Applied Tropical Agriculture
Volume 25, No.2, 45 - 59, 2020

ASSESSMENT OF STORED FLOUR TYPES AND EFFECTIVENESS OF FREEZING, SUN-DRYING AND HERMETIC STORAGE IN THE MANAGEMENT OF RED FLOUR BEETLE, *TRIBOLIUM CASTANEUM* (HERBST) IN ILORIN

Yusuf, R. O., *Ojumoola, O. A., Uddin II, R. O. and Adesiyun, A. A

Department of Crop Protection, University of Ilorin, PMB 1515, Ilorin, Nigeria
**Corresponding author's email: ojumoola.oa@unilorin.edu.ng*

Abstract
Infestation and contamination of flour by the red flour beetle, Triboliumcastaneum (Herbst) is a major constraint to flour storage especially in many households of sub Saharan Africa region. Unlike grain protection, flour protection does not lend itself to the use of plant powders, ash, sand and other admixture-based materials often employed by householders in the region as innocuous and cheap alternatives to synthetic insecticides. Scanty information however exists on how effective the few methods used for stored grains insect pest management will be for stored flour. In this study, flour use and T. castaneummanagement practices of householders in Ilorin, Nigeria was investigated ina survey using questionnaires. Effects of different duration of freezing, sun-drying and hermetic storage treatments on adult and larval mortalityof T. castaneum and on population growth in three commonly stored flour types identified during the survey were also evaluated in the laboratory at the Department of Crop Protection, University of Ilorin, Ilorin Nigeria. Furthermore, the effect of each physical method on organoleptic characteristics of treated flour types was assessed. Results showed that semolina, yam and wheatflours were most preferred by householders in the study area. In addition, 12 hours of freezing and 6 hours of sun-drying significantly ($p<0.05$)caused complete adult and larvalmortalities (100.0%) whilealso preventing population increases in the three most preferred flour types even after 3 months of post-treatment storage. In contrast, hermetic storage treatment for 336 hours caused lower ($p<0.05$) mean percentage mortalities (6.0% - 16.0%; 7.0% - 12%) and higher post-treatment storage population changes (11.20 – 16.60; 160.60 – 189.80) of T. castaneumadults and larvae respectively in all the flour types. However, none of the treatments negatively affected the organoleptic characteristics of the flours at $p=0.05$. Information provided in this study will enhance utilization of locally available physical methods for effective management ofT. castaneumin the stored flours.

Keywords: *Flour, Triboliumcastaneum, freezing, sun-drying, hermetic storage, Ilorin*

Introduction

Generally speaking, flour is the powder obtained by grinding dried grains, seeds, roots or tubers. Thus, flour types are typically named after the crop from which they were milled. In Nigeria and other parts of sub Saharan Africa (SSA), maize flour, rice flour, sorghum flour, cowpea flour, soybean flour, potato flour, fermented brown yam flour and unfermented white yam flour as well as wheat flour represent important components of local dishes (Edema*et al.,* 2005; Abiodun and Akinoso, 2015).Wheat flour is the most versatile flour type in many parts of the world including SSA countries where urbanization and rising income has popularized its consumption in the last few decades (Jayne *et al.*, 2010).The versatility of wheat flourprimarily stems from the existence of different wheat species and classes from which various wheat flour types are produced. The three commonly grown species of wheat in the world today are *Triticumaestivum* (common wheat classes), *T. compactum*(club wheat classes) and *T. durum* (durum wheat classes)(Atwell, 2001; Uthayakumaran and Wrigley, 2010). Durum wheats usually have much harder kernels in comparison to all other wheat classes (Atwell, 2001). Flour obtained from the coarsely ground endosperm of durum is called semolina. When semolina is further ground into fine powder, the resulting flour is known as durum flour (Wheat Food Council, 2009).

The red flour beetle, *Triboliumcastaneum* (Herbst) (Coleoptera: Tenebrionidae) is a cosmopolitan insect pest of stored products including flour (Shafique *et al*., 2006). Though regarded as secondary insect pests, they are capable of causing considerably losses in seed weight and viability during storage (Atanasov, 1978; Li and Arbogast, 1991; Ojo and Omoloye, 2015). Contamination of stored flour by *T. castaneum*may also occur from the presence of dead insects, fecal droppings, exuviae and secretion of toxic quinones with offensive odours (Locontiand Roth, 1953; Jonfia-Essien and Navarro, 2010; Obeng-Ofori, 2010). In addition, flour infestation may increase moisture and temperature levels which in turn enhance the development of mould and other pathogens that invariably cause deterioration during storage (Shafique *et al.*, 2006).

The use of synthetic insecticides for the control of stored product insect pests is associated with a number of health and environmental problems (Rajendran and Sriranjini, 2008; Abd-El-Aziz, 2011; Yan *et al.*, 2017; Ojumoola *et al*., 2018). Thus, for the numerous farmers and householders in SSA countries, a number of cheap and innocuous alternatives to synthetic insecticides like sun-drying; low cost hermetic drums, jerry cans, plastic bags or bottles; admixture of grains with plant powders or oils; admixture of grains with sand, diatomaceous earth or other inert materials etc. have been recommended by several authors (Kitch*et al*., 1992; Adedire and Ajayi, 1996; Fields and Muir,1996; Seck*et al*., 1996; Baoua *et al.,* 2012; Yan *et al.*, 2017).Most of the management recommendations are however focused on insect pest management in stored grains and not stored flour. While many of the foregoing methods like the admixture of flour with botanical extracts or inert materials are impracticable for the management of insect pests in stored flour types, limited information exists on the effectiveness of the few practicable options.

This study thus investigated the effectiveness of three physical methods – freezing, sun-drying and hermetic storage, for the management of *T. castaneum* in selected stored flour types.

Materials and Methods

Study Area and Experimental Sites

Survey of householders was carried out in Ilorin, Nigeria (8°59'5.3" N and longitude 4°33'44.8" E).In the study area, rainfall range is between1000 mm to 1500 mm **per a**nnum. In the wet season, temperature and relative humidity is 25°C – 30°C and75% – 80% respectively while it is 33°C – 34°C and about 65% during the dry season (Akpenpuun and Busari, 2013). On the other hand, experimental studies on *T. castaneum*mortality, *T. castaneum* population growth and flour organoleptic tests were conducted under ambient laboratory conditions at the Department of Crop Protection, University of Ilorin, Ilorin Nigeria.

Sampling procedure, questionnaire and survey of householders

Householders were selected through a three-stage random sampling procedure. In the first stage, Ilorin South LGA was randomly selected out of the three existing LGAs in Ilorin. Five sub areas were then randomly selected from the chosen LGA in the second stage. In the last stage, 22 households were randomly selected from each sub area. Thus, a total of 110 householders or respondents were interviewed during the survey. Information on householders' demographic characteristics, preferred flour types and storage practices, identification knowledge of *T. castaneum* and its management practices in stored flour were collected using face validated structured questionnaires (Table 1). Information obtained during the survey informed the choice of flour type, physical methods and treatment durations used in experimental studies.

