academicJournals

Vol. 8(9), pp.93-102, September 2017
DOI: 10.5897/JSPPR2017.0247
Article Number: 5659FAD66087
ISSN 2141-6567

http://www.academicjournals.org/JSPPR

Journal of Stored Products and Postharvest Research

Review

Management of insect pests of stored sorghum using botanicals in Nigerian traditional stores

Suleiman M.[1,3*] and Rugumamu C. P.[2]

[1]Department of Zoology and Wildlife Conservation, University of Dar es Salaam, Tanzania.
[2]Department of Crop Sciences and Beekeeping Technology, University of Dar es Salaam, Tanzania.
[3]Department of Biology, Umaru Musa Yar'adua University, Katsina, Katsina State, Nigeria.

Received 6 July, 2017; Accepted 29 August, 2017

Sorghum is a security crop widely grown in arid and semi-arid ecologies. Nigeria produces 30 to 40% of Africa's sorghum. Sorghum in Nigeria is mostly produced and stored by rural farmers at the farm/village level after harvest. The prominent storage structures existing in rural areas in northern Nigeria are the mud rhumbus, thatched rhumbus and underground pits. During storage, different species of insect pests such as *Sitophilus granarius* (L.), *Sitophilus oryzae* (L.), *Sitophilus zeamais* (Motsch.), *Rhyzopertha dominica* (F.), *Oryzaephilus surinamensis* (L.), *Trogoderma granarium* (Ev.), *Tribolium castaneum* (Herbst), *Sitotroga cerealella* (Oliv.) and *Cryptolestes ferrugineus* (Stephens) were observed to cause serious damage to sorghum. The insect pests were reported to cause up to 13.12% weight loss of threshed sorghum and 8.34% weight loss to the unthreshed sorghum. *Citrus sinensis* L., *Euphorbia balsamifera* L., *Lawsonia inermis* L., *Leptidania hastata* L., *Cymbopogon nardus* and *Ocimum basilicum* are some of the plant species tested in the laboratory against *S. zeamais* and *T. castaneum* in sorghum. This paper aims to review some of the available literature on the management of insect pests of stored sorghum in Nigerian on-farm traditional granaries using some botanicals as a contribution to the components of integrated pest management (IPM).

Key words: Botanicals, insect pests, management, sorghum, traditional storage.

INTRODUCTION

Sorghum, *Sorghum bicolor* (L.) Moench is an important cereal crop grown worldwide for food and feed purposes. It is mostly cultivated in semi-arid tropics where water is scarce and drought is frequent (Mailafiya, 2003; Beshir, 2011). The crop is environment-friendly as it is water-efficient, requires little or no fertilizers and biodegradable (Rampho, 2005). Sorghum ranks second among cereals and the fifth among all crops in terms of production in Africa. In Nigerian, sorghum production represents 25% of the total cereal production in the year 2012 (FAO, 2013). Further, the United States Department of Agriculture (USDA, 2014) recognizes sorghum as a staple food crop produced in all parts of northern Nigeria.

Simonyan et al. (2007) reported that sorghum has a great advantage both on the domestic and international markets due to its increasing demand for the production

*Corresponding author. E-mail: mohammed.suleiman@umyu.edu.ng.

of food and feed products, alcoholic and non alcoholic beverages. Sorghum also has a great potential as a source of starch used as raw material in different industries (FAO, 1999; Mailafiya, 2003). Farmers and grain processors have been evolving a number of traditional practices through trial and error method, to avoid huge losses that occur in stored grains due to insect pests infestation (Mahai et al., 2015). Most of the sorghum produced in Nigeria are stored at farm/village level by rural farmers to ensure domestic consumption and seed for planting in the next season (Nukenine, 2010). Adejumo and Raji (2007) added that storage is particularly important because agricultural production is seasonal while the demands for agricultural commodities are more evenly spread throughout the year. In this circumstance, there is a need to meet average demand by storing excess supply during the harvest season for gradual release to the market during off-season periods to stabilize seasonal prices. Safe storage of grains against insect damage is a serious concern (Atanda et al., 2016). Insect pests have been the major problem of agriculture in the tropics for long as favourable conditions exist for the pest and poor post-harvest handling facilities which results in substantial waste of farm produce and hence, considerable loss to the economy (Adejumo and Raji, 2007; Onolemhemhen et al., 2011; Abbas et al., 2014; Sori, 2014). Insect pests damage to stored grains results in reduced quantity, quality, nutritive and viability of stored cereals like sorghum, maize, wheat and rice (Okonkwo, 1998). Insect pests cause serious damage to cereals stored in traditional storage structures and market stores of some parts of Nigeria (Utono, 2013a; Mailafiya et al., 2014a, b).

Insect pests control in stored grains such as sorghum has relied heavily on synthetic insecticides due to their instant effectiveness and ease of application. However, extensive use of chemical/ industrial insecticides results in environmental pollution, pest resurgence, pest resistance and lethal effects on non-target organisms, increasing cost of application and erratic supply in developing countries due to foreign exchange constraints (Kolterman et al., 2000). Hill (1997) suggested that integrated pest management (IPM) approach in maintaining pest population below economic injury level (EIL) is necessary in order to reduce hazards associated with chemical application in stored cereals. This leads to a search for eco-friendly methods such as the use of botanicals in the control of insect pests.

Information on the use of botanicals in the control of insect pests of stored sorghum in on-farm storage structures in Nigeria is scanty. However, some botanicals were evaluated to test their stored grains protective ability against some insect pests elsewhere. In Ethiopia, Sori (2014) reported that plant powders of *Chenopodium* sp., *Nicotiana* sp. and *Maesa lanceolata* had high efficacy in controlling maize weevil by causing adult mortality of 22.22 to 66.67% and reduce emergence of new progeny from 80.00 to 23.00% in Jimma Zone, Ethiopia. Plant powders of *Tagitus minuta*, *Datura stramonium* and *Carissa shimperi* were found to be effective against *S. zeamais* in stored sorghum. In Botswana, Tiroesele et al. (2015) found that plant products of garlic, chilies and peppermint caused high adult mortality and reduced progeny emergence of *C. maculatus* attacking cowpea. Hence, this paper aims at reviewing the findings of some previous works on the indigenous methods of controlling insect pests of stored sorghum in on-farm storage structures of Nigerian farmers.

SORGHUM STORAGE PRACTICES IN NIGERIA

Sorghum storage in Nigeria

Storage is an interim phase during transit of agricultural produce from producers to consumers. The main purpose of storage for small scale farmers in Africa is to ensure household supplies and seed for planting (Adetunji, 2007). Since agricultural production is seasonal while the demands for agricultural commodities are more evenly spread throughout the year, proper storage of food grains is necessary to prevent spoilage, increase keeping quality and for monetary reasons (Karthikeyan et al., 2009; Nukenine, 2010).

