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ASSESSING EFFICACIES OF INSECT PEST MANAGEMENT METHODS TO PRESERVE NUTRITIONAL COMPOSITION OF BAGGED MAIZE IN STOREHOUSES LOCATED IN MARKETS IN NIGERIA

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ABSTRACT

Maize needs to be stored using effective and safe postharvest management measures to prevent physical insect damage as well as ensure stability of nutritional quality during storage. In this study, conducted in February–December 2016, insect pest management methods for bagged maize preservation in storehouses located in markets in Nigeria were evaluated for their ability to preserve nutritional quality. Study locations were in three grain markets, namely Eleekara market in Oyo town and Arisekola market in Ibadan, Oyo State, South West Nigeria, and Ago market in Ilorin, Kwara State, North Central Nigeria. Treatments comprised *Piper guineense* (Botanical), Bularafa diatomaceous earth (DE), permethrin powder (Rambo™) (Permethrin), PICS bags (hermetic) and ZeroFly® bags (non-hermetic). The study also had negative control (Control) comprising untreated maize in polypropylene bags. In general, as a result of insect infestation, protein content increased in all treatments except PICS which had the least infestation. After 11 months of storage, Permethrin and PICS treatments had the lowest insect infestation levels and the highest energy levels. Energy level in the Botanical treatment was also high and similar to levels in Permethrin and PICS treatments most likely due to fats and essential oils in *P. guineense* being adsorbed and/or absorbed by kernels. Fat content was lower in the Control and DE treatments likely due to the Control having the highest insect infestation and the DE adsorbing and/or absorbing fat from kernels. During storage carbohydrate content decreased in all treatments except the Control. However, even in the Control, there was a clear trend of decrease in carbohydrate content. Because the Control had the highest insect (*Sitophilus zeamais*) infestation and insect damaged kernels (IDK), this trend in decrease in carbohydrate content may be insect related. Ash content increased in the ZeroFly treatment, was unchanged in Botanical, Control, and PICS treatments, and decreased in DE and Permethrin treatments. Nutritional quality variables in this study were within or close to the known value ranges for maize. Therefore, use of maize that had been fumigated well and had a relatively low initial grain MC (9.1%), in addition to the effects of the treatments most likely slowed down population growth of the several insect species that were found and contributed to preserving nutritional quality. The relatively low insect populations in all treatments, including the Control, during the February–September period probably reduced the clarity of effects of infestation on nutritional composition reported in this study.

Key words: Reduced-risk pest management, maize quality, hermetic storage, preservation, nutritional quality

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INTRODUCTION

Most grain research efforts in agriculture have focused on increasing productivity of crops in the field, with less attention paid to the postharvest quality of crops, particularly after storage with various insect pest management interventions. There is a need to match all efforts at increasing grain production in the field with equal, if not greater efforts, to preserve harvested grains from deterioration and also retain nutritional quality of food grains during storage [1]. Loss of macro and micro-nutrients in grains as a result of poor storage technologies and practices translates to a sub-clinical deficiency referred to as "hidden hunger" which occurs when the human body is not functioning at its peak due to nutrient or vitamin deficiency in the food consumed. Micro-nutrient deficiency leads to a wide range of health issues that can impair and radically shorten people's lives [2]. Decline in nutritional quality of grains could be due to adverse environmental conditions during seed production, genetics, biochemistry and storage. Improper field drying, harvesting, winnowing, storage, processing (that is to say, milling), transport to market, retailing, pests (insects, rodents and micro-organisms), bad packaging and pesticides are other factors that have been reported to cause nutritional losses in grains [1, 3].

Insect-mediated postharvest losses are considered a major source of nutritional loss in grains, impacting negatively on some nutritional components particularly, starch and protein. Such nutritional losses can affect the market price of the commodity and impact negatively on household nutrition and income [1]. Moreover, changes in color of kernels and production of mycotoxins reduce the quality of stored grains and endanger human health [4]. Maize (*Zea mays* L.) is an important cereal which ranks third in global production and consumption after wheat and rice [5]. It is a major cereal for livestock feed and human nutrition. It is also an important raw material for several agro-based industries [6]. In addition, in a market that is not controlled, the value of any surplus maize in good condition tends to rise during the off-season period [7], an indication that maize can be an important cash crop. In Nigeria, maize production is usually in two phases, first phase is planted at the on-set of rains in March and harvested in May/June, and the second phase is planted in July/August and harvested during the last quarter of the year.

