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Full Length Research Paper

Performance evaluation of termite-mound clay, concrete and steel silos for the storage of maize grains in the humid tropics

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Inadequate storage facilities have contributed to severe postharvest losses in maize in many developing countries. This study determined the potential of termite mound clay (TMC), a readily-available material in Nigeria for constructing on-farm storage silos. 3 tonnes of maize at 11.2% moisture content (MC) was loaded into each silo for an 8-month storage period. Performance evaluation was done in comparison to conventional silos constructed from reinforced concrete (RC) and galvanized steel (GS) by monitoring temperature and relative humidity inside the silos. Selected quality parameters including moisture, protein, oil, crude fibre, starch, and ash contents were also measured. Observations revealed that temperature trends were similar in all silos. A consistent increase in relative humidity was also observed but was less pronounced in the GS silo (10.6%) compared to TMC and RC silos at 15.8 and 22.2% respectively. Maize quality in TMC, RC and GS silos were found to be similar although at varying degrees, with increasing trends for MC and crude fiber contents and decreasing trends for protein, oil, starch, and ash contents. The silos have comparable performance till the fourth month of storage after which MC was significantly different (p<0.05) across silos. MC on the eighth month in TMC, RC and GS silos were 16.0, 15.1 and 12.7%, respectively. TMC silo was found adequate for short-term storage (<4 months). Construction of silos using local materials has a high potential for adoption and improved resistance of TMC silo to moisture permeation may allow for its use for longer periods.

Key word: Silo, grain storage, postharvest losses, termite mound clay, grain quality.

INTRODUCTION

The survival of a nation depends on her ability to feed her population, which depends on the readily available supply of food products at affordable prices. Sub-Saharan Africa loses about US$4 billion every year due to postharvest losses that include quantitative and qualitative degradation in harvested farm produce (World Bank, 2011; Gitonga et al., 2015). The FAO (2011) likewise reported that food losses in industrialized countries are

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actually as high as in developing countries, but in developing countries more than 40% of the food losses occur at post-harvest and processing levels, while in industrialized countries, more than 40% of the food losses occur at retail and consumer levels. These reports reflect the findings of Adejumo and Raji (2007) where poor postharvest facilities have been a major problem confronting the Nigerian agriculture sector. They estimated the consequential negative effect on the country's economy to be a loss of about 2.4 billion tonnes of food yearly (costing about US$320 Million), a problem associated with poor harvest and storage facilities mainly in maize, rice, sorghum, millet, cowpea, groundnut, soya beans, yam, cassava, plantain and other fruits. Adegbola et al. (2011) also corroborated this by reporting that food insecurity in Nigeria is significantly affected by the inability to preserve harvested produce rather than to low production volumes.

A critical factor in ensuring year-round availability of good quality food products is the provision of adequate and appropriate storage facilities which however, has been a problem in many developing countries (Flake and David, 2009; Makalle, 2012). Safe storage of agricultural produce is a critically important activity in the food supply chain that takes advantage of the surplus during harvest (Kamwendo and Kamwendo, 2014). Storage is important in guarding against shortages during scarcity and famine, providing a balanced diet throughout the year and preparing for emergencies or catastrophes. Good storage maintains the quality of produce for extended periods of time enabling a continuous supply of materials for consumption, cultivation and processing (Jonfia-Essien and Obodia, 2003; Sisman, 2005; Adejumo and Raji, 2007).

A number of factors are responsible for grain deterioration during storage and an understanding of the interrelationship of these factors is necessary to avoid rapid deterioration (Okereke and Nwosu, 1987; Sisman, 2005; Suleiman et al., 2013). Critical factors for the safe storage of grain are moisture content, temperature, and relative humidity as it affects seed life or viability, insect population, bio-deterioration due to insects and moulds as well as the rate at which chemical and enzymatic processes occur (Croissant, 1998; Al-Amri and Abbouda, 2000, 2004; Neeson and Banks, 2004; Gonzales et al., 2009; CGC, 2013). Maier (1993) has noted that an increase in grain moisture content during silo storage primarily affects grains exposed to the airspace at the top of the silo and that storability becomes compromised when the moisture content goes beyond 14.5 to 15%.

Continuous efforts have been made locally and globally to reduce maize postharvest losses in developing countries by introducing various storage facility types. However, the need for appropriate storage structures especially at the farm-level persists in developing countries where limitations in resources and safe storage conditions have to be addressed. Kaminski and Christiaensen (2014) argued that interventions should be incentive compatible and carefully targeted rather than a "one size fits all" approach.

