DIVERSITY OF STORAGE INSECT PESTS IN MAIZE AND SUSCEPTIBILITY OF MAIZE VARIETIES TO MAIZE WEEVIL (*Sitophilus zeamais*)

Florence Kalunde Tom

(B.Sc. Agriculture, UON)

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Florence Kalunde Tom

Signature.................................... Date......19/08/2011...............

This thesis has been submitted for examination with our approval as university supervisors.

Prof. Florence M. Olubayo
Department of Plant Science and Crop Protection
University of Nairobi

Signature.................................... Date......19/8/2011...............

Dr. James W. Muthomi
Department of Plant Science and Crop Protection
University of Nairobi

Signature.................................... Date......22/8/2011...............

Dr. George N. Chemining'wa
Department of Plant Science and Crop Protection
University of Nairobi

Signature.................................... Date......19/8/2011...............

DEDICATION

I wish to dedicate this piece of work to my entire family.

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I would like to thank the Almighty God for the gift of life, good health and enabling me go through the programme.

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ABSTRACT

Maize is the major source of food in Kenya grown both as a subsistence and commercial crop. Storage insect pests attacking maize continue to pose a major problem to small scale farmers in Africa where subsistence grain production supports the livelihood of majority of the population threatening the family food security. The damage affects the quality and quantity of the stored produce. The objective of this study was to determine the occurrence and the diversity of post harvest insect pests and susceptibility of maize varieties to maize weevils.

A survey was conducted between November 2008- May 2009 in different agro-ecological zones of Eastern and North Rift regions of Kenya. Whole and semi processed maize grain samples were randomly collected from farmers, traders and the National Cereals and Produce Board. Sub samples of each grain sample were incubated for 42 days and the emerging storage pests were identified to species level. Susceptibility of sixteen maize varieties to the maize weevil for laboratory and field infestation was determined. Field trials were conducted in Mwea and Waruhiu and after harvest grain samples were incubated and the insects that emerged were counted and identified to species level. Insect free grain samples of the sixteen maize varieties were inoculated with unsexed maize weevils and incubated for three months to determine percentage grain damage, seed weight loss and F1 progeny.

The main insect pests infesting maize grain samples from farmers and traders were larger grain borer (*Prostephanus truncates* Horn), maize weevil (*Sitophilus zeamais* Motsch), angoumois grain moth (*Sitotroga cerealella* Olivier) and red flour beetle (*Tribolium spp)*. Maize weevil had the highest prevalence of up to 100% in all the agro-ecological zones. Whole grain maize samples from traders had high infestation of the maize weevils of 19 insects per 100 grams compared to those from the farmers. Maize grain samples from farmers stores had high infestation of larger grain borer of three insects per 100 grams than those from traders. Samples from Ishiara National Cereals and Produce Board store had the highest infestation of 46 and seven storage insect pests per 100 grams of maize weevil and larger grain borer respectively. High levels of infestation with storage pests were recorded in Eastern province for all the major storage pests compared to the North rift region. Varieties Panner 67 and DK 8031 had the highest maize weevil infestation while varieties H614D and KCB had the highest levels of the Angoumois grain moth. Maize weevil and angoumois grain moth infestation in Mwea was high compared to Waruhiu. Inbred line CKPH080020 had the lowest index of susceptibility of 2.3 and therefore it was considered to be a resistant variety. Variety DK 8031 had the shortest median development time of 17.5 days and also had a high number of F1 progeny of 126 insects' counts after three months and the highest index of susceptibility of 8.5 thus was considered to be the most susceptible variety. Resistant varieties showed low numbers of F1 progeny, had a high median developmental time and a low percentage of seed damage and seed weight loss.

The study showed that the grain from the Eastern region had higher levels of storage insect pest infestation which can be attributed to the favourable temperatures. The maize varieties differed in the level of susceptibility to storage insect pests with inbred line CKPH080020 showing high level of resistance. Farmers should be encouraged to grow less susceptible varieties as this will reduce post harvest loss and also reduce the possibility of grains being infested with the mycotoxin producing fungi. More studies could be conducted to incorporate the resistance from CKPH080020 into other local popular susceptible maize varieties.

CHAPTER ONE

INTRODUCTION

1.1. Background information.

Maize is a stable food for the majority of households in Eastern and Central African regions and dominate the diets of the rural and urban poor (Johansson and Ives, 2001; Bonhof, 2000). Its provides 50% of calories in the diets of people in Southern Africa, 30% in Eastern Africa and 15% in Western and Central Africa (Pswarayi and Vivek, 2004). Maize has the highest grain yield per unit area, highest direct human consumption and contributes to huge financial value in global trade (Ferra, 1995). It is well adapted to different climatic conditions and can therefore be grown in different environments (James, 2003). The crop is mainly grown under rainfed conditions (Pingali and Pandey, 2001). It is classified by colour as yellow, white and mixed. White maize is preferred for human food while yellow maize is preferred for feeding farm animals because it contains large amounts of beta-carotene that converts to vitamin A which is essential for animal growth (MOA, 2007).

In Kenya maize is the most important food crop and it is grown both as a subsistence and commercial crop (De Groote *et al.*, 2004) and its per capita consumption is approximately 125 kg/year (Pingali and Pandey, 2001). Consumption of maize in Kenya is high, supplying 36% of the total daily calories and accounting for 34% of the total daily protein supply for human individuals (FAOSTAT, 2003). The crop is planted on 1.5 million hectares which is more than 30% of the arable land and is widely distributed throughout the six major agro-ecological zones (FAO, 2003). Despite the great efforts made to increase maize production the demand has occasionally outstripped the supply thus requiring importation of large quantities of maize grain.