Insect infestation is the biggest constraint in the maize value chain in Nigeria and other developing countries [8], although other storage pests, including rodents, birds and microorganisms contribute to postharvest loss of quality and quantity of the grains. In Nigeria, some of the key stored-product insect pests infesting maize are the maize weevil, *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae), the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae), the Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae), red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) and the rust red beetle, *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae) [9]. Therefore, the management of insect pests in stored maize is key to preventing significant losses such as damaged kernels, reduced weight and nutritional value during storage [10].

Presently in Nigeria, management of insect pests in stored food grains, maize included, is mostly by the use of synthetic insecticides which are now known to be fraught with health and environmental hazards [11], prompting the search for alternative insect management options. Consequently, in a study conducted in 2016, the authors evaluated storage methods for their effectiveness to preserve bagged maize in small grain stores in three municipal markets across two agro-ecological zones in Nigeria [9]. Storage methods evaluated were a natural plant-based grain protectant, *Piper guineense* (Schum & Thonn) (hereafter referred to as Botanical), a natural diatomaceous earth (DE) called Bularafa DE, and two types of grain storage bags, the Purdue Improved Crop Storage (PICS™) bag and ZeroFly® Storage Bag (ZeroFly), and a pyrethroid called permethrin with the trade name Rambo™ (Permethrin). There was also a negative control (hereafter referred to as Control). More information on *Piper guineense*, DE, ZeroFly, PICS and Rambo related to this study is reported by the authors [9].

Insect infestation levels in stored maize as a result of Botanical, DE, PICS, ZeroFly, Permethrin and Control treatments are reported by the authors [9]. However, the authors [9] did not report on efficacies of these treatments in preserving nutritional quality of maize. Therefore, the objective in the present study was to assess effects of the six treatments [9] on nutritional quality of maize during 11 months of storage.

MATERIALS AND METHODS

Study sites

This study was conducted during the period February–December, 2016 in four storehouses located in three grain markets, namely, Eleekara market in Oyo town, Oyo State, Southwest Nigeria (7°49'50.7"N 3°54'39.5"E), Arisekola market in Ibadan, Oyo State, Southwest Nigeria (7°26'08.3"N 3°54'46.1"E) and Ago market in Ilorin Kwara State, North Central Nigeria (8°29'34.8"N 4°32'59.9"E). In Ago market, there were 2 storehouses, Ago 1 and Ago 2. The study was purposely set up in grain markets partly because external infestation from non-study storehouses was highly likely and expected to be substantial.

Maize

Source of maize

The SWAN 2 maize variety used in this study was obtained from the Ijaye Farm Settlement in Akinyele Local Government Area, Ibadan Oyo State and transported to a storage facility the same day. Farmers in the settlement applied Aflasafe™ [12] in the field for the production of maize. Initial maize moisture content was checked on-farm (John Deere Moisture Chek-Plus Grain Moisture Tester – SW08120, Deere and Company, Moline, IL, USA) and determined as 9.1%.

Maize fumigation

Maize was fumigated before use to minimize field to store transfer of insect pests. Fumigation was conducted at the Nigerian Stored Products Research Institute (NSPRI), Ilorin, Nigeria in a building with large windows and doors to facilitate ventilation and worker safety. The procedures used for maize fumigation are described in Nwaubani *et al.* [9] and Ala *et al.* [13].

Storage methods (treatments)

ZeroFly® storage bag

In each storehouse, there were six 100-kg ZeroFly bags (Vestergaard Frandsen Vietnam, Hanoi, Vietnam) of maize arranged in a horizontal pattern on a single wooden pallet. These were non-hermetic ZeroFly bags. During the 11 months of the study, all six bags in each storehouse were sampled monthly. Disposable gloves were worn during the setting up of the ZeroFly treatment to prevent transfer of the incorporated pesticide on to skin.

Purdue Improved Crop Storage (PICS™)

The procedures recommended by Purdue University PICS team for using PICS bags [14] were followed during the set up. Each storehouse had eighteen 100-kg PICS bags (Lela Agro Industries Nigeria Limited, Kano, Kano State, Nigeria), each containing 80 kg of maize, arranged on four pallets. Bags on pallets were arranged in such a way that they formed two layers. At each sampling event, six bags were destructively sampled, and maize samples obtained were used for nutritional composition assessment. Additional information on the set up is reported in Nwaubani *et al.* [9].