Efforts towards the use of local and readily-available materials for building farm-level storage facilities are shown in the research by Mijinyawa et al. (2007) where termite mound clay (TMC) was used to build storage silos. Based on their study, they showed the prospect of building low-cost storage facility using TMC. Further work was done by Mijinyawa and Omobowale (2013) to evaluate some physical and mechanical properties of TMC as a building material for grain silo. They reported that bricks made from TMC are within the range expected of structural materials that are commonly used for silo construction based on physical and mechanical properties evaluated. These findings corroborated the report by Udoeyo et al. (2000) on the suitability of mound material for construction. Based on these promising results and high potential for local adoption in Nigeria, this study was aimed at the design, construction, and evaluation of farm-scale TMC silo with approximately 3.5 tonne capacity, which will be compared to storage silos of the same capacity but made from reinforced concrete (RC) and galvanized steel (GS). Evaluations were based on the monitored temperature and relative humidity in the three silos and measurements every two months over an eight-month storage period of the variables moisture, protein, oil, crude fiber, starch, and ash contents as performance parameters. It is the goal of this study to be able to provide farm-level options for maize storage made from TMC, a cheap, locally- and readily-available construction material that performs as well, if not better than silos made from the conventional RC and GS materials. Farmers, especially those in remote areas, will have easy access to construction materials that could be used to build their own viable grain storage structures.

MATERIALS AND METHODS

Maize storage silo design and fabrication

The silos investigated in this study were based on grain storage capacity of between 3 to 4 tonnes, which are applicable for storage of produce of small-scale farmers in Nigeria. Three types of maize storage silo with a capacity of 3.5 tonnes was designed and constructed for this study. The types of silo include; (1) termite mound clay (TMC), (2) reinforced concrete (RC), and (3) galvanized steel (GS) silos. The cylindrical shaped silos were designed as shallow based on the ratio of height to lateral dimensions (height = 1.7 m and diameter = 1.9 m**)** giving a storage capacity of 4.8 m^3 or 3.5 tonnes. This design is similar to those reported by Mijinyawa et al. (2007), however the current design had smaller dimension and tests were done fully loaded. Other than the material used for construction of the silos and roofing, all other design parameters such as shape, internal dimensions were the same. The roofing for the TMC and RC silos was the same, that is, corrugated galvanized steel with eaves to assist with keeping water clear off the walls whereas the GS silo had enclosed metal roofing (Figure 1).

Preliminary field inspections were carried out in different places within Ibadan and its environs, Southwestern Nigeria, to identify locations where termite mounds could be found in abundance in

Figure 1. Picture of the completed experimental site showing the termite mound clay silo (front, right-most), reinforced concrete silo (front, left-most) and galvanized steel silo (front, center) with the adjacent weather station (back showing weather vane).

order to promote the concept to local farmers. These included New-Ife Road, Aba Olorunda, Ogunranti village and Igbo Oloyin. Termite mounds were found in all the areas visited but Ogunranti village was eventually selected for sample collection because the site was found to have a higher concentration of mounds compared to the other places visited.

Maize samples

Freshly harvested shelled white maize samples were obtained from the 2010/2011 harvest from Saki, Oke-Ogun area of Oyo state. A sampling of one out of every 10 bags of 100 kg mass indicated a mean moisture content of 11.2% at the point of purchase. Silos were loaded with ~3 tonnes of white maize and stored for a period of 8 months (December 2011 to August 2012), which covered both wet and dry seasons. Maize was loaded through a chute located at the top of the silo and unloaded after storage through a discharge chute located at the base of the silo.

Proximate analysis

Samples for proximate analysis were obtained from grains located at the top of the bin through an inspection widow at the top of the silo. This process was repeated after every two months of storage. The samples were placed in sealed container and immediately refrigerated before being shipped to the laboratory for analysis. A Perten DA7200 NIR Analyzer (Perten Instruments, Springfield, IL) was used to measure selected quality characteristics of whole maize kernels based on NIR calibrations developed by Perten Instruments for bulk measurement of moisture content, protein content, oil content, crude fibre, starch content, and ash content. The full depth standard sample dish with a measuring area of 108 cm^2 was used to hold the maize samples. The instrument was set at the rotate mode and three repeats for each sample being analyzed. There were five sample replicates measured for each type of silo and at each storage period (0, 2, 4, 6 and 8 months).