The total maize production and its yield per unit area is affected by many different factors which include biotic, abiotic and socioeconomic factors (Simmons, 2003). There is a limited scope for expanding cultivated land under maize production since unused land is diminishing or is of marginal quality or just unsuitable for maize production (Muchena *et al.,* 1988). Producing higher maize yields on the existing cultivated land and prevention of losses due to storage pest of the produce is therefore the surest way of generating the extra maize grain required to feed the nation.

Small scale farmers contribute about 75% of the overall maize production. The six major maize growing agro-ecological zones in Kenya are defined by elevation, total rainfall and length of the growing season and maturity period of the adapted maize cultivars (FAO, 2000; Hassan *et al.,* 1998a). These agro-ecological zones are the humid coastal lowland tropics (HCLT) at the coast, the dry mid altitude (DMA) and the dry transitional (DT) zones which are found between the mid altitude and highland Tropic HT zones. These zones are characterized by low grain yields of less than 1.5 tonnes/ha and although they cover 29% of the maize growing area in Kenya, they produce only 11% of the total annual maize production. In central and western Kenya are the highland tropics (HT), mid altitude moist (MAM) and the mid altitude transitional (MAT) zones. Theses zones cover about 30% of the maize producing area, and have average grain yields of more than 2.5 t/ha and produce about 80% of the maize annually (De Groote *et al.* 2003).

Maize is mostly used for food, feed and for industrial purposes. As food it is consumed green, either boiled or roasted or milled when dry and processed to other food and products which include flour, processed meals and/or oils (De Vries and Toenniessen, 2001). Maize is used to make silage for livestock and processed to other feed for farm animals including poultry, pigs and horses. Maize is an intermediate product in the dairy industry as a constituent of animal feed formulation (MOA, 2007). Industrial uses include dry milling, wet milling and distillation. The products of dry milling industry are maize meal, maize flour and grits. Grits consist of coarsely ground endosperm of the kernel from which most of the bran and germ have been separated. Wet milling involves the separation of maize into constituent chemical components. Starch constitutes about 70% of the total grain mass making it the major single product of wet milling. Starch and its products are used majorly in food and paper industry where dextrins are used as adhesives. However, 85% of the maize starch is converted to refined products like high-fructose syrups, glucose syrups, dextrose, corn syrups and malto-dextrins. Through distillation and fermentation processes maize is used to produce ethyl, butyl and propyls alcohols. The nutritive value of maize has: 77% starch, 2% sugar, 9% protein, 5% pentosan and 2% ash but the protein and fat contents vary depending on the variety (Berger, 1962).

1.2. Problem statement and justification

Post harvest losses of food grain due to insect pests are a significant nutritional and economic burden to subsistence farmers in developing countries (Firdisa and Abraham 1998). Farmers in sub-Saharan Africa have repeatedly priotised the need for improved methods of storage pest control. Reduction of storage losses will help to reduce the vulnerability of small scale producers by improving household food security and improving income generating opportunities and livelihood outcomes. In the absence of an effective control measure, pest attack on cereal grain can be so severe as to reduce the commodity to empty husks and dust.

Insect damage affects the nutritional quality, taste, smell and quantity of food available until the next harvest. The average maize losses range from 9.6% to 20.2% mainly caused by storage insect and rodents in third world countries (Anon, 1978). Farm losses due to storage insect and rodent pests average about 4.5% and 1.5%, respectively (De Lima, 1979b). Population numbers of insects can be high enough to make the commodity completely unpalatable and unacceptable in the market. Lack of suitable storage structures for grain storage and absence of storage management technologies force maize growers to sell their produce immediately after harvest to minimize losses due to insect pests (Abraham, 2003). Consequently, farmers receive low prices for any surplus grain which they may produce thus compromising food security at the household level (Beyene *et al.,* 1996). Environmentally compatible stored-product control methods are urgently needed to replace synthetic pesticides that are either not available for economic or regulatory reason or are ineffective due to the increasing difficult of managing pesticide resistance (Duke *et al.,* 2003)

Synthetic chemical insecticides have been widely used for the control of pests of stored grain particularly maize weevil (*Sitophilus zeamais).* The wide spread use of insecticides for the control of stored product insect pests is of global concern with respect to environmental hazards, insecticide resistance development, chemical residues in food, side effects on non-target organisms and the associated high costs (Tembo and Murfitt, 1995). This has led to search for alternative control strategies such as resistant maize varieties against the maize weevil (*Sitophilus zeamais).*

Therefore this study was carried out with the overall objective of determining the occurrence and the diversity of post harvest insect pests and susceptibility of maize varieties to maize weevil in some maize growing regions in Kenya.

The specific objectives were:-

i) To determine the occurrence and diversity of stored product insect pests in maize from Eastern and North Rift regions of Kenya.

ii) To determine the susceptibility of maize varieties to maize weevil.