***Diatomaceous earth* (DE)**

Crude DE ore of freshwater origin was obtained from Bularafa community in Yobe State, Northeast Nigeria [9]. Each storehouse had six 100-kg bags containing maize that was properly admixed with DE at a rate of 1,000 ppm (100 g/100 kg) [15]. Details on admixing are reported in Nwaubani *et al.* [9].

***Piper guineense* (African Brown Pepper)**

African Brown Pepper, *P. guineense*, is a good reduced-risk botanical insecticide; it is also used for culinary and medicinal purposes and has been proven safe for humans [16]. Each storehouse had six 100-kg bags containing maize that was properly admixed with *P. guineense* at a rate of 15,000 ppm (1,500 g/100 kg) [15]. Details on admixing are reported in Nwaubani *et al.* [9].

Permethrin (*Rambo*™)

Rambo brand insect pest protectant powder comprising 0.6% permethrin and 99.4% inert carriers (Gongoni Company Limited, Kano, Kano State, Nigeria) was used as comparative check (positive control). Each storehouse had six 100-kg bags containing maize which was properly admixed with Rambo at a rate of 167 g/100 kg, that is permethrin concentration in maize was 10 ppm. Details on admixing are reported in Nwaubani *et al.* [9].

Untreated Control

The Control (negative control) comprised untreated maize in untreated 100-kg polypropylene bags.

Methodology and arrangement of bagged maize in the storehouses

Shelled maize placed in specialised bags (PICS™ and ZeroFly®), admixed with a protectant (DE, *P. guineense* or permethrin) in polypropylene bags and untreated maize in polypropylene bags (Control) was transported to each market. In each storehouse, six 100-kg maize-filled bags were assigned to each of the following treatments: ZeroFly, DE, Botanical, Permethrin and Control, with each treatment on a separate pallet to prevent bags from absorbing moisture from the concrete floor. Eighteen bags assigned to the PICS treatment were arranged on four pallets. The pallets for each treatment were placed 1 m apart from each other. There were 48 bags per storehouse. Two temperature and relative humidity data loggers (HOBO U12, Onset Computer Corporation, Bourne, MA, USA) were placed inside and outside the storehouses to record temperature and relative humidity values at 1-h intervals; data are reported in Nwaubani *et al.* [9].

The experimental design for this study was a randomized complete block design (RCBD) with four replications (number of storehouses) and six sub-replications (number of 100-kg bags sampled during each sampling event).

Sampling and data collection

Maize samples were obtained using a 1.2-m open-ended trier (grain probe) (Seedburo Equipment, Chicago, IL) with six openings. The trier was inserted into the maize bag in the horizontal, closed position, opened after it was properly inserted and closed up when full before it was pulled out. Maize in the trier was emptied into a 2-liter Ziploc bag (26.8 cm x 27.3 cm) through the open end of the trier and thereafter, taken to the laboratory for analysis. Samples were taken twice in two different directions in order to obtain representative samples from each bag. Each trier sample weighed ~ 350 g; hence a total of 700 g was taken from each bag during each sampling event. A small opening of about 3 cm wide was made with a scissors at seam area of every bag to accommodate insertion of the trier during sampling. The incision made on the bag was sealed with tape (Duct Tape™) which facilitated easy opening and closing of the bags during subsequent sampling.

In the PICS treatment, six bags were destructively sampled every 4 months. Destructive sampling means sampled bags were discontinued from the study and were not sampled again. The six bags that were sampled were randomly selected using randomization software at the beginning of the study.

Determination of maize nutritional composition per 50-g sample

Nutritional composition of maize was determined from the 700-g samples obtained during sampling events. From each 700-g sample collected, 250 g were weighed out, mixed thoroughly by manual agitation and 50 g were weighed out for analysis. Nutritional analysis involved determination of the levels of ash, carbohydrate, crude fibre, energy, fat and protein content. All samples were processed at the Nigerian Stored Products Research Institute (NSPRI) in Ilorin, Kwara State, Nigeria.

Nutritional composition of stored maize was conducted on wet basis following the standard method of analysis [17]. Samples for nutritional composition analysis were collected at the beginning of the study, at 4 months intervals and at the end of the study. Altogether, samples were collected four times.

Ash

Five grams of maize sample was placed in a crucible of known weight and ignited until no charred particles remained in the crucible; thereafter, the crucible was put in a muffle furnace at 550°C for 3 h or until a white ash was obtained. The crucible was then cooled in a desiccator and reweighed [17].

