

Macro- and Micro-Climatic Influence on Maize Quality and Insect Pest Management Strategies in Small Market Storehouses in Nigeria

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ABSTRACT

Weather plays a major role in the microclimate of grain storage facilities and could impact the quality of stored grain, most especially in the humid tropics where weather conditions are favorable to insect and mold formation. This study compared the influence of macro and microclimates — temperature and relative humidity (RH) in six storehouses located in three grain markets in Ibadan, Oyo, and Ilorin, Nigeria. The study was conducted from February–December 2016. Traditional Storage Practice (TSP) and Integrated Pest Management (IPM) were used in each of the markets. The average size of each storehouse was 4 m × 2.5 m × 2.5 m and each had twenty-five 100-kg polypropylene bags of maize stacked singly (not nested) in five columns. 15 bags were randomly sampled monthly for moisture content (MC) and insect counts using standard methods. Temperature and RH of the ambient and in-between grain stack were recorded using data loggers. Mean temperatures and RH for ambient, stack, and grain ranged from 29.3–30.8°C and 53.9–59.4% for the storage period. Mean insect count for the six storehouses with IPM and TSP were 1.4 and 7.6 in 700 g per bag, respectively. Ambient conditions correlated with grain stack temperature in all storehouses. MC of stored maize was not significantly affected by the location of storehouses and storage practices. However, insect population was significantly affected by storage practices. Proper grain storage management play a major role in maintaining grain quality during the storage. Commercial grain aggregators are advised to adopt the IPM strategies and ensure regular monitoring of the microclimates of bagged grain to reduce storage losses.

Keywords: integrated pest management, insect infestation, losses, maize, microclimate, moisture content

INTRODUCTION

Grains are regarded as the most important of all agricultural products stored by farmers and aggregators in the tropics and sub-tropical regions of the world (Akowuah et al., 2015). Several types of grain storage systems exist but the method of choice depends on several factors which include the purpose of storage, the volume of grain involved, storage duration and available resources (Okunade, 2013). In developing countries, poor and inadequate storage facilities contribute to slow growth of agricultural development. It has been estimated that 25 to 33.3% of the global grain crop is lost yearly during storage (Ibrahim, 2015). Traditional storage

structures are not effective for long term storage of grains due to their structural deficiencies. Improved storage structures such as warehouses with appropriate management techniques have been identified as a suitable approach for reducing grain storage losses among the rural farmers (Mishra et al., 2012).

In Nigeria and Sub-Saharan Africa, grains are usually stored on-farm, in residence, in community or market level storehouses, in large scale warehouses, and sometimes in national grain silo complexes across the country (Adejumo and Raji, 2007; Adesina et al., 2019; Olorunfemi and Kayode, 2021). The seasonal state of agricultural production in Nigeria makes grain storage inevitable because market demand is year-round.

According to Cassada and Armstrong (2008), and Pekmez (2016), grain losses (qualitative and quantitative) during storage can be attributed to different factors such as environmental factors (temperature, moisture content of grains, and humidity), storage structure type, length of storage, storage method, and biological factors (insects, pests, microorganisms and rodents). Postharvest storage facilities were identified in a study by Niamketchi (2015) as the major constraint of the grain value-chain in West Africa because the region is characterized with inadequate infrastructure which limit smallholder farmers' ability to store grain crops efficiently. This leads to a significant postharvest loss (Gerken and Morrison, 2022). Adejumo et al. (2014) also reported that lack of good storage facilities and the high humidity prevalent in the tropics, as it is in parts of Nigeria, cause post-harvest grain losses due to insect activity to exceed 30%.

Warehouses are primarily constructed to provide protection of quantity and quality of stored products (Pekmez, 2016). Generally, small storehouses are the most available storage facilities at the market-level in Nigeria. Jayas (2012) regards a store of grains as an artificial ecosystem in which weather plays a major role in the microclimate within the grain storage facilities. Seasonal variations in the environmental conditions around and within storehouses influence the microclimate of bagged grain. The magnitude of changes in these conditions and the duration impact the quality of the stored grain. (Ileleji et al., 2015). Ileleji et al. (2015) also reported that apart from temperature and relative humidity (RH), the microclimate created by stored grains is affected by solar radiation, precipitation, grain moisture and gases (CO₂ and O₂). However, temperature and RH constitute the main environmental factors influencing macro- and microclimatic condition of storehouses and the stored grains. The temperature and RH affect the equilibrium moisture content of the air surrounding the grains, and this determines storability (Omobowale et al., 2015). Hence, the control of the storage environment is an essential element in grain storage management as it involves, the controls of in-store climate and infestation-pressure which can be achieved by technically sound store design and construction (Shankar, 2014).

According to Johnson and Townsend (2009), there are three ways of preventing multiplication of deterioration agents in stored grain namely: sanitation, inspection and protection. Sanitation involves ensuring that grain to be stored are well dried to low moisture content and cleaned while inspection involves regular monitoring of the stored product in order to take adequate decision if spoilage is noticed. Protection in this concept is divided into chemical and structural

protection (Andersa, 2023). Studies have shown that more emphasis is laid on chemical protections which encourage the use of pesticides in grain storage (Erhunmwunse, 2012). The use and abuse of pesticides in grain storage especially at the market level storehouses has been reported to be harmful to human health as many grain merchants fail to follow the instructions on pesticide labels (Ikpesu and Ariyo, 2013).

Strategies for insect and pest management is a major consideration during storage (Asibe, 2023). IPM has been described by USDA-ARS (2018) as a sustainable, science-focused, decision-making procedure which involves the combination of cultural, biological, physical, and chemical tools for the identification, management, and minimize risk from pests and pest management tools and strategies in a way that reduces the general economic, health, and environmental risks. Different researchers have attributed the execution of IPM to be based on some factors such as availability of IPM tools, extension education, level of education, economic and social conditions, environmental awareness, rational thinking, moral values, government policies, consumer preference, and retail marketing (Parsa et al., 2014; Lefebvre et al., 2015; Jayasooriya and Aheeyar 2016, Rezaei et al., 2019).

