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BIOINSECTICIDAL ACTIVITIES OF *Azadirachta indica* AND *Moringa oleifera* AGAINST MAIZE WEEVIL (*Sitophilus zeamais*) AND RICE WEEVIL (*Sitophilus oryzae*) – A REVIEW

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ABSTRACT

Control of stored-product insect pests continues to primarily be based on application of synthetic insecticides such as organophosphates, pyrethroids and fumigants because they are effective for the management of insect infestations. The main method of pest control of stored rice grain has been chemical, using phosphine. However, the development of resistance of Sitophilus zeamais and Sitophilus oryzae to these products hinders its control, and alternative measures are necessary for its management. Integrated Pest Management (IPM) is considered the most sustainable way of controlling stored product pests. Plants are considered as a rich source of bioactive chemicals and they may be alternative source of insect pest control agents, examples: Azadirachta indica (Neem plant) commonly known as Dongoyaro and Moringa oleifera leaf commonly known as drumstick. Plant extracts are more effective in the way as they do not cause pollution; produce less toxicity and are bio-degradable and some plants naturally have the repellent effect against many stored grain pests. Various neem extracts are known to act on various insects in varying ways including disrupting or inhibiting the development of eggs larvae or pupae, blocking the moulting of larvae or nymphs disrupting mating and sexual communication, sterilizing adults and deterring feeding as well as inhibiting the production of chitin and the extracts have proven as potent as synthetic pesticides. Synthetic chemical causes many side effects on the environment and humans. Their indiscriminate use can lead to resistance and revival in insects and leach and contaminate the environment hence the need for natural insecticide. Researches on the development of green pesticide from plant and animal extracts and microbes are ongoing. This class of pesticide is much safer and more biodegradable. Higher plants such as neem, moringa and various herbs and spices such as garlic, clove, turmeric, etc., possessed antimicrobial and insecticidal properties. Green insecticides are expected to solve insect resistance and environmental safety. Further researches are needed for a better understanding of the efficacy and applicability of natural pesticides.

KEYWORDS: Bio-insecticide, Azadirachta indica, Moringa oleifera, Sitophilus zeamais and Sitophilus oryzae

INTRODUCTION

The maize weevil (Sitophilus zeamais), is a species of beetle in the family Curculionidae found in numerous tropical areas around the world and is a major pest of maize (Ojo and Omoloye, 2012). It is one of the most destructive stored product pests of grains, cereals and other processed and unprocessed stored products in sub-Saharan Africa (Ojo and Omoloye, 2012).

S. zeamais causes qualitative and quantitative damage to stored products with grain weight loss ranging between 20 to 90% for untreated stored maize, and the severity of damage depends on factors which include storage structures and physical and chemical properties of the produce (Muzemu et al., 2013).

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Heavy infestation of adults and larvae of maize weevil which cause postharvest losses have become increasingly important constraints to storage entomology and food security in the tropics (Nta, 2019).

As described by Medugu et al. 2020, the complete development time for the life cycle of S. zeamais is 36 days on average. The female chews through the surface of the grain, creating a hole, then deposits a small oval white egg, and covers the hole as the ovipositor is removed, with a waxy secretion that creates a plug that quickly hardens and leaves a small raised area on the seed surface which provides the only visible evidence that the kernel is infested though only one egg is laid inside each grain which hatches into a white, legless grub and remain inside and begin feeding on the grain till the larvae pupate while inside, then chew a circular exit hole, and emerge as an adult beetle (Medugu et al., 2020). A single female may lay 300 to 400 eggs during her lifetime while adults can live for 5 to 8 months with breeding conditions requiring temperatures between 15 and 34°C and 40% relative humidity for the adults to emerge, the females move to a high surface and release sex pheromones that attracts males to this pheromone (Medugu et al., 2020).

The maize weevil commonly attacks standing crops, in particular, maize before harvest, and is also commonly associated with rice and infests raw or processed cereals such as wheat, oats, barley, sorghum, rye and buckwheat (Muzemu et al., 2013). It can breed in crops with a moisture content of a much wider range than S. oryzae, and has been found in fruit, such as apples during storage, although the maize weevil cannot readily breed in finely processed grains, it can easily breed in products such as macaroni and noodles, and milled cereals that have been exposed to excessive moisture (Muzemu et al., 2013)

Early detection of infestation is difficult as S. zeamais larvae feed on the interior of individual grains, often leaving only the hulls, a flour-like grain dust, mixed with frass is evident (Nta, 2019). Infested grains contain holes through which adults have emerged and a possible indication of infestation is grain, when placed in water, floating to the surface (Abebe et al., 2009). Ragged holes in individual grains, similar to damage caused by the rice weevil and granary weevil, may indicate infestation in which an increase in temperature may be detected in large stores of grains while the most obvious sign of infestation is the emergence of adults (Nta, 2019). A study recorded, 5 weeks after infestation, the emergence of 100 adults per kg per day (Medugu et al., 2020).

Maize is a cereal grain first domesticated by indigenous peoples in southern Mexico about 10,000 years ago (Alonso and Avila, 2011). The leafy stalk of the plant produces pollen inflorescences and separate ovuliferous inflorescences called ears that yield kernels or seeds, which are fruits (USDA, 2018).