Percent ash content was calculated thus:

$$\text{Ash (\%)} = \frac{\text{Weight of ash}}{\text{Weight of original sample}} \text{ x } 100$$

Carbohydrate

The total percentage carbohydrate was determined by difference method which involves adding the total percentage values of crude protein, crude fat, crude fibre, moisture and ash constituents of the sample and subtracting it from 100 [17].

$$\text{CHO (\%)} = 100 - (\text{\% Moisture} + \text{\% Crude ash} + \text{\% Crude protein} + \text{\% Crude fat} + \text{\% Crude fibre})$$

Crude fibre

Crude fibre was estimated using the standard method of analysis [17]. Percentage crude fibre was calculated thus:

$$\text{\% Crude Fibre} = \frac{W2 - W3}{W1} \text{ x } 100$$

where,

W1 = Weight (g) of sample

W2 = Weight (g) of insoluble matter (weight of crucible + insoluble matter - weight of crucible)

W3 = Weight (g) of Ash (crucible + Ash - wt. of crucible)

Energy (Kcal/100 g)

Energy was calculated by the sum of percentages of fat, carbohydrate and protein multiplied by their Artwater factors (Protein = 4; Carbohydrate = 4; Fat = 9 Kcal/g) [17].

$$\text{Energy} = \frac{\text{fat x } 9 + \text{carbohydrate x } 4 + \text{protein x } 4 \text{ kcal}}{100 \text{ g}}$$

Crude fat

Crude fat was estimated using the standard method of analysis [17]. Percentage fat was calculated thus:

$$\text{\% Fat} = \frac{\text{Weight loss of sample (extracted fat)}}{\text{Weight of sample}} \text{ x } 100$$

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Protein content
Protein content was estimated using micro-Kjedahl method with KELPLUS nitrogen estimation system [17]. Percentage nitrogen content was calculated thus:

$$\%\ \text{Nitrogen} = \frac{\text{Volume of acid x Molarity of standard acid x 0.014}}{\text{Weight of sample}} \text{ x } 100$$

where:
0.014 = Molarity of nitrogen which has been divided by 1000 [17]
Jones conversion factor of 6.25 was used to convert nitrogen to crude protein [18].

$$\%\ \text{Crude Protein} = \text{Nitrogen content x } 6.25$$

Data analysis
Statistical analysis was performed with SAS Version 9.4 [19]. The effects of treatment and month, and interactions were assessed using analysis of variance (ANOVA) methods (PROC MIXED). A repeated measures model in a randomized complete block design was utilized, with storehouse as the blocking factor and month as the repeated factor. The simple effects of treatment in a given month were assessed with protected planned contrasts (SLICE option in an LSMEANS statement). Additionally, the SLICE option was used to assess simple effects of month in a given treatment. Percentage data analyses for protein content, fat content, crude fibre, carbohydrate, and ash were conducted using an arcsine transformation to stabilize variances but untransformed percentages are reported.

RESULTS AND DISCUSSION

Temperatures inside storehouses that comprised replications 1, 2, 3 and 4 at Ago 1, Ago 2, Arisekola, and Eleekara markets during the 11 months of the experiment ranged between 25.5–35.7, 25.3–34.0, 25.8–33.1 and 26.3–33.4°C, respectively. This corresponded to means of 29.8, 30.0, 28.8 and 29.7°C, respectively. For RH, values ranged between 36.8–56.4, 34.0–74.1, 35.3–75.9 and 36.8–72.2%, respectively. This corresponded to means of 56.4, 56.5, 60.8 and 57.6%, respectively. Grain moisture content values ranged between 6.5–14.6, 6.2–14.7, 8.3–15.1 and 8.5–14.7%, respectively. This corresponded to means of 11.3, 11.3, 12.4 and 11.8%, respectively. Corresponding equilibrium moisture content levels were 11.5%, 11.5%, 12.3% and 11.7%, respectively, based on average temperature and RH values.

Maize contains protein, fat and carbohydrate, making it a complete food for both humans and livestock. Variations in the proximate composition of stored maize are presented in Tables 1 and 2. The preservation of nutritional value of grains during the storage period depends on grain initial moisture content and maintenance of appropriate storage conditions, primarily temperature and relative humidity (RH) inside the storehouse. Nutritional quality of stored maize is affected by insect pests and rodents

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because of their feeding activities [20] and storage duration. Clearly, storage pests cause significant qualitative losses, ultimately reducing nutritional quality [21].

