activities by Farmers

A household survey was conducted within the study area. The choice of the sub-county was based on their being the major groundnut production area. The survey was based on all groundnut-growing households. The respondents were smallholder farmers. The questionnaires were developed based on information collected after conducting focus group discussion involving participants drawn from one of the major farmers' co-operative societies in the area.

Sampling of Groundnut Kernels from the Households

Samples were collected from multiple points in each farmer's storage bags with the number of sampling points being based on the volume of the storage material. The pods and kernels of three groundnut varieties namely: Nyadongo (Virginia), Nyakipingi (Runner) and Nyaela (Red Valencia) were collected in November 2020 which was available varieties in the study area, Khwisero Sub County, Kenya. In this study, the engineering properties of groundnuts focused on the measurable physical properties of groundnut pods and kernels at the harvest time, which are length, width, thickness, surface area, volume, sphericity, weight, moisture content, true density, bulk density and porosity, which were determined for the three different varieties viz., Nyadongo (Virginia), Nyakipingi (Runner) and Nyaela (Red Valencia). The pods were selected from the bulk volume of each groundnut varieties so that greater variations were eliminated and that the linear dimensions conform to those of Sayed et al., (2001). For consistency of results, a hundred pods and a hundred kernels of each groundnut variety was collected, measured and analyzed. Weights were taken as masses of the hundred groundnut samples at the harvest time. The 100-unit mass was determined using the precision of electronic balance to an accuracy of 0.001g. A mean of 10 replications was recorded, each at a time. The bulks were put in a container weighing 126g.

Evaluation of the Performance of the Existing Drying Technologies

The study sought to evaluate the performance of the existing drying technologies. Three drying methods were used in the study; traditional sun drying, drying using one the popular dryer in the community and the modified dryer. Study procedures were that 369 samples of groundnuts were sampled after harvesting, the nuts were sorted and cleaned and moisture content determined. From the cleaned and mixed lot, three weighed samples were randomly drawn and allocated to each of the three cited drying methods. The samples were dried continuously for using each method for 10 days. The following were determined on three times a day; ambient temperature, relative humidity, temperature and RH inside the dryers. The moisture content of the nuts for the three trials were established and recorded. At the end of drying period the ground nuts were shelled and the moisture content of the nuts and kernels determined. Nuts color, mass, moisture content, aflatoxin after drying, and at 7 days interval for six we weeks were observed for chances of aflatoxin colonization.

Evaluation of the Performance of the Existing Dryers

Three drying methods evaluated in the study were;

i. Traditional Sun drying (Open Sun drying)
ii. Drying using one of the popular dryers in the community (Greenhouse Effect Solar Drier)
iii. The modified Greenhouse Effect Solar dryer

Study procedures were that 369 samples of groundnuts were taken after harvesting, the nuts were sorted and cleaned and moisture content determined. From the cleaned and mixed lot, samples were randomly drawn and allocated to each of the three cited drying methods. The samples were dried continuously by using all three study methods simultaneously for 10 days.

The following were determined on three times a day; ambient temperature, relative humidity, temperature and RH inside the dryers. The moisture content of the nuts for the three trials was established and recorded. At the end of drying period the ground nuts were shelled and the moisture content of the nuts and kernels determined. Moisture content was determined three times for three days. Nuts colour and moisture content after drying were observed after six weeks for chances of aflatoxin colonization.

Data Analysis

Relationship between the drying of the pod and the kernel: Analysis was carried out to establish the drying relationship between the pod and the kernel. The pod was assigned letter X while the kernel was assigned letter Y for the purpose of analysis. The correlation coefficient was calculated to establish whether there existed any relationship between the pod and the kernel. Regression analysis was computed to establish an equation fore predicting the moisture content of the kernel when the moisture content of the pod is known.

The following formulae were adapted for computing the Correlation Coefficient and the Regression Analysis.

Correlation Coefficient (r):

$$r = \frac{N\sum XY - \sum X \sum Y}{\sqrt{\{N\sum X^2 - (\sum X)^2\}}.\sqrt{N\sum Y^2 - (\sum Y)^2\}}} \text{......Eq. 1}$$

Regression Analysis:

Equation: Y = a + bX

Where:

$$b = \frac{N\sum XY - \sum X \sum Y}{N\sum X^2 - (\sum X)^2} \text{......................Eq. 2}$$

$$a = \frac{\sum Y - b\sum X}{N} \text{..............................Eq. 3}$$

RESULTS AND DISCUSSIONS

Computational Analysis for the Engineering Properties of Groundnuts

In this study, the engineering properties of groundnuts focused on the measurable physical properties of groundnut pods and kernels at the harvest time, which are length, width, thickness, surface area, volume, sphericity, weight, moisture content, true density, bulk density and porosity, which were determined for the three different varieties viz., Nyadongo (Virginia), Nyakipingi (Runner) and Nyaela (Red Valencia) and results are presented in Table 1 and 2 respectively.