A typical grain storage structure at market level is characterized by a four - cornered concrete building that provides some level of protection for stored grains from ambient fluctuations. These small warehouses (small storehouses) give room for quality inspection and application of control measures when needed (Danso et al., 2019). Rodent attacks, insect infestation and leakages have been identified as common problems in many store houses in Nigeria. (Igbeka, 2013). Therefore, the primary goal of this study was to examine how structural modifications to storehouses to improve sealing influences the microclimate and grain quality within the structures. In this study, we compared the influence of macro- and microclimate — temperature and relative humidity (RH) of six storehouses using traditional storage practice (TSP) and integrated pest management (IPM) at three grain markets in Ibadan, Oyo and Ilorin, Nigeria.

MATERIALS AND METHODS

Study Locations and Rehabilitation of Storehouses

Two (2) storehouses located in three (3) grain markets namely Bodija (Ibadan) located on 7°26'08.3"N 3°54'46.1" E, Eleekara (Oyo) 7°49'50.7" N 3°54'39.5"E and Mandate (Ilorin) 8°28'44.3"N 4°30'11.2"E, Nigeria, were selected for this study. The average size of each storehouse was 4 m × 2.5 m × 2.5 m. Storehouses at Oyo (Eleekara) and Ilorin (Mandate) markets had corrugated metal roof and wooden door. The storehouses in Ibadan (Bodija) market had concrete decking and metal doors. One (1) storehouse from each market was renovated (plastering of cracks, replacement of spent corrugated sheets and provision of concrete floor) with a vent equivalent to about 3% of the total wall area. The other storehouses were left untouched under conditions and practices similar to how the grain marketers store their produce in the market typically characterized by poorly sealed roof and doors, with cracked floors and walls (Figure 1-2).



Figure 1: One of the Traditional Storage Practice (TSP) storehouses in the study



Figure 2: One of the Integrated Pest Management (IPM) storehouses in the study

Maize for Storage, Sampling, And Data Collection

Maize (SWAN 2 variety) was purchased from Ijaye Farm Settlement in Akinyele Local Government Area, Ibadan Oyo State, Nigeria. The maize which was dried to about 8.2% moisture content (wet basis) was harvested manually, shelled, and cleaned by winnowing after which they were placed in 100-kg polypropylene bags, transported by road and placed on wooden pallets in the storehouses at the markets. Twenty-five 100 kg bags were stored in each warehouse out of which 15 were randomly sampled each month during the study. Each

sampled bag was slightly unstitched at the seam using scissors to create an opening into the bag. About 1000 g maize samples were drawn from each bag using a sampling probe. 700 g of the gabbled samples were used for insect counts. The temperature, relative humidity, and the equilibrium moisture content (EMC) of the air in the interstitial space of the bagged corn were recorded monthly using the GrainMate moisture meter probe (Armstrong et al., 2017; Sesi Technologies, Kumasi, Ghana). The probe was inserted into the bag and the readings were taken after the meter displays a stabilized reading which is about 6 minutes. This procedure was repeated 3 times the mean values and standard deviation were estimated.

Temperature and Relative Humidity Monitoring in The Storehouses

HOBO Pro V2 data loggers (Onset Computer Corporation, Bourne, MA USA) were placed outside of each storehouse and inside the storehouse — in-between grain stacks — to record the temperature and relative humidity at 1-hour intervals. The data loggers were placed in-between the stack at approximately 0.7 m above the floor while the one outside was placed at about 2.5 m above the paved floor. These data were downloaded monthly onto a computer and analyzed along with grain moisture and insect population (number of insect count). Temperature and relative humidity were also measured and recorded separately within the grain stack and inside the grain bag manually with an electronic probe and subsequently referred to as stack and grain temperature and relative humidity, respectively.

Statistical Analyses

Data obtained from field and laboratory experiments were analyzed with SAS Version 9.4 (SAS Institute, Cary, NC). A randomized complete block design (RCBD), with three (3) replications was used. The market was the block or replication TSP and IPM were considered treatments. Data for dependent variables — MC, number of insects were fitted by a four-level and three-level linear regression model using the first-order function. Macroclimatic condition: ambient temperature and ambient RH; and microclimatic condition: grain temperature and grain RH were the independent variables. Models were generated to predict the MC and insects count using IPMD and TSP for the storehouses. ANOVA, correlation, and regression were performed by General Linear Models (GLM), PROC CORR, and simple linear regression (PROC REG) respectively using 95% confidence interval.

RESULTS

Temperature and Relative Humidity in The Storehouses and Maize Moisture

Mean daily temperature and RH in the storehouses at the three markets ranged between 29.6 to 30.8°C and 53.9 to 59.4 % respectively during the 11 months storage period (Table 1). The monthly mean temperature and RH levels ranged from 25.7–33.7°C and 36.7–90% respectively across all the storehouses.

Table 1: The range and mean for temperature, relative humidity (RH) and moisture content (MC) for Bodija, Eleekara and Mandate storehouses using IPMD and TSP practices

Variable	Bodija		Eleekara		Mandate	
	TSP	IPMD	TSP	IPMD	TSP	IPMD
Temperature (°C)	26.6–35.2	25.8–34.2	26.7–33.5	26.7–36.2	25.8–33.2	25.7–32.6

Relative Hum (%)	33.9–77.6	31.7–75.8	33.5–72.3	33.2–71.3	37.2–68.0	37.3–70.0
MC (%wb)	8.1–14.8	8.3–13.9	8.0–14.4	8.0–14.2	8.6–13.6	8.6–19.3
Mean						
Temperature (°C)	30.8	29.7	30.5	30.5	29.6	29.8
Relative Humidity (%)	59.4	58.6	56.1	57.2	54.1	53.9
MC (%wb)	12.0	12.0	11.5	11.7	11.3	11.4
Insect Count/700g	1	10	2	6	2	7

The moisture content of stored maize in Bodija, Eleekara and Mandate storehouses ranged between 8.2 and 14.1% and 8.5–13.5% for IPMD and TSP practices, 8.4–13.7% and 8.6–13.2% for IPMD and TSP practices, 8.8–13.2% and 8.9–13.0% for IPMD and TSP practices respectively. The ANOVA showed significant ($P < 0.05$) regression models, as reflected by small probability values for dependent variables. The regression analysis of ambient temperature, grain temperature, and ambient RH on the insects count across the storage period in Mandate storehouse was not significant. However, regression analysis of stack RH, ambient RH, and grain RH on the insects count for the storage period in Mandate storehouses was significant ($P < 0.05$).