Table 1: Overview of questions from questionnaire administered to householders in Ilorin, Nigeria to assess their identification knowledge and management practices of *T. castaneum* in stored flour

Data Section	Description
1. Householders' demographics	Sex; age (<18, 18 – 30, 31 – 50, > 50); marital status (married, single); highest level of education (primary, secondary, tertiary, no formal education); household size (1 – 2, 3 – 5, 6 – 10, > 10)
2. Flour purchase and storage practices of householders	Type of flour often stored at home (Wheat flour, yam flour, semolina flour, others types); Primary source of flour (Local market, supermarket, home milled, other sources); Quantity of flour often stored (< 5 kg, 5 – 20 kg, 21 – 50 kg); In what is flour often stored at home (Nylon bag, local sack, lidded plastic container, Nylon bag combined with lidded plastic container, fridge/freezer); Maximum storage duration of flour at home (< 1 month, 1 – 3 months, 4 – 6 months, > 6 months)

3. Householders' identification knowledge of *T. castaneum*in stored flour	What does *T. castaneum* adult look like? (Like sugar ant, like cowpea beetle, like maize weevil, like small cockroaches, I don't know); Which life stage of *T. castaneum*have you observed in your stored flour? (adults only, larvae only, both adults and larvae, neither adults nor larvae)
4. Householders' management practices of *T. castaneum* in stored flour	What is the primary method used to prevent infestation of stored flour at home? (Store only quantity that can be consumed in a short period; place flour in freezer immediately after purchase; expose flour to sunlight before storage; No preventive measures applied); How do you deal with already infested flour at home? (sieve out live insects, freeze flour and sieve out dead insects, prepare flour without removing insects, discard insect infested flour)

Source and Type of Flours

Semolina, yam and wheat flours were used in all experiments carried out in the study. Wheat flour (Golden Penny brand), semolina (Semovita brand) and brown (fermented) yam flour were obtained from the local Ipata market in Ilorin. The flour types varied in particle size (texture), such that yam flour < wheat flour < semolina. Before use, flours were sterilized in a freezer (Thermocool-250 refrigerator model)for 7 days to disinfest them of any infesting insects.

***T. castaneum* Culture**

Population of *T. castaneum* that had been maintained for several generations on wheat flour was obtained from the Nigerian Stored Product Research Institute (NSPRI), Ilorin, Nigeria. One kilogram (1 kg) of wheat, semolina and yam flours in separate 1 L plastic containers were infested with 50 unsexed adults each under ambient laboratory conditions (27± 2^{o}C; 70±5% relative humidity and 12:12 h photo period). Larvae that emerged from each flour type were removed using a 2 mm mesh sieve and cultured separately to obtain new adults which were then used in the experiments.

Experiments and Experimental Procedures

The effects of freezing, sun-drying and hermetic storage methods at different duration of treatment on *T. castaneum* mortality and population growth in the three flours types were investigated in separate experiments laid out in a Completely Randomized Design and replicated 5 times for each treatment combination.

Effects of Freezing on Adult and Larval Mortality

Treatment combinations in this experiment consisted of the three flour types – wheat, semolina and yam flour types and four duration of freezing – 1, 3, 6 and 12 hours. One hundred grams (100 g) of each flour type was put in a 250 mL plastic container after which 20 adult *T. castaneum*beetles were introduced and allowed to acclimatize for 24 hours. The containers were thereafter placed in the freezer (Thermocool-250 refrigerator model) for 1 hour at -18°**C**after which they were removed. The number of deadadults in the replicated flour types was then determined by counting. Insects that failed to respond when repeatedly prodded were regarded as dead. The same procedure described above was followed to determine the effect of freezing on mortality of adults in the three flour types after 3, 6 and 12 hours. In the same way, the mortality effects of 1, 3, 6 and 12 hours of freezing on *T. castaneum*larvae was investigated using 20 last instars. Data was also collected as previously described on the number of dead larvae after each period.

***E*ffects of Sun-Drying on Adult and Larval Mortality**

In this experiment, treatment combinations consisted of the three flour types and two durationof sun-drying i.e. 3and 6 hours. One hundred grams (100 g) of each flour type was measured into small circular flat stainless trays (c.a. 30 cm diameter) and spread thinly. Twenty adult beetles were put in the flours and immediately covered with light transparent polythene sheets held in place with paper tape. The insects were allowed to acclimatize within the flour for 24 hours after which the trays were placed in the sun for 3 hours (12:00 P.M – 3:00 P.M). The number of dead adults in each replicated flour type was thereafter determined by counting. Following the same procedure, the mortality effect of 6 hours (12:00 P.M – 3:00 P.M) of sun-dryingon *T. castaneum* adults in the three flour types was determined. Similarly, the effects of 3 and 6 hours of sun-drying on larval mortality were investigated using 20 last instar larvae.

Effects of Hermetic Storage on Adult and Larval Mortality

Treatment combinations consisted of the three flour types and three duration of hermetic storage i.e. 72 hours (3 days), 168 hours (7 days) and 336 hours (14 days). 250 mL lidded plastic containers (which were a smaller version of the lidded plastics containers often used for flour storage by householders in the study area) were modified into a hermetic system and used in this experiment. Each container was filled to the brim with a flour type after which twenty adult beetles were introduced and left to acclimatize for 24 hours. Thin polythene sheet was placed over the top of the flour-filled container which was in turn covered firmly with its lids and hermetically sealed with paper tape. The hermetic plastic containers were then placed in the laboratory cupboard for 72 hours after which they were unsealed and data collected on adult mortality. The same procedure was followed to determine the effect of 168 and 336 hours of hermetic storage on adult mortality in the three flour types. Similar experiments on the effect of hermetic storage durations on larval mortality were also conducted using 20 last instar larvae.

Effect of Freezing, Sun-drying and Hermetic Storage Methods on Population Growth

Effect of each management method on population growth of *T. castaneum* in the three flour types was done in the same way as the mortality studies except that 20 adults and 20 last instar larvae were introduced simultaneously into flours and subjected to each of freezing, sun-drying and hermetic storage management methods. Flours were also subjected to 30 and 60 days of hermetic storage instead of the 3-, 7- and 14-days durations used in the mortality studies. At the end of the different durations of freezing and sun-drying treatments, flours (with dead or living insects) were repackaged into 250 mL transparent lidded plastic containers and stored post-treatment inside a dark cupboard under ambient laboratory conditions for 30 days. Post-treatment storage was done to determine the extent to which the different durations of freezing and sun-drying treatments will inhibit population growth. On the other hand, flour types subjected to hermetic storage for 30 and 60 days were taken to have been treated and stored simultaneously. Population changes in the flour types at the end of post-treatment storage were obtained by subtracting the initial from the final numbers of adults and larvae.