Monitoring temperature and relative humidity

The temperature and relative humidity (rh) data were collected at the headspace just above the grains in each silo using the Lascar USB-EL-2 data loggers (Lascar Electronics, Erie, PA, USA) that were programmed to record data every five minutes. Likewise, the ambient temperature and rh data were obtained from a weather station that was installed on site (Figure 1). The average daily readings of the data logger were generated and were used to obtain the cumulative two-month temperature and relative humidity by averaging all readings within a two month period. For example, month 2 temperature is the average temperature for the entire Day 1 to Day 60 of the experiment; month 4 temperature is the average temperature for Days 61 to 120, and so on. Day 0 temperature is the initial temperature reading in the bin after it has been filled with the maize samples. The same averaging was followed for the relative humidity data.

Data analysis

Linear regression analysis was used to determine the extent to which temperature and relative humidity influenced selected parameters including: Moisture, protein, oil, crude fiber, starch, and ash contents in each of the maize storage silo. There was one experimental silo for each type of silo, thus an attempt to address simple pseudo replication was done by analyzing data using the mixed model but it is still recognized that inferences for this study be limited as being preliminary or exploratory. The PROC MIXED, adjusted Bonferroni's, and adjusted Dunnett's tests in SAS, Version 9.4 were used to compare means of all measured parameters (SAS Institute Inc., 2013). Analysis were done for each parameter to compare and determine: (a) Effect of storage periods (2-, 4-, 6-, and 8-months) for each type of silo, (b) effect of type of silo (TMC, RC, and GS) at different storage period, and (c) differences of all measured parameters to the control (Day 0). The level of significance for all comparisons was p<0.05.

RESULTS AND DISCUSSION

Effect of temperature and relative humidity on quality of maize stored in different types of silo

The ambient and cumulative 2-month average temperature and relative humidity (rh) for the three types of storage silo (TMC, RC, and GS) for the eight months storage period with results from comparative analysis are shown in Table 1. The overlapped cumulative 2-month average temperature and rh are likewise shown graphically in Figure 2. The decrease in temperature in the TMC silo (4.1°C) was higher than both RC and GS silos with an average decrease of 2.4 and 1.5°C, respectively. Temperature readings inside all three silos followed the trend of the ambient conditions but were consistently higher, which agreed with the findings of Alabadan (2006) where temperatures inside the wooden maize storage bins were likewise higher by about 1 to 5°C than ambient during the wet period in Nigeria (between July and November) and about 8°C higher during the dry period (from December to March). This indicated that outside temperature contributed to warming and/or cooling inside the silo but other factors, such as respiration or possible insect and fungal activities, may have also contributed to temperature changes inside the silos. A comparison of temperature at the same storage time across the three silo types showed no significant differences, except for the higher temperature observed in the RC silo on the eighth month of storage. Significant changes in rh were observed for every two months interval for ambient and all types of silo indicating fluctuations in rh occurred during the entire storage period. Across type of storage structures, the rh in the TMC and RC were similar from 2 to 8 months of storage while the GS silo had consistently lower rh throughout the storage period. The increase in rh on the eighth month of storage in the TMC, RC, and GS were 22.2, 15.8 and 10.6%, respectively. Increasing trend in ambient rh was reflected in the observed increasing trend in rh for all three silos, although at varying rates across types of silo. The ambient rh was consistently higher than readings inside all three silos over the entire storage period, which agreed with the findings of Devereau et al. (2002) where temperature increase resulted in increase of partial pressure at saturation thus, a corresponding decrease in rh.

The combination of changes in both temperature and rh are critical factors that affect the quality of stored maize. Linear regression analysis was performed to determine the extent to which temperature and rh influenced the increase in selected quality parameters (moisture, protein, oil, crude fibre, starch, and ash contents) with results summarized in Table 2. Results indicated that changes for all measured quality parameters were affected more by changes in relative humidity than by changes in temperature, except for moisture content of maize stored in the GS silo where the effect of temperature and rh were similar. Considering that temperature is related to changes in rh, temperature variation throughout the day and night, across seasons and more importantly for long term storage will have corresponding rh changes, which at elevated rh levels will contribute to grain deterioration (Devereau et al., 2002).

