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RESEARCH PAPER OPEN ACCESS

Integrating storage structures and store time in maize grains postharvest losses evaluation in Northern Zone of Tanzania

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Abstract

Maize is the most important cereal crop in Tanzania, thus its postharvest losses are a big threat to food security. This study integrated maize store-time with five storage methods namely Perdue Improved Cowpeas Storage bags (PICS), Metal Drums, *Kihenge*, Polyethylene bags with insecticides and Polyethylene bags without insecticide. Trials were established following a randomized complete block design with five treatments at Kilimanjaro, Arusha and Manyara, and treatments were monitored for weevil's infestation for six months consecutive. The results showed PICS bag was the most efficient storage method in minimizing insect damaged kernels as it only contributed to 1% of the insect damaged kernels, while other methods such as Metal drum, *Kihenge* Polyethylene bag with insecticide and Polyethylene bag without insecticide resulted in 4%, 23 %, 29%, and 43% insect damaged kernels respectively after six month store–time. The correlation matrix showed similar results with coefficients of correlation–0.378, –0.272, 0.045, 0.037 and 0.516 respectively. With regards to store-time PICS bag and Metal drum had the lowest number of insect damage throughout six-month store-time. Polyethylene bag with insecticide was able to keep the kernel insect free only for three months while Polyethylene bag without insecticide kept grains free of weevil infestation only for one. There was no suggesting time to store grains using *Kihenge* due to its fewer numbers of observations.

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Introduction

Maize (*Zea mays* L.) is a primary cereal and one most important food and cash crop aregrown in almost every agro-ecological location in Africa (Suleiman and Rosentrater, 2015). Tanzania as one of the Sub-Saharan African countries, maize is a central source of earnings and caloric intake, amounting 20% of the cereal-based dietary sources (Jones *et al.,* 2011).

In the country, maize is grown twice a year in two rainfall seasons i.e. long rains 'Masika' and short rains 'Vuli' (Verheye, 2010). Maize contributes about 20% of the country Gross Domestic Product (GDP), over 30% household income, 60% of dietary calories and 50% of protein intake (Suleiman and Rosentrater, 2015; Amani, 2004, URT –MAFC, 2013). Average maize yields in Tanzania under farmers conditions is about 1.4t/ha, which is quite low (FAO, 2015). Inspite of bimodal rainfall and favorable conditions for maize production in the Northern Zone of Tanzania i.e Arusha, Kilimanjaro, and Manyara, contributes 10-15% of the total yield (Zorya and Mahdi, 2009).

In order to secure the little production we have, there should be a determined strategy on modeling storage structure and its store-time so that the produced grains will endup being consumed with the intended community rather than storage insect pest. In most of developing countries, postharvest losses of maize grain are significantly higher, ranges 20–30% of the produced grain, storage insects account for up to 40% of the physical value and nutritional value of grain degradations (Chomchalow, 2003; Matthews, 2006; Kumar and Kalita, 2017). Despite the facts that, assurance of proper improved storage structures boost up food availability at the household level (Proctor, 1994; Holst *et al.,* 2000), yet Tanzania government have geared much emphasis on increasing agricultural production and its productivity, with little efforts on modeling prevailing storage structures in relation to store-time as a way forward towards postharvestlosses minimization.

Furthermore, most of the Tanzanian farmers in Northern Zone rely on traditional storage facilities such as raised grass–thatched, mud–plastered hut on pillars and *Kihenge* for food and seed preservations (Rugumamu, 2003; Makalle, 2012), ignoring the improved storage techniques such as metal silos, hermetic bags, and warehouses facilities. Basically, traditional storage facilities hold are highly preferred compared with improved one because they are relatively simple and accessible with minimum investment cost. Studies have been conducted on the promotion of improved storage structures (De Groote *et al.,* 2013; Teferra *et al.*, 2012;William *et al.,* 2017) with no considerations on modeling the prevailing traditional structures store-time, knowing that, farmers are diverse in purchasing power and innovation adaptation i.e. early adopter, late adopters, and laggards.

Farmers need to be well informed on the contributions of store-time and storage structure in insect damaged kernels as one of their decision supporting tools for enhancing household food safety and security which is the main focus of this study. This work intends to establish a clear link between storage structure and store-time by recommending proper store time for each structure.

The main research questions are; is there any significant difference in maize postharvest losses under various storage structures? Second, what is a recommended length of time for maize storage under various structures as far as maize postharvest losses are concerned? In this study, maize postharvest losses have been defined in the context of storage moisture trends, storage structures, store time and degree of insect damaged kernels.

Methodology

Description of the study sites

This study was conducted in the Northern Zone of Tanzania particularly in Manyara, Arusha and Kilimanjaro regions. Three Districts were purposively chosen in each of the three regions .The Districts by regions include: Manyara (Babati, Hanan'g,and Mbulu), Arusha (Monduli, Arumeru and Karatu), and Kilimanjaro (Siha, Hai and Moshi rural) (Fig 1).