Organoleptic Characteristics of Dough Prepared from Treated Flour Types

Flour of the same type subjected to one of the three management methods for different durations in the population growth experiment were combined. Each of the resulting nine treatments was prepared into doughs using hot distilled water. Three control treatments consisting of each flour type that had not been subjected to any of the management methods were also prepared. Dough of each treatment and controls were coded and served to a panel of 10 randomly selected volunteers. The colour, taste, aroma and general acceptability of dough samples were scored using the 9-point hedonic scale of measuring food preferences (Peryam and Pilgrim, 1957). The points on the scale ranged from Like Extremely (9) to Dislike Extremely (1).

Data Analysis

Questionnaire data were analyzed and summarized using frequencies and percentages. Where respondents failed to provide answers missing values were declared and excluded from analysis. Data on insect mortality, population growth and organoleptic tests were subjected to a one-way analysis of variance. Mean separation was done using the Tukey's Honestly Significant Difference (HSD) at 5% level of significance. All data analyses were done using the IBM SPSS statistics software (version 21).

Results

Demographic Characteristics of Surveyed Householders

The demographic characteristic of 110 householders in Ilorin, Nigeria is presented in Table 2. About 71% of the respondents were female with majority (59.1%) falling between the age range of 18 and 30 years. Furthermore, 62.7% were married and more than half (70.9%) had one form of tertiary education or the other. Also, majority of households (50.9%) in the study area had an average size of between 3 to 5 persons.

Flour types Purchase and Storage Practices of the Householders

Semolina accounted for 36.8% of the flour types often stored by householders in Ilorin (Figure 1). It was followed by yam and wheat flours with 29.2% and 26.4% respectively. Other flour types like cassava flour, plantain flour, and baking flour together accounted for just 7.5% of the total. The primary source of flour stored by householders in Ilorin is presented in Figure 2. Majority of the householders (61.3%) obtained their flour from the local market while 31.1% sourced it from supermarkets. Few respondents (3.8%) milled their flour at home while others (3.8%) reported getting their flour as gifts from friends and relatives.

Figure 3 shows the distribution of householders in Ilorin by quantity of flour often stored. More than half of householders (59.4%) stored less than 5 kg of flour at a time. On the other hand, 5 to 20 kg was frequently stored by 36.8% of householders in the study area. Only a very small percentage (2.8%) of respondents stored between 21 and 50 kg of flour at a given time.

Table 2: Demographic Characteristics of Householders in Ilorin South Local Government Area, Kwara State, Nigeria (N=110)

Variable		Total Respondents	
		Number	%
A.	**Sex**		
	Male	32	29.1
	Female	78	70.9
B.	**Age (years)**		
	< 18	27	24.5
	18 - 30	65	59.1
	31 - 50	15	13.6
	> 50	3	2.7
C.	**Marital status**		
	Married	41	37.3
	Single	69	62.7
D.	**Highest level of education**		
	Tertiary	78	70.9
	Secondary	28	25.5
	Primary	4	3.6
	No formal education	0	0
E.	**Household size**		
	1 - 2 persons	20	18.2
	3 - 5 persons	56	50.9
	6 - 10 persons	30	27.3
	> 10 persons	4	3.6