In the TMC silo, changes in rh accounted for 54% of the change in moisture content (mc), 55% in protein content (pc), 41% in oil content (oc), 33% in crude fiber content (cfc), 46% in starch content (sc) and 39% in ash content (ac). The change in temperature accounted for 6 to 25% of changes in these quality parameters. In the RC silo, the extent of the effect of changes in rh ranged from 23 to 47%, that is, 47% of changes in mc, 43% in pc, 24% in oc, 23% in cfc, 45% in sc, and 32% in ac. The change of temperature in the RC silo explained 0 to 24% of the changes in all measured quality parameters. For the GS silo, changes in mc were explained by changes in both temperature and rh (18 and 15%, respectively). Changes in pc, oc, cfc, sc and ac (27, 35, 20, 23 and 36%, respectively) were explained by changes in rh while those due to changes in temperature only ranged from 0 to 10%.

Results indicated that quality of maize stored in the GS silo were the least affected by changes in temperature and rh. This may possibly be explained by differences in construction materials where the TMC and concrete are more likely to be susceptible to moisture permeation through pores within their micro-structure while the GS silo practically has zero breathability or porosity. Also, the difference in roof material across silos may explain some of the differences in rh; the GS silo is enclosed while the TMC and RC silo had potential areas where water seepage may occur (Figure 1). While the temperature of the roof was not monitored in this study, Devereau et al. (2002) presented another possible explanation for increased rh inside the silos. They reported that the roof of storage buildings can get cold at night while the air rising from stored grains may be relatively warm and moist; the air can then be cooled and can reach saturation when in contact with the cold roof resulting in condensation on the underside of the roof and corresponding increase in rh.

Effect of duration of storage in TMC, RC, and GS silos on selected maize quality parameters

Table 3 summarizes the results for comparing the effect of storage time on various quality parameters that were

Table 1. Cumulative 2-month average temperature and relative humidity in three types of storage silo at different storage periods.

Type of storage silo	Storage period, months	Cumulative 2-month average	
		Temperature (°C)	Relative humidity (%)
Ambient condition	0	28.7^{a}	66.7^{a}
	2	27.7^{b}(1.2)	65.9^{b}(12.9)
	4	28.3^{ab}(1.3)	74.0^{c}(5.0)
	6	26.1^{c}(1.1)	79.6^{d}(9.0)
	8	25.0^{d}(0.7)	84.9^{e}(3.1)
Termite mound clay	0	$31.6^{a,1}$	$62.5^{a,1}$
	2	$29.6^{b,1}$(1.3)	$63.2^{b,1}$(2.6)
	4	$31.0^{a,1}$(1.4)	$67.9^{c,1}$(2.0)
	6	$29.2^{c,1}$(1.2)	$73.8^{d,1}$
	8	$27.5^{d,1}$(0.8)	$78.3^{e,1}$(0.8)
Reinforced concrete	0	$31.8^{a,1}$	$56.5^{a,2}$
	2	$29.6^{b,1}$(1.3)	$63.2^{b,1}$(3.3)
	4	$30.9^{ab,1}$(1.4)	$68.4^{c,1}$(2.3)
	6	$29.7^{c,1}$(1.3)	$73.8^{d,1}$(2.7)
	8	$29.4^{c,2}$(1.0)	$78.7^{e,1}$(1.7)
Galvanized steel	0	$29.2^{a,2}$	$54.1^{a,2}$
	2	$30.3^{ab,1}$(1.6)	$59.7^{ab,1}$(1.5)
	4	$31.9^{b,1}$(1.8)	$62.0^{bc,2}$(1.0)
	6	$29.8^{ab,1}$(1.9)	$63.0^{bc,2}$(1.0)
	8	$27.7^{c,1}$(1.5)	$64.7^{c,2}$(0.6)

Values enclosed in parentheses correspond to standard deviation for the specific two-month temperature or relative humidity readings. Superscript letters (that is, $XX.X^{a}$) provides comparison of means across the storage periods within the same storage silo type where means with the same letter are not significantly different (Adjusted $p < 0.05$; superscript numbers that follow letters (that is, $XX.X^{x,1}$) compares means for a specific storage period across the three storage silo types with the same number indicating no significant difference (Adjusted $p < 0.05$).

measured every two months for the 8-month storage period in each type of storage silo; these are denoted by the superscript letters indicated in the mean values. Parameters with an increasing trend over the period of storage included mc and cfc while the remaining quality parameters (pc, oc, sc, and ac) showed decreasing trends.