It is estimated that 60 to 70% of sorghum produced in Nigeria are stored at home level in indigenous structure ranging from bamboo baskets to mud structures, gunny bags and modern bins (Karthikeyan et al., 2009). The findings reported by Mahai et al. (2015) revealed that majority (96%) of farmers of Madagali and Ganye Areas of Adamawa State in Nigeria stored their sorghum grains after harvest, and 4% consume it immediately after harvest. It is observed that some Nigerian farmers store their sorghum in non-threshed form, tied in bundles or untied, while some keep threshed grains in structures such as thatched rhumbus, mud rhumbus and underground pits (Adejumo and Raji, 2007; Mahai et al., 2015). Further, sorghum, in threshed and unthreshed forms, are stored in different structures such as granaries and store rooms by subsistence farmers of Kebbi State, Nigeria (Utono, 2013a).

The structure used for grain storage depends on the level of storage such as on-farm, village and city or central. On-farm storage involves individuals where each head of household provides storage facilities for preserving small quantities of farm produce after harvest for consumption and future sales, while village may involve individuals (family granary) or group of individuals (community stores). The city and central storage facilities include large warehouses that are usually owned by government agencies and non-governmental organizations (Nukenine, 2010). Since most sorghum in Nigeria are produced by rural farmers, storage at farm level will be emphasized in this paper, and also, the systems used for sorghum storage in Nigeria is centrally focused on the northern Nigeria because this is the zone where most of the Nigerian sorghum is produced.

The prominent storage structures existing in rural areas of northern Nigeria include the mud rhumbus, thatched rhumbus, underground pits and store rooms (Utono, 2013a; Mahai et al., 2015). These traditional storage structures are made of local materials such as paddy straw, bamboo poles, wooden planks, reeds, ropes and mud bricks (Adejumo and Raji, 2007; Karthikeyan et al., 2009). The major storage structures that are commonly used for storing sorghum after harvest in rural areas of northern Nigeria are described hereunder.

Mud rhumbus

Adejumo and Raji (2007) described mud rhumbus as specially built structures made from a mixture of dry grass and clay. Similarly, Mahai et al. (2015) reported mud and grasses as materials used for construction of mud rhumbus in northern Nigeria. A mud rhumbus consists of a bin resting on large stones, wood or mud pillars about 50 cm off the ground (Mada et al., 2014). The mud rhumbus is constructed in circular, cylindrical, spherical or rectangular shape with single apartment or multipurpose apartment (Nukenine, 2010). The height of mud rhumbu is usually about 1.5 m with a diameter of about 1 m and is covered with thatched roof. A mud rhumbu has a maximum capacity of 500 to 8000 kg of unthreshed sorghum and millet (Adejumo and Raji, 2007; Mada et al., 2014; Mahai et al., 2015). Nukenine (2010) noted that mud rhumbus is associated with dry conditions, under which it is possible to reduce the moisture content of the harvested sorghum grain to a satisfactory level simply by sun-drying it. This situation improves storage condition and hence could provide protection to stored sorghum against insect infestations.

Thatched rhumbus

Thatched rhumbus are made of woven grasses resting on irregular stones and or tree logs. The elevation of a thatched rhumbu above the ground is generally low, between 100 and 600 mm (Adejumo and Raji, 2007). This makes it vulnerable to pests attack especially rodents, since they can easily reach the floor of the rhumbu. To overcome this, FAO (2011) suggested the use of supporting legs of about 0.9 m long, equipped with baffles (rat guards) to raise the floor of rhumbus above the ground to protect rats and moisture from easy access to stored sorghum. The wall of the thatched rhumbu is made up of two layers of woven grasses, being reinforced with two or three tension rings. The roof is usually conical in shape made up of straw/thatch, tree stem, polythene sheets, and ropes and usually of two to three layers to prevent water seepage (Adejumo and Raji, 2007). They are usually cylindrical or circular in shape with various capacities which range from 500 kg to 8, 000 kg, depending on the size of the farm produce (Adejumo and Raji, 2007; Chattha et al., 2014). Grains are usually stored in thatched rhumbus in unthreshed form and they include sorghum and millet. Despite earlier reports by Gilse (1964) that sorghum stored in traditional granaries made of plant materials were more severely damaged by stored product insects than those in mud granaries, thatched rhumbus have been used for storing sorghum and millet for long by rural farmers of northern Nigeria and offered considerable protection to the grains (Adejumo and Raji, 2007; Utono, 2013a). If improved by placing them on supporting legs equipped with rat guards as mentioned earlier, and walls sealed with polythene sheets, thatched rhumbus could perform as or even better than the mud rhumbus.

Underground pits

Underground storage of grain is an ancient practice still in use in some dry land areas where sorghum is a staple food grain (Boxall et al., 2004). It was earlier reported that the use of pit storage was mainly for sorghum and has been the main method of long-term grain storage from pre-Neolithic times up to the early 19th century (Sterling et al., 1983; Boxall, 1998). Conceived for long term storage, underground pits vary in capacity which ranges from a few hundred kilograms to 200 tones (FAO, 1994). They are usually cylindrical, spherical or amphoric in shape (Gilman and Boxall, 1974). Boxall et al. (2004) observed that the walls of underground pits are lined with stones, paddy straw ropes, loose straw or other plant material. They added that after filling, straw is placed on the top of the sorghum before closing with a plaster of mud and cow dung mixture. It was further advanced by Nukenine (2010) that the entrance into the pit might be closed either by heaping earth or sand onto a timber cover, or by a stone sealed around with mud. The use of underground pits for storing sorghum is being discontinued due to underground water seepage and the time-consuming process of unloading which makes withdrawals inconvenient, but Nukenine (2010) observed that they are used in areas where the water table is low so that it does not endanger the content. However, as the structure is hermetic, considerable concentrations of carbon dioxide accumulate during storage, which has the advantage of reducing insect attack on the grain. This prevents easy access to the stored sorghum by insect pests and hence reduces grain loss (Boxall et al., 2004).

Storage period

Nukenine (2010) reported that grain storage periods generally range between 3 and 12 months across Africa, depending on agro-ecological zone, ethnic group, quantity of the commodity, storage condition and crop variety. This is supported by Mailafiya et al. (2014a) that grain storage in Dalwa market of northern Nigeria is often about 6 to 12 months at farm and domestic level in traditional or improved/semi-modern storage structures such as rhumbus, cribs, bins and bags, that are not insect-proof. It was earlier reported that grains such as sorghum and millet could be stored in traditional granaries for 1 to 5 years, especially if the cereal is in unthreshed form (Adejumo and Raji, 2007).