The mathematical expressions generated from the regressions for the prediction of MC and insects count with IPMD and TSP practices shown for Bodija storehouses (Eq. 1–4), where subscripts in the equations indicate practice type.

$$MC_{IPMD} = 4.96024 + 0.02159(A) - 0.00315(B) - 0.07490(C) + 0.15158(D) \quad 1$$

$$MC_{TSP} = 5.69614 - 0.02416(A) - 0.00203(B) - 0.05658(C) + 0.14941(D) \quad 2$$

$$Insect_{IPMD} = 14.65999 - 0.73678(A) - 0.03335(B) + 0.29851(C) \quad 3$$

$$Insect_{TSP} = -18.28740 + 2.28932(A) - 0.75166(B) + 0.49527(C) \quad 4$$

where A – ambient temperature (°C), B – ambient RH (%), C – grain temperature (°C), and D – grain RH (%).

The mathematical expressions generated from the regressions for the prediction of MC and insects count with IPMD and TSP practices are presented for Eleekara storehouses (Eq. 5–8), where subscripts in the equations indicate practice type.

$$MC_{IPMD} = 4.78025 + 0.07221(A) - 0.00325(B) - 0.12809(C) + 0.14884(D) \quad 5$$

$$MC_{TSP} = 6.27329 - 0.10785(A) - 0.01213(B) + 0.02013(C) + 0.15471(D) \quad 6$$

$$Insect_{IPMD} = -89.57320 + 0.92174(A) + 0.44135(B) + 0.97496(C) \quad 7$$

$$Insect_{TSP} = -240.82042 + 7.62205(A) + 1.21029(B) - 2.22492(C) \quad 8$$

The mathematical expressions generated from the regressions for the prediction of MC and insects count with IPMD and TSP practices are presented shown for Mandate storehouses (Eq. 9–12), where subscripts in the equations indicate practice type.

$$MC_{IPMD} = 11.51947 - 0.08667(A) + 0.00014777(B) - 0.16207(C) + 0.12952(D) \quad 9$$

$$MC_{TSP} = 8.13286 + 0.02994(A) - 0.01002(B) - 0.17068(C) + 0.15074(D) \quad 10$$

$$Insect_{IPMD} = 6.14826 - 1.17164(E) + 0.52598(B) + 0.51785(D) \quad 11$$

$$Insect_{TSP} = -16.12074 - 0.57449(E) - 0.20776(B) + 1.40222(D) \quad 12$$

where A – ambient temperature (°C), B – ambient RH (%), C – grain temperature (°C), and D – grain RH (%), E – stack RH (%).

Insect Count

Highest insect count for Bodija, Eleekara and Mandate storehouses were recorded in December except in storehouse in Bodija with IPMD which had its peak in August (Fig. 3–5). More so the highest number of insects across the six storehouses was 56 per 700 g sampled grains in Bodija storehouse with TSP practice (Fig. 3).

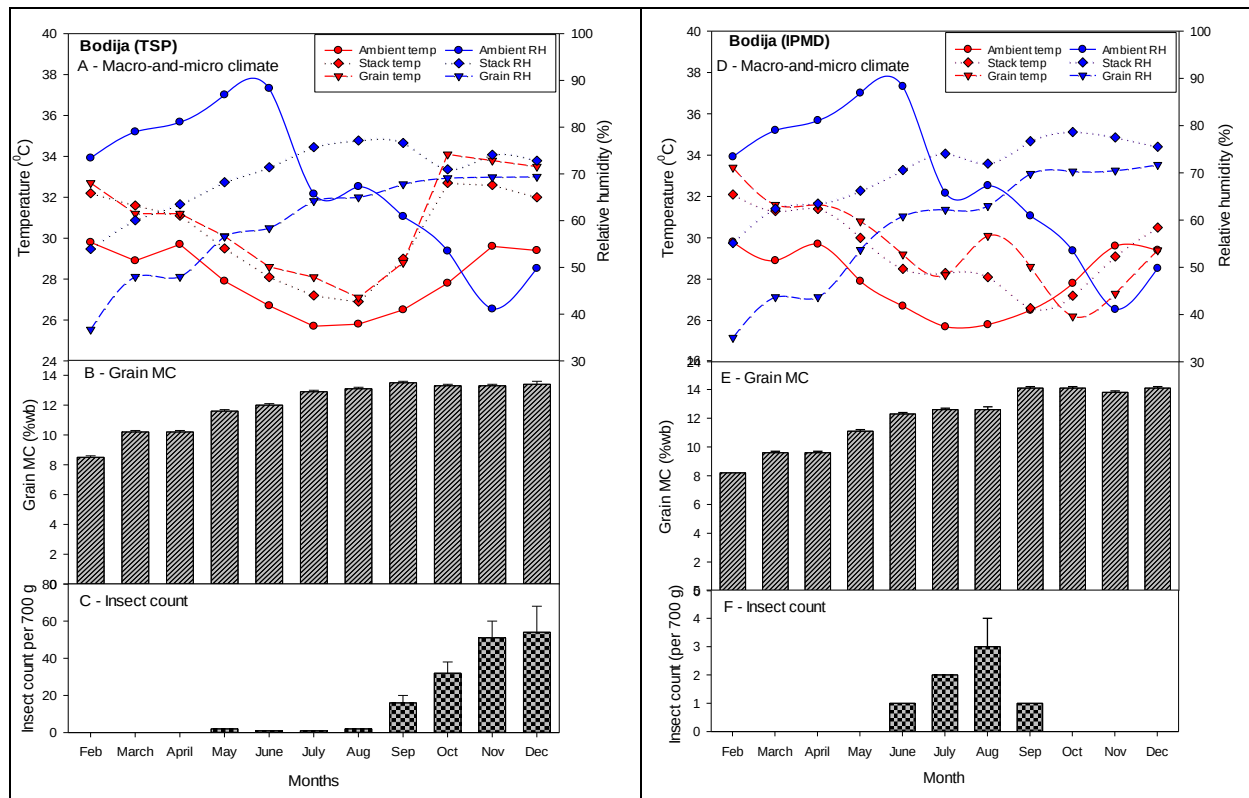


Figure 3: Bodija storehouse: Macro-and-micro climate (A), Grain MC (B), Insect count (per 700 g) (C) for TSP; and Macro-and-micro climate (D), Grain MC (E), Insect count (per 700 g) (F) for IPMD, respectively.