The maize plant is often 3 m (10 ft) in height, though some natural strains can grow 13 m (43 ft), and the tallest recorded plant reached 45 feet (14 m) (Karl, 2012). The stem is commonly composed of 20 internodes of 18 cm (7 in) length while the leaves arise from the nodes, alternately on opposite sides on the stalk, and have entire margins and the apex of the stem ends in the tassel, an inflorescence of male flowers (Oldenburg et al., 2011). When the tassel is mature and conditions are suitably warm and dry, anthers on the tassel dehisce and release pollen which is anemophilous (dispersed by wind), and because of its large settling velocity, most pollen falls within a few meters of the tassel (Oldenburg et al., 2011).

Maize is widely cultivated throughout the world, and a greater weight of maize is produced each year than any other grain which made a total world production in 2018 as 1.15 billion tonnes, led by the United States with 34.2% of the total and China produced 22.4% of the global total (FAO, 2020). Maize has become a staple food in many parts of the world, with the total production of maize surpassing that of wheat or rice adding to being consumed directly by humans (often in the form of masa), maize is also used for corn ethanol, animal feed and other maize products, such as corn starch and corn syrup (Listman et al., 2019). Sugar-rich varieties called sweet corn are usually grown for human consumption as kernels, while field corn varieties are used for animal feed, various corn-based human food uses (including grinding into corn meal or masa, pressing into corn oil, and fermentation and distillation into alcoholic beverages like bourbon whiskey), as chemical feedstocks and also used in making ethanol and other biofuels (Listman et al., 2019).

Sitophilus oryzae also known as rice weevils is the most important species that causes damage to rice grains in storage (Nwaubani et al., 2014). The rice weevil is a small, reddish-brown to black insect of the order Coleoptera and family Curculionidae (ki-Jeong et al., 2018). These insects are cosmopolitan in distribution and have originated in far East region, can exist anywhere where physical conditions for growth are favourable and the grain is left undisturbed for some time (Togola et al., 2013).The adult female rice weevil lays an average of 4 eggs per day and may live for four to five months (producing 250-400 eggs) in a single generation and can be completed in around 28 days, and eggs hatch in about 3 days and larvae feed inside the grain kernel for an average of 18 days while the pupal stage lasts for an average of 6 days (5-16 range) with the new adult remaining in the seed for 3 to 4 days while its cuticle hardens and matures (Somnath and Kaushik, 2014).

Rice, Oryza sativa, is an edible starchy cereal grain in the grass plant family Poaceae and is one of the world's most important food crops (Costa et al., 2016).

Roughly one half of the world population, including virtually all of east and Southeast Asia, is wholly dependent upon rice as a staple food and 95 percent of the Worlds rice crop is eaten by humans (Copatti et al., 2013). Rice is cooked by boiling, or can be ground into flour; also it is eaten alone and in great variety of soups, side dishes and main dishes in Nigeria and other countries (Tashikalma et al., 2014). Rice has been cultivated since ancient times and Oryza is a classical Latin word for rice (Nascimento et al., 2015). Most of the rice varieties grown in the world belong to the species Oryza sativa which has it origin in Asia (Ki-Jeong et al., 2018). In Asia in particular, rice comprises a basic component of the daily diet and it occupies one of the top positions of commodities with the highest worldwide production according to FAOSTAT, 2019 (Statistics division of the Food and Agricultural Organization of the United Nations). The oil deriving from rice, namely rice bran oil (RBO), is one of the most commonly used cooking oil in Asia (Togola et al., 2013).

Insects can alter the micro-environment of the grain by making it more favourable to fungal growth thereby leading to discoloration, distortion, unpleasant odors and loss of seed viability (Gautam et al., 2013). These insects feed on cereal grains and legumes during storage and cause reduction in their quality and quantity (Ojiako et al., 2016). Adults and larvae of Sitophilus zeamais and Sitophilus oryzae reduce grain weight, nutritional value, and the germination ability of stored seeds (Hagstrum et al., 2012). Damage occurs from reduction of the grain weight, loss of nutritive value and germination, contamination by mites and fungi to loss of commercial value of the product (Souza et al., 2012).

Control of stored-product insect pests continues to primarily be based on application of synthetic insecticides such as organophosphates, pyrethroids and fumigants because they are effective for the management of insect infestations (Zettler and Arthur, 2000; Upadhyay and Ahmad, 2011). The main method of pest control of stored rice grain has been chemical, using phosphine (Hossain et al., 2014). However, the development of resistance of Sitophilus zeamais and Sitophilus oryzae to these products hinders its control, and alternative measures are necessary for its management (Ribeiro et al., 2013). Integrated Pest Management (IPM) is considered the most sustainable way of controlling stored product pests (Ribeiro et al., 2003). Plant resistance, a component of IPM, reduces the population density of pests below the economic injury level without additional costs to the farmer, and is compatible with other pest control methods (Seifi et al., 2013).

Plants are considered as a rich source of bioactive chemicals and they may be alternative source of insect pest control agents, examples: Azadirachta indica (Neem plant) commonly known as Dongoyaro and Moringa oleifera leaf commonly known as drumstick (Ojiako et al., 2013).