INSECT PESTS AND THE DAMAGE THEY CAUSE TO STORED SORGHUM

Insect pests of stored sorghum

Abate et al. (2000) observed that arthropod pests are one of the major constraints to agricultural production in Africa. A large number of insect and mite pests attack crops during all stages of growth- from seedling to storage. Some of the insect pests that attack sorghum grains in the store include the *Sitophilus* spp. (Coleoptera: Curculionidae), *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae), *Sitotroga cerealella* (Olivier.) (Lepidoptera: Gelechiidae), *Trogoderma granarium* (Everts) (Coleoptera: Dermetidae), *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae), *Tribolium confusum* (Duval) (Coleoptera: Tenebrionidae) and *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) (Gilse, 1964; Utono, 2013a; Mailafiya et al., 2014a, b). The biology of major insect pests of stored sorghum is briefly discussed in the following sub-sections.

Sitophilus species

Sitophilus zeamais is described by van Emden (2013) as a 3.5 to 4.0 mm long beetle with large round punctures on the thorax. The head is protruded into rostrum, with a biting-chewing mouthpart type. According to Robinson (2005), the antennae of *S. zeamais* are elbowed and slightly clubbed. Chapman (2009) further describes the elytra as highly sclerotized that cover the hind wings. Female *S. zeamais* deposit their eggs in grain kernel which hatch into white grub-like and apodous larvae that feed inside the grain and excavate tunnels as they develop. This feeding habit causes most of the damage to the grains (Robinson, 2005; Anankware et al., 2012; Rugumamu, 2012). Golob et al. (2002) reported that the larva of *S. zeamais* pupates inside the kernel and the life cycle completes in about 35 days under favourable conditions of 27°C and 70% relative humidity (RH). The developmental and feeding activities of the weevils often lead to severe powdering and tainting of the grain with their excrements (Adedire, 2001). The infested grains are also rendered susceptible to cracking and mould infection as a result of respiration of the weevils that heats the grain and drives water vapour to other areas where it condenses to wet the grain, thereby reducing their market value (van Emden, 2013).

Sitophilus oryzae and *S. zeamais* are winged and very similar with large round punctures on the thorax and elytra and four large lighter patches on the elytra. However, *S. oryzae* is smaller with 2 to 3 mm body length (van Emden, 2013). The snout is long (1 mm), almost one-third of the total length. The head with snout is as long as the prothorax or the elytra (Rees, 2007; van Emden, 2013). Females generally lay eggs within a kernel but they may lay multiple eggs per kernel and more than one larva can develop within a single kernel (Rees, 2007; USAID, 2011). Life cycle of *S. oryzae* may take only 26 to 32 days during hot summer months, but requires a much longer period during cooler weather. The eggs incubate for about 3 days and hatch into apodous larvae which eat their way into the germ of the grain (Adedire, 2001). The pupa is naked and lasts for an average of 6 days and the new adult remains in the seed for 3 to 4 days to harden and mature (Koehler, 2015). Adults make a small, circular emergence hole, as compared to large, and oblong emergence hole made by the wheat/grain/granary weevil (*S. granarius*) which is also 2 to 3 mm long, but has no light patches on the elytra and the punctures are elongated rather than round (van Emden, 2013). *S. granarius* is a major problem in storage causing significant annual losses of wheat all over the world. The damaged wheat grains become unfit for consumption and planting (Rahman et al., 2003). *S. granarius* is seldom found in the hot tropical region except in grains transported from the temperate countries (Adedire, 2001; Rees, 2007). Although, the primary hosts of *S. oryzae* and *S. granarius* are rice and wheat, respectively, they also attack stored sorghum as their secondary host (Adedire, 2001). Their small size, feeding habit and developmental activities of the larvae result in hollowing the grains and thus possible cause of extensive economic injury to the infested grains. Additionally, infestations of *S. oryzae* could make grain to heat, leading to excessive mould growth (Rees, 2007).

Rhyzopertha dominica (F.)

This is a member of the Family, Bostrychidae and commonly called the lesser grain borer. Adults are 2 to 3 mm in length, reddish-brown and cylindrical (Rees, 2007). The elytra are parallel-sided, the head is not visible from above, pronotum has rasp-like teeth at the front, and the thorax is large which gives the adult insect a humpbacked appearance (Robinson, 2005). The female lays an egg outside the kernel, and the newly hatched larva bores into the kernel where it completes development (Kavallieratos et al., 2012). The young larvae are mobile in grain bulks but become immobile and gradually more C-shaped as they pupate within grain and adults can emerge without leaving an emergence hole (van Emden, 2013). Life cycle takes about 4 weeks at 34°C and 70% RH (Rees, 2007; USAID, 2011; van Emden, 2013). Adults and larvae of *R. dominica* feed primarily on entire grain of stored cereals including sorghum, leaving behind empty husks and grain dust (Adedire, 2001; Rees, 2007; USAID, 2011). They are also found on a wide variety of foodstuffs including beans, dried chilies, turmeric, coriander, ginger, cassava chips, biscuits and wheat flour (Wakil et al., 2011). Adedire (2001) observed that adults of *R. dominica* feed on the grain germ, while the larvae devour the endosperm. This infers that the grain would perhaps lose its viability, quantitative and qualitative values and hence leading to serious damage that could affect food security and general income to the farmers.

Sitotroga cerealella (Olivier)

This is commonly called Angoumois grain moth. Adult *S. cerealella* are smaller than other stored product moths (Canadian Grain Commission (CGC), 2013a). It is a small buff or yellowish-brown moth with a wing expense of 10 to 18 mm (Adedire, 2001). Females lay up to 250 eggs on or near the surface of stored grain. The eggs hatch into larvae which bore into grain kernels remaining inside until maturity (Rees, 2007). Before pupation, the larva prepares a hole making way out of the grain, but it does not go out, leaving characteristic exit pin holes on the grain surface (Johnson, 2014; DAF, 2016). It is through this hole that the fully developed adult moth eventually comes out of the grain leaving silken 'door' still attached to grain and does not feed (Adedire, 2001; Rees, 2007; USAID, 2011). The complete life cycle lasts for 25 to 28 days at 30°C and 80% RH (USAID, 2011). *S. cerealella* is a primary pest of stored whole cereal grains including sorghum which infests ripening grains in the field and also conveyed into the store where it continues its destructive activities (Adedire, 2001). The biting mouth parts of the larvae of Angoumois grain moth make them so much destructive that even outcompete that of *Sitophilus* especially in very dry grains or when the condition is less favourable to the latter (Haines, 1991). Adedire (2001) observed that apart from direct loss caused by the feeding and developmental activities of the larvae, infested grains could probably be rendered susceptible to colonization by secondary insect pests, fungi and changes in grains' physical characteristics.