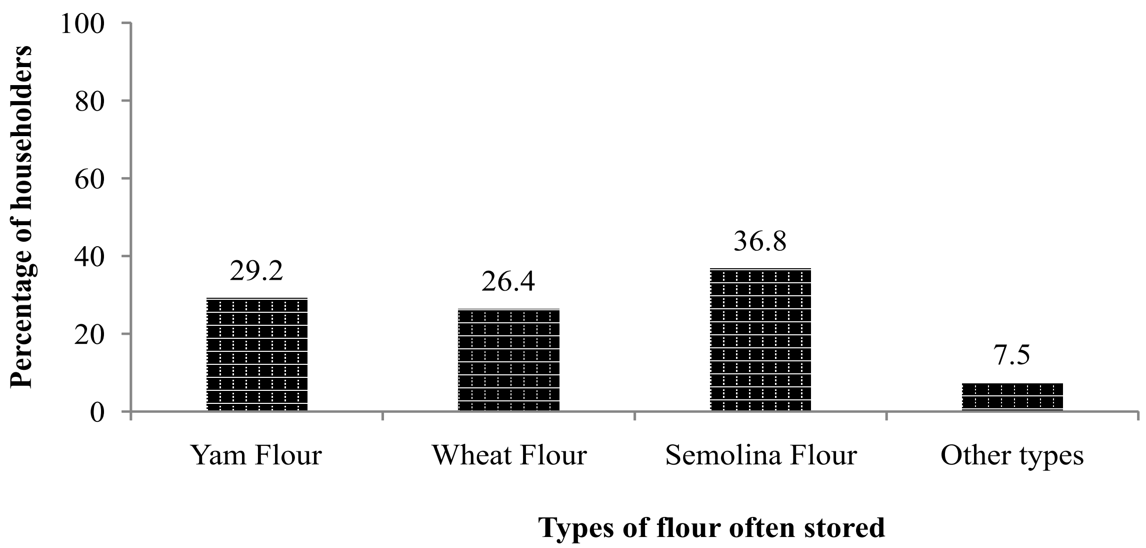

Figure 1: Distribution of householders in Ilorin by type of flour often stored

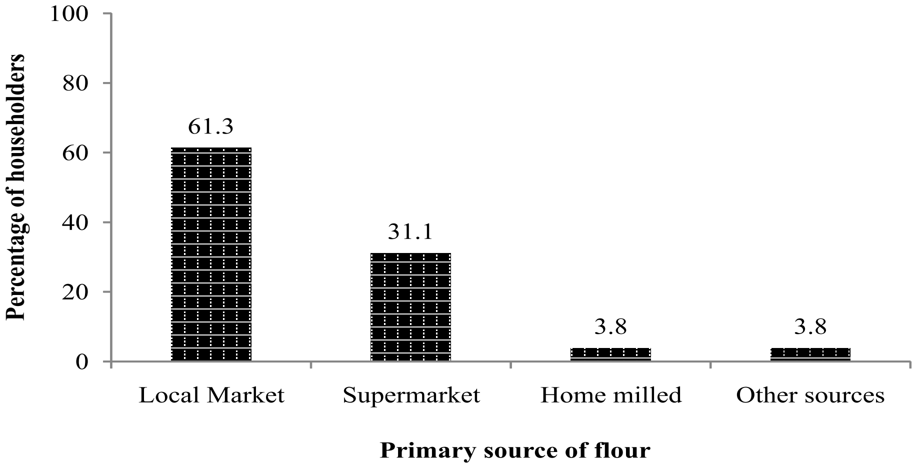

Figure 2: Distribution of householders in Ilorin by primary source of flour

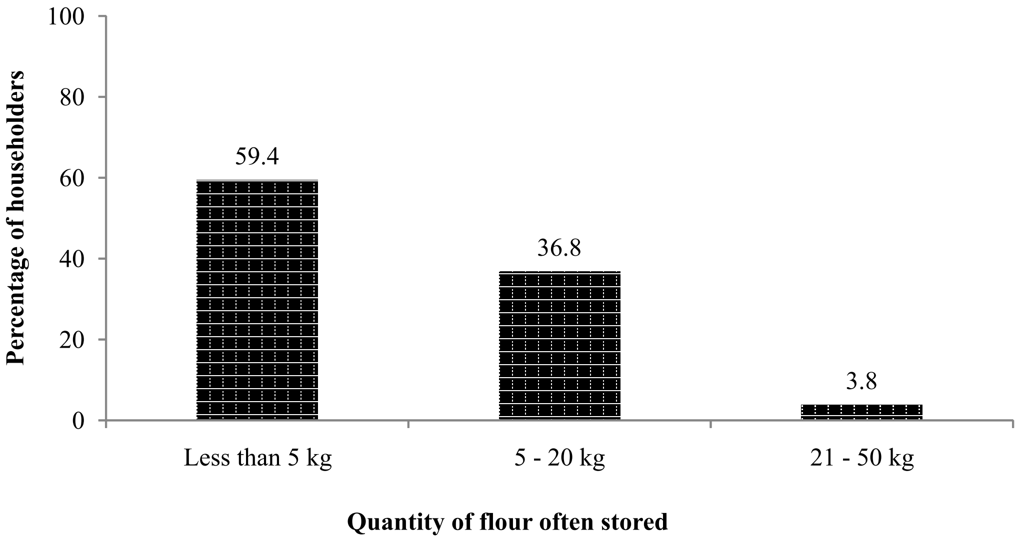

Figure 3: Distribution of Householders in Ilorin by Quantity of Flour Often Stored

Flour storage method of householders in Ilorin is shown in Figure 4. Lidded plastic containers were the most frequently (47.2%) used method. The use of local jute sacks and fridge/freezers respectively accounted for just 17.9% and 15.1% of total storage methods.Nylon bags alone (11.3%) or nylon bags combined with lidded plastic containers (8.5%) were also used to store flour by householders in the study area. Figure 5 shows the distribution of householders in Ilorin, Nigeria by the maximum storage duration of flour. Majority of householders (42.5%) stored their flour for less than a month. Similarly, 40.6% of householders reported storing flour for a period of 1 to 3 months. On the other hand, 12% of respondents stored flour for a maximum period of 4 to 6 months while only 4.7% stored flour for more than 6 months.

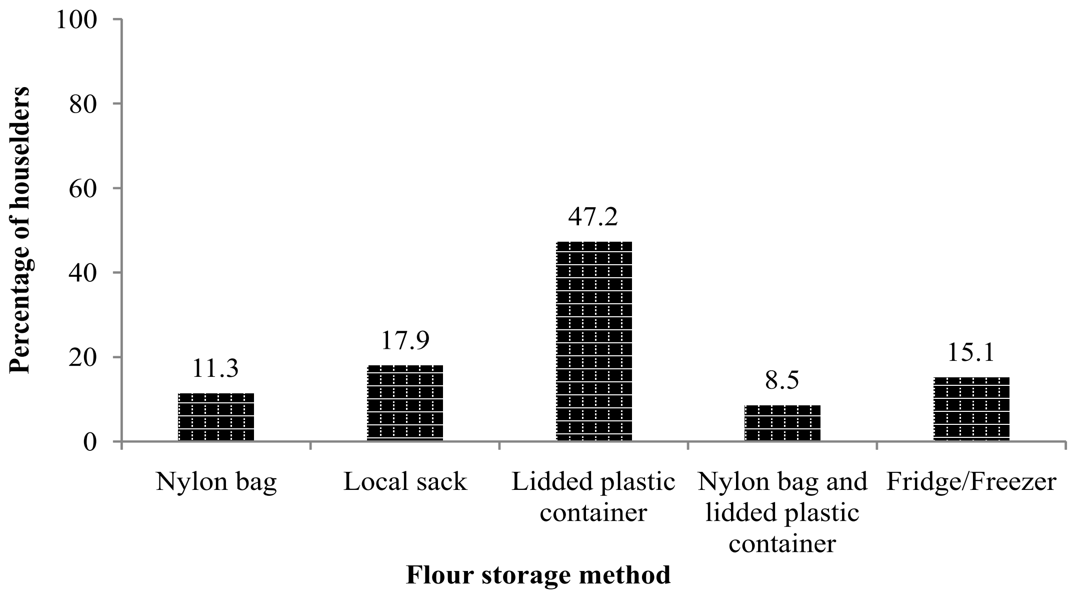

Figure 4: Distribution of householders in Ilorin by flour storage method

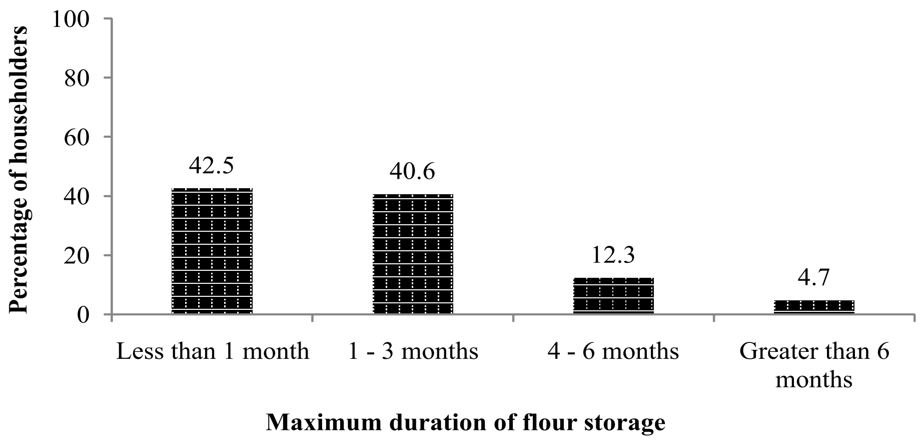

Figure 5: Distribution of householders in Ilorin by maximum storage duration of flour

Householders' Identification Knowledge of *T. castaneum*in Stored Flour Types

The identification knowledge of householders and management practices for *T. castaneum* in Ilorin is presented in Table 3. Majority of respondents (62.4%) reported that the adults of *T. castaneum*lookedlike the cowpea beetle while only 15.6 % compared it to the maize weevil. About 14.7% of respondents were unable to describe the stored flour beetle. Similarly, majority of householders (38.1%) had only observed *T. castaneum*larvae in stored flours. A lower percentage of respondents (27.6%) observed only the adults while 18.1%had observed both the adult and larval stages in stored flour. About 16.0% of respondents however reported that they had neither seen nor observed both the adult and larval stages of *T. castaneum*.

Householders' Management Practices of *T. castaneum* in Stored Flour

To prevent infestation of flour by *T. castaneum*, majority of householders (54.0%) store quantities that can be consumed within a short period (Table 3). Some householders (35.0%) however employed refrigeration or deep freezing to prevent flour infestation. Only 9.0% of respondents prevented infestation by sun-drying flour before storage while 2.0% did not take any preventive measures. When flour had already been infested, majority of householders (85.0%) simply sieved out the live insects before use while 10.0% controlled infestation by freezing the insect-infested flour and then sieving out the dead insects.