Insect infestation data in which Botanical, DE, PICS, ZeroFly and Permethrin treatments assessed in this study significantly reduced infestation relative to the Control have been reported [9]. In relation to the Control treatment, insect population levels found were low to moderate and this was most likely due to the fact that maize used was well fumigated (nearly insect-free) before the study commenced and was of relatively low initial grain moisture (9.1% MC) [9]. Rapid stored grain insect pest population growth typically occurs in environmental conditions that exist in Nigeria [31]. Densities of insects such as *Sitophilus zeamais*, *Cryptolestes ferrugineus*, *Tribolium castaneum* and *Liposcelis* spp. featured at varying levels in the treatments during the period of storage [9]. The activities of these species likely influenced some changes in the nutritional composition of stored maize over the study period. Previous studies have reported that changes in the nutritive value of cereal grains occur during storage [22] and are usually due to insect infestation [23].

Analysis of crude protein content data found the main effect treatment and the month-treatment interaction were not significant ($P > 0.05$) (Table 1). However, the main effect month was significant ($P < 0.05$) (Table 1). During storage from February to December, protein content increased in all treatments except PICS (Table 2). Numerically, maize samples in the Control had the highest protein content (12.0 ± 0.2) in December (Table 2). Protein content values found in this study were within the 7.71–14.60% range previously reported by Ijabadeniyi and Adebolu [24] and 10.67–11.27% range reported by Ullah et al. [25] for three maize varieties grown in Nigeria. This implies that in all treatments, there was no substantial change in protein content relative to the varieties in the studies by Ijabadeniyi and Adebolu [24] and Ullah *et al.* [25]. Generally, an increase in crude protein content in all treatments was found with increasing storage period. Previous studies have related this increase in protein content during storage to feeding activity of infesting insect pests [1, 23]. The distribution of protein in maize has been reported as ~ 13.2% in bran, 8.6% in endosperm and 34.4% in the germ layer of the kernel [26]. *Sitophilus zeamais* was the predominant primary and coleopteran insect pest found during the assessment of Botanical, DE, PICS, ZeroFly, Permethrin and Control treatments [9]. There were more *S. zeamais* in all the treatments in December, but numbers were highest in the Control. Number of insect damaged kernels (IDK) increased in all treatments except PICS during the 11 months of storage; in December, PICS and Permethrin treatments had the lowest IDK [9]. *Sitophilus zeamais* is known to preferentially feed on the endosperm of maize, and hence the residual uneaten kernel tends to have a higher percentage of protein [1]. Extent of infestation by *S. zeamais* is likely the explanation for the higher protein content values in all treatments except PICS in December than in February. The PICS treatment had the lowest *S. zeamais* infestation and IDK [9], and this may explain the same protein content values for February and December. Internal feeders are known to feed on the endosperm [27]. Increase in protein content may also be attributed to the contamination of the maize samples with adult insect body parts and parts of immature stages within the kernels (for example. crushed larvae and pupae) and excretory waste like uric acid [1].

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In the case of energy, main effects treatment and month were significant (Table 1). However, the month-treatment interaction was not significant (Table 1). The PICS (386.1 ± 1.6) and Permethrin (383.3 ± 1.6) treatments had more energy than the Control (380.4 ± 0.7) in December (Table 2). The PICS and Permethrin treatments with the highest energy levels in December also had the lowest insect infestations and IDK [9]. This inverse relationship between insect infestation or IDK and energy levels suggests insect feeding activity lowers energy levels of kernels. Insects consume primarily the germ and endosperm, both of which have a lot of the energy content in maize kernels. Therefore, no significant change in energy levels in the PICS and Permethrin treatments during the 11 months of storage was most likely due to low insect infestation [9]. Similarly, there were no significant changes in energy levels in the Botanical treatment, although the reason for this could be the fact that *P. guineense* contains fats and essential oils which were adsorbed and/or absorbed by the kernels [27]. Data from this study are supported by Swaminathan [28] who reported no significant decrease in energy content of stored grain under hermetic conditions. Additionally, Okolo *et al.* [29] reported that duration of storage does not significantly affect energy content of stored cereal grains.