Trogoderma granarium (Everts)

The Khapra beetle, *T. granarium*, is a dermestid beetle and a serious pest of stored grains. Adults of *T. granarium* are 1.8 to 3.8 mm long, have wings but do not fly nor eat (Robinson, 2005; Musa et al., 2007). Elytra are yellowish brown to reddish brown, and have a brown and yellow colour pattern. The pronotum is usually darker than the elytra, and the dorsal setae are pale yellow. Full grown larvae which are the grain destructive stage of the insects are about 6 mm long, brown to yellowish brown (Robinson, 2005). Eggs are laid singly on the surface or in crevices of the food and the life cycle lasts for 25 days at optimum conditions of 33 to 37°C and 40 to 75% RH (Rees, 2007). The beetle breeds most rapidly under hot, dry conditions and has a potential to spread internationally through international trade (Musa and Dike, 2009). It is also among the most serious and widest occurring insect pests in stored cereal grains including sorghum in tropical and subtropical regions of Asia and Africa (Dwivedi and Kumar, 1998; Adedire, 2001). Adults of *T. granarium* are short-lived and do not feed on commodity, while the larvae commence feeding on the germ and eat deep into the grain which results in hollowing the grains coupled with severe powdering (Adedire, 2001; Rees, 2007). These activities may possibly lead to serious damage to the stored grain and also the seed viability may be lost.

Tribolium species

Red flour beetle, *T. castaneum* and confused flour beetle, *T. confusum* are similar in their biology (van Emden, 2013). The adults are reddish-brown and about 3.5 mm long (Robinson, 2005). The three antennal segments of *T. castaneum* are clubbed and abruptly wider than the preceding segments, while those of *T. confusum* are widen gradually towards the tip. The sides of the thorax of *T. castaneum* are clearly curved, whereas in *T. confusum*, the thorax has fairly straight sides in dorsal view (van Emden, 2013). Eggs are laid directly on flour or other food material, and are attached to the surface with a sticky substance. Fecundity for both species is about 84 eggs at 25°C and 30% RH and 539 eggs at 32.5°C and 70% RH (Robinson, 2005). Odeyemi (2001) earlier reported that adult females of *T. castaneum* copulate many times and lay up to 500 eggs in the commodity throughout their adult life. Full-grown larvae are 6 to 7 mm long, yellowish white, head and terminal segment brown, and with distinct urogomphi. Pupation takes place in the flour, and the life cycle takes 20 days to complete at 35 to 38°C and >70% RH (Rees, 2007). But USAID (2011) reported that it can take *T. castaneum* 30 days to complete its development under favourable conditions. However, van Emden (2013) reported a prolonged duration for the insect's life cycle which is 7 to 12 weeks at 27°C. Adults live for many months under optimum conditions of 33 to 35°C and 70% RH (USAID, 2011). *T. castaneum* is a secondary pest commonly observed among several commodities such as sorghum, maize, wheat and cotton seeds (Khashaveh et al., 2009; Naseem and Khan, 2011). Both adults and larvae of the insect feed on the flour created by breakage of the grain or damage by primary pests (van Emden, 2013). Therefore, the feeding activity of *T. castaneum* may result in quantitative loss to stored products, while its frass as well as excreta would perhaps affect their quality.

Oryzaephilus surinamensis **(L.)**

Adult saw-toothed grain beetle, *O. surinamensis* is an active, dark brown, slender beetle 2.5 to 3.5 mm long which can be easily recognized by the six distinctive saw-like projections on each side of the thorax (Odeyemi, 2001; Rees, 2007). Its flattened body is well adapted for crawling into cracks and crevices (Odeyemi, 2001). The elytra are longitudinally grooved, while three longitudinal ridges are found along the top surface of the thorax (Rees, 2007). There are well developed wings in both sexes (Mason, 2003). *O. surinamensis* is one of the key stored grain pest which occurs worldwide (Hashem et al., 2012). It is considered to be a secondary pest in stored cereals including sorghum, and other cereal products, infesting bulks already damaged by primary feeders (Rees, 2007). They can also establish on whole grains with minor cracks or mechanical lesions (Pricket et al., 1990). After pre-oviposition period of 5 to 6 days, each female is capable of laying about 350 to 400 eggs and depositing them either loosely in flour or other milled grain products or tucked in a crevice of a grain kernel at 30°C in 6 to 8 months (Odeyemi, 2001; Mason, 2003). Eggs hatch in 3 to 8 days and the larvae begin to feed within a few hours of hatching (Mason, 2003). Larvae are typically free-living, mobile, external feeders and not concealed (Rees, 2007). Under favourable conditions, larvae complete their development in 12 to 15 days. Pupae develop in about 4 to 7 days and total development time from egg to adult varies from 21 to 51 days, depending on temperature (Calvin, 1990). The life cycle was also reported to complete in 20 to 22 days at 30 to 33°C and 70 to 90% RH, while the optimum conditions for development of the insect are 30 to 35^0C and 70 to 90% RH (Halstead, 1980; Odeyemi, 2001; Rees, 2007). *O. surinamensis* is very cold tolerant and infestations could develop at 17 to 37°C and 10 to 90 RH (Rees, 2007). Adults normally live for 6 to 10 months, or even up to 3 years but quickly die on dust-free, undamaged grains (Surtees, 1965; Calvin, 1990). Considering feeding habits of adults and larvae of *O. surinamensis* and their low humidity tolerance, severe damage to infested sorghum may possibly occur.

Cryptolestes ferrugineus **(Stephens)**

The rusty grain beetle, *C. ferrugineus* is a worldwide cosmopolitan pest of stored products, particularly grains. Adults are flat, small, shiny light brown beetles, about 1.5 to 2 mm in length (Odeyemi, 2001; Rees, 2007; CGC, 2013b). Adults are good fliers and are readily identified by their very long antennae (Weaver and Petroff, 2004). This is a secondary pest attacking cereal grains and their products, and other dried materials of plant origin, packaged and processed goods (Rees, 2007). An adult female of *C. ferrugineus* lays up to 40 eggs on or amongst the commodity which hatch into mobile larvae (Odeyemi, 2001; Rees, 2007). Upon hatching, the larvae seek out food preferring to feed on the germ of the kernel. Larvae and pupae develop singly under the seed coat covering the germ of cereal seeds (Suresh et al. 2001). Adults are long-lived, walk with characteristic sway, feed on commodity and fly actively at temperatures above 21°C (Rees, 2007). Development is completed in 21 days at 35°C and 100 days at 20°C (Odeyemi, 2001). Robinson (2005) further observed that development of *C. ferrugineus* from egg to adult takes 69 to 103 days at 27°C. The rate of development of *C. ferrugineus* was reported to be retarded and its mortality increased at low humidities (below 40%) and grain moisture content was low (12%) (Odeyemi, 2001; CGC, 2013b).