Table 3: Identification Knowledge and Management Practices of *Tribolium Castanuem* in Stored Flour by Householders in Ilorin South Local Governement Area, Kwara State, Nigeria (N=110)

Variable		Total Respondents	
		Number	%
A.	**Identification knowledge of *T. castaneum***		
i.	Description of adult stage in stored flour		
	Like sugar ants	3	2.8
	Like cowpea beetle	68	62.4
	Like maize weevil	17	15.6
	Like small cockroaches	5	4.6
	I do not know	16	14.7
	Total	109	100
ii.	Life stages observed in stored flour		
	Adults only	29	27.6
	Larvae only	40	38.1
	Both adults and larvae	19	18.1
	Neither adults nor larvae	17	16.2
	Total	105	100
B.	**Management practices for *T. castaneum***		
i.	Method used to prevent infestation of flour		
	Store quantity that can be consumed in a short period	54	54
	Place in the freezer immediate after purchase	35	35
	Expose flour to sunlight before storage	9	9
	No preventive measures applied	2	2
	Total	100	100
ii.	Method of dealing with already infested flour		
	Sieve out the live insects	85	85
	Freeze flour and sieve out dead insects	10	10
	Prepare flour without removing insects	4	4
	Discard insect infested flour	1	1
	Total	100	100

Effects of Management Methods on Adult and Larval Mortality

More adults were observed to have been killed in all three flour types after sun-drying for 3 hours than by freezing for the same duration(Table 4). In addition, while 12 hours of freezing was needed to achieve complete adult mortality (100.00%) in the flours, only 6 hours of sun-drying was needed to achieve the same. There was however no significant difference ($p>0.05$) in the percentage adult mortalities observed in wheat, semolina and yam flours exposed to 12 hours of freezing and 6 hours of sun-drying. Similarly, no statistical difference ($p>0.05$) was observed in the mean percentage mortalities of adult T. castaneum in the three flour types at all duration of sun-drying. The lowest mean percentage mortalities of T. castaneum adults were observed in flour types subjected to different duration of hermetic storage treatments. Statistically fewer percentage ($p<0.05$) of adult T. castaneum were observed to have been killed in yam flour (78.00%) than in semolina (93.00%) after 6 hours of freezing treatment.

The mean percentage mortalities of T. castaneum larvae in the flours after exposure to different duration of freezing, sun-drying and hermetic treatments are shown in Table 5. More larvae were killed by sun-drying for 6 hours than by freezing for the same duration. Complete larvae mortalities were observed with 12 hours of freezing and 6 hours of sun-drying in each flour type. After 3 hours of sun-drying, the mean percentage mortality of larvae was lowest (56.00%) in yam flour and was significantly different ($p<0.05$) from those of the wheat and semolina flours. Larval mortalities values in flours stored hermetically were generally very low irrespective of treatment duration and were not significantly different ($p>0.05$) among the three flour

Table 4: Percentage mortality of *T. castaneum* adults in three flour types after freezing, sun-drying and hermetic treatments

Flour type	Mean percentage mortality of *T. castaneum* adults								
	Freezing				Sun-drying		Hermetic		
	Duration of treatment (hours)								
	1	3	6	12	3	6	72	168	336
Wheat	8.00	20.00	85.00[ab]	100.00	64.00	100.00	0.00	10.00	16.00[a]
Semolina	4.00	26.00	93.00[a]	100.00	58.00	100.00	0.00	5.00	11.00[ab]
Yam	4.00	21.00	78.00[b]	100.00	62.00	100.00	0.00	5.00	6.00[b]
SEM	3.7	6.6	3.9	0.0	2.1	0.0	0.0	1.4	1.7
	NS	NS		NS	NS	NS	NS	NS	

Mean values in a column followed by the same letter(s) are not significantly different at P=0.05 according to Turkey's Honestly Significant difference.

SEM: Standard Error of Mean

NS: Not Significant

Table 5: Percentage mortality of *T. castaneum* larvae in three flour types after freezing, sun-drying and hermetic treatments

Flour type	Mean percentage mortality of *T. castaneum* larvae								
	Freezing				Sun-drying		Hermetic		
	Duration of treatment (hours)								
	1	3	6	12	3	6	72	168	336
Wheat	10.00	40.00	83.00	100.00	66.00[a]	100.00	0.00	8.00	10.00
Semolina	8.00	43.00	85.00	100.00	65.00[a]	100.00	0.00	5.00	12.00
Yam	3.00	45.00	91.00	100.00	56.00[b]	100.00	0.00	5.00	7.00
SEM	3.5	3.6	2.9	0.0	1.7	0.0	0.0	1.3	1.0
	NS	NS	NS	NS		NS	NS	NS	NS

Mean values in a column followed by the same letter(s) are not significantly different at P=0.05 according to Turkey's Honestly Significant difference.

SEM: Standard Error of Mean

NS: Not Significant

Effects of Management Methods on the Population Growth of *T. castaneum*

Effects of Freezing on the Population Growth of T. castaneum in Three Flour Types

After 30 days post-treatment storage, an increase was observed in the populations of *T. castaneum* adults and larvae within all flour types subjected to 1 hour, 3 hours and 6 hours of freezing (Table 6). In contrast, no change occurred in the flour types exposed to 12 hours of freezing after 30 days post-treatment storage. The highest mean changes (9.20 and 8.60) in adult populations were observed in semolina exposed to freezing for 1 and 3 hours respectively. These values were closely followed by those of wheat (7.20 and 7.00) after freezing for 1 and 3 hours respectively. Population changes in yam flours subjected to 1 and 3 hours of freezing was, however, significantly lower ($p<0.05$) than in semolina and wheat at the same durations. The lowest mean changesin larval population (0.00) after 30 days post-treatment storage was also observed in wheat, semolina and yam flours subjected to 12 hours of freezing. On the other hand, flour types exposed to just 1 hour of freezing treatments had the highest mean change in larval population. Other treatment combinations had intermediate mean larval population change values that were significantly different ($p<0.05$) from the highest and lowest after 30 days post-treatment storage.

Table 6: Change in *T. castaneum* population in three flour types after freezing treatment and 30 days post treatment storage under ambient conditions

Flour Type	Duration of freezing (hours)	Duration of storage after freezing (days)	†Mean change in *T. castaneum* life stages	
			Adults	Larvae
Wheat	1	30	7.20^{d}	228.40^{f}
	3	30	7.00^{d}	110.60^{c}
	6	30	4.40^{bc}	85.80^{b}
	12	30	0.00^{a}	0.00^{a}
Semolina	1	30	9.20^{d}	193.40^{d}
	3	30	8.60^{d}	171.40^{d}
	6	30	3.60^{abc}	91.60^{b}
	12	30	0.00^{a}	0.00^{a}
Yam	1	30	4.40^{bc}	197.20^{e}
	3	30	2.60^{ab}	88.20^{b}
	6	30	3.80^{bc}	81.00^{b}
	12	30	0.00^{a}	0.00^{a}
SEM			1.1	5.5

Mean values in a column followed by the same letter(s) are not significantly different at P=0.05 according to Tukey's Honestly Significant Difference