CHAPTER TWO

LITERATURE REVIEW

2.1. Maize production and associated constraints

Maize (*Zea mays* L) is the most important staple crop in Kenya for over 90% of the population with the small holder farming systems accounting for about 75-80% of the total production (Muui *et al.,* 2007). It is grown in a wide range of climatic conditions ranging from semi-arid to the humid zones and it's wholly dependent on rainfall. About 17% of the country is suitable for the rain fed crop production (Odhiambo, 1988). Farmers choose the variety to plant based on factors such as suitability for agro-ecological zone, disease and pest resistance, yield potential, kernel size and maturity period. Hybrids have been bred to suit different ecological zones in the country.

The per capita consumption of maize in Kenya is approximately 125 kg per year (Pingali and Pandey, 2001). Its key importance in food security is evident in the total area under maize crop where nearly every farmer in the country grows maize even in the harshest environments. The main food crop consumption levels in the year 2008 were estimated to be maize 36 million 90 kg bags, wheat-10 million 90kg bags, rice- 0.3 million 90 kg bags, beans-6.5 million 90 kg bags and irish potatoes- 3.4 metric tones (MoA, 2008). When the national food production levels are constrained, maize grain importation takes the greatest share of the government expenditure on food importation. Further, food security in the country is pegged on the number of maize grain bags harvested or the projected maize grain harvested. The strategic grain reserve in the country which is majorly maize grain reserve has been proposed to be raised from 4 million to 6 million 90 kg bags by the end of 2010/2011 financial year. The constant growth of the world's population makes it necessary to use all available resources for the production of food. Despite the great efforts made to increase maize production, the demand has occasionally outstripped the supply, requiring importation of large quantities of maize grain. There is limited scope for expanding cultivated land under maize production since unused land is diminishing or is of marginal quality or just unsuitable for maize production (Muchena *et al.,* 1988). Producing increased maize yields on the existing cultivated land by use of certified hybrid seed and prevention of losses due to pests and diseases is the surest way of generating the extra maize grain required to feed the nation.

Maize yields have been on the decline as indicated by yield gap between experimental research station plot and average yields that farmers typically realize on their farms (De Groote , 2002). Decline in maize production is attributed to biotic and abiotic stresses. The biotic constraints include insect pests, diseases and weeds while the abiotic constraints include lack of farm inputs such as certified seeds, fertilizers, chemicals, high prices of farm inputs and high cost and unavailability of farm labour (Pingali 2001). However, drought and declining soil fertility are frequently cited as the most limiting factors to maize production and productivity in the semi-arid tropics (Diallo *et al.,* 2004). Attack by insect pests especially the stem borers is consistently cited as a major constraint to maize production everywhere in Kenya (De Groote , 2002). Stem borers including *Chilo partellus, C. orichalcociliellus, Busseola fusca, Eldana saccharina and Sesamia calamistis,* are estimated by Kenyan farmers to cause losses of around 15% and in some areas are recognized as the most severe pest problem facing maize production (De Groote, 2002) by contributing up to 80% grain yield losses (Kfir *et al.,* 2002). Other maize insect pests include field pests such as African armyworm, African bollworm, maize aphids, cutworms, leafhopper, chafer grub, termites and storage insect pests which include maize weevil, larger grain borer, anguomois grain moth and red flour beetles. Diseases of economic importance include grey leaf spot, head and ear smut, northern leaf corn blight, maize streak virus and ear rots. Weeds of high economic importance include purple witch weed (*Striga spp*), couch grass (*Cynodon dactylon)* and *Cyperus Rotundas*

Soils in the semi-arid regions have been over cultivated, eroded and thus highly depleted of nutrients. Several decades of nutrient depletion have transformed originally fertile soils that yielded 2 to 4 tonnes/ha of cereal grain into infertile ones where cereal crop yields of less than 1 ton/ha are common (Hassan *et al.*, 1998a). Drought is priotized as the major constraint to maize production and productivity in the semi-arid regions of Kenya. The arid and semi-arid lands that cover approximately 80% of Kenya have long experienced water shortages and drought due to unreliable and poorly distributed rains. Maize and other food crop yields in these regions have been seriously depressed putting lives and livelihoods at greater risk. The phenomenon of droughts is the main reason why Kenya is a net importer of food maize during most years (Hassan *et al.,* 1998b)

2.2. Storage insect pests of maize

Although stored grains can be destroyed by fungi and vertebrate pests, insect pests are often the most destructive because of the favourable climatic conditions for their development (Alzouma, 1990). Post harvest insect pests found in Kenya include maize weevil (*Sitophilus zeamais* Motschulsky), Angoumois grain moth (*Sitotroga cerealella* Olivier), larger grain borer (*Prostephanus truncatus* Horn), red flour beetles (*Tribolium spp*), saw toothed beetle

(*Oryzaephilus spp*), lesser grain borer (*Rhizopertha dominica*) and warehouse moth (*Ephestia elutella*) (Hill, 1990). The major insect pests in storage are maize weevil, Angoumois grain moth, larger grain borer and red flour beetles.

Maize weevil (*Sitophilus zeamais* Motschulsky Coleoptera; Curculionidae) is a major insect pest of stored maize and grain products in the tropics (Obeng-Ofori and Amiteye, 2005). The three main species attacking stored cereals are *Sitophilus oryzae, Sitophilus zeamais* and *Sitophilus grannaries* (L). Although, maize weevil is predominantly associated with maize, it can also breed on dried cassava and has alternate hosts like sorghum, rice, wheat and other grains. The species has great ability and can therefore infest ripening crop in the field and establish in the grain before harvest (Haines, 1991). Maize weevil is an important post harvest pest in stored maize especially in the tropics (Victor and Ojuarega, 1993). It is the major cause of deterioration in stored grain including maize (Demissie *et al.,* 2008). Infestation by this weevil commences in the field (Caswel, 1962), but most damage is done during storage.