No insects were found from February–May 2016 for IPMD practice in Bodija (Fig. 3) and Eleekara storehouses (Fig. 4). Also, Mandate storehouses for IPMD and TSP practices had no insects in the first 3 months of the storage period (Fig. 5).

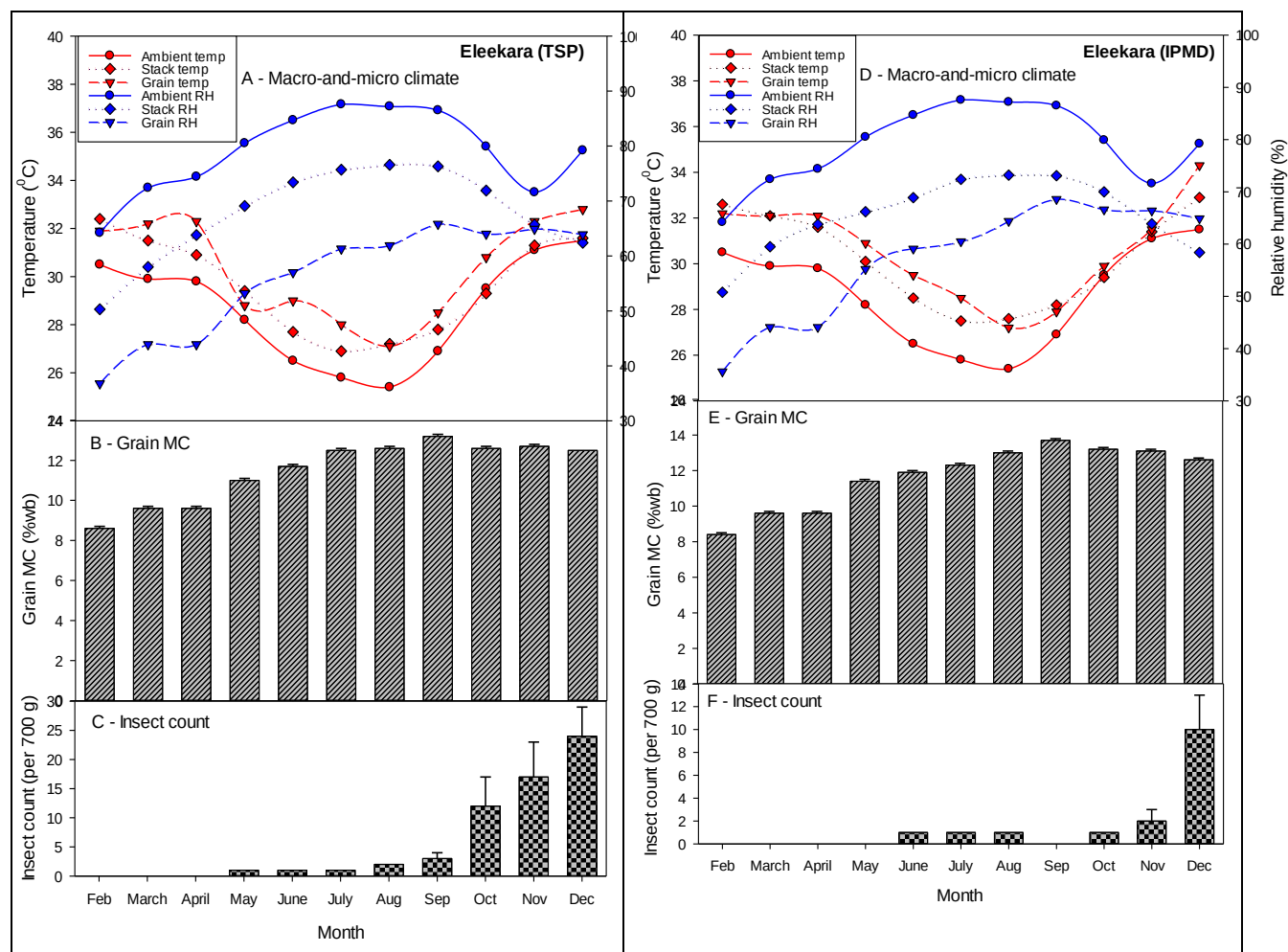


Figure 4: Eleekara storehouse: Macro-and-micro climate (A), Grain MC (B), Insect count (per 700 g) (C) for TSP; and Macro-and-micro climate (D), Grain MC (E), Insect count (per 700 g) (F) for IPMD, respectively.