Table 1: Physical properties of groundnuts pods at the time of harvest

Parameter	**Nyadongo (Virginia)**			**Nyakipingi (Runner)**			**Nyaela (Red Valencia)**		
	Min.	Max	Av.	Min.	Max	Av.	Min.	Max	Av.
Length (L) (mm)	53.0	78.0	65.5	36.5	45.5	41.0	31.5	42.5	37.0
Width (W) (mm)	17.5	26.0	21.75	21.5	33.5	27.5	14.5	19.5	17.0
Thickness (T) (mm)	14.5	19.5	17.0	12.5	18.0	15.25	8.0	10.0	9.0
Arithmetic mean diameter (Da)(mm)	28.3	41.2	34.75	23.5	32.3	27.9	18.0	24	21.0
Geometric mean diameter (D)(mm)	23.8	34.1	28.9	21.4	30.2	25.8	15.4	20.2	17.8
Surface area (mm^2)	1779.8	3653.5	2624.2	1438.9	2865.6	2091.4	745.2	1282.1	995.5
Volume V (mm^3)	7059.7	20764.3	12640.0	5132.1	14423.7	8993.2	1912.6	4316.3	2953.4
Sphericity (S)	0.45	0.44	0.44	0.59	0.66	0.63	0.49	0.48	0.48
Weight of 100 wet samples, W_1 (g)	245.0	268.5	256.8	240.0	290.5	265.3	269.5	277.5	273.5
Weight of the can used, W_3 (g)	126.0	126.0	126.0	126.0	126.0	126.0	126.0	126.0	126.0
True density ρ_t (gcm^{-3})	0.831	0.911	0.871	0.791	0.835	0.813	0.680	0.787	0.734
Bulk density ρ_b (gcm^{-3})	0.505	0.668	0.587	0.456	0.510	0.483	0.303	0.488	0.391
Porosity (%)	39.2	26.7	33.0	42.4	38.9	40.7	55.5	38.0	46.8
Initial moisture content at harvest (%)	23.0	28.9	25.95	22.7	27.4	25.05	21.3	25.9	23.6

Table 2: Physical Properties of Groundnuts Kernels at the Time of Harvest

Parameter	**Nyadongo (Virginia)**			**Nyakipingi (Runner)**			**Nyaela (Red Valencia)**		
	Min.	Max	Av.	Min.	Max	Av.	Min.	Max	Av.
Length (L) (mm)	25.0	30.0	27.5	20.0	25.0	22.5	5.5	18.0	11.8
Width (W) (mm)	9.0	12.0	10.5	7.6	10.5	9.1	2.5	9.0	5.8
Thickness (T) (mm)	5.5	6.7	6.1	3.0	5.5	4.3	2.3	4.5	3.4
Arithmetic mean diameter (Da) mm	13.2	16.2	14.7	10.2	13.7	12.0	3.4	10.5	7.0
Geometric mean diameter (D) mm	10.7	13.4	12.1	7.7	11.30	9.6	3.2	9.0	6.2
Surface area (mm^2)	362.4	564.2	460.0	186.3	401.2	289.6	32.2	254.5	120.8
Volume (mm^3)	641.5	1260.0	927.7	239.1	755.6	463.3	17.2	381.8	124.8
Sphericity (S)	0.43	0.44	0.43	0.38	0.45	0.43	0.57	0.5	0.52
Initial moisture content when freshly harvested (%)	36.0	42.0	39.0	35.0	40.0	37.5	30.0	38.0	34.0
Weight of 100 wet samples W_1 (g)	256.4	376.0	316.2	200.8	270.1	235.5	218.9	234.7	226.8
True density ρ_t (gcm^{-3})	0.764	0.797	0.781	0.738	0.764	0.751	0.737	0.744	0.740
Bulk density ρ_b (gcm^{-3})	0.467	0.494	0.479	0.460	0.461	0.461	0.458	0.462	0.460
Porosity (%)	38.9	38.5	38.7	37.6	39.6	38.6	37.3	37.9	37.6

Sphericity

It was observed that the sphericity of the pods varied from 0.36 to 0.68 while that of the kernels, 0.38 to 0.57 with standard deviation of 0.13 and 0.11 respectively. This helped reach the conclusion that the groundnut pods and kernels are not perfectly spherical in shape due to relatively lower sphericity.

Arithmetic Mean and Geometric Mean Diameters

The Arithmetic and Geometric mean diameters for the pods were 27.5 mm and 24.2 mm, respectively, with standard deviations of 3.12 mm and 2.65 mm respectively; while that for the kernels were 11.2 mm and 9.3 mm, with standard deviations of 3.18 mm and 2.417 mm respectively; these values conform to the findings of Baryeh (2001).

Surface area and Volume

The average surface area for the pods and the kernels were calculated as 1903.7 mm^2 and 290.1 mm^3 respectively while the respective volumes of the groundnut pods and kernels were calculated 8195.5 mm^3 and 505.3 mm^3.

Moisture Content

The study found that the average weight of ten pods and ten seeds of each variety measured separately at the time of harvest (wet groundnut pod and kernel) were 26.5g and 15.42 g respectively. The study found that the average moisture content for both the pods and the seeds were measured as 24.8% and 36.8% (wet basis), respectively.

Computation of Groundnut Porosity

The True Density of the pods was 0.806 gcm^{-3} while the True Density of the kernels was 0.757 gcm^{-3}. The averaged mean of their bulk densities was 0.487 gcm^{-3} and 0.467 gcm^{-3}, respectively. The mean percentage porosity for the groundnut pods and kernels was determined as 40.2% and 38.3%, respectively.

The engineering properties of groundnuts were determined for three distinct varieties: Nyadongo (Virginia), Nyakipingi (Runner), and Nyaela. These physical properties include length, width, thickness, surface area, volume, sphericity, weight, moisture content, true density, bulk density, and porosity (Red Valencia). Abioye et al. (2016) reported the mean length, width, and thickness, as well as their dependency on moisture content. The dimensions of these physical parameters would be critical in the creation of grading machines and their separation from undesired materials (Ogunjimi et al., 2002), as well as in the development of decorticating equipment. Abioye et al. (2016) showed that as moisture content increased, geometric mean diameter, sphericity, and surface area increased. The increase in geometric characteristics values could be attributed to the seed's dependence on its three major dimensions.