SEM: Standard Error of Mean

†Change in *T. castaneum* population = Final population – 20

Effects of Sun-drying on the Population Growth of T. *Castaneum* In Three Flour Types

Presented in Table 7 is the mean population growth of T. *castaneumin* wheat, semolina and yam flour after sun-drying and 30 days post-treatmentstorage under. There was no change in adult and larval populations in the flour types exposed to 6 hours of sun-drying after 30 days post-treatment storage. Wheat flour after 3 hours of sun-drying had the highest mean change (6.80 and 76.00) in adult and larval populations respectively. These values were followed by semolina with 4.60 and 70.00 respectively. Yam flour treated by sun-drying for 3 hours had significantly lower (61.80) mean change in larval population compared to wheat and semolina. There was a significant difference ($p<0.05$) in the mean population change of T. *castaneumin* wheat, semolina, and yam flour types after 6 hours of sun-drying and 30 days post-treatment storage when *compared to the population in each flour type treated for 3 hours.*

Effects of Hermetic Storage on the Population Growth of *T. castaneum*

There was an increase in adult and larval populations of *T. castaneum* in the three flour types subjected to 30 and 60 days of hermetic storage treatments(Table 8). Irrespective of treatment and storage durations, no significant differences ($p>0.05$) were observed in the mean population change of adult *T. castaneum* in each of wheat, semolina and yam flours. In contrast, flour types stored hermetically for 60 days had a significantly lower ($p<0.05$) mean change in population of *T. castaneum* larvae compared to those treated and stored for 30 days. However, there were no significant differences in the mean change in larvae population of *T. castaneum* in the flour types treated and stored for the same duration at p=0.05.

Table 7: Change in *T. castaneum* population in three flour types after sun -drying treatment and 30 days post treatment storage under ambient conditions

Flour Type	Duration of sun-drying (hours)	Duration of storage after sun-drying (days)	†Mean change in *T. castaneum* life stages	
			Adults	Larvae
Wheat	3	30	6.80[c]	76.00[c]
	6	30	0.00[a]	0.00[a]
Semolina	3	30	4.60[bc]	70.00[c]
	6	30	0.00[a]	0.00[a]
Yam	3	30	3.00[b]	61.80[b]
	6	30	0.00[a]	0.00[a]
SEM			0.7	2.3

Mean values in a column followed by the same letter(s) are not significantly different at P=0.05 according to Tukey's Honestly Significant Difference
SEM: Standard Error of Mean
†Change in *T. castaneum* population = Final population – 20

Table 8: Change in *T. castaneum* population in three flour types after hermetic treatment and 30- and 60-days post treatment storage under ambient conditions

Flour Type	Duration of hermetic treatment (days)	Duration of storage after hermetic treatment (days)	†Change in *T. castaneum* life stage	
			Adults	Larvae
Wheat	30	30	13.60	180.60[b]
	60	60	11.20	160.60[a]
Semolina	30	30	12.80	185.20[b]
	60	60	16.60	161.00[a]
Yam	30	30	12.80	189.80[b]
	60	60	12.60	163.80[a]
SEM			2.4 NS	4.4

Mean values in a column followed by the same letter(s) are not significantly different at P=0.05 according to Tukey's Honestly Significant Difference.
SEM: Standard Error of Mean
NS: Not Significant
†Change in *T. castaneum* population = Final population – 20

Organoleptic Characteristics of Dough Prepared From Treated Flour Types

Table 9 shows the mean organoleptic characteristics of doughs prepared from each flour type after freezing, sun-drying and hermetic storage treatments. The mean score for aroma, taste, colour and general acceptability was reasonably high for all treated samples with most of the samples being moderately liked. The organoleptic characteristics of all treated and control flour samples were also statistically the same at p=0.05.

Table 9: Organoleptic characteristics of dough made from three flour types subjected to freezing, sun - drying and hermetic treatments

Flour used to make dough	Flour Treatment	Aroma	Taste	Colour	General acceptability
Wheat	Freezing	6.70	7.40	7.20	7.60
	Sun-drying	7.20	7.80	7.60	7.90
	Hermetic	7.10	7.40	7.60	7.50
	Control	8.00	7.90	8.00	8.00
Semolina	Freezing	7.30	7.40	7.60	7.70
	Sun-drying	7.30	7.00	7.50	7.40
	Hermetic	7.70	7.90	7.80	7.90
	Control	7.90	8.00	8.00	8.00
Yam	Freezing	7.00	6.90	7.20	7.10
	Sun-drying	7.40	7.50	7.60	7.60
	Hermetic	7.40	7.60	7.50	7.50
	Control	7.80	7.90	7.90	8.00
SEM		0.1	0.9	0.1	0.9
		NS	NS	NS	NS

Mean values in a column followed by the same letter(s) are not significantly different at P=0.05 according to Turkey's Honestly Significant difference.

SEM: Standard Error of Mean

NS: Not Significant

Discussion

Food preparation in many African households is mainly the responsibility of the adultfemales. This probably explains the higher percentage of female and young adults amongst respondents in the present study. The study area also has a number of institutions of tertiary education which may explain the relatively higher literacy level observed in our study. The higher frequency of semolina purchase and storage again reflects the presence of a higher number of young adult householders who have shifted from the traditional non-wheat-based flour meals as a consequence of urbanization (Jayne *et al.*, 2010). Similarly, the preference for local markets as the source of flour is probably due to the relative availability, accessibility and price bargaining opportunities such markets offer consumers.

As shown in this study, *T. castaneum* is often confused with other similar and common stored products insect pests. While weevils unlike beetles have an elongated snout or rostrum, beetles are distinguished by their truncated forewings or elytra (Beck and Blumer, 2011). The flour beetles *T. castaneum* and *T. confusum* are reddish in colour with similar size, shape and habits. They may however be differentiated by the three distal antennal segments which *are abruptly enlarged* in *T. castaneum but gradually enlarged inT. confusum*(Good, 1933).

Cooling or freezing isan effective food preservation and pest management strategy that is not readily accessible to most householders in many SSA countries due to costs associated with the required facilities and absence of reliable power supply (Abowei, and Tawari, 2011; Olaoye and Ntuen, 2011; Adeyeye, 2017). This might explain why only a few employed refrigerators or freezers for flour storage in the present study. Lidded plastic containers, local sacks and nylon bags used by several householders in this study increased the susceptibility of stored flour to pathogen and insect pest infestation that inadvertently lead to deterioration and wastage (Shafique *et al*., 2006; Abd-El-Aziz, 2011). For example, Kumari *et al.* (2017) reported that maize grains stored in plastic and jute bags had significantly higher aflatoxin levels, higher weevil damage and lower seed germination. By storing smaller quantities for a few months, householders therefore ensure complete flour consumption before deterioration sets in.

Sun-drying also serves as a viable pest management option in places where power supply is erratic (Olaoye and Ntuen, 2011; Adeyeye, 2017). In the study area, daytime temperatures during the dry season could be as high as 33°C – 34°C offering a cheap alternative to cooling or freezing (Kitch *et al*., 1992; Akpenpuun and Busari, 2013). Furthermore, adults and larvae of *T. castaneum* may be removed using sieves with appropriate mesh sizes. As indicated by some respondents in this study, consumer indifference may ur.

cause flour to be prepared without sieving out insects especially when *T. castaneum* infestation is very low or perceived to be insignificant.