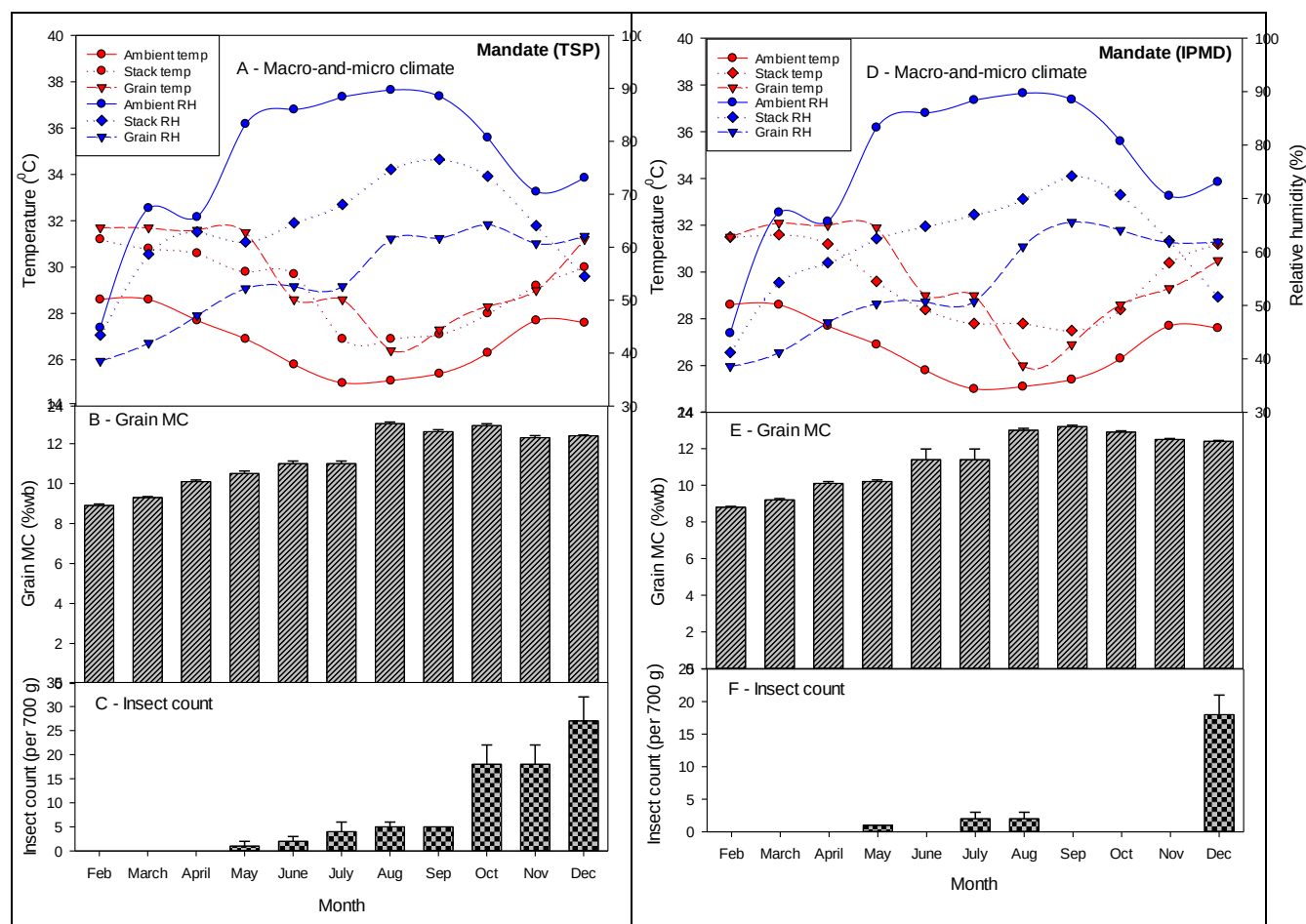


Figure 5: Mandate storehouse: Macro-and-micro climate (A), Grain MC (B), Insect count (per 700 g) (C) for TSP; and Macro-and-micro climate (D), Grain MC (E), Insect count (per 700 g) (F) for IPMD, respectively

DISCUSSION

Grain losses at the market-level storehouses have been attributed to little consideration given to structural protection, climatic influence, and poor storage management (Akowuah et al., 2015; Afzal et al., 2019). Monitoring of temperature and RH fluctuations is inevitable for proper grain storage management in any storage structure, market-level storehouses inclusive (Befidaku, 2014). During the 11-month storage period, temperature in the six storehouses were favorable for insect development. The following observations were discussed with respect to the macro- and micro-climate influence on grain quality (grain MC and insect count) at the study locations.

Bodija Market

In the IPMD storehouse, the monthly mean ambient temperature was high and relatively stable in the first three months (29.0–29.9°C) of the storage period while the mean ambient RH gradually increased (75 to 90%) from February to June 2016, and declined gradually till the end of the storage period (December 2016) (Figure 3). More so, the mean ambient temperature trend gradually declined from April to August, and gradually rose after the August rain break

till the end of the storage period. Consequently, the trend observed can be attributed to low rainfall from February to April, and a gradual decrease in rainfall events towards the end of the year (September to December 2016). Interestingly, the mean grain MC gradually rose (8.2 to 14.1%) with a concurrent rise in mean grain RH and mean stack RH (February to September) as shown in (Figure 3).

The continuous gradual rise in the mean stack RH levels from March to September (wet season) can be attributed to the ventilation of the warm and humid ambient air in the storehouse causing condensation on the cool wall and floor surfaces. In addition, the last four months of the storage period showed that the mean grain RH and mean stack RH had minimal fluctuations while the mean grain MC was relatively stable (about 14.0%) which may be attributed to the dry season period (Figure 3). This indicates that stack RH and grain RH directly influence the grain MC. This condition observed corroborated with Abass et al. (2017) that grains in a single stack tend to gain or lose moisture to the surrounding air when held for several months. This indicates that RH plays a major role in influencing the microclimate in stored grains thereby contributing to the rate of moisture gain or loss in the grain bags. Bradford et al. (2018) reported that the high RH prevalent in humid climates raises the moisture content of dried commodities stored in porous woven bags, enabling fungal and insect infestations. There were no insects found in the first four months of storage while there was presence of insects (June to September) during the storage period which was generally low (1–3 insects per 700 g of maize) as shown in (Figure 3). This can be attributed to the initial low moisture content of the grains (8.6%) as the grains were well-dried to a safe storage level to avoid susceptibility to insect infestation. Despite the absence of insects in the last three months of storage, there was a gradual rise (26.0–29.6 °C) in grain temperature and RH levels (70.0–72.1%), while grain MC was relatively stable at about 14.1% (Figure 3). This may indicate the presence of biological activity (fungal) due to the presence of hot spot(s) in the stored grains in the bag. The mean stack temperature followed the mean ambient temperature trend, indicating that the ambient temperature directly influences the stack temperature (Figure 3). More so, the mean grain temperature and RH trends followed the mean stack temperature and RH trends, indicating the stack temperature and RH contributes to the grain temperature and RH fluctuation trends.

