International Journal of Academic Research and Development
ISSN: 2455-4197
Impact Factor: RJIF 5.22
www.academicsjournal.com
Volume 3; Issue 1; January 2018; Page No. 741-748

Insect pests associated to stored maize and their bio rational management options in sub-Sahara Africa

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Abstract
Maize (Zea mays L.) is one of the most important cereals crop in the world both as food for man and feed for animals. However, its productions and yields in Ethiopia in particular, and Africa in general have been highly affected by an array of biotic and abiotic stresses. Among biotic constraints, insect pests are most often considered. The most important of these pests in the field and storage are Lepidopterous stalk borers and Coleopterous weevils. In Ethiopia among other things, food security has been greatly threatened by excessive post-harvest losses grains like maize by insect pests. However, less attention has been given to this crucial area (post-harvest area) over the past years compared with increment in production. The objective of this seminar review, thus is to trigger and remind researchers, policy makers and other concerned bodies towards addressing post-harvest loss reduction especially due to storage insect pests.

Keywords: maize, storage conditions, insect pests, economic importance, management options

Introduction

Maize (*Zea mays* L.) is one of the most important cereals crop in the world both as food for man and feed for animals. It is also known as queen of cereals because of very high yield potential [1]. Besides, it is the third after wheat and rice in area coverage and total production in the world [2, 3]. It is also the major staple food in Africa contributing significantly to the agricultural sector [4] and it is the staple crop, accounting for an average of 32% of consumed calories in Eastern and Southern Africa, and rising to 51% in some countries [5].

In sub-Saharan Africa too, maize is one of the most important grain staples for agricultural income and caloric intake accounting for nearly 20% of the plant-based food supply [6]. In Ethiopia also, it is one of the major cereal crops grown for its food, feed, firewood and construction values [7]. However, its productions and yields in Ethiopia in particular, and Africa in general have been highly affected by an array of biotic and abiotic stresses [4, 8]. Among biotic constraints, insect pests are most often considered [9, 10, 11]. The most important of these insect pests in the field and storage are Lepidopterous stem borers and Coleopterous weevils, respectively [12]. Accordingly, in Ethiopia among other things, food security has been greatly threatened by excessive post-harvest losses grains like maize caused by stored product insect pests, under small holder on farm situations and at a nation level, primarily caused by the maize weevil and Angoumois grain moth [13]. This is because of lack of suitable grain storage structures and absence of storage management technologies that force growers to sell their produce immediately after harvest. Consequently, farmers receive low market prices for any surplus grain they may produce [4].

Hence, farmers have not been as such the beneficiaries of this increased production and productivity potential of new varieties of grains [12]. As a result, there is an urgent need to maintain quality of stored grains and their proper management [14]. As a result, the objective of this review is to trigger and remind researchers, policy makers and other concerned bodies towards addressing post-harvest loss reduction of maize and other grains due to insect pests. This paper therefore, reviews the origin and importance of maize grain**,** maize storage conditions, the associated insect pests and their economic importance, as well as their management options

The Origin and Importance of Maize

700 years ago, maize (*Zea mays* L.), is believed to be originated in central Mexico from a wild grass and was transformed into a better source of food by Native Americans. Nutritionally, it contains approximately 72% starch, 10% protein and 4% fat, supplying an energy density of 365 Kcal/100 g [15]. In addition, it has higher content of protein and fat as compared to other cereals. It also contain vitamin B-complex such as B1 (thiamine), B2 (niacin), B3 (riboflavin), B5 (pantothenic acid) and B6 that makes it commendable for hair, digestion, skin, heart and brain. Furthermore, it contains vitamin A, C and K together with large amount of beta carotene and fair amount of selenium that helps to improve thyroid gland and play important role in proper functioning of immune system [16]. Accordingly, maize (*Zea mays* L.) is one of the most important cereals crop in the world both as food for man and feed for animals. It is also known as queen of cereals because of very high yield potential (Nand, 2015). Besides, it is the third after wheat and rice in area coverage and total production in the world [2, 3].