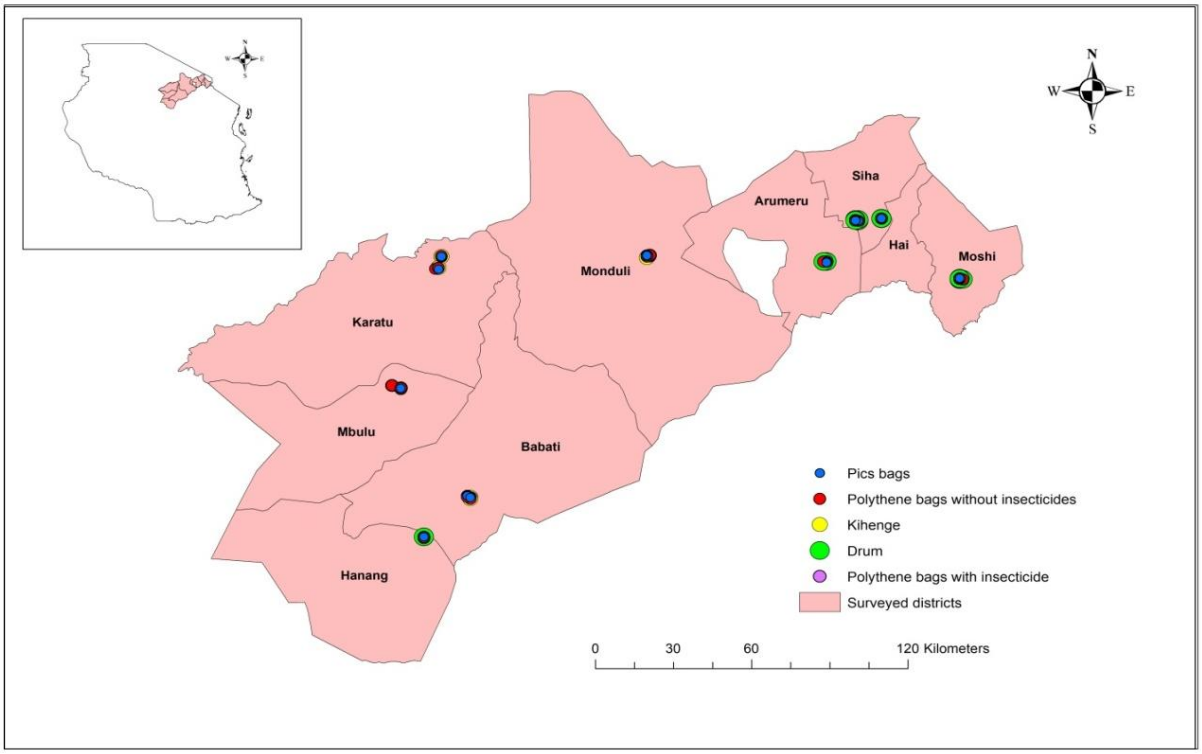

Fig. 1. Study locations and distribution of maize storage structures in the Northern Zone of Tanzania.

The Districts were selected due to the fact that they are the major maize growing areas of the north Tanzania, and also based on their production statistics and preference by Taking Maize Agronomy into Scale in Africa (TAMASA) project which funded this research.

Household sample selection

The sampling frame was the maize farming households in the study Districts. Random sampling from 10x10km grids was established in the study Districts based on GPS coordinates. From each 10mx 10m grid, three 1km x1km grids were randomly selected. In each of this 1km x 1km grids12 households were randomly selected for enumeration. A survey included 270 households (30 households from each District). The survey was conducted between August 2017 and May 2018. Semi-structured questionnaires were used to collect data on the household social economic profile, marketing aspects and number of farmers growing different crops in the study area growing different crops. In total, 591 farmers were covered for this assessment. In addition to the household interviews, Focus Group Discussions (FGD) was conducted, with the involvement of Agricultural extension staffs so as to get in-depth qualitative information of storage structures and their management. After the survey, four households were purposely selected based on their maize storage volume and type of storage structure or methods used. Then the identified methods were used for the study to assess the efficiency of the storage structure.

Experimental design

The experiment consisted of five treatments evaluated in a Randomized Complete Block Design (RCBD) with four replications. The treatments were:

T1: Polyethylene bags without insecticides (untreated control);

T2: Polyethylene bags with insecticide (Actelic supper or Shumba);

T3: Metal Drums without insecticide;

T4: Kihenge without insecticide;

T5: PICS bag without insecticide.

A piped ion stick of about 0.5 m long and 3.5 cm in diameter was used to draw 1kg/household of the maize grains from the top, middle, and bottom of each of the identified storage structure. In total, four maize samples representing four replications were collected in each sampling location. Maize samples were kept in paper bags to prevent moisture alteration and transported to the NM-AIST laboratory for assessment. The same procedure was repeated throughout six-months consecutively i.e. from November 2017 to April 2018. In addition as back up, 100kg of maize grains/treatment from farmer's preferred maize variety were used to test effectiveness of the treatments i.e. in Polythene bags with insecticides, Polythene bags without insecticides (Actelic Super and Shumba from well certified/ registered Agro-dealers depending on farmer's storage preference in each district and rates of insecticide application were based on manufacturer recommendations). PICS bags, Metal Drums filled to their full capacity depending on their sizes and Kihenge also filled to their capacity by farmers. In all cases, the researcher ensured maize grains for all the study farmers were standardized for the required quality to allow for the present experiments.

Maize Grain Sample and Data Collection

A random sample of 1kg grains was drawn from each of storage structures/methods and evaluated for insect damaged kernels. A handheld Grain Moisture Tester (MINIGAC1 was used to collect kernel moisture content. Kernel moisture data were collected on monthly bases from November 2017 to April 2018. Sampled grains were sorted to separate the unbored grain and insect damaged kernels, thereafter counted to calculate the percentage of insect damaged kernels in the sample following formula by Harris and Lindblad, (1978).

$$\text{Percentage of insect damaged kernels} = \frac{\text{Number of damaged grains}}{\text{Total number of grains counted}} x100\%$$

Data analysis

The data were processed and entered into an MS Excel 2010 spreadsheet and analyzed using R statistical software version 3.5.1. Statistical parameters such as frequency distribution table, descriptive statistics tables, Correlation tests, multivariate regression, *P*–values, Coefficient of determinations (R–squared), Akaike Information Criteria (AIC) and variables coefficients were input in model selection criteria based for a Stepwise Regression algorithm. Multivariate regression models were employed leading into the evaluation of maize postharvest losses under selected storage structures with respect to store time, so as to establish levels of maize grains postharvest loss on the identified storage structures with regards to store time. Significant differences in insect-damaged kernels parameters were concluded based on the statistical significance levels of their coefficient of the interaction at $P \leq 0.05$. Furthermore, the Multicollinearity and significance of the predictors were tested based on the Variance Inflation Factor (VIF) for each predictor in the model as suggested by (Zuur *et al.,* 2010).

Results and discussions

Maize Storage Structures in Northern Zone of Tanzania

The results show that, five storage structures/methods namely *Kihenge*, Metal drums, PICS bags and Polyethylene bags with and without insecticides have been identified (Fig.1 and Fig. 5). Polyethylene bags and PICS bags were found to be the most dominant structures in most sites; Metal drums were common storage structure in Siha, Hai and Moshi rural while *Kihenge* were found to be dominant in Babati, Karatu and Monduli as clearly shown in Fig. 1.

The results also indicated that the majority of the maize growers in the study area employ more than one storage structure/method at a time based on the storage purpose and the harvested volumes (Fig. 2).

The most predominant storage structures among sampled households were the Polyethylene bag without insecticide treatment amounting (63%). The second common storage structures were Polyethylene bag with commercial insecticide Shumba or Actellic dust (Fig. 2). Polyethylene bags were either stacked on the floor in an upright position or stacked on top of one another in the kitchen area or in an empty room depending on the number of harvested bags. The *Kihenge* were established close to farmhouses and were observed to be relatively inexpensive in terms of materials, though its construction requires intensive labor. The size of the structures was flexible and based on the grains volume to be stored. This storage structure was not dominant and counted for about 1% of the respondents and they were mainly found in Karatu, Hanang and Babati Districts. Maize grains stored under these structures were not treated with any kind of insecticides.

Table 1. Household demographic characteristics of respondents covered in this study.

Variable	Levels	Percentage
Informal income earned	Yes	10
	No	90
Wage earned	Yes	7
	No	93
Health status	Yes	92
	No	8
Rent land availability	Yes	81
	No	19
Social groups	Yes	35
	No	65
Food security	Yes	44
	No	56

Another storage structure identified in the study area was Metal drums. This structure was highly dominant in Siha and Hai Districts and it accounted for about 7% of the respondents. The capacity of one Metal drum was about 180kg. Maize grains stored in Metal drums were not treated with insecticide or any other treatment and they were mainly kept for household food consumption. The fifth storage structure identified was PICS bags. This structure was adopted by 13% of the sampled households; grains stored were mainly for food consumption.