Similarly, in the TSP storehouse, the ambient conditions were the same as the IPMD storehouse. The stack temperature levels in the TSP storehouse followed the same trend with the ambient temperature throughout the storage period, which was similar in the IPMD storehouse, however the stack temperature levels in TSP storehouse were generally higher (26.6–32.7°C) than the IPMD storehouse (26.6–32.1°C). Consequently, there was better ventilation in the IPMD storehouse than the TSP storehouse which can be attributed to the structural modification in the IPMD storehouse. The absence of insects in the first three months of storage can be attributed to the initial grain MC which was about 8.6% indicating that the grains were well dried prior to storage. Furthermore, most stored grain insects find it difficult to live on very dried grains. It also conforms to already established studies that grain storage in tropical regions can store effectively between 3–4 months if the grain is well dried to a safe storage MC level (Adejumo and Raji, 2007; Adesina et al., 2019). However, with an accentuated steady rise of mean grain RH, there was emergence of insects which gradually increased from 2 to 58 insect counts per 700 g (May to December) with a corresponding and gradual rise in the mean grain

MC during the same period (Fig. 3). This aligned closely with the findings from a similar study carried out by Danso et al. (2018) where rise in RH supports increment in insect population. Interestingly, the mean grain MC gradually rose (8.6 to 13.0%) from February to September with an increase in mean ambient RH. However, as the mean ambient RH levels were below 69% (September to December) and continuous ambient temperature rise, there was a rise in grain and stack temperatures (28.5–34.0°C and 28.6–32.5°C) with a significant rise in the mean insect counts (18–58 insects per 700 g) as shown in Figure 3. Increased biological activities of insects as a result of insect population growth in stored grains brings about an increment in grain temperature (Jian, 2019). There were no insects found in the first three months of the storage period in both storehouses which can be attributed to the initial conditions of the grains (cleaned and fumigated grains with 8.6% MC), properly sealed bags and cleaned storehouses. On observation in both storehouses, the mean grain temperature and RH generally followed similar trends with the mean stack temperature and RH respectively, indicating that the microclimate of the stacks in the storehouse influences the microclimate condition in the grain bags. This indicates that monitoring the microclimate in the storehouse can give a pre-insight to the microclimate of the grains in bags during the early storage period.

The results for the regression analysis showed that ambient temperature and RH, grain temperature and RH showed good influence on the grain MC (Adjusted R^2 value of 0.9999) with grain temperature and grain RH having the most influence in IPMD storehouse in Bodija market. More so in the TSP storehouse, regression analysis results showed that grain RH had the highest impact, closely followed by grain temperature among the least influence of ambient temperature and ambient RH on grain MC respectively (Adjusted R^2 value of 0.9992). The microclimate conditions in the grain bag will directly have an impact on the moisture content level of the grains in both storehouses. The regression analysis showed that ambient temperature and grain temperature had greater influence with ambient RH on the insect count (Adjusted R^2 value of 0.7941) in IPMD storehouse in Bodija market as compared to TSP storehouse where there was little influence on insect count. Ambient RH played a major role in affecting the outcome in the TSP storehouse which can be attributed to the practice carried out and a possibility of leakage(s) in the roof and crevice(s) which is characterized by most typical storehouses in this market.

Ambient temperature and stack temperature correlated in both storehouses, while there was a negative correlation between the ambient RH and stack RH in both storehouses in Bodija market. This shows that the ambient temperature is a good indicator for stack temperature, however ambient RH is a poor indicator for the stack RH in TSP and IPMD storehouses in Bodija market respectively (Nguyen, 2014). Furthermore, in both storehouses, grain temperatures strongly correlated with stack temperatures, while a strong correlation was found between the grain RH and stack RH respectively. This suggests that the surrounding air in the storehouse should be kept cool and dry always to prevent the presence of high moisture because grains are hygroscopic in nature.

Eleekara Market

The mean ambient temperature trend at Eleekara market was very similar to Bodija market. In the IPMD storehouse, the mean ambient RH gradually increased (65.0 to 88.0%) from February

to September 2016, and declined gradually towards the end of the storage period but rose by 10% in December 2016 (Figure 4). In addition, the mean stack and grain RH followed the trend of the ambient RH, however there was a noticeable decrease in the last 3 months of the storage period. Consequently, the trend observed may be attributed to frequent rainfall events in the year (May to September 2016) and gradual decrease in rainfall towards the end of the year (October to December 2016). More so, the mean ambient temperature trend gradually declined from March to August (about 30.0 to 26.0°C), and gradually rose after the August rain break till the end of the storage period (31.2°C) as shown in Figure 4. The fluctuations in the RH level for ambient, stack and grain conditions influenced the mean grain MC which resulted to a gradual rise in the mean grain MC (8.6 to 13.8%) from February to September, and a decrease in the last three months (13.1 to 12.1%) of the storage period. A reduction in mean grain MC level during the dry season (September to December) was also observed in a similar study carried out in Ghana by Danso et al. (2018). This can be attributed to the increased humidity (64.1 to 88.0%) (Figure 4). at the macroclimate as experienced in the wet season (April to October) and decreased humidity during the dry season period (October to December) with RH less than 80% in the Western part of Nigeria. Interestingly, the mean grain MC trend increased gradually corresponding to the rise in the mean ambient RH and insects respectively, however when mean ambient RH levels were below 87% (September to December 2016) there was no rise in the mean grain MC. A similar trend was observed in Bodija storehouse (IPMD) at mean ambient RH (< 69%). This implies that the ambient RH varies across different locations but plays a similar role in influencing the microclimate in the storehouse hence contributing to the rate of moisture gain or loss in the grain bags. Seed and commodities are hygroscopic, and their moisture content will vary in response to the relative humidity of the air to which they are exposed (Bradford et al., 2016). Bakhtavar et al. (2019) noted that ambient RH and temperature affect seed moisture content and their seed moisture isotherm. Consequently, the presence of insects in the sampled grains were low (< 4 insect counts per 700 g) in the first ten months of storage despite the favourable microclimate conditions (mean grain temperature and RH: 27.8–33.0°C and 65–88% respectively) for rapid insect multiplication. This can be attributed to the initial grain MC level and the IPMD practice which helped to suppress insect growth rate from February to October. This suggests that the initial grain MC and IPMD practice contributes significantly to the grain quality preservation during the storage period in storehouses at market location. In addition, the mean stack temperature and RH followed the mean ambient temperature and RH trends, indicating that the ambient macroclimatic conditions directly influence the stack microclimatic conditions (Figure 4). Also, the mean grain temperature and RH closely followed the mean stack temperature and RH trends.