Along with the aforementioned importance, the current inevitable world population growth and seriousness of food insecurity issue in Africa [17], will place increasing demands on the production and productivity of cereals like maize [18]. As a result, increasing and improving maize production and utilization have been suggested as one major strategy for alleviating the danger of hunger and malnutrition. Thus, maize has been spread out quickly and changed production systems in Africa as a popular and widely cultivated food crop. Now a days, it is a major staple food crop grown in diverse agro-ecological zones and farming systems, and consumed by people with varying food preferences and socio-economic backgrounds in SSA [19].

Maize Storage Conditions

Storage is one part of the post-harvest system through which food grains like maize passes on its way from the field to the consumer. It is particularly important in agriculture, because agricultural production is seasonal while the demands for agricultural commodities are more evenly spread throughout the year. Thus, there is a need to meet average demand by storing excess supply during the harvesting season for gradual release to market during off season periods [20]. As a result, storage helps to smooth out variations in market supply both from one year to the next and from one season to the next by taking produce off the market in surplus seasons and releasing it back onto the market in lean seasons [21, 22, 23]. Accordingly, grains are stored by farmers for their consumption and/or for seed purposes, and by traders as well as marketing agencies for financial gain in general [24].

Grain storage periods across Africa, generally range between 3 and 12 months and their length depends on the agro-ecological zone, ethnic group, the quantity of commodity stored, the storage condition, the crop variety stored, etc.[17]. A variety methods, practices and facilities were used traditionally by farmers in order to store their grains. For instance, maize could be stored either shelled or unshelled and in the latter case, maize is shelled manually in a staggered manner when required for consumption (sale). Shelling of maize is also done by using hired machines especially when production is large [25]. In addition, the structures used for grain storage depends on the level of storage such as on-farm, village and city (central storages). On farm storage involves individuals, while village storage may implicate individuals (family granary) or a group of individuals (community stores). The city and central storage facilities include large warehouses and are usually own by government agencies or non-governmental organizations (national or international) and they are usually built with expertise from the developed world [17].

Generally, grains are stored in distinct entities such as silos, warehouses, bags, containers and even in piles on the ground [26]. But, the use of traditional storage structures, as well as storage of cereals like maize in the houses by small scale and subsistence farmers in Africa leads to considerable losses. On the contrary, air-tight storage technologies like the metal silos which are said to have zero storage loss are expensive for the individual farmer to afford. There are, therefore costs and benefits to storage regardless of the storage structure used [27].

Accordingly, proper storage of grains continues to be a challenge for subsistence farmers in SSA including Ethiopia [28]. In other way saying, the lack of suitable storage structures for storing grains and absence of storage management technologies often forces the smallholders to sell their produce immediately after harvest. Consequently, farmers receive low market prices for any surplus grain they may produce [4, 29]. Besides, tropical climatic conditions and poor sanitation of grain storage such as maize (that are highly favorable for insect growth and development) in SSA also encourage insect pest attack and have been compounding the problem. As a result, farmers are not as such the beneficiaries of this increased production and productivity potential of new varieties of maize [30]. Hence, safe storage of grains like maize is very crucial, as it has directly impacts on poverty alleviation, food and income security, as well as prosperity for the smallholder farmers [31].

Insect Pests Associated To Stored Maize

Insect pests that affect stored grains like maize are referred to as postharvest insect pests or storage insect pests. They are generally members of two major groups or orders insects such as Coleopteran (beetles) and Lepidoptera (moths) [32]. Of these two groups of insect pests, beetles in which both the larva and adults are responsible for damage (loss), are more diversified and highly destructive in comparison to moths in which only the caterpillars are harmful life stage that causes the damage [14]. The species from both orders can complete their life cycles in less than 30 to 35 days and lay many eggs which results in rapid build-up of populations that consume and contaminate various stored products, and they undergo complete metamorphosis [33].