Termite mound clay silo

In the TMC silo, significant increases in mc from the original 11.2% were observed in months 2, 6, and 8 of storage, that is, by 0.6, 1.7 and 2.6% mc increases from its previous 2-month average mc readings, respectively. As already mentioned earlier, this may be because the TMC silo is susceptible to moisture transfer such that substantial increases in rh during these periods may have resulted in increased mc. This increase in mc has repercussions on other potential damages that may be brought about by increased potential for growth of microorganisms that can damage the stored maize samples.

Inversely, there were decreases in pc by 0.3, 0.4, 0.4 and 1.2% in months 2, 4, 6, and 8, respectively. The decrease observed in the eighth month was significantly higher than other storage periods, that is, a cumulative decrease of 2.3% pc from the original pc of maize samples (10.6%). Di Domenico et al. (2015) reported increasing pc for up to the sixth month followed by a decreasing trend. Closer examination of ambient conditions during storage showed that temperature and rh conditions for the two studies were similar only from around the sixth month, which is when the pc values for both studies were observed to decrease. As Di Domenico et al. (2015) indicated, the decrease in pc may possibly be due to the presence of insects and microorganisms, which were observed in the current study to be present (results not shown). Bhattacharya and Raha (2002) also indicated that loss in pc during the early stages of fungi invasion can be explained by proteolysis and formation of simpler compounds such as amino acids, which could be

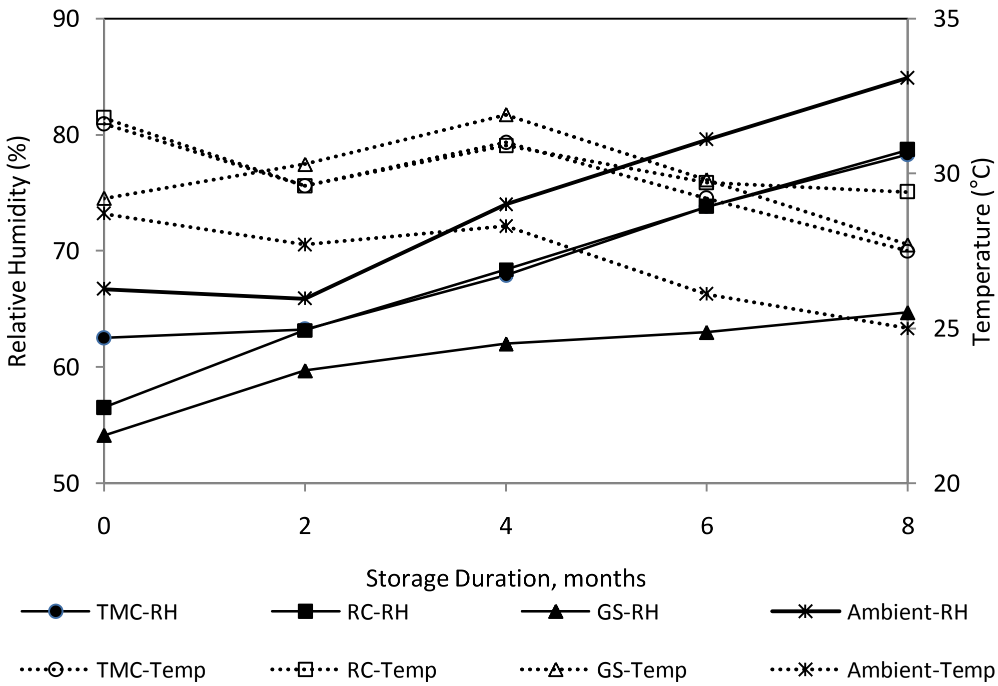

Figure 2. Plot showing cumulative average temperature (Temp) and relative humidity (RH) readings during the eight-month storage period for ambient condition and inside the three types of silo: termite mound clay (TMC), reinforced concrete (RC) and galvanized steel (GS).

utilized by fungi. They noted however that pc may tend to increase later in storage when fungi are present because of the formation of fungal protein that becomes part of the seed pc.

The original maize samples had oc of 5.1%. During storage, no specific trend in increase or decrease in oc was observed. However, the cumulative decrease observed in months 6 and 8 (0.6 and 0.5%, respectively) was significant and accounted for about a 10% decrease in oc. This agreed with the findings of Bhattacharya and Raha (2002) and Simic et al. (2007) with the latter reporting decrease in oc during storage by 0.82% in maize at 25°C/75% rh and 0.55% at storage conditions at 12°C/60% rh. The decrease in oc had been associated with lipid auto-oxidation and increasing free fatty acids concentration with storage time (Bhattacharya and Raha, 2002; Lin et al., 2014).