Studies by Tigar *et al.* (2004) showed low presence of *Sitophilus zeamais* at the initial harvest stage and high field infestation after several months of maize stooking. Infestation by the weevil commences in the field (Demissie *et al.,* 2008a) but most damage is done during storage. At the harvest time all developmental stages of this insect are present. Adults first emerge just before harvest and emergence continues for some time thereafter (Giles and Ashman, 1971). Grain loss as of 12% to 20 % is common (Giga *et al.,* 1991) but up to 80% loss has been reported in the untreated kernels (Pingali and Pandey, 2001). The characteristic feature of maize weevil is reddish brown elytra with four spots on the wing cover with two in each wing, elbowed antennae and long snout

Angoumois grain moth (*Sitotroga cerealella* Olivier) is a major pest of stored grains throughout the tropics and sub-tropics. Infestation may start before harvest (that is field infestation) in the ripening panicle and the infested grains are carried into the stores, crop losses can be very high increasing directly with time. It is known to attack the following crops: maize, wheat, sorghum, barley and millet but all cereals are vulnerable including paddy rice (Abate *et al.,* 2000).the characteristic feature of red flour beetle is hind wings with a long fringe of hairs, sharply pointed at the tip (FAO, 1985).

Red flour beetle, (*Tribolium castaneum* Herbst), is a serious pest of stored grains and products. The characteristic feature of red flour beetle is uniformly reddish brown eltrya with finely punctured lines and the antennae last three segments abruptly enlarge to form a club-shaped tip (FAO, 1985). It is a secondary pest of stored cereals and various food stuffs causing considerable financial losses. It has the highest rate of population increase recorded for any stored product pest. Red flour beetle attacks a wide range of commodities (Oppert, 2003). The larvae and adults are destructive and they feed on cereals, cereal products, nuts, spices, coffee, cocoa, dried fruits and sometime pulses. The larvae and adults are secondary pests of cereal grains and both show preference for the germinal part of the grains they penetrate deep into the stored produce. Red flour beetles attack stored grain products, including flour, cereals, pasta, biscuits, beans and nuts causing loss and damage (Vayias *et al.,* 2008). They may cause an allergic response but are not known to spread disease and cause no damage to structures or furniture (Campell *et al.,* 2007)

Larger grain borer (*Prostephanus truncatus* Horn) is a serious pest that was accidentally introduced into East Africa in the 1980s through Tanzania (Golob and Hodges, 1982; Golob and Hanks, 1990). Its characteristic feature is elytra apically flattened steeply inclined curved ridges at the sloping part (Haines, 1991). It is a serious pest of stored maize and cassava that was introduced into Kenya in 1983 through the imported maize. It was first reported in Taita Taveta (Meikle, 2001). The international trade, normal beetle flight activity and the pests' ability to survive and breed outside the storage environment have limited the success of control campaigns. These survival mechanisms make it likely that the pest would continue to spread in Africa wherever agro-climatic conditions and food sources were favourable (Hill and Nang'ayo, 2003). Larger grain borer attacks maize and dried cassava tubers in on farm stores. The adults bore the grains and cassava and create a lot of dust. Both the larvae and adults feed on the produce and cause damage. Grains are eventually hollowed out and cassava roots bored and reduced to dust internally. Cassava losses of 70% after 4 months period of storage have been reported (Hodges, 1986).

2.3. Losses associated with storage insect pests

Losses by storage pests threaten household food security (Bekele *et al.,* 1996). Stored products are attacked by more than 600 species of beetle pest, 70 species of moths and about 355 species of mites causing qualitative and quantitative losses (Rajendran, 2002). Insect contamination in food commodities is an important quality control problem of concern for food industries. These losses caused by storage insect pests may be qualitative or quantitative (Hill, 1990). Storage insect pests as they develop on stored produce they feed continuously resulting in weight loss of the produce. Infested produce is also contaminated with insect debris and therefore increases dust content. As the insect pests develop they bore holes in the grains and often discolour the produce and also affect the taste and odour of the produce (Joffe, 1963). Stored produce insect pests promote mould development due respiratory water they produce and due to inadequate ventilation, this lead to the development of hot spots and mould growth (Hyde *et al,* 1973). Storage insect pests infesting seeds, damage the embryo causing reduced germination in seed material. Also the feeding on the embryo by the insect pest will tend to reduce the protein content of the grain thus reducing the nutritional value (FAO, 1985).

The annual loss of the on-farm stored maize due to insect pests in Kenya has been reported to average 4.5 % (De Lima, 1979a). The weight, quality and germination of maize get reduced during the season of high insect infestations (Haines, 1991). Post harvest insect pests jeopardize food security and are a major constraint to maize production in Kenya. They attack maize both in the field and in storage and make it impossible to store surplus grain. The insect pests cause 10-30% grain weight loss of stored maize which directly relate to damage levels (Gwinner et. al, 1996).