Storage insect pests can be broadly grouped in two groups such as internal feeders (primary pests) and external feeders (secondary pests or bran bugs). That means insects that attack sound grains such as maize and cause damage to them are called primary pests. In the contrary, those that attack already damaged grains and cause further damage are called secondary pests [34]. However, it must be noticed (emphasized) that primary pests does not necessarily refers to more importance the pests, but simply implies to the dynamic processes involved whereby secondary pests can cohabitate (follow) primary pests and inflict serious and economic losses, especially under long-term storage [35]. Examples of primary pests include the maize weevil, rice weevil, lesser grain borer and larvae of the Angoumois grain moth. Examples of secondary pests include Indian meal moth, saw toothed grain beetle, red and confused flour beetles and flat grain beetle [36].

Besides, there is also a third group of insects that infest stored grains that are known as mold feeders. This group does not directly damage the grain through feeding; instead, they contaminate the grain mass through their presence and their metabolic activity. Mold feeders feed on molds (fungi) growing on grain stored at excessive moisture levels. The presence of mold feeders in grain mass usually indicate that grain is going out of condition and that some mold growth has occurred. According to him examples of mold feeders include foreign grain beetle, rusty grain beetle, hairy fungus beetle and psocids [36].

Generally, a myriad of insect pests attack stored grains such as maize in Africa in general and in SSA including Ethiopia in particular [37]. Of these insect pests species, Angoumois grain moth (*sitotroga cerealella*), lesser grain borer (*Rhyzopertha dominica*), larger grain borer (*Prostephanus truncates*), rice weevil (*Sitophilus oryzae*) and maize weevil (*Sitophilus zeamais*) have been recognized as an increasingly important problem to maize production in Africa [38].

Economic Importance of Insect Pests Associated To Stored Maize

Post-harvest insect pests associated to grains such as maize are the first from the invasive forces to begin the interaction with the grain. Consequently, they are one of the major threats to the grains quality maintenance during storage [24]. Besides, they are the most damaging of all other pests and the most difficult to control due to their small size, feeding behavior and ability to attack grain before harvest [39]. Majority of these insect pests are cosmopolitan and polyphagus in their feeding behaviors [40]. They cause their damage (loss) on stored grains mainly by direct feeding both in field and storage. In addition to direct consumption, they also contaminate their feeding media through excretion, molting, their own existence, leaving their dead bodies, body fragments, webbing and an unwanted odor or flavor [41]. In most cases, they (insect pests) also pre-dispose the stored grains like maize to secondary attack by disease causing pathogens such as fungi [10]. Besides, a major concern with the presence of insects in storages is potential to vector disease organisms [36]. This is because many of them possess hairs and indentations on their exoskeletons that can serve for mechanical vectoring of pathogens. For instance, maize weevils have been reported to carry or vector several fungi species, including *Aspergillus niger*, *A. glaucus*, *A. candidus*, *Penicillium islandicum*, *P. citrinum*, *Fusarium semitectum* and yeasts [42].

Hence, in terms of economic importance in general, storage insect pests mainly and fungi to a lesser degree reduce the quality, as well as value of grain in storage. But, losses due to rodents and birds are typically quite infrequent and minor [43]. Consequently, infestation by the insect pests in grain storage such as maize, and damage and loss that result from them poses a major threat in food security not only to farmers in SSA including Ethiopia, but also globally, especially in resource poor nations [44].

Management Options of Stored Maize Insect Pests

Chemical Control

Two major chemical methods used for managing insect pests of stored grains such as maize recently are fumigation and grain protection by contact insecticides [45].

Fumigation

Fumigants are chemicals available as gases, liquids and in solid formulations, but act on the insect pests of stored grains such as maize in gaseous state [24]. Fumigation is one of the most effective management method in which insect pests are exposed to a poisonous gaseous environment, by applying a grain fumigant. It is applied in buildings, ware houses; small bags, soil, seed and stored products, and fumes generated by fumigants enter the body of insect through the spiracles and spread to trachea and tracheoles and bind to the hemolymph components [14]. Accordingly, fumigation plays a key role in grain preservation as it controls insects developing inside and outside the grain, and crawling and hidden pests [24].

Currently, phosphine and methyl bromide are the two common fumigants used for stored-product protection over the world [46]. Among these fumigants, the usage of methyl bromide was phased out in developed countries due to its ozone depletion effects and instead, phosphine is widely used now a day [47]. Thus, phosphine is the most widely used fumigant not only in Africa, but also in the world due to its low cost and ease of application. It is also the preferred chemical for routine grain disinfestations in the developing countries like SSA including Ethiopia where other alternative techniques such as controlled atmosphere storages, are expensive or cannot be readily adopted [24].