For CFC, the values remained similar to the original 0.2% for storage periods of 2 to 6 months except on the eighth month when it increased to 0.5%. Considering that crude fiber is mainly concentrated in the seed coat with smaller proportions in the endosperm and germ walls, results indicated that it is likely that no changes affecting the seed coat occurred during the storage period until later, that is, at about the eighth month. It is possible that the presence of insects may have reduced other maize compositions such as starch, which rendered the grain to have higher cfc. It was noted however, that the cfc obtained in this study were generally lower than the typical values provided by FAO (1992) for maize at 0.8 to 2.9%.

The original sample had starch content of 60.6%, which is the major chemical component of maize. It was found to significantly decrease by 1.3% (month 6) and 1.5% (month 7), that is, to 59.3 and 59.1%, respectively. These findings on decreasing sc during storage were consistent with those reported by Bhattacharya and Raha (2002) and Labuschagne et al. (2014), which with prolonged storage was partially associated with increasing population of storage fungi that utilizes starch as a source of energy.

The ac of the samples started at 1.06%, which decreased significantly from months 4, 6, and 8 to 0.91, 0.94 and 0.96%, respectively. This indicated that the total amount of minerals present in the maize lot were reduced starting from about the fourth month of storage in the TMC silo. Ash is mainly concentrated in the bran and observed presence of insects (data not shown) may have an effect on the decreasing ac due to insect feeding and reproduction that may reduce the mineral content of the grains.

Reinforced concrete silo

The trends in changes in quality parameters for maize samples stored in the TMC silo were found to be similar to those stored in the RC silo, that is, increasing trends

Table 2. Summary of linear regression analysis for determination of the effect of temperature and relative humidity on selected maize quality parameters during bulk storage in silos.

Type of storage silo	Quality parameters (%)	Linear regression analysis R^2	
		Temperature (°C)	Relative humidity (%)
Termite mound clay	Moisture content	0.08	0.54
	Protein content	0.10	0.55
	Oil content	0.19	0.41
	Crude fiber	0.07	0.33
	Starch content	0.06	0.46
	Ash content	0.25	0.39
Reinforced concrete	Moisture content	0.05	0.47
	Protein content	0.02	0.43
	Oil content	0.08	0.24
	Crude fiber	0.01	0.23
	Starch content	0.00	0.45
	Ash content	0.24	0.32
Galvanized steel	Moisture content	0.18	0.15
	Protein content	0.01	0.27
	Oil content	0.05	0.35
	Crude fiber	0.00	0.20
	Starch content	0.00	0.23
	Ash content	0.10	0.36

over the period of storage for mc and cfc and decreasing trends for pc, oc, sch, and ac. The mc of maize samples stored in the RC silo were significantly higher than the original 11.2% mc for storage periods of 4, 6, and 8 months with mc of 11.8, 13.3 and 15.1%. This temperature increase may be because of the potential for moisture transfer through the concrete material used for building the RC silo although it may not be as permeable as the TMC silo. No specific trend on changes in pc was observed, however all were consistently lower than the original 10.6% protein content. There was no significant change in oc for the entire eight months of storage. The cfc was likewise stable at 0.2% from the start of storage to the 6th month of storage and was only significantly higher on the eighth month of storage. Starch content showed a decreasing trend and was significantly lower from the fourth to eighth month of storage compared to the original 60.6%. On the eighth month of storage, the sc was already 3.6% lower than the original sc. The ac of 1.06% was also reduced during storage which was significantly lower from the fourth month of storage (0.95%) and remained the same (0.99%) during the sixth and eighth month.

Galvanized steel silo

In the GS silo, the mc also followed the increasing trend but it did not increase as fast and to as high as the mc of maize stored in the TMC and RC silos. The original mc of 11.2% was only significantly different for the sixth month (11.8%) and eighth month (12.7%), which are both still considered safe levels of mc for storage. This may be attributed to the construction material, galvanized steel, which is not permeable to water as compared to those used in the TMC and RC silos. The increase in mc could possibly be attributed to the increase in rh as have also been discussed earlier. Similar to the TMC and PC silos, the pc in the GS silo was significantly decreased but only at a later storage time, that is, on the sixth month to 9.6% pc and on the eighth month to 9.9% pc. Also similar to that of samples in the RC silo, the cfc did not change over the entire eight month of storage. The sc, on the other hand, only became significantly different from the original 60.6% when it decreased to 59% on the eighth month. As in the TMC and RC silos, the ac of maize stored in the GS showed significant difference to the original 1.06% with ac values reduced to the range of 0.94 to 0.97% starting on the fourth to the eighth month.