Table 2. Crops produced in cropping season 2016/17 in Northern zone of Tanzania.

Crop	Percentage	Average harvest/kg/household	Average Price/kg	Average income/Tsh/household
Maize	45.5	2013	577	1,221,017
Sunflower	8.6	1387	2130	2,954,310
Tomatoes	2	1286	345	9,815,154
Beans	12.5	513	1354	576,572
Pigeon peas	15.4	466	1366	679,846
Coffee	2.4	425	2873	921,220
Irish potatoes	4.7	427	439	1,787,900
Other Crops	9.9			

Fig. 5 displays five identified storage structures, there were no separate room for maize storage, the store-room were multipurpose with a lots of stuffs together with maize which might attract destructive organisms such as rodents.

Household Livestock Value in Relation to the Storage Structure

The results also showed that, there was an association between household with livestock and the application of insecticides (Shumba or Actelic dust) as one of storage structure. The average livestock and assets values of the household were 9,362,900.00Tsh and 8,238,150.00Tsh respectively. Majority of the household are both crop farmers and livestock keepers, whereby about 90% of the household own livestock mainly local cow.

This justifies their high purchasing power as well as decisions towards employed storage techniques.

Table 3. Income value of different activities in the study area during season 2017/18 cropping season.

Sources	Average[i]
Off-farm income	670,600/year
Wage and salaries	142,500/month
Remittances	61,039/year
Business	566,950/year
Land rent	69,000/year
Gift	18,700/year
Livestock value	9,362,900.00

[i]The average value was calculated by total value of counted source entities in all household divided by number of household in the study area.

Furthermore, there is an association between household livestock value and the application of insecticides as one of storage method with $\chi 2$ (233) = 279, *P*–value 0.021, whereby the two major insecticides applied were Shumba and Actelic dust. Boughton *et al.* (2007) reported similar findings that there is a high correlation between purchasing power of an individual and value of assets he/she is possessing.

Social Economic Profile of the Study Area

The majority (67%) of respondents had Primary Education and only few had education levels higher than Primary education (Table 1 and Fig. 2). Both males and female were highly involved in the study even though males comprised of 52% of respondents. The majority of respondent were within the age of 15–35. About 61% of the respondents were married. About 90% of the respondents were not employed and 44% of respondents were food secure (Table 1). Other social characteristics are as presented in Table 1.

Table 4. Access to social services by households in the Northern zone of Tanzania in season 2016/17.

Services	Mean distance/Km	Median distance/Km	Maximum distance/Km
Distance from household to the animal market	6.5	5	40
Distance from household to a water source	2.8	0	13
Distance from household to crop market	5.4	4	40
Distance from household to fertilizer shop	7	6	40
Distance from household to certified seed shop	7.7	6	48
Distance from household to health centers	3.6	2	35
Distance from household to extension services	3.2	1	40
Distance from household to the tarmac road	0.3	5	13
Distance from household to electricity sources	3.4	1	25

Crops Production Trend in for 2017/18 Season

From the descriptive statistics (Table 2), maize was the main crop produced by the majority (45.5%) of the farmers with a production average of 2,013kg per acre household during the 2017/18 cropping season generating an average of 1,221,017 Tanzanian Shilling (TSH) per household. The price and total income from other crops in the study area Table 2. In the Northern Zone of Tanzania, maize is the main crop produced by majority of the household and hence standing as the most produced staple food in terms of volume and second cash earning crop, the conclusions are in line with Miller and Hayenga, (2001) who also confirmed that maize contributes to per capita energy consumption and incomes, especially in the developing countries. With this regards, inner grain storage motive is income security to the community.

Table 5. Association between storage structure and insect damaged kernels.

Structures	Metal drum	Polyethylene 1	Kihenge	Polyethylene2	PICS Bag	%IDK
Metal drum	1.000					
Polyethylene1	–0.267	1.000				
Kihenge	–0.086	–0.097	1.000			
Polyethylene 2	–0.334	–0.380	–0.122	1.000		
PICS Bag	–0.260	–0.296	–0.095	–0.371	1.000	
%IDK%	–0.272	0.037	0.045	0.516	–0.378	1.000
P–values	0.114	0.0001***	0.0001***	0.0001***	0.0787	

***, **And * = significant at P ≤0.001, 0.01and 0.05 respectively, Polyethylene 1= Polyethylene bag with Insecticide, Polyethylene 2= Polyethylene bag without Insecticide, IDK= Insect damaged kernels.

Thus modeling of its storage structure with their respective store-time is of high importance so as to attain its equilibrium price.

Average Income from Different Sources andAccess to Social Services by Households in Northern Zone of Tanzania

Data on average income from different sources is presented in Table 3. Livestock had the highest value (9,362,900.00Tsh) followed by off farm income (670,600/year) while income from gifts was the lowest as it was only (18,700Tsh). The values of other income generating activities are as shown in Table 3. Majority of social services can be accessed by the household with an average distance ranging from 2.8km to 7.7km (Table 4). However, few households were located up to 48km away from social service centers (Table 4). Major social services were close to most household within a range of 2.8km to 7.7km which ensure their accessibility. However, some few households were a bit far from the surveyed households (40km), making farmers incur some transportation cost, which in turn could slow down the adoption rate of new technologies. Following Gebremedhin and Hoekstra, (2007) line of thinking, individual's accessibility to extension services is definitely linked to an increase in the adoption rate in improved agricultural technologies.

Table 6. Insect damaged kernels under different maize storage structures/methods in the Northern zone of Tanzania during 2017/18 cropping season.

Storage structure	Total sampled grains	*Total insect damaged kernels	**% insect damaged kernels
PICS Bags	1kg	121	1
Metal drums	1kg	484	4
Kihenge	1kg	2783	23
Polyethylene bag with Insecticide	1kg	3509	29
Polyethylene bag without Insecticide	1kg	5203	43

* Total Damaged grains were counted throughout six months consecutive, **Insect damaged kernels %= (Total insect damaged kernels/ Total grains)*100.

The strong empirical proof exists that shorter travel distances to markets increase the profitability of adopting the yield–rising technologies (Diao *et al.,* 2008). Furthermore, access to social services enhances professional and social interactions among farmers which speedup technology adoption. Taking education level as a major factor toward technology adoption, there were slight variations in education level with regards to gender, females with no education exceed males by 4%, and females with post-secondary education were 2% less compared with males (Fig. 2). As declared by Feder and Slade, (1984), educated farmers are assumed to be early adopters of new technology and are expected to be more knowledgeable of advanced farming systems.