Abioye et al. (2016) found that as moisture level increases, bulk density drops. It may be because the increase in volume is greater than the net increase in mass of the bulk seed. True density increased linearly with moisture content. Coskun et al. (2006) found a similar trend in coffee and sweet corn true density. The findings of Abioye et al. (2016) may be attributed to the nut's larger mass expansion than volume expansion on moisture gain.

Firouzi et al. (2009) determined some physical properties of groundnut grains at three different moisture contents 8, 20 and 32% dry basis. According to Firouzi et al. (2009), the angle of repose of groundnut increased in line with increasingly moisture content. The least angle of repose was obtained at the moisture level of 8% (db.). The value (30.3) is slightly greater than that of the average values for medium sizes of groundnuts obtained by Akcali et al. (2006) looked at the moisture of level of 5% db (26.6 to 29.0%). They also showed that with increasing kernel size, the angle of repose decreased. Davies (2009) drew the following conclusions from his research on the physical parameters of 7.6% moisture groundnut seeds. For example, 14.21 mm long grains had an arithmetic and geometric mean diameter of 7.94 mm.

In recent years, various attempts have been made to create solar drying processes, mostly for agricultural purposes. However, open-air drying has known constraints for large-scale production. Degradation owing to biochemical or microbiological reactions, high area requirements, and insect infestation are a few examples. Drying times for certain commodities can be lengthy, resulting in post-harvest losses (more than 30 percent). The use of natural convection to dry agricultural products reduces post-harvest losses and improves dried product quality (Forson et al., 2007). Energy from non-renewable sources is either unavailable, unreliable, or prohibitively expensive in many rural areas of most developing countries. In such circumstances, solar dryers become increasingly commercially viable.

Characterization of the Solar Drying Technologies Existing

The study sought to characterize the Solar drying technologies existing in Khwisero Sub County, Kenya. The following data were collected for the three solar drying technologies existing in Khwisero Sub County, Kenya. The study found that on sunny days, the temperature inside the modified greenhouse effect solar dryer (50°C) is relatively higher than the maximum outdoor temperature (27°C). This shows that the modified greenhouse effect solar dryer has the higher capacity to dry the groundnuts effectively compared with the conventional open sun drying technique (27°C) and natural circulation solar drier with single cover which recorded a maximum temperature of 35°C. From the primary observation, the Modified greenhouse solar dryer can retain heat up to a maximum of 50°C thus consistently assuring the farmer of steady temperature within the 24 hours suitable for gradual and effective drying of groundnuts resulting in quality kernels Fig. 2.

Design Parameters	Solar Drying Technique	Drying Parameter
1. Open Sun Drying Design Parameters: • Produce are exposed directly to solar radiations. • Affordable. • Easily available. • Requires little skill. • Affected adversely by change of weather.		Min. Temperature of 20^0C recorded Max. Temperature of 27^0C recorded Min. Relative Humidity of 40% recorded Max. Relative Humidity of 50% recorded
2. Solar drier with single cover Design Parameters: • Produce are spread on trays. • Protected from UV rays. • Relatively cheap. • Requires skilled labour. • Partially stores heat to dry produce overnight.		Min. Temperature of 30^0C recorded. Max. Temperature of 35^0C recorded. Min. Relative Humidity of 30% recorded. Max. Relative Humidity of 40% recorded.
3. Greenhouse effect drier Design Parameters: • Produce are spread on trays, • Produce protected from deteriorating effects of UV rays. • Relatively costly to construct, requires skilled labour. • Fully stores heat to dry produce overnight.		Min. Temperature of 35^0C recorded. Max. Temperature of 50^0C recorded. Min. Relative Humidity of 15% recorded. Max. Relative Humidity of 30% recorded.

Figure 2: The solar drying technologies used in Khwisero Sub-County.

Evaluation of the Performance of the Existing Drying Technologies

The study sought to evaluate the performance of the existing drying technologies. Three drying methods were used in the study; traditional sun drying, drying using one of the popular dryer in the community and the modified dryer. Study procedures were that 369 samples of groundnuts were sampled after harvesting, the nuts were sorted and cleaned and moisture content determined. From the cleaned and mixed lot, three weighed samples were randomly drawn and allocated to each of the three cited drying methods. The samples were dried continuously for using each method for 10 days. The following were determined on three times a day; ambient temperature, relative humidity, temperature and RH inside the dryers. The moisture content of the nuts for the three trials were established and recorded. At the end of drying period the ground nuts were shelled and the moisture content of the nuts and kernels determined. Nuts colour, mass, moisture content, aflatoxin after drying, and at 7 days interval for six we weeks were observed for chances of aflatoxin colonization.

According to findings, majority of the farmers in Khwisero Sub County Kenya dried their groundnuts on average of 11-12 days using open sun-drying technique with an array of challenges leading to huge postharvest losses. The period of drying was shorter in the periods of sunny hot weather but slower during the rainy and cold weather. However, some farmers mixed the subsequent harvests with the kernels already drying and this made it difficult to determine the exact number of days of drying, coupled with the possibility that some kernels may not dry properly, a situation that makes the kernels susceptible to aflatoxin. A frame drying rack identified by Dambolachepa et al. (2019) can reduce aflatoxin contamination in groundnuts by 75%. Moreover, compared to A-frame and drying rack drying, Mandela cock drying was the most successful. The current study suggests harvesting at physiological maturity and drying using a Mandela cock or A-frame and drying rack. More research is needed on biological aflatoxin control.