Losses suffered by farmers due to insect infestation of stored maize grains are 4.5% by the maize weevils (De lima, 1979), while weight loss of 35% has been attributed to larger grain borer *(Prostephanus truncatus)* alone (Muhihu and Kibata, 1985). The global post harvest grain losses caused by insect damage and other bioagents range from 10% to 40% (Raja *et al.,* 2001; Papachristos and Stamopoulos, 2002). On a world wide basis, as much as 10% of the stored cereal grains is estimated to be lost through insect infestation (Larry, 2000). Damage to bulk stored agricultural products is estimated to be between \$1.25 and 2.5 billion per year (Scholler *et al.,* 2006).

World wide seed losses ranging from 20% to 90% have been estimated for untreated maize due to the maize weevil (*Sitophilus zeamais).* Weevil damage results directly in loss of food/reduced grain weight and may also reduce future maize production for farmers who plant saved grain as seed a practice that accounts for about 70% of all maize planted in Eastern and Southern Africa (Pingali and Pandey,2001). There also may be health risk associated with consuming weevil infested maize grain as it has been reported to commonly have higher levels of *Aspergillus flavus* contamination than non infested maize kernels (Smalley, 1998). Damaged grain has reduced nutritional value, low percentage germination, reduced weight and market value. Weevils transport spores of *Aspergilus flavus* and therefore, predisposes grain to contamination with aflatoxins. In sub-Saharan Africa proper storage of maize seeds for use in the next season continues to be a challenge for subsistence farmers due to the storage insect pests.

2.4. Factors affecting infestation and distribution of storage insect pests of maize

The climatic conditions in the tropics favour the cultivation of numerous food crops but are also favorable for the development and proliferation of storage pests and fungal diseases which cause considerable damage in storage and constitute an obstacle to processing (Mutlu and Hountondji, 1990). Stored products insect pests are primarily thermophillic in nature and therefore their growth and survival is greatly influenced by temperature. The lower development threshold for most stored product pests is approximately 18^0C, while the optimum developmental range is approximately 25^0-35^0C (Fields and Korunic, 1999). Therefore, storage pests are a great problem in regions where relative humidity and temperatures are high but temperature is the overriding factor that influences the rate of insect multiplication. At a temperature of around 32^0C the rate of multiplication could be up to 50 times monthly increase in the number of insects number.

Grain moisture content considerably affects pest status and therefore, effective drying used in the control of moulds will also lessen the problems of insect pest infestation. Low grain moisture contents will greatly reduce the spectrum of pest species (Proctor, 1994). Physical disturbance of grain by turning it from one level to another can reduce live grain weevil infestation to a considerable extent thus retard its further development (Joffe, 1963). Maize grains when sufficiently dry (12-13% moisture content) are dormant and respire very little. The traditional concept of sealed storage as a means of controlling insect pest infestation depends on the fact that insect pests use up the little available oxygen and die where there is restriction of air circulation (Abraham, 2003). Most storage insect pests will die when the oxygen in the storage atmosphere is reduced to 2 % (Hyde *et al.,* 1973). Therefore, when air tight conditions are maintained, infestation can be controlled and probably eliminated before serious damage is done.

Insect behaviour patterns such as adult oviposition and larval feeding can affect pest status (Proctor, 1994). Storage insect pests can sense when the conditions are not favourable and delay oviposition to increase the chances of survival of the new pests by ensuring they lay eggs when the conditions are favourable for their development. The development of infestation may also be affected by the diapause habit which characterizes several storage insects. Diapause may postpone population development usually in un-favourable conditions and it may also impair the effectiveness of control measures, including fumigation and the use of contact insecticides as surface sprays for clean up treatment in storage structures (Joffe, 1963). Locomotory avoidance behaviour especially in the flour beetle is also of considerable interest (Wildey, 1987). Also storage insect pests are affected by the management practices such as use of abrasive and dehydrating agents like wood ash or presence of other inert materials in grain and prevention of initial infestation. Storage insect pests if left uncontrolled can increase in numbers and reduce the produce into empty husks (Rajendran, 2002).

2.5. Management of storage insect pests in maize

Many pest control methods have been developed over time to combat the post harvest insect pest infestations. The commonly used methods for control of insect infestation involve use of chemicals, cultural control or manipulation of the storage environment to make it unfavourable for insect development, botanical pesticides, breeding for resistant varieties, use of natural enemies such as disease vectors, use of sterile insects to interfere with normal reproduction and repellants. Traditional methods of controlling post harvest insect pests involve mixing of either ash or hot pepper with the grain.

2.5.1. Chemical control

The chemicals used for the control of storage insect pests include non-fumigants, fumigants and botanical pesticides. The non-fumigants are formulated as dusts or emulsifiable concentrates (White and Leesch, 1995). The fumigants are volatile and are mostly used to fumigate the stores and they are developed to retain their insect-toxic properties for extended periods. Fumigation is one of the most successful methods to protect cereal grains from infestation of stored product insect pest. Under favourable conditions a fumigant will reach all parts of the store and the stored commodity and usually be effective on eggs and adults as well as hidden stages of pest species (Shaaya *et al.,* 1997). It is more convenient than the use of grain protectants because they can be applied to bulk of grains (Loth *et al.,* 2010). The universally available fumigants used for disinfestations of stored commodities are methyl bromide although it's being phased out due to its ability to cause ozone depletion. The now recommended fumigant now is methyl iodide (Faruki *et al.*, 2005). However, some pest control methods like fumigation are too expensive at the farm level.