Effect of type of silo at specific storage times on selected maize quality

Table 3 summarizes the results of comparisons done on selected maize quality parameters at the same storage time across the TMC, RC, and GS silos; these are denoted by the superscript numbers indicated in the mean

Table 3. Quality of maize stored in three types of storage silo at different storage periods.

Type of storage silo	Storage period (months)	Moisture content (%)	Maize quality parameters (%)				
			Protein content	Oil content	Crude fibre	Starch content	Ash content
Termite Mound clay	0	11.2^{a,1}(0.1)	10.6^{a,1}(0.1)	5.1^{a,1}(0.1)	0.2^{a,1}(0.0)	60.6^{a,1}(0.1)	1.06^{a,1}(0.03)
	2	11.8^{b,1}(0.1)	10.3^{ab,1}(0.1)	4.8^{a,1}(0.2)	0.2^{a,1}(0.1)	60.5^{a,1}(0.5)	1.01^{a,1}(0.03)
	4	11.7^{b,1}(0.2)	9.9^{bc,1}(0.1)	4.7^{ab,1}(0.4)	0.2^{a,1}(0.0)	60.1^{ab,1}(0.6)	0.91^{b,1}(0.05)
	6	13.4^{c,1}(0.1)	9.5^{c,1}(0.4)	4.5^{c,1}(0.1)	0.3^{ab,1}(0.1)	59.3^{b,1}(0.2)	0.94^{b,1}(0.04)
	8	16.0^{d,1}(0.2)	8.3^{d,1}(0.2)	4.6^{bc,1}(0.4)	0.5^{b,1}(0.2)	59.1^{b,1}(0.7)	0.96^{b,1}(0.04)
Reinforced concrete	0	11.2^{a,1}(0.1)	10.6^{a,1}(0.1)	5.1^{a,1}(0.1)	0.2^{a,1}(0.0)	60.6^{a,1}(0.1)	1.06^{a,1}(0.03)
	2	11.4^{ab,12}(0.1)	9.9^{bd,1}(0.1)	4.8^{a,1}(0.2)	0.2^{a,1}(0.1)	60.3^{ab,1}(0.2)	1.00^{ab,1}(0.06)
	4	11.8^{b,1}(0.2)	10.0^{bd,1}(0.2)	4.7^{a,1}(0.2)	0.2^{a,1}(0.1)	59.7^{b,1}(0.6)	0.95^{b,1}(0.02)
	6	13.3^{c,1}(0.3)	9.1^{c,1}(0.5)	4.6^{a,1}(0.5)	0.2^{a,1}(0.1)	59.3^{b,1}(0.7)	0.99^{b,1}(0.02)
	8	15.1^{d,2}(0.3)	10.0^{d,2}(0.3)	4.7^{a,1}(0.5)	0.4^{b,1}(0.1)	58.2^{c,1}(0.7)	0.99^{b,1}(0.04)
Galvanized steel	0	11.2^{a,1}(0.1)	10.6^{a,1}(0.1)	5.1^{a,1}(0.1)	0.2^{a,1}(0.0)	60.6^{a,1}(0.1)	1.06^{a,1}(0.03)
	2	11.3^{ab,23}(0.2)	10.2^{ac,1}(0.2)	5.0^{a,1}(0.2)	0.3^{a,1}(0.1)	59.8^{ab,1}(0.4)	1.02^{ab,1}(0.04)
	4	11.0^{a,2}(0.3)	10.2^{ac,1}(0.3)	4.6^{a,1}(0.2)	0.2^{a,1}(0.1)	60.4^{a,1}(0.2)	0.94^{b,1}(0.03)
	6	11.8^{b,2}(0.3)	9.6^{b,1}(0.3)	4.5^{a,1}(0.4)	0.3^{a,1}(0.0)	59.9^{ab,1}(0.5)	0.96^{b,1}(0.03)
	8	12.7^{c,3}(0.4)	9.9^{bc,2}(0.4)	4.7^{a,1}(0.2)	0.3^{a,1}(0.1)	59.0^{b,1}(0.9)	0.97^{b,1}(0.07)

Values enclosed in parentheses correspond to standard deviation for the specific two-month temperature or relative humidity readings. Superscript letters (that is, XX.X^{a}) provides comparison of means across the storage periods within the same storage silo type where means with the same letter are not significantly different (Adjusted $p < 0.05$; superscript numbers that follow letters (that is, XX.X^{x,1}) compares means for a specific storage period across the three storage silo types with the same number indicating no significant difference (Adjusted $p < 0.05$).

values. Note that at the onset, all maize samples loaded in the three silos had the same quality characteristics.