Damage caused on stored sorghum by insect pests

Recently, various researchers investigated the damage caused by insect pests, especially *S. zeamais,* to maize (Baidoo et al., 2010; Ileke and Oni, 2011; Edeldouk et al., 2012; Rugumamu, 2012; Muzemu et al., 2013; Khaliq et al., 2014; Akunne et al., 2015). However, attention on stored sorghum is inadequate. The information obtained shows that the studies carried out both in the storage structures and laboratory, to investigate the damages caused by various insect pests to sorghum in storage were on combine infestation, while a few concentrated on single infestation. In a laboratory test for instance, Beshir (2011) reported that *T. granarium* caused 16.13% weight loss to stored sorghum within 6 months of storage, while *R. dominica* infestation resulted in 26.50% weight loss. Suleiman et al. (2012) reported that *S. zeamais* is a serious insect pest of sorghum with weevil perforation index (WPI) of 50.0. It is shown that a high sorghum grain perforation of up to 65.5% after four months exposure to *S. zeamais* was recorded under laboratory conditions (Suleiman et al., 2013). Goftishu and Belete (2014) also recorded sorghum grain damage of 29.33% sixty four days after introduction of *S. zeamais*. Similarly, a grain damage of 53.30% was obtained in sorghum after 28 days of storage under laboratory conditions of 32 ± 2°C and 65 ± 5% RH (Suleiman, 2014). These laboratory assessments have indicated that insect pests cause severe damage to stored sorghum which could likely lead to food insecurity, especially in rural areas where sorghum serves as their primary food.

The available literature shows that there is need for more research on the laboratory studies of insect infestation of sorghum, more especially in the northern Nigeria, where most of the Nigerian sorghum is produced. More insect pest species and various sorghum varieties need to be incorporated in future researches. This may lead to a search for more strategies in the management of insect pests infesting stored sorghum.

For trials in the storage structures, Gilse (1964) earlier reported presence of *S. zeamais*, *S. oryzae*, *R. dominica*, *S. cerealella*, *T. castaneum*, *L. serricorne*, *G. ugandae* and *O. Mercator* in sorghum stored in Nigerian granaries which caused severe damage to the grains. Utono (2013a) recorded 13.12% weight loss of threshed sorghum, while 8.34% weight loss was obtained in unthreshed sorghum infested by various insect pests (*T. castaneum*, *R. dominica*, *S. zeamais*, *L. serricorne*, *P. interpunctella*, *S. cerealella* and *C. cephalonica*) in traditional storage structures of the farmers of Kebbi State, Nigeria. A moderate infestation resulting in 73.00% damage of sorghum by insect pests was recorded by Mailafiya et al. (2014a) in Dalwa market of northern Nigeria. Similarly, Mailafiya et al. (2014b) recorded grain damage (5.275%) by *S. zeamais, T. castaneum, R. dominica* and *T. granarium* on sorghum traded in Maiduguri, northern Nigeria. Although, the available literature on storage structures trials is scanty, the available information reveals that there are various insect pests that cause substantial damage to stored sorghum. It is therefore necessary to search for alternative methods such as the use of botanicals which can be incorporated with the traditional storage systems as IPM strategies in order to reduce grain damage and losses as well as minimize exposure to chemical hazards of synthetic insecticides.

BOTANICAL CONTROL OF INSECT PESTS OF STORED SORGHUM

The hazardous nature of synthetic insecticides leads to search for less hazardous and environment-friendly methods such as the use of botanicals in the control of insect pests. The practice of using natural sources against pests for storage of various household items dates back to the very earliest periods of known history (Karthikeyan et al., 2009). Rugumamu (2015) considers botanical method as an indigenous pest management for reducing damage caused by pests. Recently, the effects of different plant materials on repellency, adult mortality, oviposition, adult emergence, total development period, grain damage and seed germination were assessed by many researchers (Rotimi and Evboumwam, 2012; Muzemu et al., 2013; Rugumamu, 2014, 2015). But most of the researchers concentrated on maize and cowpea grains, while a few worked on sorghum as discussed in the following paragraphs.

Among the five plant powders tested by Suleiman et al. (2012), *Jatropha curcas* L.*, Euphorbia balsamifera* L. and *Lawsonia inermis* L. were found to be more effective in protecting sorghum grains against *S. zeamais* infestation by resulting in total (100%) adult mortality within 28 days after treatment. They also reported absence of adult emergence when 20 g of sorghum grain was treated with 2 g of *J. curcas* leaf powder, which showed similar effect with that of the conventional insecticide (permethrin powder). Further, it was found that leaf powder of *J. curcas* applied at 10% (w/w) gave sorghum grain a complete protection against *S. zeamais* attack by resulting in zero weevil perforation index which was not significantly different ($P > 0.05$) from permethrin powder (Suleiman et al., 2012). In a field investigation, it was found that extracts from *Cymbopogon nardus* and *Ocimum basilicum* had repellent activity against *T. castaneum* in threshed sorghum stored in store rooms in Kebbi State, northern Nigeria (Utono, 2013b). Powders of *Allium sativum* L.*, Capsicum frutescens* L. and *Zingiber officinale* Rosc were reported to have caused total (100%) adult mortality of *S. zeamais* in sorghum grains 14 days after introduction under laboratory condition (Suleiman, 2014). The spices were also found effective in reducing grain damage of sorghum from 53.30% in the control to 3.30 to 33.30% in the botanical treatments, depending on the concentration applied.

The little information gathered has revealed that more laboratory investigations are required on those botanicals with insecticidal properties that have been tested and found effective against insect pests of other stored grains by some researchers (Musa et al., 2007; Ileke and Oni, 2011; Khaliq et al., 2014; Rugumamu, 2014, 2015; Tilahun and Daniel, 2016; Oni et al., 2016). This would likely contribute to IPM strategies in controlling insect pests of stored sorghum by using botanicals incorporated with other alternatives such as improvement of local storage structures which may conceivably minimize the use of synthetic insecticides and at the same time reduce damage to stored grains.

ANALYSIS OF CHALLENGES AND OPPORTUNITIES OF UTILIZING BOTANICAL PESTICIDES IN NIGERIA

Golob et al. (2002), Okrikata and Oruonye (2012) and Rajashekar et al. (2012) outlined the challenges to utilization of bio-pesticides. They also suggested strategic solutions to the challenges which would possibly enhance sustainable use of bio-pesticides under the framework of integrated pest management in Nigeria as well as outside the country in general. Some of the major limitations and the suggested solutions are discussed below.