For many farmers in Sub-Saharan Africa, Mandela cock is one of the suggested drying methods for groundnuts. This technique is widely employed in many nations in Southern Africa because it reduces moisture content, yield losses, and the risk of aflatoxin contamination (Matumba et al., 2018). The most important factors affecting groundnut quality, quantity, and marketing are drying and harvesting timing (Okello et al., 2010). The current findings matched those of Hell and Mutegi (2011), who found that moisture and temperature influenced A. flavus post-harvest contamination of stored commodities. Okello et al. (2010) claimed drying reduced pod moisture content to 8-10%, appropriate for storage.

Groundnut Pods

From the analysis of the research on the groundnut pods, in the Open Sun Drying (1A, 2A and 3A), the initial average weight of the pods was 281.6 grams and the final average weight was 200.9 grams. This showed a total weight loss of 80.7 grams, which translated to 11.5 grams per day or 0.5 grams per hour for the 7 days. In terms of percentage, it translated to 28.7% weight loss which was 4.1% per day or 0.17% weight loss per hour for the 7 days. The moisture content changed from the initial average of 24.1% to the final average of 6.5%. This translated to a loss of 17.6% for the 7 days or 2.5% per day. The moisture loss per hour was 0.1% per hour for the 7 days.

The data of the groundnut pods on the solar drier with single cover (1B, 2B and 3B) showed an initial average weight of 282.3 grams and final average weight of 194.5 grams. This showed a total weight loss of 87.5 grams for 3 days which translated to 29.2 grams per day or 1.22 grams per hour. The percentage of weight loss was 31.0% for 3 days which translated to 10.3% per day or

0.43% per hour. The moisture content changed from the initial average of 24.6% to the final average of 3.03%. This showed a 21.57% moisture loss which was 7.2% per day or 0.3% per hour for the 3 days.

The Greenhouse effect drier (1C, 2C and 3C) took 1 and ½ days to completely dry the groundnut pods from the initial average weight of 282.0 grams to the final average weight of 192.4 grams. This translated to average weight loss of 89.4 grams, which was 59.6 grams per day or 3.31 grams per hour for the 1 and ½ days. The percentage weight loss was 31.7% for the 1 and ½ days of drying. This translated to 21.13% per day or 1.17% per hour. The percentage moisture loss was from the initial average of 24.3% to the final average of 2.23% which translated to 14.71% per day or 0.82% per hour for the 1 and ½ days.

Groundnut Kernels

The analysis of the research findings showed that the data collected for the groundnut kernels in the open sun drying (1A, 2A and 3A) had the initial average weight of 306.17 grams and the final average weight of 205.1 grams. This showed a total weight loss of 101.07 grams, which translated to 8.42 grams per day or 0.35 grams per hour for the 12 days. In terms of percentage, it translated to a total of 33.0% weight loss which was 2.75% per day or 0.11% weight loss per hour for the 12 days. The moisture content changed from the initial average of 38.1% to the final average of 10.8%. This translated to a total moisture loss of 27.3% for the 12 days or 2.28% per day. The moisture loss per hour was 0.1% per hour for the 12 days.

The data analysis for the solar drier with single cover (1B, 2B and 3B) showed an initial average weight of 306.6 grams and final average weight of 201.3 grams. This showed a total weight loss of 105.3 grams for 6 days which translated to 17.55 grams per day or 0.73 grams per hour. The total percentage of weight loss was 34.34% for the 6 days which translated to 5.72% per day or 0.24% per hour. The moisture content changed from the initial average of 37.8% to the final average of 8.2%. This showed a total of 29.6% moisture loss which was 4.9% per day or 0.21% per hour for the 6 days.

The Greenhouse effect drier (1C, 2C and 3C) took 3 days to completely dry the groundnut kernels from the initial average weight of 308.6 grams to the final average weight of 199.0 grams. This translated to a total average weight loss of 109.6 grams, which was 36.5 grams per day or 1.5 grams per hour for the 3 days. The total percentage weight loss was 35.4% for the 3 days of drying the kernels. This translated to 11.18% per day or 0.5% per hour. The percentage moisture loss was from the initial average of 38.1% to the final average of 7.0% which translated to 10.3% per day or 0.43% per hour for the 3 days.

Table 3: Quality of Nuts after drying: Hand Shelling (Sample of 100 Pods each)

QUALITY OF NUTS AFTER DRYING (HAND SHELLING 100 PODS WITH GROUNDNUTS KERNELS)							
Samples(n)	**No. of pods dried with pods**	**No. of Kernels dried with pods**	**No. of Shrinked nuts**	**No. of quality dried**	**% Shrinked nuts**	**% Quality of Drying**	**% Post-Harvest Loss**
1A	100	212	37	185	17.45	82.55	17.45
2A	100	207	32	185	29.93	70.07	29.93
3A	100	243	39	194	16.05	83.95	16.05
1B	100	230	23	207	10.00	90.00	10.00
2B	100	220	24	199	10.90	89.10	10.90
3B	100	212	23	193	10.80	89.20	10.80
1C	100	261	13	240	5.01	94.99	5.01
2C	100	243	12	233	5.02	94.98	5.02
3C	100	231	13	122	5.60	94.40	5.60

The open sun-drying technique yielded an average of 78.9% quality dried nuts and 21.1 % loss in every 100 pods dried. The Solar drier with single cover yielded an average of 89.4% quality dried nuts and 10.6 % loss in every 100 pods dried. The greenhouse effect drier yielded an average of 94.8% quality dried nuts and 5.2 % loss in every 100 pods dried. The greenhouse effect drier offered the best green opportunity in obtaining the highest quality of groundnuts kernels with very minimal losses.