Plant extracts are more effective in the way as they do not cause pollution; produce less toxicity and are bio-degradable and some plants naturally have the repellent effect against many stored grain pests (Tanzir, 2013). Repellent, means having the ability to repel insects to enter or move across a surface which is treated with these repellents (Ishfaq et al., 2019). The use of coating of repellent on packaging is helpful in order to prevent insect infestation at that portion where further research is to be conducted (Mullen et al., 2012). Different repellent formulations have been tested through the years though natural and synthetic combinations were used in the studies of senior authors which included insect growth regulators neem oil, moringa oil, methyl salicylate and DEET derivatives (Mullen et al., 2012).

Azadirachta indica A. juss, known as neem plant, in the mahogany family Meliaceae, is a tree with attractive breed-leaves ever greens that can grow up to 30m tall and 2.5m in girth (COED, 2013). According to Invasive Plant Risk Assessment (IPA), (2016); Neem tree, A. indica is described as having spreading branches from rounded crowns as much as 10m across, they remain in leaf except during extreme drought, when the leaves may fall off while the short usually straight trunk has a moderately thick, strongly furrowed bark and the roots penetrate the soil deeply at least where the site permits and particularly when injured; they produce suckers which tends to be especially prolific in dry localities, with a smooth, ellipsoidal drupe fruit up to almost 2cm long when ripe and yellow or greenish yellow that comprises a pulp endorsing a seed which is composed of a shell and a kernel, each about half of the seeds weight and the kernel used most in pest control, bearing fruit after 3-5years and becomes fully productive in 110years and from then produce up to 50kg of fruit annually and may live for more two centuries.

Neem according to Barstow, (2018) is thought to have originated in Disam and Burma, however, the exact origin is vineartain and its distribution is as follows: Grown from the southern tip of Kerala to the Himalayan hills, in tropical to sub-tropical regions, in semi-arid to wet tropical regions, and from sea level to about 700m elevation. Neem was introduced to Africa earlier this century and now well established in at least 30 countries, particularly these in the region along the Sahara's southern fringe, where it has become an important provider of both fuel and lumber and has also been established in Fiji Mauritius, the Caribbean and many countries of central and South Africa over the last centuries (Barstow, 2018).

Neem is ubiquitous in the northern Nigeria and popularly referred to in Hausa language as "DogonYaro" it is drought resistant and common in town and villages and sometimes planted in large numbers along roadside (Chaudhari et al., 2015). The growing accumulation of experience demonstrates that neem products work by intervening at several stages of an insect's life (Ojiako et al., 2016).

The ingredients from this tree approximate the shape and structure of hormones vital to the lives of insects thus, the bodies of insects absorb the neem compounds as if they were the real hormones, but this only blocks their endocrine systems (Chaudhari et al., 2015). Various neem extracts are known to act on various insects in varying ways including disrupting or inhibiting the development of eggs larvae or pupae, blocking the moulting of larvae or nymphs disrupting mating and sexual communication, sterilizing adults and deterring feeding as well as inhibiting the production of chitin and the extracts have proven as potent as synthetic pesticides (Srivastata et al., 2013).

Drumstick, Moringa oleifera leaf is a multi-purpose tree native to north-western India (Ali et al., 2017). It is widely cultivated, fast growing edible plants that are naturalized in the tropics (Lim, 2012). It is grown in settle areas as a backyard vegetable and often times utilized as a boarder plant (Imohiosen et al, 2014). The moringa tree is a deciduous perennial tree that is regarded as one of the world most successful tree since almost every part of it is useful (National Research Council, 2006). It requires an annual rainfall of between 250-3000mm; It is a drought resistance tree, although in drought conditions it may lose it leaves but recovers when the rain arrivals; Grows best at altitudes up to 600m but will grow at altitude 1000m; survive in a temperature range of 25-40^{o}C but it is known to tolerate temperature of 48^{o}C and light frost (Olson, 2001).

ECONOMIC IMPORTANCE OF CEREALS

About 2.7 billion metric tons of cereals were produced in Nigeria in 2020 (Statista, 2021). Cereals and legumes are critical to the nutrition of many, including infants (Achaglinkame et al., 2017). Most grain legumes are rich in proteins and other essential micronutrients (Chibarabada et al., 2017). Combination of cereal and legumes provides diets with adequate calories, essential minerals and almost all essential amino acids (Singh and Pratap, 2016). Bio-fortified cereals can contain essential nutrients such as Zinc and provitamin A (Listman et al., 2019) and can play important roles in solving many nutrition-related health problems (Trono, 2019).

Grains are a global staple and the main source of food and energy to many (Khaneghah et al., 2018). They are highly universal due to their ability to thrive under a wide range of environmental conditions (Chibarabada et al., 2017) and are easy to handle and transport (Paul et al., 2020).

Economic importance of maize

Maize (Zeamais L. Poaceae) has always been preferred to any other crop, including cassava because most of the world's civilizations developed around grains rather than tuber crops (Fakorede, 2001). It ranks 3rd after wheat and rice, owing to the large areas and total production output of the crop (Adiaha, 2017). The crop was introduced into Nigeria probably by the Portuguese (Olaniyan, 2015).

In Nigeria, the crop is called with many vernacular names 'agbado' (Yoruba), 'ibokpot' (Efik) and 'masar' (Hausa) and extensively cultivated in United States with about 50% production (Adiaha, 2017).