One of the limitations to the utilization of botanicals as insecticides in Nigeria is that most of the data on bio-pesticides are obtained from laboratory trials with little from field trials. Rajashekar et al. (2012) further observed that data on the effectiveness and long-term mammalian toxicity are unavailable for some botanicals, and tolerances for some have not been established. It is therefore necessary to further study field assessment of insecticidal properties of botanicals found effective in laboratories in order to explore more of their benefits. Additionally, since most of the grains and other products are stored for future use, further studies are required to evaluate the toxicity of bio-pesticides against mammals in order to ensure their safety for consumption. This corroborates Golob et al. (2002) who stated that adverse effects of insecticidal plants on the consumer need to be assessed so that any potential vertebrate toxicity is understood.

Another limitation is the use of bio-pesticides and the quantity of botanicals especially powders, to be applied on stored commodities. Most farmers who use botanicals in their stores use them to treat small amounts to high-value crops such as cowpea. Medium to large-scale operations that have several tonnes of stored produce to protect would find it enormously difficult to collect enough plant material to treat the grain at a suitably enough concentration (Golob et al., 2002). To overcome this limitation, large-scale production of insecticidal botanicals is necessary. Also, using the volatile properties of some botanical extracts could help to overcome the practical constraints of treating large amount of commodity.

Okrikata and Oruonye (2012) noted that the perception of most farmers that the use of bio-pesticides is traditional and hence inefficient limits utilization of botanicals to protect stored products against insect pests. In view of this, farmers and other grain processors need to be educated on the benefits of the use of bio-pesticides and their effectiveness in the control of stored products insect pests. The Nigerian government should also promote mass enlightenment campaigns through the efforts of both public and private sectors to create high level of awareness amongst the citizenry on the available alternatives to synthetic pesticides.

CONCLUSION

This review has revealed that sorghum production is one of the major farming activities in northern Nigeria largely by subsistence farmers and the produce need to be stored after harvest for future use. Most of the storage structures at on-farm level are traditional mud and thatched rhumbus, some farmers use store rooms while a few use underground pits. Sorghum is largely stored in threshed and unthreshed forms in these traditional stores which are made of local materials and easily accessible by pests. If not properly protected, infestation will possibly be established by insect pests of different kinds leading to substantial damages to stored sorghum which may result in serious postharvest losses, economic constraint and hence general food insecurity. In order to minimize the use of hazardous nature of synthetic insecticides and improve food security, the use of plant materials in various formulations could be incorporated with the use of traditional storage structures as a contribution to IPM strategy in controlling insect pests of stored sorghum and other grains. Improvement of the structures such as elevation of thatched rhumbus higher than the conventional ones and fitting the supporting legs with rat guards might also be useful. Although there were various investigations on the use of botanicals against different insect pests of stored products, little was done on insect pests of stored sorghum. It is therefore recommended to carry out more research on the use of botanicals in the management of insect pests of stored sorghum and other grains in traditional storage structures.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abate T, Huis AV, Ampofo JKO (2000). Pest management strategies in traditional agriculture: An African prospective. Ann. Rev. Entomol. 45:63-65.

Abbas AB, Ndunguru G, Mamiro P, Alenkhe B, Mlingi N, Bekunda M (2014). Post-harvest food losses in a maize-based farming system of semi-arid savannah area of Tanzania. J. Stored Prod Res. 57:49-57.

Adedire CO (2001). Biology, Ecology and Control of Insect Pests of Stored Cereal Grains. In: Ofuya TI and Lale NES (eds.). Pests of Stored Cereals and Pulses in Nigeria. Dave Collins Publications, Akure, Nigeria. pp. 59-94.

Adejumo BA, Raji AO (2007). Technical appraisal of grain storage systems in the Nigerian sudan savannah. Agricultural Engineering International: The International Commission on Agricultural Engineering (CIGR). J. Sci. Res Dev. Invited Overview IX(11):1-12.

Adetunji MO (2007). Economics of maize storage techniques by farmers of Kwara State, Nigeria. Pak. J. Soc. Sci. 4(3):442-450.

Akunne CE, Chima GN, Ononye BU, Okafor KP (2015). Comparative efficacy of *Cymbopogon citratus* and *Psidium guajava* powders as poison against *Sitophilus zeamais* (Motschulsky) in stored maize grains. Open Sci. J. Biosci. Bioengr. 2(4):41-44.

Anankware PJ, Fatunbi AO, Afreh-Nuamah K, Obeng-Ofori D, Ansah AF (2012). Efficacy of mullti-layer hermetic storage bag for biorational management of primary beetle pests of stored maize. Acad. J. Entomol. 5(1):47-53.

Atanda AS, Agoda S, Ihionu GC, Usanga AE (2016). Protection of grains and cereals-A Review. App. Sci. Report. 13(2):96-106.

Baidoo PK, Mochiah MB, Owusu-Akyaw M (2010). Levels of infestation of three different portions of the maize cobs by the weevil *Sitophilus zeamais* (Motschulsky). J. Sci. Technol. 30(3):21-26.

Beshir TSD (2011). Susceptibility of stored sorghum grains in Renk area to infestation by the Khapra beetle and the Lesser grain borer. Ph.D. Thesis. University of Khartoum, Sudan. 105p.

Boxall RA (1998). Grains post-harvest loss assessment in Ethiopia: Final report. [Working Paper]. University of Greenwich Natural Resources Institute. 33p.

Boxall RA, Gebre-Tsadik M, Jayaraj K, Ramam CP, Patternaik BB, Hodges RJ (2004). *Sorghum.* In: Hodges R, Farrell G (eds.). Crop Post-Harvest: Science and Technology. Blackwell Publishing Ltd. 2:128-144.

Calvin D (1990). Sawtoothed and Merchant Grain Beetle. Department of Entomology Entomological Notes, Penn State College of Agricultural Sciences. http://ento.psu.edu/extension/factsheets/sawtoothed-and-merchant-grain-beetle Accessed on 08/11/2016.

Canadian Grain Commission (CGC) (2013a). Angoumois grain moth, *Sitotroga cerealella* (Olivier). Canadian Grain Commission. https://www.grainscanada.gc.ca/storage-entrepose/pip-irp/agm-adg-eng.htm. Accessed on 23/08/2016.

Canadian Grain Commission (CGC) (2013b). Rusty grain beetle, *Cryptolestes ferrugineus* (Stephens). Canadian Grain Commission. https://www.grainscanada.gc.ca/storage-entrepose/pip-irp/rgb-cr-eng.htm Accessed on 25/08/2016.

Chapman RF (2009). The Insects Structure and Function (4th edition). Cambridge University Press. New York. 770p.

Chattha SH, Lee TS, Mirani BN, Hasfalina CM (2014). Effects of storage methods, storage duration and different geographical locations on quality of stored wheat (*Triticum aestivum*) in sindh, Pakistan. J. Biodiv. Env. Sci. 5(4):378-392.