For the second month of storage, only mc showed significant difference across the three types of silo; no difference was observed for pc, oc, cfc, sc and ac. The mc of maize (11.8%) in the TMC silo during the second month of storage was significantly higher than the mc of maize (11.3%) stored in the GS silo. Maize stored in the RC silo (11.4% mc on second month of storage) was not significantly different to those stored in the TMC and GS silos.

Similar results were observed for the fourth and sixth months of storage where once again only mc of maize samples stored in the GS silo showed significant difference to the mc of maize stored in the TMC and RC silos. There was no significant difference in mc for maize stored in the TMC and RC at 11.7 and 11.8%, respectively for the fourth month and 13.4 and 13.3%, respectively for the sixth month. Both TMC and RC had significantly higher mc than maize stored in the GS silo, which was at 11.0 and 11.8% for the fourth and sixth months, respectively.

During the eighth month, differences in mc and pc across type of silo were observed; the other parameters, that is, oc, cfc, sc, and ac were not significantly different across the three types of silo. All three silos contained maize samples with significantly different mc with maize in the TMC silo having the highest at 16%, followed by RC at 15.1% and the lowest was in the GS silo at 12.7% mc. These results provide an indication of the degree of possible moisture transfer occurring in each of the three silos. The pc of maize stored in the TMC was significantly lower (8.3%) compared to both the RC (10.0%) and GS (9.9%) silos. There was no significant difference in pc of maize in the RC and GS silos.

Conclusion

The combination of changes in both temperature and rh are critical factors that affect the quality of stored maize. It will be noted that ambient conditions and conditions in the TMC, RC, and GS silos used in this study consistently showed significant changes in relative humidity at each two month interval. Based on results from linear regression analysis, changes observed in all of the measured quality parameters, that is, moisture, protein, oil, crude fibre, starch and ash contents, were affected more by changes in relative humidity than by changes in temperature. The only exception was moisture content of maize stored in the GS silo, which was affected similarly by temperature and relative humidity.

The trends in changes in quality parameters for maize samples stored in the TMC silo were found to be similar to those stored in the RC and GS silos, that is, increasing trends over the period of storage for moisture and crude fiber contents and decreasing trends for protein, oil, starch, and ash contents. The rate of increase in moisture content was lower for maize samples stored in the GS silo, which may be an indication that maize stored in the GS silo will continue to store better than those in the other silos. These differences across type of silo may be attributed to the higher potential for moisture permeation in the TMC and RC silos compared to zero permeability in the GS silo.

The performance results of the selected quality parameters of the TMC, RC and GS silos are generally comparable across the same storage period, except for the sixth and eighth months for moisture content and for the eighth month for protein content. Differences in moisture content with higher mc for maize stored in TMC and RC silos than those stored in the GS silo were observed in the sixth month, which may again be explained by potential moisture transfer in silos made from termite mound clay and concrete. During the eighth month of storage, the moisture content across all three silos were different with the highest observed in the TMC and lowest in the GS silo, which can once again may be explained by differences in potential for moisture transfer because of the construction materials used. Likewise, on the eighth month, maize stored in the TMC had significantly lower protein content to those in the RC and GS that had comparable protein contents.

These findings indicate that the current design of the TMC silo will perform similar to the conventional RC and GS silos when used for up to four months of storage. Further design modifications will need to be incorporated to address the potential moisture permeation that resulted in significantly higher moisture content maize, which consequently renders it to be more prone to deterioration. These findings are very important and will greatly impact the farmers in the sub-Saharan Africa where many are in very tight financial situations. Being able to show the potential of using termite mound clay, which is a readily available resource and that farmers can easily tap will provide venues for them to store their produce for future use or sale. Further work on improving the resistance of the TMC silo to moisture permeation is necessary to allow for provisions for longer duration storage. Recent advancements in structural composite technology can be evaluated and used for the development of composites using termite mound clay as a component. Studies should also be conducted to look into appropriate aeration regimes for stored grains inside TMC silos in the humid tropics.

Conflict of Interest

The authors have not declared any conflict of interest.

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