Stored products insect pests like *T. castaneum have an optimum body temperature of* 25-33°C and may thus be controlled effectively through exposure to temperatures below or above the optimum level*(*Banks and Fields, 1995). *Insects, however, have a lower tolerance for temperatures above optimum levels than for temperatures below it. For example,* Banks and Fields (1995)showed that 12°C above optimum temperature causes death to stored products in less than a day while the same degrees below the optimum temperature has no lethal effects on the insects. The foregoing might explain why sun-drying caused more *T. castaneum* mortality within a shorter period than freezing in the present study.

Hermetic storage method was not as effective as sun-drying or freezing methods for the management *T. castaneum*as revealed by this study. *This is contrary to the findings of* Zhang *et al*. (2015) *and Yan et al. (2017) who reported complete mortality of T. castaneum within 12 and 14 days of* hermetic storage treatment respectively. Hermetic storage involves the creation of a modified atmosphere that consists of depleting oxygen levels (hypoxia) and elevated levels of CO_2 (hypercarbia) within storage structures (Navarro *et al.*, 2012). With time, the modified atmosphere causes insect respiration and other biological activities to slow down and stop as the insect finally dies of desiccation (Murdock *et al*., 2012). The effectiveness of hermetic storage for insect pest management strategy thus depends on the type of hermetic structure and the integrity of the hermetic system created. *Yan et al. (2017) showed that hermetically* sealed polyethylene terephthalate (PET) bottles containing red flour beetle-infested wheat flour had depleted oxygen levels that arrested beetle development after three months unlike unsealed bottles with higher oxygen levels and increased populations. Duration of hermetic storage is another factor that influences hermetic structure effectiveness with increased mortalities and lesser population changes expected over time (Murdock et al., 2012;Yan et al., 2017). In this study also, a gradual increase in *T. castaneum* mortality was observed as hermetic storage duration increased. However, despite increasing hermetic storage duration from 3 to 60 days, the treatment was not effective suggesting the occurrence of some air leaks or other compromise in integrity of the hermetic structure used in the present study.

Using a scanning electron microscope, Asiyanbi-Hammed and Simsek (2018) observed that the particle size of fermented yam flour was smaller than that of refined wheat flour. It has also been reported that diffusion of molecules through flour mass in storage is slower in finely ground compact flours (Labuza and Hyman, 1998;Cenkowskiet al., 2000; Yan et al., 2017). While freezing (for 6 hours) or sun-drying (for 3 hours) in this study, cold or hot air molecules probably diffused at a slower rate through yam flour with fine particle than through the gritty semolina causing significantly lower numbers of insects to be killed in former than in the latter flour type. Similarly, *T. castaneum* population changes observed in yam flour were often lower compared to other flour types at the same durations of freezing and sun-drying probably due to differences in nutritional composition. According to Asiyanbi-Hammed and Simsek (2018), the proximate composition of yam flour is different from that of refined wheat flour. The authors reported relatively lower protein and fat content but higher total starch and fiber contents in yam flour. Since the initial population of *T. castaneum* used in our study was reared for several generations on wheat flour, subsequent generations of the insect might have become more adapted to wheat and other wheat-based products like semolina than to yam flour.

The organoleptic attributes of all three flour types were not negatively affected by each of the physical management methods used in this study. Evans (1987), however, showed that irrespective of the heating method, temperatures of between 60 to 65°C for a few seconds or minutes will kill insects in stored grains but may negatively affect seed viability or the quality of baking flour obtained from treated grains. It is therefore important to ensure a safe balance between commodity tolerance and insect intolerance when applying physical methods for insect pest management in stored products (Neven, 2000).

Conclusions

It was concluded from this study that semolina, yam and wheat flours are the most frequently stored flour types by householders in Ilorin, Nigeria. We have also demonstrated that freezing and sun-drying these flour types for 12 and 6 hours respectively will kill both adult and larval stages of the red flour beetle and also effectively inhibits population growth. Smaller types of the lidded plastic containers, used to store flour by most householders in Ilorin, were modified for hermetic storage but found to be ineffective for *T. castaneum* management in the three flour types. Further research is thus needed to identify effective ways of using these containers or other affordable materials for hermetic storage of flour and for *T. castaneum* management in stored flour.

References

Abd El-Aziz, S. E.(2011). Control strategies of stored product pests. *Journal of Entomology, 8: 101-122*

Abowei, J. F. N. and Tawari, C. C. (2011). The classification facilities and practices of culture fisheries in Nigeria. *Research Journal of Applied Science, Engineering and Technology*,3(10): 1096-1107

Abiodun, O. A. and Akinoso, R. (2015). Textural and sensory properties of trifoliate yam (*Dioscoreadumetorum*) flour and stiff dough 'amala'. *Journal of Food Science and Technology*,52: 2894–2901.

Adedire, C. O. and Ajayi, T.S. (1996). Assessment of insecticidal properties of some plants as grain protectants against the maize weevil, *Sitophiluszeamais* (Mots). *Nigerian Journal of Entomology*, 13: 93 – 101

Adeyeye, S. A. O. (2017). *The role of food processing and appropriate storage technologies in ensuring food security and food availability in Africa.Nutritional Food Science, 47(1): 122 – 139*. Retrieved from https://doi.org/10.1108/nfs-03-2016-0037

Akpenpuun, T. D. and Busari, R. A. (2013). Impact of climate on tuber crops yield in Kwara State, Nigeria. *American International Journal of Contemporary Research*,*3(10)*:52 - 57

Asiyanbi-Hammed, T. T. and Simsek, S. (2018). *Comparison of physical and chemical properties of wheat flour, fermented yam flour, and unfermented yam flour. Journal of Food Processing and Preservation*,*e13844*. Retrieved from https://doi.org/10.1111/jfpp.13844 [Accessed 29 02 2019]

Atanasov, K.H. (1978). Damage by the rust red grain beetle on stored grains and its products. *RastitelnaZashchita*, 26: 19-20.

Atwell, W.A. (2001). Wheat flour: Practical guideline for the food industry. Eagan press handbook series. 2-7.Retrieved fromhttps: //aaccipublications.aaccnet.org/doi/pdf/10.1094/ 189112725X.001 [Accessed 24 02 2019].

Baoua, I. B., Margam, V., Amadou, L. and Murdock, L. L. (2012). Performance of triple bagging hermetic technology for postharvest storage of cowpea grain in Niger. *Journal of Stored Products Research*, 51: 8- 15. Retrieved from https://doi.org/10.101/l.j.jspr.2012.07.003 [Accessed 28 02 2019]

Banks, H. J. and Fields, J. B. (1995). Physical methods for insect control in stored-grain ecosystem. In: Stored grain ecosystem (Jayas D.S., White N.D.G., Muir W.E. eds), Marcel Dekker, New York, pp. 353-409

Beck, C. W. and Blumer, L. S. (2007). A handbook on bean beetles, *Callosobruchus maculatus*. The National Science Foundation. Available at:www.beanbeetle.org [Accessed 06 03 2019].