Statistical Analysis: Analysis of Variance (ANOVA)

(1) The percentage moisture content of the groundnut varieties was measured at the end of the first three days and the following tables were developed for the purpose of ANOVA:

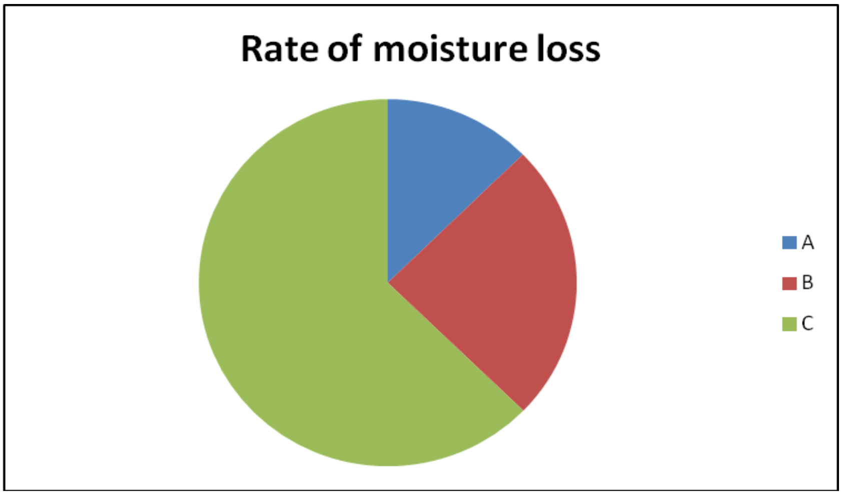
One way ANOVA Tables with 5% significance ($\alpha = 0.05$) and their corresponding F Critical Values were used to determine the validity of hypothesis, whether there existed an observable difference among the drying methods viz Open Sun Drying (A), Solar Drier with Single Cover (B) and Solar Drier with Double Cover (C) and the Two-way ANOVA was used to detect whether there existed variation in drying each groundnut variety viz Virginia (1), Runner (2) and Red Valencia (3) which are locally known as Nyadongo, Nyakipingi and Nyaela, respectively in the three drying technologies. The degrees of freedom were calculated; and the F ratio was used to judge whether the difference among the several drying methods was significant or just a matter of sampling fluctuations.

Data Presentation

(a) Average rate of moisture content loss in the three driers per hour

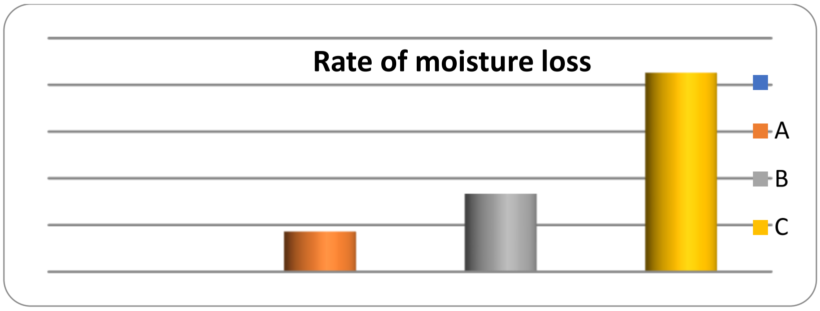
Drying Technology A	Drying Technology B	Drying Technology C
0.0861	0.1669	0.426

Key: A - Open Sun Drying; B - Solar Drier with Single Cover; C - Solar Drier with Double Cover



Key: A - Open Sun Drying; B - Solar Drier with Single Cover; C - Solar Drier with Double Cover

Figure 3: Average Rate of Moisture Content Loss in the Three Driers per Hour.



Key: A - Open Sun Drying; B - Solar Drier with Single Cover; C - Solar Drier with Double Cover
Figure 4: Average Percentage Quality of Nuts Dried using the Three Different Technologies.

Drying Technology A	**Drying Technology B**	**Drying Technology C**
77.33	88.33	92.00

Key: A - Open Sun Drying; B - Solar Drier with Single Cover; C - Solar Drier with Double Cover