Since 1960's grain protectants mainly organo phosphates and carbamate insecticides have been employed on a worldwide basis in management programmes for pest control in stored grains (Redlinger *et al.,* 1998). Protectants are usually applied when commodities are loaded in storage at intervals (Arthur, 1996). Malathion has been used for years as grain protectact, but some insect species including the maize weevil have developed significant levels of resistance to it (Perez, 1999). The development of insecticide resistance is of great concern in post harvest ecosystem because it could lead to the elimination of some protectants from management programmes thus the need for registration and availability for more protectants.

The use of plants as traditional protectants of stored products is an old practice used all over the world. Farmers neglected this practice after the Second World War, with the advent of synthetic insecticides. However, research emphasis has been to find some alternative insecticides from plants with lower mammalian toxicity and low persistence in the environment (Catherine and Abdelaziz, 1993). Plants such as Neem seed powder *Azadiracter indica,* Pepperfruit seed *Denittia tripetata* (Duruigbo, 2010), *Aframomum melegueta, Zingiber officinale* (Birkett *et al,* 2009), Black pepper *Piper nigrum* (Tindall, 1992) *Lantana camara* and *Tephrosia vogelli* (Ogendo *et al,* 2003) have been used as protectants against maize weevil. Plant materials for protection of stored grain are utilized in different forms; powder, ash, volatile oils, non-volatile oils and extracts (Catherine *et al,* 1992; Rajeandran and Sriranjirini, 2008). Small scale farmers in Kenya admix botanicals with cereals and pulse grains (Dudu, 1996). However, there's very little quantitative experimentation illustrating the effectiveness of these materials. Regulatory restriction on use of insecticides, awareness of environmental pollution, the increasing cost of storing insecticides, erratic supplies, worker safety and consumer desire for pesticide free product have led to pest management specialists reappraising natural products such as inert dusts (Arthur, 1996).

There are four groups of inert dusts which can be differentiated by their chemical composition or their level of activity. They include mineral dusts such as rock phosphate and ground sulphur, lime, limestone and salt. These have shown some activity against the stored product pests (Golob, 1997). Powdered clay and dusts have been traditionally used as control measure by applying a thick layer on stored grain, but high doses are required for effective control (Golob, 1997). Silica aerogels are produced by drying aqueous solutions of sodium silicate. They are very light hydrophobic powders that are effective at lower rate than the diatomaceous earth (Vayias and Athanassiou, 2004). Potential inhalation hazards have limited the use of silica aerogels (Golob, 1997). Diatomaceous earth is almost pure silicon dioxide made up of fossilized diatoms (Amin, 2006). Diatoms are algae and are abundant in all aquatic ecosystems but can also occur in terrestrial environments (Athanassiou *et al,* 2009; Stathers *et al.,* 2008).

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2.5.2. Cultural control

Traditionally, storage losses due to post harvest insect pests have been kept within acceptable limits by combination of management practices. Cob selection at the time of harvest for good husk cover and the absence of existing infestation have been reported to delay the build up of maize weevil (*Sitophilus zeamais)* population but not the larger grain borer (Borgemeister *et al.,* 1996). Similarly storing maize with or without husks above the cooking fire has worked effectively against the traditional storage insect pests but not the neo-tropic destructive pests such as the larger grain borer (Ajibola, 1989). Farmers just clean their stores before storing new harvests, use wood ash and do timely harvesting to control insect pest infestation (Demissie et al 2008b)

2.5.3. Use of resistant varieties

Genetic resistance of maize grain to storage insect pests is an important component of integrated pest management to small holder farmers. However, post harvest losses have been aggravated by maize breeding programmes that have for long emphasized on selection for high yielding trait without regard to resistance to postharvest pests. Intrinsic levels of maize weevil resistance in maize grain have shown large difference among genotypes from Eastern, Southern and Western Africa and Latin America (Giga and Mazazura, 1991; Kossou *et al.,* 1993).

The basis of grain resistance to weevil is due to resistance mechanism; antibiosis, non-preference and tolerance (Painter 1968). Non-preference for oviposition, food or shelter, antibiosis which involves adverse effect of plant on the biology of insect and resistance through recovery or active ability to withstand infestation. Host plant resistance to insects is environmentally safe, economically feasible and socially acceptable as a tactic of integrated pest management (Heinrich *et al.,* 2004). High level of resistance is indicated by low amount of powder and also the larger grain borer reproduction is adversely affected on resistance ears and is indicated by small size of adult population (Harish, 2001). High level of resistance against maize weevil is indicated by low seed weight loss, low seed damage, low numbers of F1 progeny for one generation and low susceptibility index (Abebe *et al.,* 2009). Physical characteristics such as size, kernel hardness and testa thickness influence the resistance to storage insect pests. Also moisture content affects resistance to maize weevil, increase in moisture content increases susceptibility of maize to maize weevil and other storage insect pests. Smaller seeds which are hard and with less moisture content are more resistant than bigger grains which are loose, soft and contain higher moisture content since they are easily attacked.