Cenkowski, S., Dexter J. E. and Scanlon, M. G. (2000). Mechanical compaction of flour: The effect of storage temperatureon dough rheological properties. *Canadian Agricultural Engineering*,42(1):1-17

Edema, M. O., Sanni, L.O. and Sanni, A. I.(2005). Evaluation of maize-soy-bean flour blends for sour dough maize bread production in Nigeria. *African Journal of Biotechnology*, 4 (9): 911–918

Evans, D. E. (1987). The survival of immature grain beetles at low temperatures. *Journal of Stored Products Research*, 23: 79-83

Fields, P. G. and Muir, W.E. (1996). Physical control. In: Integrated management of insects in stored products (Subramanyam, B.,Hagstrum D.W. eds.), Marcel Dekker Inc., New York, pp. 195-221

Good,N.E. (1933). Biology of the flour beetles *Triboliumconfusum* Duv., and *Triboliumferrugineum* Fab. *Journal of Agricultural Research*, 327 – 334

Jayne, T.S., Mason, N.,Myers, R.,Ferris, J.,Mather, D.,Beaver, M.,Lenski, N.,Chapoto,A. and Boughton,D. (2010). Patterns and trends in food staples markets in Eastern and Southern Africa: Toward the identification of priority investments and strategies for developing markets and promoting smallholder productivity growth. MSU international development working paper No. 104. Department of Agricultural, Food and Resource Economics, Department of Economics, East Lansing: Michigan State University.

Jonfia-Essien, W. A. and Navarro, S. (2010). Effect of storage management on free fatty acid content in dry cocoa beans. *Julius-Kühn-Archive,* 425: 963

Kitch, L.W., Ntoukam, G.,Shade, R.E., Wolfson,J. L. and Murdock, L.L. (1992). A solar heater for disinfesting stored cowpeas on subsistence farms. *Journal of Stored Products Research*, 28: 261-267

Kumari, A., Kumar, V., Amitabh,A., Kumar, A., Kumar, M. and Kashyap V.(2017). Qualitative loss of maize under different bag storage modes. *International Journal of Current Microbiology and Applied Science,*6(12): 177-183. Retrieved from https://doi.org/ 10.20546/ ijcmas. 2017. 612. 023 [Accessed 27 02 2019]

Labuza, T. P. and Hyman, C. R.(1998). Moisture migration and control in multi-domainfood Trends in *Food Science Technology*, 9(2):47-55. Retrieved from https://doi.org/10.1016/S092 4-2244(98)00005-3 [Accessed 02 03 2019]

Li, L. and Arbogast, R. T. (1991). The effect of grain breakage on fecundity, development, survival and population increase in maize of *Triboliumcastaneum* (Herbst) (Coleoptera: Tenebrionidae). *Journal of Stored Products Research*, **27**: 87-94

Loconti, J. D. and Roth, L. M. (1953). Composition of the odorous secretion of *Triboliumcastaneum*. *Annals of Entomological Society of America*, 4: 281 – 289

Murdock, L.L., Margam, V.,Baoua, I.,Balfe,S. and Shade, R.E. (2012). Death by desiccation: Effects of hermetic storage on cowpea bruchids. *Journal of Stored Products Research*, 49: 166-170

Navarro, S., Timlick, B., Demianyk, C. J. and White, N. D. (2012). Controlled and modified atmospheres. Stored Product Protection, Manhattan, Kansas State University,pp. 191-201.

Neven, L.G. (2000). Physiological responses of insects to heat. *Postharvest Biology and Technology,* 21: 103-111

Obeng-Ofori, D. (2010). Residual insecticides, inert dusts and botanicals for the protection of durable stored products against pest infestation in developing countries. *Julius-Kühn-Archiv*e, 425: 774

Ojo, J. A. and Omoloye, A.A. (2015). Life History of the Tamarind Weevil, *Sitophiluslinearis*

(Herbst) (Coleoptera: Curculionidae), on Tamarind Seed. *Journal of Insects*1-5. Retrieved from http://dx.doi.org/10.1155/ /2015/429579[Accessed 26 08 2020]

Ojumoola, A.O.,Bamidele, D. A. and Uddin II, R. O. (2018). Influence of three legume seed types on development of *Callosobruchusmaculatus* (F.) and its susceptibility to *Azadirachtaindica*aqueous leaf extracts. *Agrosearch18(1):77-89.*Available at:https://www.ajol.info/index.php/agrosh/article/view/176123[Accessed 27 02 2019]

Olaoye, O. A. andNtuen, I.G.(2011). Spoilage and preservation of meat: a general appraisal and potential of lactic acid bacteria as biological preservatives. *International Research Journal of Biotechnology*, 2: 033- 046

Peryam, D. R. and Pilgrim, F. J. (1957).Hedonic scale method of measuring food preferences. ***Food*** *Technology*,11: Suppl., 9-14

Rajendran, S. andSriranjini,V. (2008). Plant products as fumigants for stored-product insect control. *Journal of Stored Products Research*, 44: 126-135

Seck, D., Haubruge,G.,Marlier,E. and Gaspar, C. (1996). Alternative protection of cowpea seeds against *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) using hermetic storage alone or in combination with *Bosciasenegalensis* (Pers) Lam ex Poir. *Journal of Stored Products Research*, 32:39–44

Shafique, M., Ahmad, M., Chaudry, M. A. (2006). Feeding preference and development of *Tribolium castaneum* (Herbst.) in wheat products. *Pakistan Journal of Zoology*,*38(1): 27-31*

Uthayakumaran, S., Wrigley, C. W. (2010). *Wheat: characteristics and quality requirements. In: Cereal grains (*Wrigley C. W., Batey I. L. eds.), Wood head Publishing Limited, Cambridge, United Kingdom, pp. *59-111.*Retrieved from https://doi.org/10.1533/9781845699529.2.59 [Accessed 25 02 2019]

WFC, Wheat Food Council (2009). Types of wheat flour. Available at: http://www.wheatfood.orgsites/default/file/atachments/wfc-type-wheat-flour booklet-20009.pdf [Accessed 25 02 2019].

Yan, Y., Williams, S. B., Murdock, L. L. and Baributsa, D.(2017). Hermetic storage of wheat and maize flour protects against red flour beetle(*Triboliumcastaneum*Herbst). PLoS ONE 12(9): e0185386. Retrieved from https://doi.org/10.1371/journal.pone.0185386

Zhang, C., Rosentrater, K. A., Bern, C. J. (2015). Laboratory-scale hermetic storage of wheat and maize against theinfestation of red flour beetle (*Triboliumcastaneum*) and maize weevil (*Sitophiluszeamais*).ASABE Annual International Meeting. St. Joseph, Michigan, p. 1. Retrieved from http://elibrary.asab.org//abstract.asp?aid=45860&t=5 (Accessed07032019)