Maize Postharvest Losses under the Prevailing Storage Techniques with Respect to Store–Time

Maize Insect Damaged Kernels under Different Storage Structures: From the correlation matrix shown in Table 5, Polyethylene bags without insecticide had high grain damage with large coefficient of correlation (0.516) and a significant *P*–value of 0.0001, while the least grain damage was found to be on PICS Bags with insignificant coefficient of correlation of –0.378 (Table 5).

Similar results were observed from the total loss percentage calculated, whereby Polyethylene bags without insecticide had about 43% of insect-damaged kernels while insect damaged kernels under PICS bags were 1% (Table 6).

Table 7. Interaction between store–time and insect damaged kernels under PICS bag during 2017/18 cropping season.

Coefficients	Estimates	Std.Error	t–value	*P*–value
Intercept	8.181826	0.050593	161.718	0.001***
IDK (January)	–0.118456	0.045135	–2.624	0.01*
IDK (February)	0.081999	0.042052	1.950	0.05*
IDK (April)	–0.018865	0.009618	–1.961	0.05*

***, **And * = significant at P ≤0.001, 0.01and 0.05 respectively. X=Insect damaged kernels with respect to store-time, Y=Total insect damaged kernels under PICS bag, IDK=Insect damaged kernel.

From the results, PICS bags and metal drum were found to have no association with numbers of insect-damaged kernels with a correlation of coefficient –0.378,–0.272 respectively and *P*–value >0.05 (Table 5). However, polyethylene bag without insecticide were found to have a strong association with insect-damaged kernels with a correlation of coefficient of 0.516. Maize Insect Damaged Kernels under Different Storage–time: Results indicated that maize can be stored in the PICS bags throughout six–month store–time with minimum insect damaged kernels, contrarily to Polyethylene bag without insecticide which showed a significant increase in insect-damaged kernels as store time increases (Fig 4).

In this figure, experiments were set in November 2017 and monitored monthly for six month until April 2018.

Table 8. Interaction between store –time and insect damaged kernels under the Metal drum in 2017/18 cropping season.

Coefficients	Estimates	Std. Error	t–value	*P*–value
Intercept	8.033959	0.040561	198.072	0.001***
IDK (November)	0.123834	0.027238	4.546	0.001***
IDK (December)	–0.029301	0.017265	–1.697	0.09
IDK (January)	–0.056448	0.017459	–3.233	0.001***
IDK (March)	0.056681	0.018410	3.079	0.01**
IDK (April)	–0.018477	0.009217	–2.005	0.05*

***, ** And * = significant at P ≤0.001, 0.01 and 0.05 respectively. X= insect damaged kernels under different store-time, Y= Total insect damaged kernels under Metal Drum, IDK= insect damaged kernels.

It was clear that, normal bags without insecticides was consistently inferior to other methods and high infestation was noted as of month one (i.e. November 2017) Fig 4.

Maize Postharvest Loss under PICS Bags for Six Month Store-time:

PICS bag scored the least coefficient of correlation –0.378 which implies negative associations between storage structure and insect damaged kernels i.e. the more grains stored under PICS bag number of insect damaged kernels reduced by 0.378 units (Table 5). Similar results have been observed from the descriptive statistics, whereby PICS bag was found to be the best in minimizing insect damaged kernels with least contributions (1%) (Table 5). The observed results are in line with Hell *et al.* (2010) that, Purdue Improved Crop Storage (PICS) can preserve maize grain with less than 0.5% dry weight losses over a six month storage period in field tests without the use of chemicals. These results are highly associated with its building design which allows no oxygen circulation, thus there will be neither growth nor development of insect pest invaded grain in the field and on storage. As reported by William *et al.* (2017), the triple plastic linings inside PICS bag significantly hamper oxygen movement within the stored grain resulting in a negative response on the insect survival rate.

Table 9. Interaction between store –time and insect damaged kernels under Polyethylene bag (with and without insecticide) in the Northern zone of Tanzania in 2017/18 cropping season.

Coefficients	Estimates	Std.Error	t-value	*P*-value
Intercept (with insecticide)	8.242355	0.055938	147.347	0.001***
Intercept (without insecticide)	8.263875	0.061862	133.585	0.001***
IDK January (with insecticide)	–0.003121	0.001239	–2.518	0.01**
IDK November(without insecticide)	–0.006950	0.002765	–2.513	0.01**

*** And ** = significant at P ≤0.001 and 0.01 respectively. X=Insect damaged kernels with respect to store-time, Y=Total insect damaged kernels under Polyethylene bag, IDK= insect damaged kernels.

Furthermore, from the generated multivariate linear regression model we found that maize grains can be stored in the PICS bags for six months consecutive with minimum insect damaged kernels considering its insignificant *P*–value 0.06 and least AIC of –135.09 (Table 7 and Model1). The results confer with Bauoa *et al.* (2012) that, PICS bags secure maize grains against storage insect pests with no insect damaged kernels throughout 6 months consecutively. Hence, PICS bags can be regarded as one of the improved storage structures to maize postharvest losses minimizations to sustain food security. In order to stimulate PICS bag adoption rate, there should be deliberate measures from all necessary stakeholders to ensure its accessibility and availability with affordable price contrary to the prevailing one i.e. 5000Tsh/unit which seems to be expensive.

Table 10. Interaction between Storage Structure and Stored Grains Moisture Trends.

Coefficients	Estimates	Std.Error	t –value	P–value
Intercept	8.118699	0.078611	103.277	0.001***
PICS bags	–0.009196	0.007071	–1.301	0.1984
Polyethylene bag without insecticide	–0.009135	0.007675	–1.190	0.2387
Kihenge	–0.003937	0.014860	–0.265	0.7919
Polyethylene bags with insecticide	–0.004321	0.002401	–1.800	0.0769.
Metal drum	0.035733	0.007031	5.082	0.001***

*** = significant at P≤ 0.001.

Model 1: $Y_{\text{Jan, Feb, April}} = 8.18 - 0.12x_{\text{Jan}} + 0.08x_{\text{Feb}} - 0.002x_{\text{April}} + C$

Maize Postharvest Loss under Metal drum for Six Month Store-time:

Metal Drum can be ranked second storage structure in minimizing insect damaged kernels with a coefficient of correlation of –0.272 and *P*–value 0.114, this indicates an inverse association whereby, numbers of insect damaged kernels are decreasing by

0.272 units after grains being stored under this structure. A similar result has been observed from the descriptive statistics accounting about 4% of the insect damaged kernels (Table 5 and 6). The results are similar to De Groote *et al.* (2013) which demonstrated that metal silos (Metal drum) were found to be effective in preventing stored maize against the larger grain borer and maize weevils with no any pesticides applications.