Use of Contact Insecticides

Contact insecticides are solid or liquid formulations of man-made insecticides which are toxic to insects and exert their effect when insect pests of stored grain such as maize come into direct contact with them. Most of these available for post-harvest use were originally developed to protect field crops and then found to be useful for stored products [48]. They play a significant role in grains preservation along with other control measures, regular hygiene and sanitation measures. Insecticides kill insects previously exist, as well as hinder cross-infestation and re-infestation of non-infested grains [24].

Synthetic organic chemicals that are currently approved for use in stored gain insect pest’s management fall into one of three groups: organophosphates, carbamates and synthetic pyrethroids [48]. These insecticides have been used in management of stored grains as grain admixture treatments, residual surface and space treatments [21]. But, use of contact insecticides as protectants by direct admixture with grain has been decreasing in recent years and instead use of them as with residual sprays, fogging and aerosol applications is likely to continue in grain storage [24]. Perhaps, synthetic pesticides have been used by the majority of smallholder farmers in many parts of Africa for protection grains such as maize against storage insect pests [49].

However, over the years, negative attributes have been associated with synthetic pesticide use. These includes the presence of toxic residue in food products, toxicity against non-target species, development of resistance by targeted species [50], high persistence and its associated environmental pollution, direct toxicity to users and increased risk to workers safety [51]. Their indiscriminate use also leads to give raise of secondary insect species due to the destruction of their natural enemies in storage ecosystem [52]. These problematic situations of insecticides, along with possibility of misuses of pesticides have been making them less attractive and demand a vigorous search for alternative insect pest control practices [53]. These situations hence, inspired the search for safe, effective, pest specific and economical alternative methods including inert dusts, botanicals, varietal resistance, biological control and others [54].

Accordingly, in recent years, the aforementioned bio-rational options have been suggested as alternative to chemical pesticides for protection of grains against insect pests [45]. In addition to aforementioned problematic situation, none of the existing products will entirely fulfill all of the criteria for use in storage ecosystems [37]. Hence, these chemicals do not have very promising future for food grains such as maize and they may be used with hazard restrictions [55].

Management by Natural Plant Products or Botanicals

Botanicals refer to the chemicals that are produced by plants, and repel approaching of insects, deter feeding and oviposition on the plant or disrupt the behavior and physiology of insects in various ways [56]. These include spices, medicinal and other plants [57]. These pesticidal plants are utilized in two main ways in post-harvest protection; first which suitable for farmers in developing countries and for organic farming is that plant tissue or crude plants products such as aqueous or organic solvent extracts are used directly. The second approach is that the active compounds are isolated, identified and chemically synthesized. If feasible, these compounds or their active analogues are synthesized and marketed by the chemical industry [58]. The later sophisticated methods are inappropriate for small-scale subsistence farmers, but they may eventually have commercial applications for large-scale storage [48].

The use of such locally available plant materials for stored-product protection is a common practice, and has been believed to have more potential in subsistence and traditional farm storage conditions in developing countries [59] like Ethiopia. It has been also well argued that they (botanicals) are an appropriate technology for resource-poor smallholder farmers [60], especially in SSA for their several advantages over synthetic pesticides. These include they are one of the most important locally available and biodegradable methods [61]. Besides, they are easily produced by farmers, small-scale industries and are potentially less expensive [62]. Furthermore, unlike synthetic pesticides, they often have several modes of action, and their toxicity against insect pests of may be expressed by: (1) directly killing particular life stages of the insect, (2) interfering with mating or suppressing reproduction, (3) acting as a repellent or affecting host finding and selection in a way that prevents infestation or (4) reducing or preventing feeding. Having more than one mode of action by many botanicals contribute to the efficacy of them in reducing insect pests damage of food grains. Another merit could be that the potential for insects to develop resistance to a botanical with many modes of action is reduced [48]. Environmental or vertebrate toxicity may also be lower when botanicals rely more upon anti-feedancy and repellency than say direct insect toxicity [63]. They are also nontoxic to non-target organisms [64]. Consequently, they maintain biological diversity of natural enemies which make their use a sustainable pest management alternative in agriculture [65].