The harder a seed is the more resistant is to storage pests. Maize with thick and hard pericarp are hard to penetrate by the storage pests hence they are resistant (Kelvin, 2002). The pericarp acts primarily as a barrier against storage insect pests. Other factors contributing to grain resistance to maize weevils include increased sugar content and ferulic acid (Classen *et al.,* 1990; Arnason *et al.,* 1994). Currently in Kenya KARI/CIMMYT are developing three early maturing hybrid varieties for resistance trait to larger grain borer and maize weevil damage. The code names for the varieties are KATEH2007-1, -2 and -3. These maize materials have been tested among others nominated by the private sector/seed companies in national performance trial for three and two seasons by KEPHIS to confirm agronomic and insect resistance trait respectively. From the study KATEH2007-3 and KATEH2007-2 were found to be resistant to maize weevil and larger grain borer (Likhayo *et al.,* 2010)

2.5.4. Biological control

Stored products pests are at time affected by diseases caused by pathogenic fungi, bacteria, protozoa or viruses. The effect of entomopathogenic fungus, *Beauveria bassiana* is mortality of the maize weevil (Oduor *et al.,* 2000; Hildalgo *et al.,* 1998). Entomopathogenic nematodes are lethal endoparasites of insects (Gaugler, 2002). They enter the host through natural body openings, penetrate into the hemocael, release bacteria that kill the host within 24-48 hrs and make the environment inside the insects suitable for nematode development. The only free living stage, the infective juvenile leaves a depleted host and searches for a new host. For control of larger grain borer also a predatory beetle *Teretrius nigrescens* Lewis has been discovered (Hill and Nang'ayo, 2003).

Natural enemies can be used for control of the storage insect pests. Among the natural enemies that could act as biological control agents of the maize weevil is the wasp, *Anisopteromalus calandrae* (Howard) (Hymenoptera: Pteromalidae), a dominant parasitoid naturally found in granaries (Parichat *et al.,* 2010). It is a solitary ectoparasitoid that parasitizes numerous stored product beetles. The female wasp parasitizes coleopteran larvae that are feeding inside the grain kernels (Arbogast and Mullen, 1990). Also sterile insect's pests can be released into the population to mate with the fertile population resulting in infertile offsprings thus controlling the increase of the storage insect pests. The sterile insects are mostly males so as to mate with the female insects resulting in infertile eggs thus prevents increase in number of the insect pests.

2.5.5. Modification of storage environment

Storage insect pests are dramatically affected by temperature. Varying the temperatures depending on the species optimum temperature can be used to control the pests by maintaining temperatures which are not favourable for the growth and development of the pest. Post harvest storage insect pests require oxygen for respiration, regulating the amount of air circulating in the store can be used to control the insect pests. Reduced oxygen supply for the insect pests will lead to death of the pests hence controlling them (Hyde *et al.,* 1973).

CHAPTER THREE

OCCURRENCE AND DIVERSITY OF STORED PRODUCE INSECT PESTS IN MAIZE FROM EASTERN AND NORTH RIFT REGIONS OF KENYA

3.1. Abstract

Maize is a major source of food in Kenya and it is grown both as a subsistence and commercial crop. Losses due to storage insect pests have been related to high temperatures and relative humidity prevalent in the production areas. These damages affect the quality and quantity of the stored produce. The objective of the study was to determine the occurrence and diversity of storage insect pests in maize from Eastern and North rift regions of Kenya. A survey was conducted in different agro-ecological zones of Eastern and North Rift regions of Kenya between November 2008-May 2009. Whole and semi-processed maize grain samples were collected from farmers, traders and National Cereals and Produce Board stores in Kitui, Machakos, Makueni, Uashi-Gishu and Trans-Nzoia. Storage pests were identified after direct extraction and incubation for 42 days. The main storage insect pests infesting maize were larger grain borer, maize weevil, angoumois grain moth and red flour beetle. Maize weevil had the highest prevalence in all the agro-ecological zones. Whole grain samples from traders had high infestation of maize weevil of up to 19 insects per 100 grams compared to those from farmers. Maize grain samples from farmers stores had high infestation of larger grain borer of up to three insects per 100 grams than those from traders. Samples from Ishiara National Cereals Board had the highest infestation of 46 and seven insects per 100 grams of maize weevil and larger grain borer respectively. High levels of infestation with storage pests were recorded in Eastern province for all the major storage pests than North rift region. The study showed that grains from

Eastern region had higher levels of infestation with storage pests which could be attributed to higher temperatures that favour the pests.

3.2. Introduction

Maize is Kenya's principal crop and despite the great efforts made to increase its production the demand has occasionally outstripped the supply requiring importation of large quantities of maize grain (FAO, 1994). Stored product pests are particularly important because they attack the final agricultural product. Insect pest are one of the major constraints of maize production in Kenya. The main post harvest pests in Kenya include maize weevil (*Sitophilus zeamais* Motschulsky), Angoumois grain moth *(Sitotroga cerealella* Olivier), larger grain borer *(Prostephanus truncatu*s Horn) and flour beetle (*Tribolium spp*). The weight, quality and germination of the maize get reduced in season of high insect infestation (Haines, 1991) and population numbers of insects can be high enough to make the commodity completely unpalatable and unacceptable in the market this leads to farmers selling their produce immediately after harvest to minimize losses due to insect pest (Abraham, 2003). Consequently farmers receive low prices for any surplus grain they may have compromising food security at household level (Beyene *et al.,* 1996). Environmentally compatible methods of controlling storage insect pests are urgently needed to replace synthetic pesticides that are either not available for economic or regulatory reason or ineffective due to the increasing difficult of managing pesticide resistance (Hill, 1990). Therefore the objective of the study was to determine the occurrence and diversity of storage insect pests in maize from Eastern and North rift regions of Kenya.