In relation to fat content, the main effect month and the month-treatment interaction were significant. However, the main effect treatment was not significant (Table 1). After 11 months of storage, fat content was lowest in the Control (5.0 ± 0.2) and DE (4.7 ± 0.1) treatments. The likely reason for the lower fat content in the Control in December may be the higher insect infestation levels that were found in this treatment [9], which resulted in consumption of the germ which is rich in fat. A significant reduction in fat due to insect infestation over prolonged storage duration has previously been reported [23, 30]. In a study conducted by Ijabadeniyi and Adebolu [24], a decrease in fat content and increase in the ash content of infested wheat samples stored for 6 months was attributed to increased insect population. In the case of DE, lower fat content in December may be due to the fact that DEs absorb fats. It is also interesting to note that the only case where there was a consistent increase in fat content over the storage period was in the Botanical treatment, and this may be due to the fact that *P. guineense* contains fats and essential oils [27] which could have been increasingly absorbed and/adsorbed by kernels. In some cases, increase in fat content may be a result of carbohydrate depletion due to insects preferentially feeding on it (carbohydrate) and not an actual increase in fat [30].

Regarding crude fibre, a similar pattern as in fat content was observed with the main effect treatment not being significant but the month and month-treatment interaction were significant (Table 1). In the Control, PICS, and Permethrin treatments, there was a reduction in crude fibre between February and December (Table 2). In the case of the Control, the reduction in crude fibre is most likely due to insect feeding because this treatment had the highest infestation and IDK [9]. However, in the PICS and Permethrin treatments which had the lowest infestation levels [9], some other undetermined factor(s) contributed to the decrease in crude fibre. A study by Ullah et al. [25] reported that crude fibre content from stored maize ranged between 0.8–2.35%. In December, the crude fibre content range for all treatments in this study was 1.4–

1.9%. However, Ijabadeniyi and Adebolu [24] reported a crude fiber range for maize of 2.07–2.77%.

In the case of carbohydrate content, the main effect treatment and the month-treatment interaction were not significant but month was significant (Table 1). In both February and December, there were no differences in carbohydrate content values among treatments (Table 2). Except in the case of the Control, carbohydrate content values were higher in February than December, that is, decrease with increase in storage time. Despite the carbohydrate content in the Control being similar throughout the storage period, there was a clear trend of decrease during storage (Table 2). This trend of decrease observed in the Control may be insect-related because this treatment had the highest infestation and IDK [9]. Reductions in the carbohydrate content of stored cereals have been reported to correspond to insect infestations and/or storage period [30]. This is also in line with Okolo *et al*. [29] who stated that starch is an easier target for internal feeders due to their feeding behavior which results in relatively more endosperm being consumed. Indeed, insect infestation is known to decrease carbohydrate content of stored grains [1]. Data in this study did not establish a clear link between insect infestation level and carbohydrate content. Carbohydrate content of maize in this study was in the 70.9–74.8% range; this is approximately the same as the 69.67–74.55% range reported for stored maize by Ullah *et al*. [25]. This implies that in all treatments, there was no substantial change in carbohydrate content relative to the varieties in the Ullah *et al*. [25] study.

Regarding ash content, the main effects treatment and month, and their interaction were all significant (Table 1). In February, there were no differences in ash content among treatments (Table 2). In December, ash content was highest in the ZeroFly treatment (1.6 ± 0.1) (Table 2). Ash content values in this study ranged between 1.10–1.60% and are in the range of 0.70–2.50% reported from different maize hybrids in Nigeria [24]. This implies that in all treatments, there was no substantial change in ash content relative to the varieties in the study by Ijabadeniyi and Adebolu [24]. Increase in the ash content of grains with insect infestation and prolonged storage period have been reported [23, 24]. However, in this study, ash content in December was higher than in February in only the ZeroFly treatment (Table 2). In the Botanical, Control, and PICS treatments, February and December ash content values were similar. In DE and Permethrin treatments, ash content in December was lower than in February. Therefore, there was no clear relationship between insect infestation [9] and ash content.

The maize used in this study had been fumigated well and had relatively low initial grain moisture content (MC) (9.1%); these two factors likely slowed down insect population growth of the several species that were found [9]. All treatments were without insects until 3 months into storage (May) when they were detected; insect numbers in the Control were not as high as would be typically found in ordinary polypropylene bags of untreated maize in storehouses in Nigeria during the June to September period [9, 31]. Nutrient content of infested stored grain depends upon the grain type, the type of insect pest and the level of infestation [1]. The generally low insect populations in all treatments, including the Control, during the February–September period may have contributed to reducing the clarity of the effects of insect infestation on nutritional composition reported in this study. Therefore, in some cases the link between the individual quality response variables and insect infestation level did not exhibit clearly.