Annual maize production at about 5.6 million hectares out of 9 million hectares in Africa has been reported by Panchal et al. (2011) to be cultivated to maize in Nigeria. Data of IITA (2014) reported 8 million tons of maize been produced in Nigeria. Agriculture has always been a means of foreign exchange earnings while the intensive production of crops like maize enhances or improves the economy of the country (Ayeni, 1991). Production of maize in Nigeria has increase the income of small-holder farmers, serving as a local cash crop and intensive production of maize has been viewed as a measure of reducing hunger while combating global food insecurity (Ayeni, 1991).

Importance of maize cannot be over-emphasized in the developing world, including the potential to mitigate the present food insecurity and alleviate poverty (Arong and Njila, 2005). Maize is a preferred staple food for over 900 million poor consumers, 120-140 million poor farm families and about one third of malnourished children (CIMMYT and IITA, 2010). In sub-Saharan Africa, absence or shortage of maize invariably leads to famine and starvation and it is estimated that by 2025, maize would have become the crop with the greatest production in developing countries and the world, and by 2050, the demand for maize in developing countries will double (CIMMYT and IITA, 2010). Due to the fact that maize is highly responsive to production inputs; its food and industrial uses are many, and its production potential can hardly be matched by any of the other major cereals and it's therefore, definitely a solution to hunger, which can salvage the famine population (Arong and Njila, 2005). It is an important staple food for more than 1.2 billion people in Sub-Saharan Africa (SSA) and Latin America and all parts of the crop can be used as food and non-food products and as a versatile crop; maize has been put to a wider range of uses than any other cereal (Olaniyan, 2015). Maize is widely consumed as food in many parts of the world, and it is a staple food in developing countries, particularly in continents of Latin America, Asia and Africa and it's also a basic ingredient for some indigenous drinks and food products while in the developed world, maize is largely used as livestock feed and raw material for industrial products, and in developing countries it is mainly used as food (Olaniyan, 2015).

Maize is a staple food for about 50% of Sub-Sahara African population and an important source of carbohydrate, protein, iron, vitamin B and minerals (Olaniyan, 2015). As food, the whole grain, freshly green or dried, may be used or may be processed traditionally by wet and dry milling methods to give a variety of food products, also preparation and uses of maize alone or in combination with other food material as staple food or snacks in Nigeria include the followings: ogi (in hot and cold forms), tuwo, donkunnu, maasa, couscous, akple, gwate, nakia, egbo, abari, donkwa, ajepasi, aadun, kokoro, elekute etc. (Abdulrahaman and Kolawole, 2006)

Economic importance of rice

Rice (Oryza sativa) is a staple food in many countries of Africa and other parts of the world and the most important staple food for about half of the human race (Imolehin and Wada, 2000). Saka and Lawal (2009) classified rice as the most important food depended upon by over 50 percent of the World population for about 80 percent of their food need. Due to the growing importance of the crop, Food and Agricultural Organization (FAO, 2001) estimated that annual rice production should be increased from 586 million metric tons in 2001 to meet the projected global demand of about 756 million metric tons by 2030.

Research has shown that production and processing technologies have not been able to meet the increasing demand for rice (FAO, 2001). In the West African sub region, Nigeria has experienced a well-established growing demand for rice caused by rising percapita consumption and consequently the insufficient domestic production had to be complemented with enormous import both in quantity and value at various times (Saka and Lawal, 2009).

Rice is Nigeria's most popular food crop which has remained a key component of most households' diet across various parts of the country (National Bureau of Statistics, 2014). This has made the crop a topical issue in political discussions on food security in the country (Erenstein et al., 2003). However, the nation's rice production has fallen short of its demand leading to increased importation of the commodity and has made the country become one of the leading importers of the commodity in the West African sub-region (Kagbu et al., 2016; Iwuchukwu and Udegbunam, 2017).

Grain Storage

Storage is critical to post-harvest management, and almost all harvested grains undergo storage before reaching consumers' tables (Hiruy and Getu, 2018b). The grain industry's primary challenge in developing countries is inadequate storage facilities and adequate knowledge and experience on post-harvest management of grains, also storage management of harvested grains and measures to prevent the insect from thriving in stored grains is of great concern to food processing and storage industries (Paul et al., 2020). Storage structures and facilities extend shelf life and reduce PHLs by protecting grains against environmental factors, rodents' and insects while restriction on the utilization of insecticides during storage makes grains storage more challenging and even under optimum storage conditions, grains can be contaminated by insects (Mapfeka et al., 2019).

An acoustic insect detection method will detect both hidden and open insects in stored grains without opening the storage structure and the technology involved the use of sound software that collected insect noise, screened and amplified them, and classified them based on their amplitude (Banga et al., 2019).

Farmers use different storage systems in different locations of the globe, traditional facilities used include granaries, cribs (Mapfeka et al., 2019), gunny bags and wooden boxes (Manandhar et al., 2018). Traditional storage structures are used mainly by small-holder farmers in developing countries (Tibagonzeka et al., 2018). Traditional storage structures are not very reliable, grain quality can easily be compromised and the structure can dilapidate easily (Mapfeka et al., 2019). Traditional storage and handling facilities are ineffective against mold and insects (Kumar and Kalita, 2017; Sankara et al., 2016) and are influenced by the external environment, grains can also quickly develop mold during the wet seasons, loss their quality and develop safety issues (Garbaba et al., 2018).