Similarly, in the TSP storehouse, the mean stack temperature and RH levels followed a similar trend with the mean ambient temperature and RH trends throughout the storage period =, which was similar to the IPMD storehouse. Consequently, it was observed that the grain mean temperature and RH trends also followed the trends of the mean stack temperature and RH respectively, which suggests that the stack microclimate may influence the grain microclimatic conditions. This explains the importance of proper ventilations in grain storehouses to ensure grains are properly preserved over time. The mean grain MC gradually rose (8.6 to 13.5%) from February–September as the mean ambient RH increased (68.0 to 88.0%), indicating that the ambient RH may influence the moisture content of stored grains. There was a rise in grain mean

temperature (26.5–31.1°C) corresponding to a spike in the mean insect counts (4–23 insects per 700 g) in the last four months of the storage period. The rise in the grain temperature may be attributed to the increased insect activities compared to the preceding months in the stored grain. This observation is consistent with (Danso et al., 2018) findings which indicated that temperature rise was related to insect activities in the grain bags. Insect counts were relatively low in the first seven months of the storage period, which was similar to the IPMD storehouse. Ambient macroclimate (temperature and RH) and stack (temperature and RH) correlated in both storehouses in Eleekara market. This suggests that the ambient macroclimate is a good indicator for stack microclimate in TSP and IPMD storehouses in Eleekara market respectively. In both storehouses, grain temperatures strongly correlated with stack temperatures, while a good correlation was found between the grain RH and stack RH respectively. This suggests the need for the storehouses to be kept cool and dry always to prevent the presence of high moisture because grains are hygroscopic in nature.

In addition, the results for the regression analysis which showed that ambient temperature, ambient RH, grain temperature, grain RH showed influence on the grain MC (Adjusted R^2 value of 0.9988) with grain temperature and grain RH having the most influence in IPMD storehouse in Eleekara market. In the TSP storehouse, regression analysis results (Adjusted R^2 value of 0.9975) showed that grain RH had the highest influence on grain MC among other variables - ambient temperature and RH, and grain temperature respectively. This indicates that the grain MC will increase as grain RH increases if the surroundings of the stored grains are exposed to high humidity over time. The regression analysis showed that among the variables of ambient temperature and RH, and grain temperature, ambient RH had a greater influence on the insect count (Adjusted R^2 value of 0.5939) in IPMD storehouse in Eleekara market as compared to TSP storehouse (Adjusted R^2 value of 0.7069) where ambient temperature and RH had more influence on insect count. Most significantly, the influence of RH cannot be overemphasized on the grain MC as well as creating a conducive atmosphere for insects, however this influence can be reduced or slowed down as shown in IPMD storehouse.

Mandate Market

In the IPMD storehouse, the monthly mean ambient temperature showed a steady decline from the the February to July (28.8 to 25.2°C), before gradually rising from August till December while the mean ambient RH was low (about 45%) at February but began to rise and remained slightly stable from July to September before a steep decrease towards the end of the storage period. (Figure 5). This trend was similar to IPMD storehouses in Bodija and Eleekara markets which can be attributed to the seasonal change and rainfall event fluctuations during the year in the Western and North Central part of Nigeria. The trend of the mean grain MC showed that the ambient weather condition variations influenced the pattern of the mean grain MC gradual rise and fall. The mean grain MC experienced two peaks (August and September) at mean ambient RH of 90%, with corresponding ambient temperatures of 24.8 and 25°C respectively. These conditions provide availability of moisture in the surrounding air which can facilitate moisture pickup of stored grains. The mean grain MC gradually increased (8.8 to 13.4%) as mean ambient RH increased (40 to 90.1%) and insects emerged during the same period (March to August). This may indicate that insects thrive in a moist environment. More so, there was a surgency in the number of insects (18 insects per 700 g) found in December 2016

corresponding to a mean grain temperature of 30.7 °C . This indicates the presence of a high insect population and rapid insect activities leading to heat production thereby raising the temperature of the grains in the bag. Stored product insect pests rely on a warm environment to remain active. IPMD practice in the IPMD storehouse was very effective in limiting insect population growth rate as compared to the TSP storehouse in the Mandate market. On observation, the mean insect count trend did not follow the mean grain MC trend. In addition, the mean stack temperature and RH followed the mean ambient temperature and RH trend, indicating that the ambient temperature directly influences the stack temperature. More so, the mean grain temperature and RH trend followed the mean stack temperature and RH trends, indicating the stack temperature and RH can influence the grain temperature and RH.