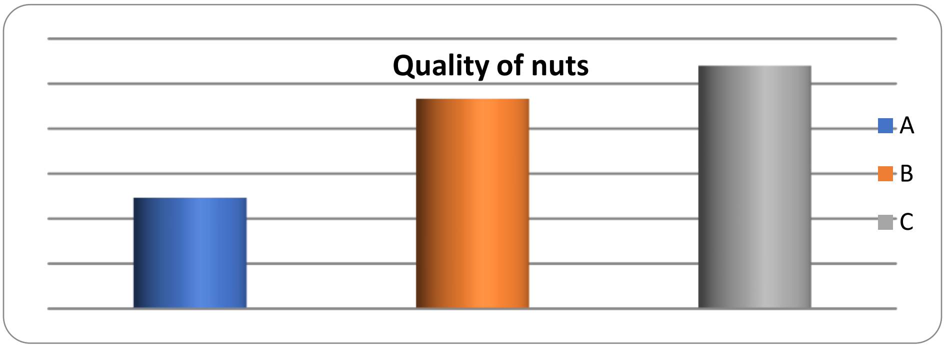
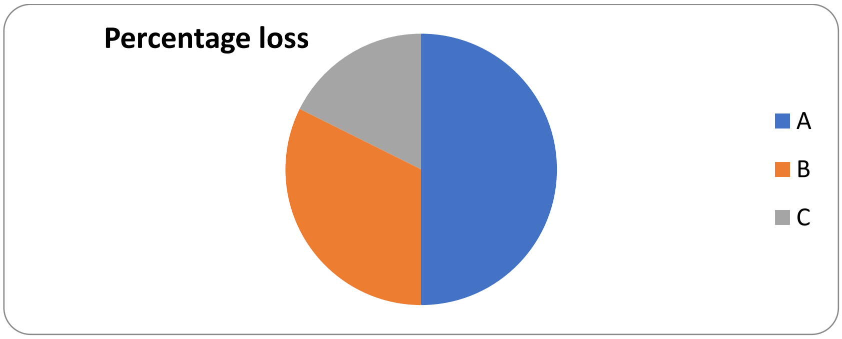


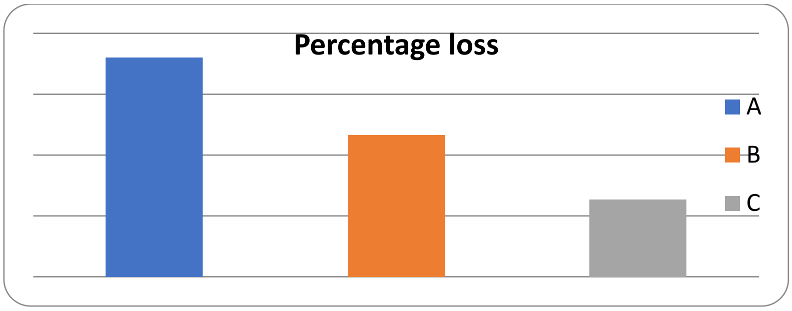
Figure 5: Percentage Loss: Groundnut Kernels Shrunk during Shelling.

Drying Technology A	**Drying Technology B**	**Drying Technology C**
36.0	23.3	12.7

Key: A - Open Sun Drying; B - Solar Drier with Single Cover; C - Solar Drier with Double Cover



Key: A - Open Sun Drying; B - Solar Drier with Single Cover; C - Solar Drier with Double Cover
Figure 6: Loss by Groundnut Kernels Shrunk during Shelling.



Key: A - Open Sun Drying; B - Solar Drier with Single Cover; C - Solar Drier with Double Cover
Figure 7: Percentage loss by groundnut kernels shrunk during shelling.

Relationship between the Drying of the Pod and the Kernel

Regression analysis was computed to establish an equation fore predicting the moisture content of the kernel when the moisture content of the pod is known.

Table 4: Regression analysis between the drying technology and open sun drying

Pods: X **Kernels: Y**				
X	Y	X^2	Y^2	XY
24.1	38.1	580.81	1451.61	918.21
21.1	35.4	445.21	1253.16	746.94
20.9	35.0	436.81	1225.00	731.50
19.9	34.1	396.01	1162.81	678.59
19.5	33.9	380.25	1149.21	661.05
19.4	31.8	376.36	1011.24	616.92
$\sum X = 124.90$	$\sum Y = 208.30$	$\sum X^2 = 2615.45$	$\sum Y^2 = 7253.03$	$\sum XY = 4353.21$

Drying Technology - Solar Drier with Single Cover

Pods: X **Kernels: Y**				
X	Y	X^2	Y^2	XY
24.6	37.8	605.16	1428.84	929.88
20.0	33.7	400.00	1135.69	674.00
15.5	33.1	240.25	1095.61	513.05
11.1	29.4	123.21	864.36	326.34
11.1	28.5	123.21	812.25	316.35
11.1	26.2	123.21	686.44	290.82
$\sum X = 93.40$	$\sum Y = 188.70$	$\sum X^2 = 1615.04$	$\sum Y^2 = 6023.19$	$\sum XY = 3050.44$

Drying Technology - Solar Drier with Double Cover

Pods: X **Kernels: Y**				
X	Y	X^2	Y^2	XY
24.3	37.7	590.49	1421.29	916.11
10.1	31.1	102.01	967.21	314.11
5.1	24.4	26.01	595.36	124.44
5.1	9.4	26.01	88.36	47.94
5.1	7.1	26.01	50.41	36.21
$\sum X = 49.70$	$\sum Y = 109.70$	$\sum X^2 = 770.53$	$\sum Y^2 = 3122.63$	$\sum XY = 1438.81$

Table 5: Relationship between the drying of the pod and the kernel

Drying Technology	**Correlation Coefficient**	**Analysis**	**Regression Equation**
Open Sun Drying	0.94	There is high correlation between the drying of the pod and the kernel, about 94%	a= 11.66 b= 1.107 Y=11.66+1.107X
Solar Drier with Single Cover	0.94	There is high correlation between the drying of the pod and the kernel, about 94%	a= 20.54 b= 0.701 Y=20.54+0.701X
Solar Drier with Double Cover	0.78	There is high correlation between the drying of the pod and the kernel, about 78%	a= 9.416 b= 1.26 Y=9.416+1.26X