DAF (2016). Insect Pests of Stored Grain. Department of Agriculture and Food. https://www.agric.wa.gov.au/pest-insects/insect-pests-stored-grain Accessed on 23/08/2016.

Dwivedi SC, Kumar R (1998). Evaluation of *Cassia occidentalis* leaf extract on development and damage caused by *Trogoderma granarium,* Khabra beetle. J. Ecotoxicol. Env. Mon. 8:55-58.

Edeldouk E, Akpabio E, Eyo J, Ekpe E (2012). Bio-insecticidal potentials of testa powder of melon, *Citrullus vulgaris* Schrad for reducing infestation of maize grains by the maize weevil, *Sitophilus zeamais* Motsch. J. Bio. Agric. Healthcare 2(8):13-17.

FAO (1994). Grain storage techniques. Evaluation and trends in developing countries. Food and Agriculture Organization of the United Nations Agricultural Bulletin No. 109.

FAO (1999). Sorghum: Post-harvest operations. Natural Resources Institute, Food Security Department. *INPhO - Post-harvest Compendium.* Food and Agriculture Organization of the United Nations. 33p.

FAO (2011). Rural structures in the tropics: Design and development. Food and Agriculture Organization of the United Nations, Rome, Italy. 500pp.

FAO (2013). Food and agricultural commodities production. *FAOSTAT*. Food and Agriculture Organization of the United Nations. http://faostat.fao.org/site/339/default.aspx

Gilman GA, Boxall RA (1974). Storage of food grains in traditional underground pits. Trop. Stored Prod. Infor. 29:6-9.

Gilse PH (1964). The insect infestation of sorghum stored in granaries in Northern Nigeria. Bull. Entomol. Res. 55(3):573-588.

Goftishu M, Belete K (2014). Susceptibility of sorghum varieties to the maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) Afr. J. Agric. Res. 9(31):2419-2426.

Golob P, Birkinshow LA, Starthers TE, Meyer AN, Belmain SR, Farrell G, Hodges RJ (2002). Pest management. In: Golob P, Farrell G, Orchard JE (eds.) Crop Post-Harvest: Science and Technology, Volume 1. Blackwell Science Ltd. 566p.

Haines CP (1991). Insects and Arachnids of Tropical Stored Products: Their Biology and Identification. 2nd edition. Natural Resources Institute, Chatham, Kent, Uk. 246p.

Halstead DGH (1980). A revision of the genus *Oryzaephilus* Ganglbauer, including descriptions of related genera (Coleoptera: Silvanidae). Zool. J. Linn. Soc. 69(4):271- 374.

Hashem MY, Ahmed SS, El-Mohandes MA, Gharib MA (2012). Susceptibility of different life stages of Saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae) on modified atmospheres enriched with carbon dioxide. J. Stored Prod. Res. 48:46-51.

Hill DS (1997). The Economic Importance of Insects. Chapman and Hall, 395p.

Ileke KD, Oni MO (2011). Toxicity of some plant powders to maize weevil, *Sitophilus zeamais* (Motschulsky) [Coleoptera: Curculionidae] on stored wheat grains (*Triticum aestivum*). Afr. J. Agric. Res. 6(13):3043-3048.

Johnson D (2014). Insect Pests of Stored Grains: Angoumois Grain Moth. University of Kentucky College of Agriculture, Food and Environment. https://entomology.ca.uky.edu/ef156. Accessed on 23/08/2016.

Karthikeyan C, Veeraragavathatham D, Karpagam D, Firdouse SA (2009). Traditional storage practices. *Indian J. Trad. Know.* 8(4):564-568.

Kavallieratos NG, Athanassiour CG, Arthur FH, Throne JE (2012). Lesser grain borers, *Rhyzopertha dominica* select rough rice kernels with cracked hulls for reproduction. J. Insect Sci. 12(38):1-7.

Khaliq A, Nawas A, Ahmad NH, Sagheer M (2014). Assessment of insecticidal potential of medicinal plant extracts for control of maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). Basic Res. J. Agric. Sci. Rev. 3(11):100-104.

Khashaveh A, Ziaee M, Safaralizadeh MH, Lorestani FA (2009). Control of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) with spinosad dose formulation in different seedoils. Park. J. Agric For. 33:203-209.

Koehler PG (2015). Rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae). IFAS Extension. University of Florida. 2p. http://entnemdept,ifas.edu/creatures/.

Kolterman D, Thiessen EJ, Wells E (2000). Kansas on-farm postharvest chemical use. *Kansas* Agricultural Statistics, 4p.

Mada DA, Mahai S, Adamu IG, Girei MM (2014). Toxicity study on pesticide of cereal, legume and oil seed with regard to storage structures of Ganye, southern Adamawa State – Nigeria. Int. J. Engr. Res. Dev. 10(3):33-39.

Mahai S, Jamala GY, Mada DA, Medugu IA (2015). Assessment of sorghum storage methods in Madagali and Ganye areas of Adamawa State, Nigeria. The Int. J. Engr. Sci. 4(10):01-06.

Mailafiya DM (2003). The performance of *Prostephanus truncatus* (Horn) on different sorghum varieties grown in Ghana. *M.Sc. Thesis*. University of Ghana. 109p.

Mailafiya DM, Dauda Z, Degri MM, Kabir BGJ, Maina YT (2014a). An appraisal of insect pests associated with cereal grains traded in Maiduguri, Borno State, Nigeria. Int. Letts. Nat. Sci. 14:76-83.

Mailafiya DM, Maina TY, Degri MM, Gadzama UN (2014b). Traders' perception of food grain storage and pest management in Dalwa market, Borno State, Nigeria. J. Agric. Crop Res. 2(4):62-70.

Mason LJ (2003). Grain Insect Fact Sheet E-228-W: Sawtoothed Grain Beetle, *Oryzaephilus surinamensis* (L.). Purdue University, Department of Entomology. http://extension.entm.purdue.edu/publications/E-228.pdf.

Musa AK, Dike MC (2009). Life cycle, morphometrics and damage assessment of the Khapra beetle, *Trogoderma granarium* Everts (Coleoptera: Dermstidae) on stored groundnuts. J. Agric. Sci. 54(2):135-142.

Musa AK, Dike MC, Amatobi CI, Onu I (2007). Laboratory evaluation of some botanicals for the control of *Trogoderma granarium* Everts (Coleoptera: Dermestidae) on stored groundnuts. JORMAR 4(1-2):56-62.

Muzemu S, Chitamba J, Mutetwa B (2013). Evaluation of *Eucalyptus tereticornis*, *Tagetes minuta* and *Carica papaya* as stored maize grain protectants against *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae). Agric. For. Fish. 2(5):196-201.

Naseem MT, Khan RR (2011). Comparison of repellency of essential oils against red flour beetle *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae). J. Stored Prod. Postharvest Res. 2(7):131-134.