Most of the farmers in sub-Saharan Africa chose to store their grains at home after bagging (Hengsdijk and de Boer, 2017). Grains intended for consumption are stored for a longer time (Abdoulaye et al., 2015). The metal silos are quite effective and can adequately maintain grain quality but cannot be afforded by many farmers in developing countries (Manandhar et al., 2018). Modern storage structures are more expensive and only used by wealthy farmers with small family sizes (Ndiritu and Ruhinduka, 2019). Other problems that mitigate the acceptance of modern storage structures are difficulty in transporting them to rural areas, access to spare parts, high maintenance and running cost, limited harvest, and low market value of produce (Tibagonzeka et al., 2018).

POST-HARVEST LOSSES OF GRAINS

Postharvest losses (PHLs) can be quantitative, qualitative or economic, but most research on PHLs concentrate more on quantitative losses, with very few reporting qualitative and economic losses (Kitinoja et al., 2018). About 32 % (1.3 billion tones) of the food produced for human consumption gets lost or wasted every year (Kitinoja et al., 2018; Kumar and Kalita, 2017; Tomlins et al., 2016). Fortunately, cereals and oil seeds have the lowest overall global losses ranging between 9 - 18 % (Janila et al., 2016; Mezgebe et al., 2016; Tomlins et al., 2016). Most of the PHLs occur between harvest and consumption (Bradford et al., 2018).

On-farm PHLs account for about 5 % (Arun and Ghimire, 2019), and storage losses account for 6-10 % (Chegere, 2018; Janila et al., 2016). Storage accounts for the highest PHLs in developing countries (Shisiali, 2018). Chegere (2018) reported 2.9 % lost between harvest and storage of maize in sub-Saharan Africa and 1.1 % lost during marketing. Inefficient handling and storage technology account for the massive grains PHLs in developing countries (Kumar and Kalita, 2017). In some places, storage can account for more than 10 % loss; for instance, in Ethiopia, 31 % loss was reported in maize by Garbaba et al., (2018) during 6 months storage, in Nigeria, 10 to 30 % loss was reported by Danbaba et al., (2019) in the rice supply chain, in Kenya, 17.6 % loss was associated with off-farm storage (Mwangi et al., 2017). Grain PHLs of 30 % were reported by Baoua et al. (2014) in four West African countries, Tibagonzeka et al., (2018) reported 17-41 % in Uganda and Befikadu (2018) reported 50 % in Ethiopia.

Causes of postharvest losses

Deterioration of grains after harvesting is a global issue and it commonly occurs during storage and transportation (García-Mosqueda et al., 2019; Xue et al., 2017). PHLs of grains are caused by pest infestation, microbial and rodents attacks (Mapfeka et al., 2019; Mezgebe et al., 2016; Quellhorst et al., 2020; Schmidt et al., 2018). The fungal attack is the most disastrous, and it causes losses and health threatening problems in improperly dried grains (Garbaba et al., 2018). Attack by fungi and pests depreciate grain qualities during medium and long-term storage (Lorenzo et al., 2020). All post-harvest insects have exceptionally high growth and proliferation rate (Said and Pashte, 2015).

The major factors account for PHLs of grains are infestation by insect–pests, rodents, imprudent store–time, unjustifiable marketing models (Swai et al., 2019), poor storage and transportation facilities (Janila et al., 2016; Swai et al., 2019; Tibagonzeka et al., 2018), spillage due to inadequate handling, and packaging facilities, reused packaging materials (Mwangi et al., 2017), use of uncertified seeds (Njonjo et al., 2019), planting mixed variety of seeds, mixing old and new seeds, harsh weather conditions, farmers disunity, limited access to loans, inadequate on-farm storage facilities (Tibagonzeka et al.,2018), limited output, access to the market (Amentae et al.,2016), bad roads, annual average rainfall (Hengsdijk and de Boer, 2017), limited access to vital farm inputs (Gunasekera et al., 2017), lack of sufficient post-harvest management intervention (Quellhorst et al., 2020; Fabi et al., 2021), lack of improved crop variety and inappropriate storage condition (Kumari et al., 2020).

Insect infestation is among the leading biotic factors that deteriorate grains during storage (Banga et al., 2020; Hiruy and Getu, 2018b). Insects cause both quantitative and qualitative losses during cereals, legumes and oil seeds (Banga et al., 2020). Moreover, post-harvest insect infestation is detrimental to grain processing qualities (Banga et al., 2020) and can develop objectionable flavors and odors (Said and Pashte, 2015). Coleopterous weevils and lepidopterous stalk borers are the most devastating insects in both fields and stores (Hiruy and Getu, 2018b). Many insects are pathogenic; they also transmit diseases and physical destruction (Seetharamu et al., 2020).