Accordingly, use of green pesticides particularly for stored grains such as maize insect pests is being recommended globally [63]. However, only few botanicals are used on a commercial scale [66], that means only few plants have led to major commercial pesticidal products similar to those produced by the synthetic pesticides industry. Neem products from *Azadirachta indica,* Pyrethrum from *Tanacetum cinerariifolium* and rotenone from *Derris* and *Lonchocarpus* sp. are commercial examples of botanical pesticides that have been developed and are being traded globally [65]. But, subsistence farmers throughout SSA often lack the financial resources to buy good quality commercial insecticides to protect their stored grain and their inappropriate use of conventional pesticides can result in the risks to human and environment. As a result, traditional storage methods using indigenous plant materials with insecticidal properties could, if improved, offer a low-cost, safer and more dependable method of storage protection, while reducing the increasing reliance upon conventional pesticides. Thus, botanicals could offer a solution for the problems of availability, health risks, costs and resistance in the case of synthetic pesticides, and for the lack of equipment for hermetic storage, gamma irradiation and controlled atmospheres [57].

However, problems with botanical insecticides are lack of consistency (maintaining a particular standard), safety concerns and sometimes odor [66]. Traditional methods of their preparation are often variable and lead to inconsistent efficacy. This problem is compounded by inherent differences in plant chemistries that may be genotypic or spatio-temporal variations caused by abiotic factors such as altitude, rainfall and soil type or different chemistries expressed in different plant parts [67]. This inconsistency in efficacy remains one of the major difficulties that stand in the way of exploitation of pesticidal plants [65]. Besides, other obstacles of them include doubts to their efficacy due to their slow action and lack of rapid knock-down effect; instability of the active ingredients when exposed to direct sunlight and high cost of commercially formulated botanical pesticides [59]. Thus, the promotion of these botanicals particularly with optimized applications, based on knowledge of the active plant chemicals would greatly benefit resource poor farmers in SSA [68].

Management by Resistance Variety of Grains

Resistance of plant or plant materials (Host plant resistance (HPR)) to insects are defined as the relative amount of heritable qualities possessed by a plant or its materials (like for instance, its seeds) which influence the ultimate degree of damage done by the insects. But, in the case of stored grains such as maize, resistance refers to the ability of a certain crop variety to produce grains that maintain better quality than commonly cultivated varieties following long storage under similar insect populations [69]. Three mechanisms of resistance have been studied and they are antibiosis, non-preference and tolerance. Antibiosis refers to condition where the biology of the pest is adversely affected after feeding on the plant (the seed). Antixenosis (non-preference) represents a condition where the plant and the seed are not desirable as a host and post-harvest pests seek alternative hosts, while tolerance refers to a situation where the plant (the grain) is able to withstand or recover from insect pest damage [4].

The types of resistance factors have been reported as they include both morphological and biochemical traits, and work individually or collectively [70]. Nevertheless, resistance is rarely totally dependent on a single mechanism; there are often overlaps between the morphological and biochemical bases of resistance [71]. For instance, kernel resistance is due to physical barrier through mechanical fortification of the pericarp cell wall and antibiosis through the toxic effects of phenolic acid amides and peroxidase activity localized in the aleurone layer [72]. In addition, synergistic act the aforementioned both factors have been reported in several wheat, rice and maize varieties to protect them against *Tribolium castaneum*, *Rhizopertha dominica*, *Trogoderma granarium*, *Sitophilus* spp., *Plodia interpunctella* and *Sitotroga cerealella* [73].

But, breeding for the resistance to stored grain insect pests was ignored initially (in the past), probably due to the long duration from crop establishment to postharvest screening for resistance and the high cost involved [74]. However, as a result of the widespread use of insecticides and its associated risks, it has been recommended recently as alternative methods of control. This is because it is selective [75], the cheapest, effective and ecologically safe method of protecting grains such as maize against insect pests in Africa [4]. It also helps to avoid health risks and requires little or no scientific knowledge by the farmers [76]. Moreover, it is also maintain high levels of resistance for a long time despite upsurge of biotypes [77]. It is therefore, evident that breeding for resistance to post-harvest insect pests is important for small and large-scale farmers alike [76].