It is important to note that at the mean temperatures of 28.8–30.0°C that existed in storehouses during this study, nutritional quality of grain was most likely adversely affected. In un-infested maize, lysine which is a protein building block, can decrease by as much as 14.3–20.7% in maize at temperatures of 25–45°C [32]. Therefore, some changes observed may be related to physiological changes of the maize. Maize kernels are living and respire [33]. In the process of respiration, they may use nutrients (starch) for that function which may affect relative nutrient composition.

CONCLUSION

Nutritional quality variables in this study were within or close to the known value ranges for maize. Therefore, storage of maize that is nearly insect-free (well fumigated) and well dried (9.1% MC), in addition to the effects of the management methods (Botanical, DE, PICS, ZeroFly, and Permethrin) used most likely slowed population growth of the several insect species that were found and contributed to much less nutritional quality reduction than could have been if insect pest populations were much higher.

Data from the present study and Nwaubani *et al*. [9] show the PICS technology was the most effective at keeping insect infestations in check and preserving maize quality. Therefore, hermetic technologies such as PICS, ZeroFly® Hermetic bags, and GrainPro SuperGrainbags need to be more widely adopted for maize storage.

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Table 1: ANOVA for main effects Treatment (Trt) and Month (Mon), and interactions for Protein Content (PC), Energy (ENER), Fat Content (FC), Crude Fiber (CF), Carbohydrate (CHO) and Ash Content (AC) in 700 g samples of maize from Arisekola, Eleekara, and Mandate markets sampled from February (Feb.) to December (Dec.) of 2016. Treatments comprised Botanical, Control, Diatomaceous Earth (DE), Purdue Improved Crop Storage (PICS) bags, Permethrin and ZeroFly® bags for maize samples taken in February, June, October, and December when PICS bags were destructively sampled

Variable	Source	df	*F*	*P*
PC				
	Trt	5, 15.2	0.75	0.5984
	Mon	3, 254	26.86	<0.0001
	Trt*Mon	15, 270	1.80	0.3741
ENER				
	Trt	5, 15	5.50	0.0045
	Mon	3, 180	7.57	<0.0001
	Trt*Mon	15, 181	1.71	0.0520
FC				
	Trt	5, 18	2.43	0.0749
	Mon	3, 172	6.04	0.0006
	Trt*Mon	15, 173	3.08	0.0002
CF				
	Trt	5, 15	0.23	0.9425
	Mon	3, 176	10.02	<0.0001
	Trt*Mon	15, 179	1.94	0.0225
CHO				
	Trt	5, 64.8	1.59	0.1742
	Mon	3, 260	28.40	<0.0001
	Trt*Mon	15, 270	1.15	0.3116
AC				
	Trt	5, 118	3.92	0.0025
	Mon	3, 205	7.83	<0.0001
	Trt*Mon	15, 206	2.19	0.0078

df, degrees of freedom; *F*, the analysis of variance (ANOVA) F-value; *P*, ANOVA P-value

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Table 2: Mean percentages of Protein Content (PC), Energy (ENER), Fat Content (FC), Crude Fiber (CF), Carbohydrate (CHO) and Ash Content (AC) (means ± SEs) in 700 g samples of maize from Arisekola, Eleekara, and Mandate markets sampled from February (Feb.) to December (Dec.) of 2016. Significant differences among treatments for each month are denoted with different lower-case letters and differences among months for each treatment are denoted by different upper-case letters, (P < 0.05, SAS, Tukey's Honestly Significant Difference Test). If there are no upper-case letters in a column there was no significant difference between months ($P \geq 0.05$)