The major insects for stored cereals are lesser grain borer (Rhyzopertha dominica), granary weevil (Sitophilus granarius L.), rice weevil (Sitophilus oryzae L.), maize weevil (Sitophilus zeamais Motschulsky), rusty grain beetle (Cryptolestes ferrugineus), flour mill beetle (Cryptolestes turcicus), merchant grain beetle (Oryzaephilus mercator), saw-toothed grain beetle (Oryzaephilus surinamensis L.), long headed flour beetle (Latheticus oryzae), red flour beetle (Tribolium castaneum), confused flour beetle (Tribolium confusum), Large flour beetle (Tribolium destructor Uyttenboogaar), Angoumois grain moth (Sitotroga cerealella), Indian meal moth (Plodia interpunctella), and Yellow mealworm (Tenebrio molitor L), stored legumes are bean weevil (Acanthoscelides obtectus), peaweevil (Bruchus pisorum), and cowpea beetle (Callosobruchus maculatus), pulse beetle (Callosobruchus chinensis L.) and flat grain beetle (Cryptolestes pusillus) and the typical insect pest of oil seeds is the Khapra beetle (Trogoderma granarium) (Banga et al., 2020). The gas composition of the storage atmosphere affects insect activities in general. Insect activities significantly decrease under a CO_2 saturated atmosphere and higher temperature (Carvalho et al., 2019). A modified atmosphere with higher CO_2 and low O_2 concentrations provides a safe condition for grain storage (Dowell and Dowell, 2017). The reproduction potentials of stubborn insects can be blocked by modifying the storage atmosphere and changes observed in the response of stored-product insect under different O2 and CO2 concentrations (Carvalho et al., 2019). The findings of Diarra and Amoah (2019) revealed that hermetic bagging could increase storage temperature to 27 °C and lower O_2, relative humidity and moisture to 6.4 %, <70 % and <14 %, respectively in tropical areas, creating an atmosphere unfavorable to insect activities and mold growth. Improper handling can affect the integrity of grains packaging and affect their permeability. Exposure to extreme environmental conditions degrades packaging materials and facilitates insect and fungal activities (Baoua et al., 2018). Chelladurai et al. (2016) reported that stretching during loading and offloading, exposure to sunlight and prolonged storage can affect the O_2 and CO_2 uptake pattern of silo bags.

The need for reducing postharvest losses

There is an urgent need to curtail PHLs due to accelerated population growth, climate change, and the continuous diminishing of essential natural resources (Arun and Ghimire, 2019; Schmidt et al., 2018). Increasing 2.4 % insignificant crop yield is required to meet the global food demand by 2050 (Nawaz and Chung, 2020). Grain losses due to insect infestation are paramount to the African economy and the world (Adarkwah et al., 2017). Reducing PHLs is essential in improving food security and increasing farm income (Chegere, 2018; Kumar and Kalita, 2017). It is also a synonym for increasing agricultural production (Arun and Ghimire, 2019; Stathers et al., 2020).

PHLs of grains are a significant threat to food security in many developing countries (Hiruy and Getu, 2018b; Manandhar et al., 2018). Food production in most of these countries is below the national demand (Befikadu, 2018) and there are no well-established infrastructures, guidelines, and standards in most developing countries (Neme and Mohammed, 2017). Unlike in developed nations, where PHLs occur during distribution and consumption, PHLs occur during harvest, post-harvest handling and storage (Swai et al., 2019). In developing countries, food wastes and losses are usually discarded, while in countries with emerging and developing economy they are converted to useful substances such as ethanol (Melikoglu and Turkmen, 2019).

CONTROLLING POSTHARVEST LOSSES

Insect infestation can be controlled by proper pre-and post-harvest management using safe and affordable techniques (Hiruy and Getu, 2018). Adequate cleaning and sanitation are important prevention measures and can eliminate pests, dormant eggs and immature organisms (Paul et al., 2020). Infestation techniques must align with regulatory safety measures and market specifications before acceptance (Paul et al., 2020). Disinfection capacity, safety and environmental concern is the significant factors designating the efficiency of insect control (Paul et al., 2020). It is essential to understand insect behavior, growth requirement, and lifecycle in eliminating those (Banga et al., 2020). Insect's dispersal patterns and walking behavior are essential in understanding their distribution and population dynamics (Vélez et al., 2019). In addition, understanding the disinfection principles of control measures is also crucial in avoiding insect resistance to the treatment (Paul et al., 2020). Incessant insecticide resistance demonstrated by storage insects continues to be the major challenge in preventing PHLs (Umina et al., 2019). This necessitates the constant search for alternative pesticides (Vélez et al., 2017).

Different traditional methods were used for pest control in stored grains and most of these traditional methods were improved and co-opted into modern control (Tripathi, 2018). Different plant materials include oils and ashes and synthetic chemicals, are also used to improve the storability of grains (Manandhar et al., 2018). Multi-layer bagging systems and hermetic metallic silos are the recently developed technologies promoted in developing countries (Manandhar et al., 2018).

Creating awareness on the importance of using recommended Post-harvest handling and storage techniques will surely mitigate PHLs (Chegere, 2018). Many farmers are ready to embrace novel techniques when economic benefits are demonstrated and proven beyond reasonable doubt (Egessa et al., 2017). A modified marketing system with stricter quality requirements can improve the post-harvest qualities of grains as proved by Minten et al., (2021). Improved storage facilities with real-time alerts on Right handling and temperature will certainly reduce PHLs (Shisiali, 2018). The quality-quantity spoil of grains produced in developing countries started at the farm; therefore, effective remedies should be initiated at the farm level (Befikadu, 2018). The success of any post-harvest management can be measured by farmers' and agro entrepreneurs' ability to have access to finance (Egessa et al., 2017). These areas of post-harvest are receiving less attention when compared with production and most interventions are directed to production, with little allocated to post-harvest physiology and storage (Hiruy and Getu, 2018). Intervention on PHLs prevention should also target stakeholders other than farmers along the supply chains (Stathers et al., 2020). The approaches used in mitigating PHLs are stated below.