Inert Dusts

Inert dusts are dusts that are chemically unreactive and thus, used for managing insects of stored grains such as maize by physical rather than chemical means [78]. They act as a desiccant, absorbing water from the insect body and may also have an abrasive action. Water is lost because the dusts remove the waxy layer of the cuticle of the exoskeleton by adsorption. Accordingly, insects pests coated with inert dusts show massive dehydration and die very soon [14]. The use of chemically inert materials such as sand, wood ashes or minerals in large amounts fill up the interstitial space in grain bulks and offer an obstacle to insect movement [79].

There are five types of inert dusts: (a) non silica dusts (e.g., limestone, lime, katelsons); (b) ash, clays, sand; (c) diatomaceous earths, which are the fossilized diatoms of marine or freshwater origin and are composed mainly of amorphous hydrated silica; (d) synthetic silicates and precipitated silicas; and (e) silica aerogels obtained by drying aqueous solutions of sodium silicate [80]. Because the effect of inert dusts is through desiccation, their effectiveness decreases as relative humidity increases [78]. They also act slowly and take 20 or more days to cause insect mortality. Besides, they affect grain bulk density, flow ability and grain-handling properties, and the dusts containing crystalline silica may cause silicosis and other respiratory diseases [24]. However, the main advantage of using them is that they are non-toxic to humans and animals. For instance, diatomaceous earths are registered as a food additive in the USA [78].

There has been a considerable amount of historical data concerning desiccant dusts and their insecticidal effects on stored-product insects [81]. Most of the early formulations, however, were not widely accepted by the grain industries in developed countries for a variety of reasons including the high rates required for mortality, variation in toxicity among target species, damage to grain handling equipment and health problems with worker exposure to dusts. But, with the current concerns of protectant resistance and the desire of consumers for residue-free grain, these dusts have been receiving increased attention [82]. Thus, detecting and isolating valuable locally existing inert materials against post-harvest pests of maize could provide significant input in management of storage pests in Ethiopia in particular and Africa in general.

Integrated Pest Management (IPM)

Integrated pest management (IPM) has been defined as a pest management system which takes in to account the environment, the population dynamics of the pest and uses all suitable techniques and methods in the most compatible manner as possible to maintain the pest population below levels that would cause economic injury [48, 83]. IPM gives priority to non-chemical control measures and only defaults to the use of chemical controls when other options are unlikely to affords sufficient protection of stored grains like maize from insect pests (in IPM strategies, chemical control is used as a last resort). Thus, judicious use of chemical insecticides following knowledge based decision-making is strongly advocated in IPM [66]. As a result, IPM leads to a reduction in insecticide usage and consequently, limits the opportunity for the development of resistance by insect pests and the dangers that acquired to consumers, pest control staff and the environment [48].

Accordingly, in tropical agricultural systems including Ethiopia, where pesticides are increasingly expensive and pose risks to farmers, consumers and their environment, reduction of pesticide use through IPM has many economic, social and environmental advantages. Besides, it has been reported as the best option for the future, as it guarantees yields, reduces costs, is environmentally friendly and contributes to the sustainability of agriculture [71].

However, IPM has been much less well developed for the protection of stored grain, though it has been well-developed approach for the protection of crops before harvest [4]. Thus, the development and implementation of IPM strategies for insect pests of maize in traditional small-farmers storage in Africa including Ethiopia will undoubtedly require a major research and extension effort by national and international agencies as well as researchers [84].

Conclusion

In conclusion, in order to reduce losses by insect pests, proper storage of grains like maize and management of their insect pests using safe, cheap and ecological sound management options under farmer’s storage conditions are urgently required, and should be designed and implemented by any concerned bodies in SSA.

Acknowledgement

We sincerely like to thanks Addis Ababa University, zoological science department and Arba Minch University for providing us financial support to conduct this review.

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