In the TSP storehouse, the monthly mean ambient temperature and RH were the same as IPMD storehouse. The trend of the mean grain MC showed that the ambient weather condition variations influenced the pattern of the mean grain MC gradual rise and fall. The mean grain MC experienced two peaks (August and October) at mean ambient RH of 90 and 88.7%, at corresponding ambient temperatures of 25.2 and 26.2°C respectively (Figure 5). These conditions provide availability of moisture in the surrounding air which can facilitate moisture pickup of stored grains. The mean stack temperature and RH levels in the TSP storehouse followed a similar trend with the ambient temperature and RH levels throughout the storage period, which was similar in the IPMD storehouse. The mean grain MC gradually rose with an increase in mean ambient RH from February to August. However, there was a slight decline (October to December 2016) of the mean ambient RH as well as a slight drop in the mean grain MC. More so, the trend of the mean grain RH showed a gradual steady rise from the beginning (February) of the storage period till the end (December) which could have facilitated the general rise in the mean grain MC. This shows that relative humidity plays a major role in raising the moisture content level of grains. This aligned with Angelovic *et al.* (2018) findings that ambient fluctuation results in a direct impact on the temperature and RH of stored maize grain in a concrete floored warehouse. Consequently, there was no insect found in the first 3 months of storage, however there was a gradual rise in the number of insects found from May to December (2–25 insects per 700 g). This indicates a rapid insect infestation in the stored grains thereby causing reduction in the quality of the grains. Despite the similar trend of the macro- and micro- climatic conditions of the TSP and IPMD storehouses, insect infestation was more prominent during May to November with TSP practice. More so, December experienced a peak in insect counts (25 insects per 700 g) with corresponding mean grain temperatures of 31.7°C which was higher than temperatures for stack and ambient respectively. This indicates an increased metabolic activity of the insects with continuous heat production.

Furthermore, ambient macroclimate (temperature and RH) and stack (temperature and RH) correlated in both storehouses in the Mandate market. This suggests that the ambient macroclimate can be a good indicator for stack microclimate in TSP and IPMD storehouses in the Mandate market respectively. In both storehouses, grain temperatures and RH correlated with stack temperatures and RH respectively. Again, this suggests the need for the storehouses to be properly ventilated, kept cool and dry always to prevent the temperature buildup and presence of high moisture in the storehouses because grains are hygroscopic in nature.

The results for the regression analysis showed grain RH had the highest influence among ambient temperature and RH, and grain temperature on grain MC (Adjusted R^2 value of 0.9763) in IPMD storehouse in Mandate market. More so in the TSP storehouse, regression analysis results showed that grain RH had the greatest influence, followed by grain temperature on grain MC respectively (Adjusted R^2 value of 0.9992). These results showed that the microclimate conditions in the grain bag can cause a rise in the moisture content of the grains.

The variables of ambient temperature and RH, and grain temperature were non-significant for the model derived from the regression analysis on insect counts. Similar results were reported by Danso et al. (2018) and Manu et al. (2019) where lack of correlation between the number of insects and temperature was reported. However, the regression analysis using other variables — stack RH, ambient RH and grain RH on insect counts had a significant model ($P < 0.05$) as shown. Furthermore, the regression analysis showed that stack RH had the greatest influence among the other variables on insect count in the IPMD storehouse (Adjusted R^2 value of 0.8402) while the grain RH was dominant in influencing the insect counts at TSP storehouse (Adjusted R^2 value of 0.8251) in Mandate market respectively.

There was no interaction between the storehouse locations (Bodija, Eleekara and Mandate markets) and practices (IPMD and TSP) on grain MC and insect count for the storage period. The main effect of storehouse locations and practices were non-significant on grain MC. Furthermore, the main effect storehouse was non-significant for the insect count, however, the main effect of the practice (IPMD and TSP) was significant on the insects count at $P < 0.05$. This indicated that the type of practices carried out in storehouses with bagged maize could affect the number of insects that may be found during storage. In total, the study also revealed that TSP storehouses had a higher number of insects with an estimated mean of 8 insects per 700 g sampled maize while IPMD had 1 insect per 700 g sampled maize respectively. Based on the results of this study, the best practice in total was IPMD because it effectively limited the total number of insect population at the end of the storage period.

Temperature and RH monitoring in storehouses are crucial to grain MC level during storage period irrespective of the practices employed to prevent problems such as insects and molds formation. Regression equations developed from the data could be used to build a model to predict the stored grain quality outcome at market level storehouses in different locations in the western and North Central part of Nigeria. This will help structural engineers on the appropriate design for storehouses at the market level in the humid tropics. Generally, in the long term the structural defects may be one of the factors that contributed to the poor ventilation in the TSP storehouse thereby creating an atmosphere with a faster avenue for the high insect population at the end of the storage period as compared to IPMD storehouse. The results of this study showed that monitoring of stored grains and carrying out cleaning and sanitation regularly in the storehouses and its environs contributes to a better overall grain condition over a storage period. Based on this study, it was found out that monitoring the microclimate (within the stack) in the storehouse can give a pre-insight to the microclimate of the grains in bags during the early storage period (4–7 months). In addition, proper monitoring of temperature and RH fluctuations alongside MC will help grain merchants and warehouse managers determine when to fumigate or sell off the grain before reducing from food grade to

feed grade quality which determines the variation in prices and profit made. Practicing IPM in storehouses can prevent rodent infestations and slow down insect infestation rate over months of stored grains. Therefore, we highly encourage and emphasize good environmental sanitation practices in the grain markets.

CONCLUSION

Temperature and RH monitoring in storehouses are crucial to grain MC level during storage period irrespective of the practices employed to prevent problems such as insects and molds formation. Regression equations developed from the data could be used to build a model to predict the stored grain quality outcome at market level storehouses in different locations in the western and North Central part of Nigeria. This will help structural engineers on the appropriate design for storehouses at the market level in the humid tropics. Generally, in the long term the structural defects may be one of the factors that contributed to the poor ventilation in the TSP storehouse thereby creating an atmosphere with a faster avenue for the high insect population at the end of the storage period as compared to IPMD storehouse. The results of this study showed that monitoring of stored grains and carrying out cleaning and sanitation regularly in the storehouses and its environs contributes to a better overall grain condition over a storage period. Based on this study, it was found out that monitoring the microclimate (within the stack) in the storehouse can give a pre-insight to the microclimate of the grains in bags during the early storage period (4–7 months). In addition, proper monitoring of temperature and RH fluctuations alongside MC will help grain merchants and warehouse managers determine when to fumigate or sell off the grain before reducing from food grade to feed grade quality which determines the variation in prices and profit made. Practicing IPM in storehouses can prevent rodent infestations and slow down insect infestation rate over months of stored grains. Therefore, we highly encourage and emphasize good environmental sanitation practices in the grain markets.

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