Synthetic chemicals

Grains are mixed with synthetic chemicals to maintain their quality during storage (Manandhar et al., 2018). Chemical pesticides efficiently prevent post-harvest infestation; but their toxicity and persistence are of great concern (Akinneye et al., 2018). The most common fumigants used for insect control in grains during storage are Phosphine, Sulfurylfluoride, Ethyl formate, Methyl bromide and Ozone; also at the same time, organophosphates, organochlorines, carbamates and pyrethroid are the most common synthetic pesticides used (Paul et al., 2020). Spinetoram was effective against Sitophilus oryzae and Rhyzopertha dominica at the application rate of 5 and 0.1 ppm, respectively, mortality of both insects was achieved after 14 days (Vassilakos et al., 2015). The use of nano-engineered alumina insecticide powders was reported by Buteler et al., (2020). The powder is removed at the end of storage using a pneumatic system to avoid safety issues and chiral amides 8i and 8j effectively control Rhyzopertha dominica, a common wheat pest (Aguiar et al., 2019). Synthetic chemical causes many side effects on the environment and humans (Ayalew, 2020). Residual chemicals insecticides in grains were reported to cause health problems (Said and Pashte, 2015). Their indiscriminate use can lead to resistance and revival in insects and leach and contaminate the environment (Seetharamu et al., 2020). Teló et al. (2017) reported the presence of pre-harvest insecticide residues in rice husk.

Residues of thiamethoxam and chlorantraniliprole from field treatment were found in husk, bran and polish rice grains (Teló et al., 2015). Akinneye et al., (2018) reported chlorpyrifos concentration above the maximum residue limit in stored bean samples collected from Akure, Nigeria. Rumbos et al., (2018) reported that capsule suspension of pirimiphos-methyl formulations is highly persistent and cannot vanish after seven months of storage in wheat. Some processing methods were reported to reduce the storage of pesticide residues (Han et al., 2016). Han et al., (2016) showed that soaking, steaming, fermentation and distillation could reduce pesticide residues in grain products. Though a complex and expensive option, the application of ozone is reported to significantly reduce storage pesticide residues in grains (Savi et al., 2015).

Residues of bifenthrin were reduced by 37.5 % in pesticide-treated stored wheat after exposure to ozone at 60µmol/mol for 180 min, while pirimiphos-methyl residues were reduced by 71.1 % after 30 min exposure (Savi et al., 2016).

Ozone treatment effectively reduced pirimiphosmethyl residues by 91 % in maize treated with Actellic 500CE® (de Freitas et al., 2017). Exposing insecticide-treated wheat to ozone at 60µmol/mol for 120 and 180 min reduces deltamethrin residue by 80.6% and 85.7%, respectively (Savi et al., 2015). An ozone application rate of 3 mg L-1andcontinuous flow of 1.0 L min-1for ten h reduces the concentration of bifenthrin by 91.9 % and deltamethrin by92.7 % in pesticides treated rice (de Ávila et al., 2017).

Natural insecticides

Researches on the development of green pesticide from plant and animal extracts and microbes are ongoing (Seetharamu et al., 2020). This class of pesticide is much safer and more biodegradable (Omara et al., 2018). Higher plants such as neem, moringa and various herbs and spices such as garlic, clove, turmeric, etc., possessed antimicrobial and insecticidal properties (Said and Pashte, 2015). Essential oils extracted from Sydney Bluegum (Eucalyptus saligna) leaves show promising results against maize weevil in both contact and fumigation assay (Omara et al., 2018).

Allspice (Pimentadioica) leaf essential oil destroys cowpea beetle 6 and 12hours after exposure in contact and fumigation treatments respectively (Tenne and Karunaratne, 2018). Chenopodium ambrosioides L. and Cupressus sempervirens L. essential oils show insecticidal effects and inhibit fungal sporegermination in maize (Langsi et al., 2018). Carvonechemotype and Monoterpene carvone essential oil showed positive insecticidal effects against Sitophilus zeamais and Tribolium castaneum (Peixoto et al., 2015). Bay leaf essential oil can eliminate storage insect, Tribolium castaneum (Chahal et al., 2016).

Adarkwah et al., (2017) reported that a combination of diatomaceous earth (ProbeA® DE, 89.0 % SiO_2 and 5% silica aerogel) and Eugenia aromatic (fruit and flower bud) and Moringa oleifera (leaves) successfully destroyed adult Sitophilus granarius, Tribolium castaneum and Acanthoscelides obtectus within seven days. Both leaves powder and oil of Lantana Camara were reported to be toxic to an important maize storage insect, Sitophilus zeamais (Ayalew, 2020). Illicium verum and Eugenia caryophyllus essential oils reduce emergence and ovipositor and cause the death of stubborn cowpea weevil Callossobruchus maculatus at the lethal concentrations LC_{50} and LC_{95} of 9.62 and 32.78, 1.27 and11.95 µL/20 g, respectively (Matos et al., 2020). Oil produced from pyrolysis of sunflower seed hulls demonstrate higher insecticidal effects against Sitophilus oryzae and induced nutritional physiology effects that caused anti-feedant activity in Tribolium castaneum (Urrutia et al., 2021).Green insecticides are expected to solve insect resistance and environmental safety (Seetharamu et al., 2020). Further researches are needed for a better understanding of the efficacy and applicability of natural pesticides (Said and Pashte, 2015).