Drying Technology: Open Sun Drying

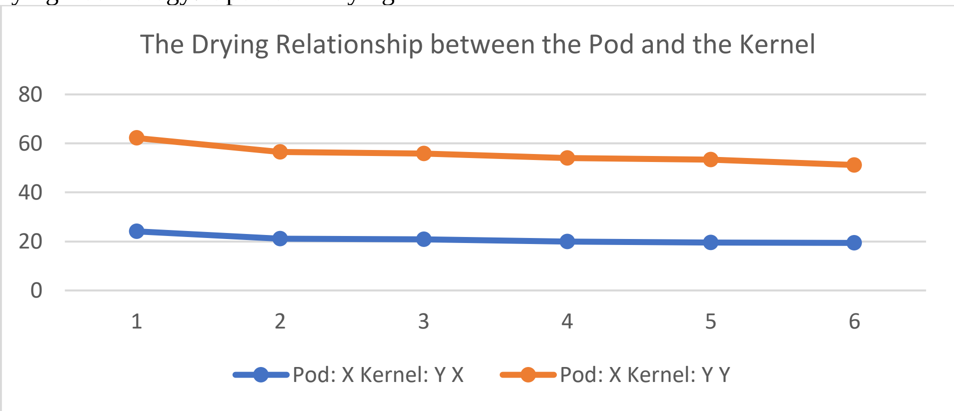


Figure 7: Drying Relationship between the Pod and the Kernel in Open Sun Drying.

Drying Technology: Solar Drier with Single Cover

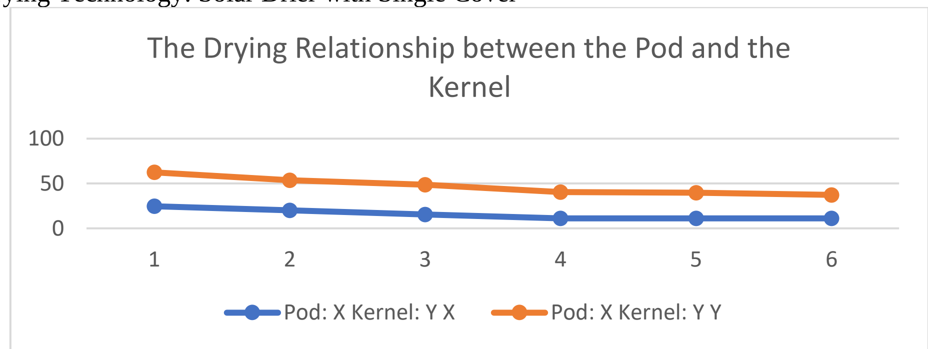


Figure 8: Drying Relationship between the Pod and the Kernel in Solar Drier with Single Cover.

Technology: Solar Drier with Double Cover

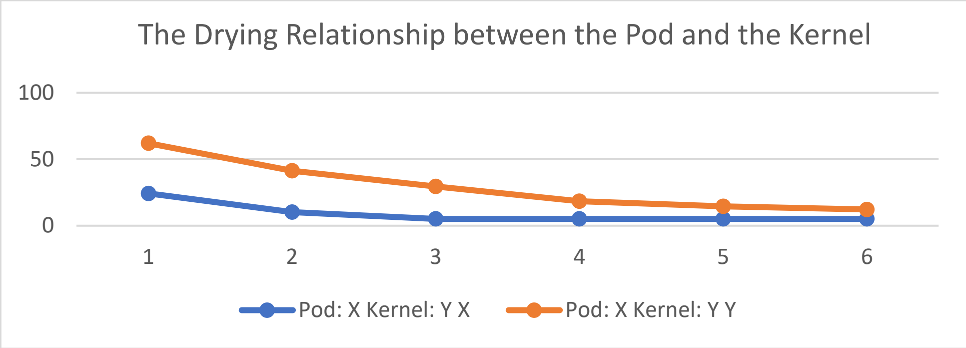


Figure 9: Drying Relationship between the Pod and the Kernel in Solar Drier with Double Cover.

Open sun drying: There is a high correlation between the pod and the kernel, of about 0.94 (94%). From the regression equation Y=11.66+1.107X, it is established that if the pod has dried up to 5.1% Moisture Content, the Kernel will still have 17.3% moisture content, which is not suitable for storage, as this may accelerate the aflatoxin rate.

Solar Drier with Single Cover: There is a high correlation between the pod and the kernel, of about 0.94 (94%). From the regression equation Y=20.54+0.701X, it is established that if the pod has dried up to 5.1% Moisture Content, the Kernel will still have 24.0% moisture content, which is not suitable for storage, as this may accelerate the aflatoxin rate.

Solar Drier with Double Cover: There is a high correlation between the pod and the kernel, of about 0.78 (78%). From the regression equation Y=9.416+1.26X, it is established that if the pod has dried up to 5.0% Moisture Content, the Kernel will still have 15.72% moisture content, which is not suitable for storage, as this may accelerate the aflatoxin rate.

The performance of the existing drying technologies was evaluated based on drying temperature and relative humidity. Muitia et al. (2018) found that both drying procedures reduced aflatoxin contamination on groundnut kernels to less than 20 ppb. The A-Frame approach had lower levels of aflatoxin (12 ppb) than the tarpaulin method.