Nukenine EN (2010). Stored product protection in Africa: Past, present and future. 10th Working Conf. Stored Prod. Protection 425:26-41.

Odeyemi OO (2001). Biology, Ecology and Control of Insect Pests of Stored Processed Cereals and Pulses. In: Ofuya TI and Lale NES (eds.). Pests of Stored Cereals and Pulses in Nigeria. pp. 95-112. Dave Collins Publications, Akure, Nigeria.

Okonkwo EU (1998). Bibliography, A bibliography of plant materials used for controlling insect pests of stored products in Nigeria. Rev. Agric. Entomol. 30p.

Okrikata E, Oruonye ED (2012). Issues surrounding the use of plant-derived pesticides (Botanicals) in pest management in Nigeria. Int. J. Sci. Nat. 3(3):487-490.

Oni MO, Ogungbite OC, Bello FO (2016). Biotoxic efficacy of two horticultural plants against infestation of *Sitophilus oryzae* on stored maize. Leonardo J. Sci. 28:109-122.

Onolemhemhen PO, Olebor JU, Umeri C (2011). The efficacy of *Xylopia aethiopica* and *Piper guineense* seeds powder on *Sitophilus oryzae* mortality. J. Agric. Soc. Res. 11(2):161-167.

Pricket AJ, Muggletun J, Llewellin JA (1990). Insecticide resistance in populations of *Oryzaephilus surinamensis* and *Cryptolestes ferrugineus* from grain stores in England and Wales. Brighton Crop Protection Conference - Pests and Diseases 3:1189-1194.

Rahman MA, Taleb MA, Biswas MM (2003). Evaluation of botanical product as grain protectant against grain weevil, *Sitophilus granarius* (L.) on wheat. Asian J. Plant Sci. 2(6):501-504.

Rajashekar Y, Bakthavatsalam N, Shivanandappa T (2012). Botanicals as grain protectants. Psychology 2012:1-13.

Rampho ET (2005). *Sorghum bicolor* (L.) Moench. www.plantzafrica.com/plantqrs/sorghum.html.

Rees D (2007). Insects of Stored Grain A Pocket Reference. 2nd Edition. CSIRO Publishing. Australia. 81p.

Robinson WH (2005). Urban Insects and Arachnids. A Handbook of Urban Entomology. Cambridge University Press. Cambridge, UK. 472p.

Rotimi J, Evboumwan CO (2012). Deterrent effects of citrus peel oils on oviposition and adult emergence of cowpea weevil, *Callosobruchus maculatus* (F) (Coleoptera: Bruhidae). Adv. App. Sci. Res. 3(6):3545-3550.

Rugumamu CP (2012). A technique for assessment of intrinsic resistance of maize varieties for the control of *Sitophilus zeamais* (Coleoptera: Curculionidae). Tanzania J. Nat. App. Sci. 3(1):481-488.

Rugumamu CP (2014). Potency of traditional insecticide materials against stored bean weevil *Acanthoscelides obtectus* (Coleoptera: Bruchidae) in Tanzania. HURIA J. 16:126-139.

Rugumamu CP (2015). Insecticidal activity of botanical pesticides on *Callosobruchus chinensis* (L.) (Coleoptera: Bruchidae) in stored green gram, *Vigna radiate* (L). Int. J. Agric. Res. 4(1):013-020.

Simonyan KJ, El-Okene AM, Yiljep YD (2007). Some physical properties of Samaru Sorghum 17 grains. Agricultural Engineering International: the CIGR Ejournal Manuscript FP 07008. Vol. IX. August, 2007.

Sori W (2014). Effect of selected botanicals and local seed storage practices on maize insect pests and health of maize seeds in Jimma zone. Singapore J. Sci. Res*.* 4(2):19-28.

Sterling RL, Meixel GD, Dunkel F, Fairhurst C (1983). Underground storage of food. *Undeeground Space.* 7:257-262.

Suleiman M (2014). Efficacy of Some Spices as Sorghum Grain Protectants against *Sitophilus zeamais* Motschulsky [Coleoptera: Curculionidae]. Afr. J. Agric. Res. 9(9):841-845.

Suleiman M, Ibrahim ND, Majeed Q (2012). Control of *Sitophilus zeamais* (Motsch) [Coleoptera: Curculionidae] on Sorghum Using Some Plant Powders. Int. J. Agric. For. 2(1):53-57.

Suleiman M, Majeed Q, Aiki IP (2013). Efficacy of four plant powders against *Sitophilus zeamais* Motschulsky [Coleoptera: Curculionidae] on sorghum grains. Int. J. App. Res. Technol. 2(6):130-138.

Suresh S, White NDG, Jayas DS, Hulasare RB (2001). Mortality resulting from interactions between the red flour beetle and the rusty grain beetle. Proc. Entomol. Soc. Manitoba 57:11-18.

Surtees G (1965). Laboratory studies on dispersion behaviour of adult beetles in grain. X. Reaction of saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.) to isolated pockets of damp and mouldy wheat. J. App. Ecol. 2(1):71-80.

Tilahun FE, Daniel DH (2016). Effect of neem leaf and seed powders against adult maize weevil (*Sitophilus zeamais* Motschulsky) mortality. Int. J. Agric. Res. 11:90-94.

Tiroesele B, Thomas K, Seketeme S (2015). Control of cowpea weevil, *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) using natural plant products. Insects 6(1):77-84.

USAID (2011). Staple Crops Storage Handbook. The United States Agency for International Development/East Africa Regional Office. 152p.

USDA (2014). Nigeria grain and feed annual, Annual report 2014. United States Department of Agriculture, 16p.

Utono IM (2013a). Assessment of grain loss due to insect pest during storage for small-scale farmers of Kebbi. IOSR J. Agric. Vet. Sci. 3(5):38-50.

Utono IM (2013b). A novel approach to control stored sorghum beetle *Tribolium castaneum* (Coleoptera: Tenebrionidae) in small-scale farmers' storerooms in Kebbi – Nigeria. PhD Theses. The University of Greewich, United Kingdom 318p.

van Emden HF (2013). Handbook of Agricultural Entomology. Wiley-Blackwell, A John Wiley & Sons Ltd., Publication. 312p.

Wakil W, Riasat T, Ghazanfar MU, Kwon YJ, Shaheen FA (2011). Aptness of *Beauveria bassiana* and enhanced diatomaceous earth (DEBBM) for control of *Rhyzopertha dominica* F. Entomological Research. 41(6):233-241.

Weaver DK, Petroff AR (2004). Sored grain. Rusty grain beetle. High Plains IPM Guide*.* A cooperative effort of the University of Wyoming, University of Nebraska, Colorado State University and Montana State University. 4p.