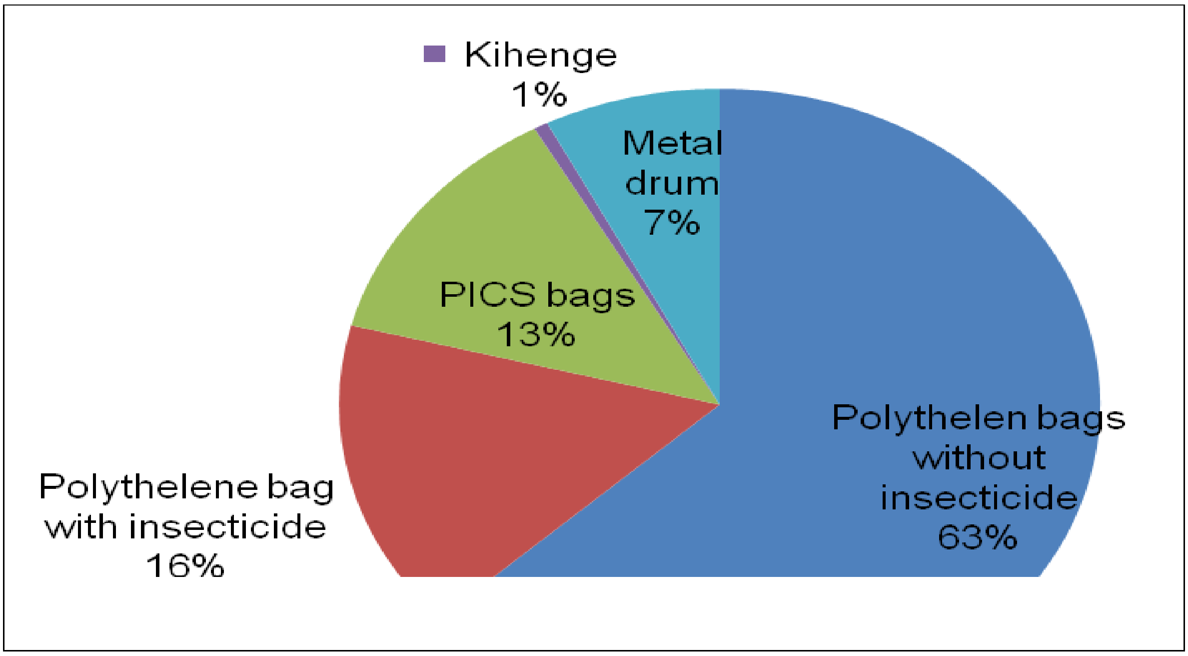

Fig. 2. Distributions maize storage structures in the Northern Zone of Tanzania.

Furthermore, Metal drum in our study proved to be effective in minimizing insect damaged kernels throughout six months store-time with *P*–value of 0.42and AIC of–164.8 (Table 8 and model 2). Metal silos (Metal drums) are effective in controlling maize weevils and the larger grain borer without the use of pesticides for at least four months during storage under conventional storage systems (De Groote *et al.* 2013; Teferra *et al*, 2012). Despite the efficiency observed under metal silo, its adoption involves some challenges such as; high initial investment cost and large storage space for the large storage volume. Regardless of the listed drawback, yet our conclusions are in line with the recommendation by Thamanga–Chitja (2004) that, the use of Metal drums for grain storage results into households food security.

Model 2: $Y_{\text{Nov, Dec, Jan, Feb, April}} = 8.03 + 0.123834x_{\text{Nov}} - 0.029301x_{\text{Dec}} - 0.056448x_{\text{Jan}} + 0.056681x_{\text{March}} - 0.018477x_{\text{April}} + C$

Maize Postharvest Loss under Polyethylene bags for Six-Month Store-time:

To evaluate the maize insect damaged kernels under Polyethylene bag (with and without insecticide) with reference to store–time, the results show that three month store–time was found to be significant for Polyethylene bag with insecticide, while bags without insecticide was only significant after one–month store–time (November) after which it was insignificant (Table 9). Furthermore, Polyethylene bag with insecticide had a coefficient of –0.003with *P*–value 0.01, Adjusted R–squared 0.08andAIC = –137.63, while, Polyethylene bag without insecticide scores a coefficient of –0.007, with *P*–value 0.01, AIC = –137.6 and Adjusted R–squared = 0.07561 (Table 9). Furthermore, from the Multivariate Linear Regression model 3 have been generated to show the relationship between variables.

Model 3: $Y_{\text{Jan}} = 8.242355 - 0.003121x_{\text{Jan}} + C$; $Y_{\text{Nov}} = 8.242355 - 0.006950x_{\text{Nov}} + C$

Polyethylene bags with insecticide are second dominant storage structure in the Northern Zone of Tanzania amounting 16%, whereby the insecticides preferred mostly were Actellic dust and Shumba. Similar to our findings, Kadjo *et al.* (2013) reported that the common insecticide used by 23% of the respondents in maize was Actellic dust. The high response of households toward Polyethylene bags with insecticide as their main storage structure might be highly associated with low cost and regular contact between farmers and extension services as a source of information (considering shorter distance averaging 3.2km). Similar to our findings, Maboudou *et al.,* (2018) asserted in his study that, availability of the insecticides and the applications knowledge fastening adoption.