For the third objective, from the analysis of the research on the groundnut pods and kernels, in the Open Sun Drying (1A, 2A and 3A), the moisture content of the pods changed from the initial average of 24.1% to the final average of 6.5% while the kernels' moisture content changed from the initial average of 38.1% to the final average of 10.8%. For pods, this translated to a loss of 17.6% for the 7 days or 2.5% per day. The moisture loss per hour in the pods was 0.1% per hour for the 7 days. For kernels, this translated to a total moisture loss of 27.3% for the 12 days or 2.28% per day. The moisture loss per hour was 0.1% per hour for the 12 days. These results imply that the rate of drying of groundnut pods is higher than the rate of groundnut kernel within the same pod. This can be attributed to the pod thickness and the pod characteristics such as porosity that influence the rate of drying of the kernels. Generally, the study concluded that the pod dries faster than the kernel giving a wrong impression to the farmers on the actual drying status of the kernel within the same pod. Most farmers assumed that when the pod is completely dry the kernel is also dry. This results to storage of kernels at a wrong moisture content causing easy colonization by aflatoxin and huge post-harvest losses. Open sun drying has proven inefficient and less effective in drying groundnuts kernels to a safe storage moisture content of between 8- 10% within a short period.

The data of the groundnut pods and kernels on the Solar drier with single cover (1B, 2B and 3B), showed that the moisture content of the pods changed from the initial average of 24.6% to the final average of 3.03% while for the kernels the moisture content changed from the initial average of 37.8% to the final average of 8.2%. For the pods, it showed 21.57% moisture loss which was 7.2% per day or 0.3% per hour for the 3 days an initial average weight of 282.3 grams and final average weight of 194.5 grams. For the kernels, it showed a total of 29.6% moisture loss which was 4.9% per day or 0.21% per hour for the 6 days. The study concluded that the rate of drying of the pods is also higher than the kernels within the same pod due to pod characteristics. The results also indicated that the rate of drying for Greenhouse effect is higher than the Open Sun Drying. This drying technique also took a lesser period of 6 days to dry groundnuts kernel to safe storage moisture content of 8.2%.

The Modified Greenhouse Effect (1C, 2C and 3C) took 1 and ½ days to completely dry the groundnut pods from the initial moisture content of 24.3% to the final average of 2.23% which translated to 14.71% per day or 0.82% per hour for the 1 and ½ days while the groundnut kernels took 3 days to completely dry from the percentage moisture of 38.1% to the final average of 7.0% which translated to 10.3% per day or 0.43% per hour for the 3 days. It offered the shortest time possible to dry groundnut kernels to a safer moisture content of 7% for storage.

In this study, the performance of the existing drying technologies was evaluated for effective groundnut drying based on drying temperature, relative humidity and final moisture content attained by kernels for safe storage. Muitia et al., (2018) observed that the two drying methods were effective in prevention of postharvest losses on groundnut kernels. The results of this study, therefore, have indicated that the greenhouse effect drier have a huge potential in mitigating postharvest losses in groundnuts by offering a pathway for improved green drying that gave lowest chances of aflatoxin colonization and the highest quality of dried nuts.

CONCLUSIONS

To increase the moisture content of the groundnut kernels increases the porosity and true density of the groundnut kernels. Moisture content increased geometric mean diameter, sphericity, and surface area.The study of moisture dependent agricultural properties ensures a longer shelf life. The drying technologies under study were open sun drying, natural circulation greenhouse effect solar drier and the modified natural circulation greenhouse effect drier. The Open sun drying depended on the prevailing atmospheric weather conditions in drying groundnuts, while the greenhouse effect solar drier and the modified greenhouse effect solar drier offered an opportunity for the farmers to dry their kernels irrespective of the prevailing weather conditions and with a lesser duration, due to their improved designs that could allow storage of heat for overnight drying. The natural circulation greenhouse effect solar driers availed an economic and a green avenue for mitigating post-harvest losses in groundnuts without using additional energy inputs.

After drying the groundnut kernels continuously and simultaneously for 3 days using the three techniques, the research findings for the Modified Greenhouse Effect solar drier recorded final moisture content of 7.1% while the Greenhouse Effect solar drier and Open Sun Drying technologies recorded final moisture content of 27.4% and 32.8% respectively on the same day. The two latter methods therefore took 6 and 12 days respectively to dry the pods up to final moisture content of 8.2% and 10.8% respectively. This study concluded that the Modified Greenhouse Effect solar drier offered the best alternative to dry groundnuts to safe moisture content within the shortest period. This could also lead to reduced drudgery in groundnut drying and significant reduction in postharvest loses resulting from delays in drying.

According to findings, majority of the farmers in Khwisero Sub County Kenya dried their groundnuts using open sun-drying technique for average of 11-12 days. The period of drying was shorter in the periods of sunny hot weather but slower during the rainy and cold weather. However, some farmers mixed the subsequent harvests with the kernels already drying and this made it difficult to determine the exact number of days of drying, coupled with the possibility that some kernels may not dry properly, a situation that makes the kernels susceptible to aflatoxin. The study established that there is an existing gap in the adoption and utilization of the available solar drying technologies by groundnut farmers. These green opportunities remain unexploited and the area has abundant solar insolation throughout the year. This poor uptake of the technology can be attributed to lack of evidenced based information on the performance of existing technologies. This has resulted to aggravated post-harvest losses in groundnuts which are a significant crop to the livelihoods of Khwisero dwellers, an area with a huge potential for green drying endowed with vast technologies.

RECOMMENDATIONS

The study recommends the adoption of the modified greenhouse effect solar drier by Khwisero farmers as a strategic approach in mitigating postharvest losses in groundnuts by offering a pathway for improved green drying that gives the lowest chances of aflatoxin colonization and the highest of quality nuts. There is need for a cost-benefit analysis for the adoption of the modified greenhouse effect solar drier by groundnut farmers.

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