CONTROL OF INSECT

Biological Control

An unexplored area in PHLs prevention is the application of microorganisms and their products; Buchholz et al., (2018) is optimistic that plant microbiota can provide a solution to PHLs. Batta and Kavallieratos (2017) explained the potentials of entomopathogenic fungi in the control of storage insects, the synergistic effect produced by combining the fungi and diatomaceous earth, chemical insecticides and natural products was excellent. Similarly, the combination of Beauveria bassiana (pathogenic insect fungi) and diatomaceous earth successfully suppressed the growth of wheat weevils during long-time storage (Wakil and Schmitt, 2015). Mbata and Warsi (2019) recommended using Habrobracon hebetor and Pteromalus cerealellae in the biological control of insects during grain storage due to their excellent host searching ability and reproductive performance under a wide range of environmental conditions.

Physical methods

This involves hermetic packaging and the use of insect desiccants dust and these methods are far safer and provide products with excellent storage qualities (Kalsa et al., 2019; Schmidt et al., 2018). Insect-desiccant dust is powders added to grains during storage which dehydrate the insect by destroying the waxy outer layer of their exoskeleton (Hiruy and Getu, 2018b). Rock inert dust eradicates maize weevils, (Sitophilus zeamais) 21 days after exposure under laboratory conditions at the application rate of 5 percent and significantly minimizes grain damage and weight loss (Hiruy and Getu, 2018a).

Adopting an air-tight packaging system such as hermetic silos and the use of super grains bags (containing layers of higher density polyethylene) will surely enable farmers to lower PHLs (Groote et al., 2013). Hermetic bags extend the storability of food grains by reducing oxygen content in the bag and increasing carbon dioxide content through respiration of the grain, insects and microbial activities (Vales et al., 2014). They are safe and effective alternative to synthetic pesticides (Abass et al., 2018). Hermetic silos efficiently mitigate insect population and growth, grain damages, dust formation and weight loss during storage (Chigoverah and Mvumi, 2016) and are more effective than hermetic bags (Groote et al., 2013).

A chemical-free, cheap triple hermetic bagging technology known as Purdue Improved Crop Storage (PICS) developed for cowpea storage is now used for other grain ssuch as maize (Baoua et al., 2014). Grains quality and germination capacity were not affected during the storage in the PICS bag and aflatoxins (A.F.s) contamination was found to be less when compared with traditional polypropylene woven bag (Baoua et al., 2014). PICS bags slow down insect growth, moisture absorption and cross infestation. It also protects nutritional qualities and maintains market value (Njoroge et al., 2014).

PICS technology is efficient and can preserve grains for at least three years (Swai et al., 2019), depending on the initial quality of the grains. Cowpea stored in a PICS bag possessed better grain quality, higher market value and better germination rate (Baoua et al., 2013). Pigeon pea seeds possess better eating and germination qualities and low content after eight months of storage in a PICS bag (Vales et al., 2014). Baoua et al. (2014) reported 95 to 100 % mortality of Prostephanus truncates and Sitophilus zeamais in maize stored in PICS bags at different locations of the West African region during 6.5 months of storage. Wheat stored in hermetic bags (PICS and SuperGrainProTM bags) and treated with industrial filter cake dust in polypropylene bags exhibit more than 90 % germination capacity after six weeks of storage (Kalsa et al., 2019).

Likhayo et al., (2018) reported only 1.2 % weight loss in properly dried maize stored in an air tight bag during six months of storage. Super Grain bags TM was found to efficiently destroy many grain harvest insects after four weeks of storage (García-Lara et al., 2013). A modified atmosphere containing pressurized CO_2 at 8bar effectively destroys adult and immature Sitophilus zeamais and Tribolium castaneum in milled rice within five hours exposure (Noomhorm et al., 2013).

CONCLUSION

Control of stored-product insect pests continues to primarily be based on application of synthetic insecticides such as organophosphates, pyrethroids and fumigants because they are effective for the management of insect infestations (Zettler and Arthur, 2000; Upadhyay and Ahmad, 2011). The main method of pest control of stored rice grain has been chemical, using phosphine (Hossain et al., 2014). However, the development of resistance of Sitophilus zeamais and Sitophilus oryzae to these products hinders its control, and alternative measures are necessary for its management (Ribeiro et al., 2013). Integrated Pest Management (IPM) is considered the most sustainable way of controlling stored product pests (Ribeiro et al., 2003). Plant resistance, a component of IPM, reduces the population density of pests below the economic injury level without additional costs to the farmer, and is compatible with other pest control methods (Seifi et al., 2013).

Plants are considered as a rich source of bioactive chemicals and they may be alternative source of insect pest control agents, examples: Azadirachta indica (Neem plant) commonly known as Dongoyaro and Moringa oleifera leaf commonly known as drumstick (Ojiako et al., 2013). Plant extracts are more effective in the way as they do not cause pollution; produce less toxicity and are bio-degradable and some plants naturally have the repellent effect against many stored grain pests (Tanzir, 2013). Repellent, means having the ability to repel insects to enter or move across a surface which is treated with these repellents (Ishfaq et al., 2019). The use of coating of repellent on packaging is helpful in order to prevent insect infestation at that portion where further research is to be conducted (Mullen et al., 2012). Different repellent formulations have been tested through the years though natural and synthetic combinations were used in the studies of senior authors which included insect growth regulators neem oil, moringa oil, methyl salicylate and DEET derivatives (Mullen et al., 2012).

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