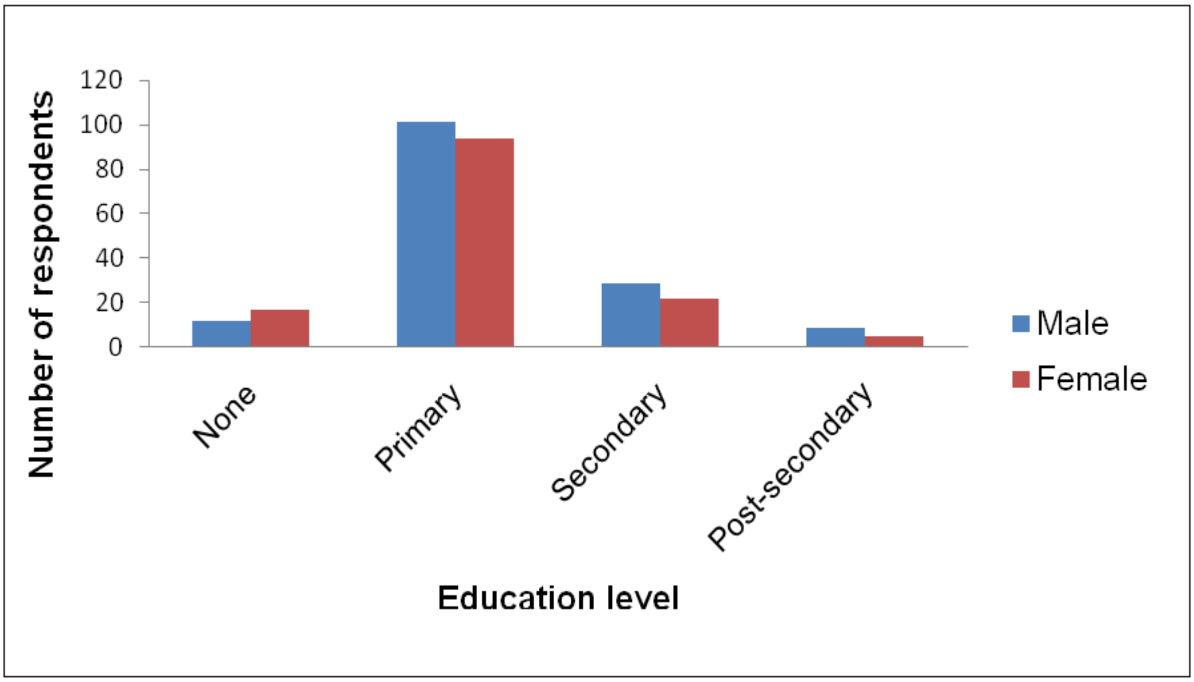

Fig. 3. Education level of respondents covered in this study.

On top of that, Pimentel and Levitan, (1986) reported that the growing trend in the applications of pesticides is highly influenced by its gradual prices increase with a comparison to other agricultural inputs. Regardless of the observed popularity, yet Polyethylene bags with insecticide have a significant contributions on maize postharvest losses amounting 29%, similar results have been observed from the correlation matrix with a coefficient of correlation 0.037 and *P*–value <0.001, this implies that there is an increase of 0.037 units of postharvest losses in the cause of store grains under Polyethylene bags with insecticide

Furthermore, from a multivariate regression models Polyethylene bags with insecticide have a justifiable three month store-time i.e. November, December and January with *P*–value 0.01 AIC = –137.63,any additional store-time resulting in more postharvest losses as shown on (Figure 4). Contrarily to Mutambuki *et al.* (2012) findings, Actellic Dust among others insecticide it is highly effective in controlling *P. truncatus*, *R. Dominica* and *S. zeamais* throughout 24week store time. Therefore, the effectiveness of insecticide depends highly on the infestation level of the household site. Ofosu *et al.*, (1998) documented that, Actellic super dust are efficient in almost three months store-time in low infestation zones. Hence, the insecticide inefficiency observed from the result might be highly associated high infestation zone of the studied area, ignorance of farmers on insecticide application i.e. proper dosage, observing expiring dates, timing and presence of counterfeit insecticide.

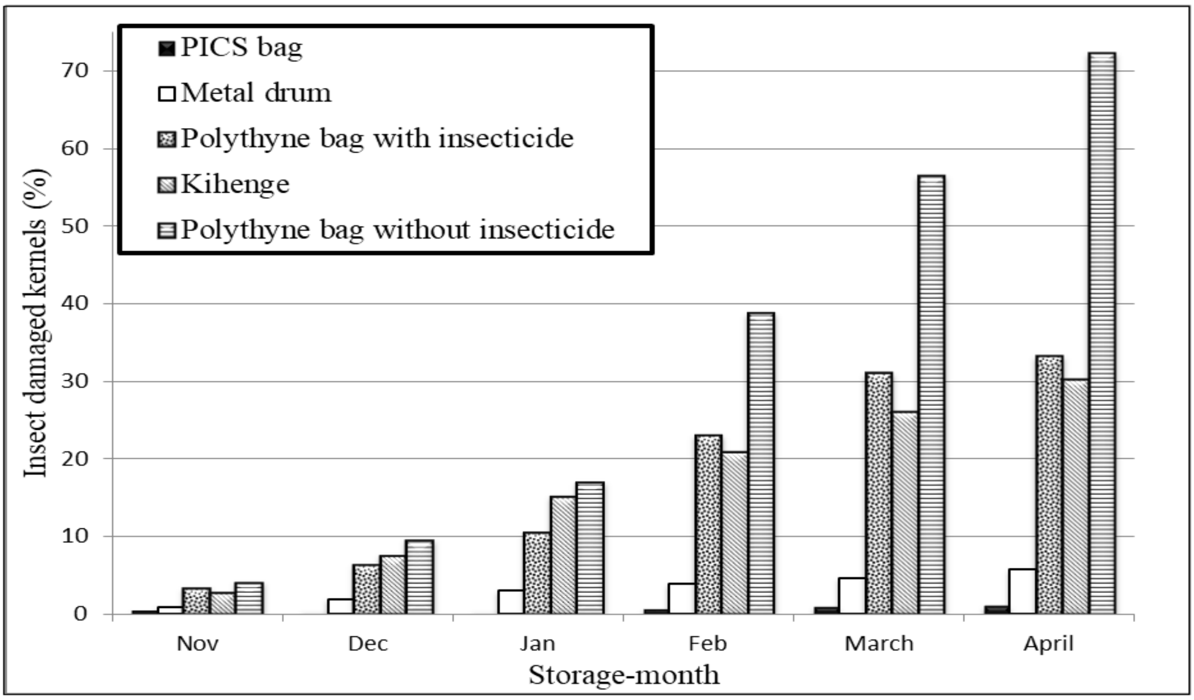

Fig. 4. Link between Insect damaged kernels and store-time during the 2017/18 season.

With regards to farmers preference and taste, modifications on insecticide efficiencies are highly recommend, also much efforts should be geared on sensitization on the reasonable store–time under this structure so that farmers can employ another storage structure or insecticide re–application to secure grain losses. Lastly, there should be personal and physical guidelines from agro–dealers to farmers on recommended dosage, application time, storage conditions, and expiring date etc. instead of relying on the attached leaflet so as to assume its maximum efficiencies.

Maize Postharvest Loss under Polythene bags without insecticide for Six Month Store-time:

Polythene bags without insecticide found to be the dominant storage structure employed with 63% of the surveyed respondents, despite its significant contributions in postharvest losses amounting 43%. Our findings are similar to Udoh *et al.,* (2000) in his study conducted in Nigeria found that the common maize storage structure found in almost all the study area was Polythene bags without insecticide. Furthermore, there is a strong correlation between store-time and insect damaged kernels with a coefficient of correlation 0.516 and *P*–value 0.001, which justify an increase in maize postharvest losses in the cause of store grains under this structure by 0.516 units.

Thamanga–Chitja (2004) reported a similar result that, Polyethylene sacks without insecticide offers tiny defense alongside storage insect pests especially borers. From the result, with an increasing maize store-time under Polyethylene bag without insecticide the high number of insect damaged kernels experienced. Moreover, similar results have been drawn from the multivariate regression model which suggests one-month store-time i.e. November with *P*–value 0.01, AIC–137.6 (Table 9 and model 4). Thamanga– Chitja (2004) reported similar findings that the maize store-time under Polyethylene sacks is almost equivalent to the *Kihenge* store–time which is almost six months with massive grains losses.