	Mon	Botanical	Control	DE	PICS	Permethrin	ZeroFly
PC	Feb.	10.6 ± 0.3abA	10.3 ± 0.2abA	10.6 ± 0.2abA	11.0 ± 0.2bAB	10.4 ± 0.2abA	10.1 ± 0.2aA
	Jun.	10.4 ± 0.2aA	10.6 ± 0.3aA	10.4 ± 0.2aA	10.5 ± 0.2aA	10.3 ± 0.2aA	10.4 ± 0.2aA
	Oct.	11.9 ± 0.2aB	10.9 ± 0.2aB	11.8 ± 0.3aB	11.8 ± 0.2aC	11.3 ± 0.3aB	11.0 ± 0.1aB
	Dec.	11.3 ± 0.1abB	12.0 ± 0.2bC	11.5 ± 0.3aB	11.5 ± 0.2abBC	11.4 ± 0.2abB	11.0 ± 0.1aB
ENER	Feb.	382.8 ± 1.2ab	380.1 ± 2.5aB	382.5 ± 1.3abB	388.7 ± 0.6c	384.6 ± 1.0abc	386.3 ± 0.8bcB
	Jun.	384.3 ± 1.6ab	380.5 ± 1.0aB	385.7 ± 1.4bB	388.9 ± 1.2b	384.1 ± 1.1ab	384.4 ± 1.4abB
	Oct.	381.4 ± 1.1bc	374.5 ± 1.9aA	378.0 ± 1.1abA	387.6 ± 0.7d	380.4 ± 1.1bc	383.8 ± 1.4cdB
	Dec.	382.5 ± 1.0ab	380.4 ± 0.7aB	377.2 ± 0.8aA	386.1 ± 1.6b	383.3 ± 1.6b	377.0 ± 2.9aA
FC	Feb.	4.8 ± 0.2abA	5.1 ± 0.1bc	4.5 ± 0.1aA	5.2 ± 0.1bcA	5.1 ± 0.1bc	5.5 ± 0.1cAB
	Jun.	5.2 ± 0.1aAB	5.4 ± 0.2a	5.6 ± 0.1aB	5.7 ± 0.1aB	5.2 ± 0.1a	5.4 ± 0.1aA
	Oct.	5.4 ± 0.3aB	4.9 ± 0.1a	4.6 ± 0.1aA	5.2 ± 0.1aA	5.1 ± 0.1a	5.9 ± 0.2aB
	Dec.	5.6 ± 0.1cB	5.0 ± 0.2ab	4.7 ± 0.1aA	5.6 ± 0.1cB	5.4 ± 0.1bc	5.7 ± 0.2cAB
CF	Feb.	1.9 ± 0.1a	2.2 ± 0.2aB	1.6 ± 0.1a	2.1 ± 0.2aB	2.0 ± 0.1aB	1.9 ± 0.1aB
	Jun.	1.9 ± 0.1a	2.1 ± 0.1aB	1.6 ± 0.1a	1.9 ± 0.1aAB	1.9 ± 0.1aB	1.9 ± 0.1aB
	Oct.	1.6 ± 0.1a	1.4 ± 0.1aA	1.5 ± 0.1a	1.5 ± 0.1aA	1.6 ± 0.1aA	1.3 ± 0.1aA
	Dec.	1.7 ± 0.1abc	1.4 ± 0.1aA	1.9 ± 0.1bc	1.5 ± 0.1abA	1.6 ± 0.1abA	1.9 ± 0.1cB
CHO	Feb.	74.3 ± 0.3aB	73.5 ± 0.5a	74.8 ± 0.3aB	74.6 ± 0.3aB	74.3 ± 0.5aB	74.1 ± 0.4aB
	Jun.	74.7 ± 0.6bB	73.1 ± 0.5a	74.5 ± 0.5abB	74.7 ± 0.4abB	74.7 ± 0.5abB	74.3 ± 0.6abB
	Oct.	71.3 ± 0.4aA	72.0 ± 0.2a	72.4 ± 0.5abA	73.4 ± 0.2bA	72.3 ± 0.5abA	71.6 ± 0.3aA
	Dec.	71.8 ± 0.3aA	71.9 ± 0.4a	72.4 ± 0.4aA	72.7 ± 0.4aA	72.3 ± 0.4aA	70.9 ± 0.6aA
AC	Feb.	1.4 ± 0.1ab	1.5 ± 0.1b	1.5 ± 0.1bB	1.2 ± 0.0aA	1.5 ± 0.1bB	1.4 ± 0.1abA
	Jun.	1.4 ± 0.1a	1.5 ± 0.1ab	1.6 ± 0.1bB	1.4 ± 0.1aB	1.5 ± 0.1abB	1.6 ± 0.1bB
	Oct.	1.3 ± 0.1a	1.3 ± 0.1a	1.4 ± 0.1aAB	1.2 ± 0.0aA	1.3 ± 0.1aAB	1.3 ± 0.1aA
	Dec.	1.3 ± 0.1b	1.4 ± 0.1b	1.2 ± 0.1abA	1.1 ± 0.0aA	1.1 ± 0.0aA	1.6 ± 0.1cB

PICS, Purdue Improved Crop Storage bags

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