The observed inefficient is highly associated with Polyethylene bag building materials which are weak in maize grains protection against insects especially borers, also the possibilities of the stored grains to absorb moisture from the floor in case of direct contact resulting into maize rotting. Thus, improvements and modifications of the Polyethylene bags specifically on suitable building materials is highly recommended with an affordable shifting cost to farmers. Also, farmers should be equipped with necessary Polyethylene bags arrangement technique to avoid direct contact with the ground.

Maize Postharvest Loss under *Kihenge* for Six Month Store-time: In this study, the traditional storage structure *Kihenge* experienced significant insect damaged kernels of about 23%. Similar results have been observed from a correlation matrix showing that, there were a significant number of insect damaged kernels in *Kihenge* with *P*–value <0.001 and correlation of coefficient of 0.045, means that there is a significant association between postharvest losses and grain stored under *Kihenge*, whereby the more grains stored under *Kihenge* the 0.045 units of postharvest loss will be experienced (Table 5 and 6).

There was no any suggested store-time under *Kihenge* basing on the multivariate regression model with a coefficient of intercept 8.15 and *P*–value <0.0001 and this is highly associated with fewer numbers of observations. Basically, *Kihenge* was adopted with only 1% of the total respondents from the baseline survey (Fig 2). World Bank, (2011) also found that the traditional mud granaries *(Kihenge)* are being abandoned due to lack of knowledge on how to construct them, lack of space as they take up a lot of room even when empty compared with sacks, lack of ability to move them rapidly in case of fire or flood and less easy to market the stored grain rapidly.

Fig. 5. Different storage structures identified during the study.

Moreover, *Kihenge* showed an increase in insect damaged kernels with respect to store-time (Fig 4). The situation can be highly associated with this storage structure because they have a lot of pore spaces on the roof, not airtight and highly exposed stored maize grains to sun and rain due to its weak construction and compositions. Thamaga–Chitja *et al.* (2004) reported the similar conclusion that Mud and twig (*kihenge*) contains a lot of holes in its structure which allows rodent and other insect pest access to the stored maize leading into maize losses and grain quality and safety deteriorations. Cracks/holes inside this structure could have acted at the residence for most insect pests (Mhlanga, 2010). Considering its building materials (mud and plant materials), the structure can be easily broken down resulting in maximum airflow as essential element attracting insect pests in storage.

Moisture Content Variations under Different Storage Structure and Store–time

Moisture content in stored grains is an important component in grain physical value. The storage structures are considered to be efficient if moisture can be maintained to the optimum levels throughout the storage time (Cuevas *et al.,* 2016). In this study, the multivariate linear regressions were generated to evaluate the interaction between storage moisture content trends and insect damaged kernels in the PICS bag, *Kihenge*, Metal drum, Polyethylene bags with insecticide and Polyethylene bags without insecticide. From the results, there were no significant variations in moisture content trends throughout six months store–time in other four storage structure except Metal drum with *P*–value 0.01 and coefficient of 0.03573 (Table 10) indicating that there is a positive relationship between moisture content trend and store-time under this structure, whereby an increase in unit store-time resulting in an increase in maize grains moisture content by 0.03573units.

The results can be highly associated with the improper sealing of Metal drum lids and/or building materials as reported during focused group discussions.

The similar scenario has been documented by Yusuf and He, (2011) that, to perfect metal silo protection against rodent and insects pest attacks on the stored grains, airtight sealing is very crucial. Following the same line of thinking, Thamaga–Chitja *et al.,* (2004) in a research conducted in Northern Kwazulu–Natal reported that sampled respondents were tightly sealed the lids of the tanks with cow dung as remedies against maize rot in the cause of tanks sweating. Thus the effectiveness of the structure is highly recommended in the moderate temperature zone following proper grain drying chains.

Conclusion

In Northern Zone of Tanzania, harvested maize grains are usually stored in the traditional storage structures regardless of their efficiency in preventing infestations. Farmers need to be well informed on recommended store-time with respect to their storage structures so as to overcome food insecurity. Furthermore, the simple and affordable moisture meters should be readily accessible to the small–scale farmer, advisory, to be integrated under the input subsidies scheme. Additionally, government and other stakeholders should develop a financial scheme to enable farmer's accessibility to the improved structure with affordable switching cost. Lastly, more studies should be done on the prevailing maize grains drying chain apart from sun drying, to evaluate their efficiencies and intervention measures, considering the contributions of storage moisture content on grain quantity and quality losses.

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References

Amani H. 2004. Agricultural development and food security in sub-Saharan Africa Tanzania Country report. Economic and Social Research Foundation (ESRF), (August). Retrieved from http://www.sarpn.org/documents/d0001583/FAO2005_Casestudies_Tanzania.pdf

Baoua IB, Margam V, Amadou L, Murdock LL. 2012. Performance of triple bagging hermetic technology for postharvest storage of cowpea grain in Niger. Journal of Stored Products Research **51,** 81–85. https://doi.org/10.1016/j.jspr.2012.07.003

Boughton D, Mather D, Barrett CB, Benfica R, Abdula D, Tschirley D, Cunguara B. 2007. Market Participation by Rural Households in a Low-Income Country : An Asset-Based Approach Applied to Mozambique. Faith and Economics **50,** 64–101. https://doi.org/10.1016/j.seares.2010.02.003

Chomchalow N. 2003. Protection of stored products with special reference to Thailand. Assumption University Journal of Technology, ***7*(1),** 31–47.

Cuevas RP, Pede VO, McKinley J, Velarde O, Demont M. 2016. Rice Grain Quality and Consumer Preferences: A Case Study of Two Rural Towns in the Philippines. PloS One **11(3),** e0150345. https://doi.org/10.1371/journal.pone.0150345

Proctor DL. (Ed.) 1994. Grain storage techniques: Evolution and trends in developing countries (No. 109). Food & Agriculture Org.

De Groote H, Kimenju SC, Likhayo P, Kanampiu F, Tefera T, Hellin J. 2013. The effectiveness of hermetic systems in controlling maize storage pests in Kenya. Journal of Stored Products Research **53,** 27–36. https://doi.org/10.1016/j.jspr.2013.01.001

Diao X, Fan S, Headey D, Johnson M, Pratt AN, Yu B. 2008. Accelerating Africa's Food Production in Response to Rising Food Prices. Washington, DC: IFPRI.

Feder G, Slade R. 1984. The acquisition of information and the adoption of new technology. American Journal of Agricultural Economics **66(3),** 312-320. https://doi.org/10.2307/1240798

FAO. 2015. The State of Food Insecurity in the World, 348. Rome. Retrieved from (www.fao.org/publications).

Gebremedhin B, Hoekstra D. 2007. Cereal marketing and household market participation in Ethiopia: the case of teff, Wheatand rice. In AAAE Conference Proceedings, 243-252.

Harris KL, Lindblad CJ. 1978. Postharvestgrain loss assessment methods. Minnesota, America Association of Cereal Chemist, 193.

Hell K, Mutegi C, Fandohan P. 2010. Aflatoxin control and prevention strategies in maize for Sub-Saharan Africa, p 534–541. https://doi.org/10.5073/jka.2010.425.388

Holst N, Meikle WG, Markham RH. 2000. Grain injury models for *Prostephanus truncatus* (Coleoptera: Bostrichidae) and *Sitophilus zeamais* (Coleoptera: Curculionidae) in rural maize stores in West Africa. Journal of economic entomology, August 2000, **93(4),** 1338-1346. https://doi.org/10.1603/0022-0493-93.4.1338

Jones M, Alexander C, Lowenberg-DeBoer J. 2011. An Initial Investigation Of The Potential For Hermetic Purdue Improved Cowpea Storage (Pics) Bags To Improve Incomes For Maize Producers In Sub-Saharan Africa," Working Papers 11-3, Purdue University, College of Agriculture, Department of Agricultural Economics. (September), 44–pages. Retrieved from https://www.researchgate.net/publication/270568951%0AAN

Kadjo D, Ricker-Gilbert J, Alexander C, Tahirou A. 2013. Effects of storage losses and grain management practices on storage: Evidence from maize production in Benin. Agricultural & Applied Economics Association's 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, *2013*., 1–37. https://doi.org/10.1017/CBO9781107415324.004

Kumar D, Kalita P. 2017. Reducing Postharvest Losses during Storage of Grain Crops to Strengthen Food Security in Developing Countries. Foods **6(1),** p 8.

https://doi.org/10.3390/foods6010008

Maboudou AG, Adégbola PY, Coulibaly O, Hell K, Amouzou E. 2018. Factors affecting the use of clay stores for maize in central and northern Bénin.Biological Control Center for Africa, International Institute of Tropical Agriculture (UTA), **8,** 1–7. http://www.regional.org.au/au/asa/2004/poster/4/1/2/1233_maboudou.htm

Makalle AM. 2012. Post Harvest Storage as a Rural Household Food Security Strategy in Tanzania. ARPN Journal of Science and Technology **2(9),** 814–821. http://www.ejournalofscience.org/archive/vol2no9/vol2no9_8.pdf

Matthews G. 2006. Integrated vector management: A new concept. International Pest Control **48(5),** 241–242. https://doi.org/10.1564/v24

Miller DJ, Hayenga ML. 2001. Price cycles and asymmetric price transmission in the U.S. pork market. American Journal of Agricultural Economics, **83(3),** 551–562. https://doi.org/10.1111/0002-9092.001.77

Mutambuki K, Ngatia CM, Mbugua JN, Likhayo P. 2012. Evaluation of the efficacy of spinosad dust against major storage insect pests. Journal of Stored Products and Postharvest Research **3(2),** 19-23. https://doi.org/10.5897/JSPPR11.074

Mhlanga N, Seidler E, Njie D, Gallat S, Lamb J, Morgan N, Diaz Rios L. 2010. FAO/World Bank workshop on reducing postharvestlosses in grain supply chains in Africa. Lessons learned and practical guidelines. FAO Headquarters Rome, Italy, 18-19.

Ofosu A, Compton JAF, Magrath PA, Acquaye, K, Ayertey J. 1998. Cost-effectiveness of different treatment regimes for maize stored in narrow cribs: a preliminary investigation. In Post Harvest Technology and Commodity Marketing: Proceedings of an International Conference, Accra, Ghana, **29,** 226-43.

Pimentel D, Levitan L. 1986. Pesticides: amounts applied and amounts reaching pests. Bioscience **36(2),** 86-91. https://doi.org/10.2307/1310108

Rugumamu CP. 2003. Insect infestation and losses of maize Zea Mays (L) in indigenous storage structures in Morogoro Region–Tanzania. Dar-es-salaam: Tanzania Journal of Science, **29(2),** 1-10. http://dx.doi.org/10.4314/tjs.v29i2.18372

Suleiman RA, Rosentrater KA. 2015. Current Maize Production, Postharvest Losses and the Risk of Mycotoxins Contamination in Tanzania. In *2015 ASABE International Meeting* p 1–28. https://doi.org/10.13031/aim.20152189434

Tefera T, Kanampiu F, De Groote H, Hellin J, Mugo S, Kimenju S, Banziger M. 2011. The metal silo: An effective grain storage technology for reducing postharvestinsect and pathogen losses in maize while improving smallholder farmers' food security in developing countries. Crop Protection, **30(3),** 240–245. https://doi.org/10.1016/j.cropro.2010.11.015

Thamaga-Chitja JM, Hendriks SL, Ortmann, GF, Green M. 2004. Impact of maize storage on rural household food security in Northern KwaZulu-Natal. Journal of Consumer Sciences **32(1).** https://www.ajol.info/index.php/jfecs/article/viewFile/52843/41445

URT-MAFC. 2013. National Agriculture Policy Draft Dar Es Salaam February 2013, 47, Retrieved from HTTP://www.tzdpg.or.tz/fileadmin/documents/dpg_internal/dpg_working_groups_clusters/cluster_1/agriculture/2._Ag_policies_and_strategies/National_ag_policies/1._2013_NATIONAL_AGRICULTURAL_POLICY_-_FINALFebruari_2013.pdf

Udoh JM, Cardwell KF, Ikotun T. 2000. Storage structures and aflatoxin content of maize in five agroecological zones of Nigeria. Journal of Stored Products Research **36(2),** 187-201. https://doi.org/10.1016/S0022-474X(99)00042-9

Verheye W. 2010. Growth and Production of Maize: Traditional Low-Input Cultivation. In: Verheye, W. (ed.), Land Use, Land Cover and Soil Sciences. Encyclopedia of Life Support Systems (EOLSS), UNESCO-EOLSS Publishers, Oxford, UK. http://www.eolss.net

World Bank. 2011. Missing food : The Case of Postharvest Grain Losses in Sub-Saharan Africa, **60371,** 27–40. https://doi.org/10.1038/ncb2790.

Williams SB, Murdock LL, Baributsa D. 2017. Storage of Maize in Purdue Improved Crop Storage (PICS) Bags. PLOS ONE, **12(1),** e0168624. http://dx.doi.org/10.1371/journal.pone.0168624

Yusuf BL, He Y. 2011. Design, development, and techniques for controlling grains postharvestlosses with a metal silo for small and medium scale farmers. African Journal of Biotechnology **10(65),** 14552-14561. http://dx.doi.org/10.5897/AJB11.1845

Zorya S, Mahdi S. 2009. High Marketing Costs and Inefficient Policies in Tanzania's Maize Market. Washington DC, USA: The World Bank Poverty Reduction and Economic Management Africa Region, 24.