3.3 Materials and methods

3.3.1 Sample collection and preparation

Samples of whole and semi-processed maize grains were obtained from traders, farmers and National Cereals and Produce Board stores between November 2008 short rains and May 2009 long rains. The samples were collected from different agro-ecological zones, Machakos, Makueni, and Kitui in Eastern Kenya and Trans Nzoia and Uashi Gishu in North rift region. In each agro-ecological zone ten farmers and ten traders were selected randomly and samples of 500g maize grains and semi-processed grains were collected for post harvest insect pests' identification. The samples collected samples were packed in brown khaki bags and stored at room temperature until evaluated for storage pests. The cereals produce board stores in which samples were collected were Makueni, Kitui, Ishiara and Machakos. The agro-ecological zones covered include lower midland zone three (LM3), lower midland zone four (LM4), lower midland zone five (LM5), lower highland zone two (LH2), lower highland zone three (LH3), upper midland zone three (UM3), upper midland zone four (UM4) and upper highland zone three (UH3).

The collected samples were sieved using 3mm sieve and any storage pests present was collected for identification. Sub samples of 100 g of each grain samples from different sources and sites were put in plastic jars and replicated four times. The grain was incubated for 42 days and the emerging pests were separated from the samples by sieving the maize across a 3mm sieve into trays. The types and number of storage insect pests that emerged after incubation were identified.

3.3.2. Insect pest identification

The adult insects were collected, counted and identified according to a key developed by Haines (1991). The insects were observed under dissecting microscope (X 50 objective). For maize weevil the features for identification were reddish brown beetle with elbowed antennae and the characteristic feature is a long snout and four spots on the wing cover with two in each wing. Red flour beetle was identified with the uniformly reddish brown colour of the beetle. The antenna is club shaped at the tip and the elytra has finely punctured lines. The larger grain borer was identified with its eltra which is apically flattened, steeply inclined curved ridges at the sloping part, elytra look like cut off at the apical end. Angoumois grain moth was identified based on its hind wings which have long fringe hairs which are sharply pointed at the tip.

3.3.3. Data analysis

Data on the storage insect pest numbers was subjected to analysis of variance (ANOVA) using Genstat statistical package (Lawes Agricultural Trust, Rothamsted Experimental Station, 2006, version 9). Means were separated using Fisher's Least Significant Difference test (LSD) at 5% probability level.

3.4. Results

3.4.1. Storage pests in maize grain samples from National Cereals and Produce Board stores

The samples collected from Kitui had larger grain borer infestation. However, this pest was not collectedfrom Machakos and Makueni areas (Table 3.1). The sample collected from Kitui had significantly ($P \leq 0.05$) higher maize weevil infestation compared to those from other areas. The maize samples collected from Machakos did not have weevil infestation but Makueni recorded the least infestationdifferent from maize grains from Makueni. Sample collected from the Kitui National Cereals and Produce Board store had significantly ($P \leq 0.05$) higher red flour beetle infestation (4.8) than the Kitui local maize sample, but this pest was not collected from Machalos and Kitui.. Maize samples collected from Machakos and Makueni did not have red flour beetle infestation but was not significantly different from local maize grain obtained from Kitui. (Table 3.1) No significant difference in anguomois grain moth was noted among the stores. This pest was not present in the samples collected in Makueni and Kitui. Generally anguomois grain moth infestation was low among all the stress sampled.

For the samples collected from the Ishiara National Cereals and Produce Board there were no significant differences in the larger grain borer and the maize weevil infestations was noted among the maize grain from the different stores and stacks. Samples collected from store three stack A had significantly ($P \leq 0.05$) higher angoumois moth infestation than all the other stores and stacks but not significantly different from those in store three stack B,C,D and store four stack A. Store four stack B had no angoumois moth infestation. Samples collected from store three stack A had significantly ($P \leq 0.05$) the highest saw toothed beetle infestation. Store four stack B had significantly ($P \leq 0.05$) lower saw toothed beetle infestation than store three stack B and store four stack A. Samples from store three stack A had significantly ($P \leq 0.05$) higher red flour beetle infestation than store three stack C and D. (Table 3.1). Samples collected from Ishiara had higher infestation of all the storage insect pests than all other National Cereals and Produce Board which were sampled.

Table 3.1: Storage insect pest species and their population in maize grain samples from National Cereals Produce Boards stores in Eastern region in March to May 2009 (Mean number of storage insect pests per 100g)

NCPB stores	Larger grain borer	Weevil	Angoumois moth	Red flour beetle
Kitui local	1.0	13.2	1.0	0.6
Kitui	6.8	29.8	0.0	4.8
Machakos	0.0	0.0	0.4	0.0
Makueni	0.0	8.2	0.0	0.0
Mean	3.8	12.8	1.2	1.4
LSD$_{(P \leq 0.05)}$	1.7	16.7	NS	3.0
CV%	33.4	96.5	369.9	165.4

Ishiara National Cereals and Produce Board

Store/stack	Larger grain borer	Weevil	Angoumois moth	Red flour beetle
3A	9.7	50.3	2.2	30.7
3B	7.3	41.2	0.8	20.7
3C	5.8	46.9	0.4	25.9
3D	12.6	41.8	0.3	26.9
4A	4.6	49.5	0.5	21.6
4B	6.2	43.0	0.0	17.3
Mean	6.7	45.6	0.5	22.4
LSD$_{(p \leq 0.05)}$	NS	NS	0.9	6.3
CV %	102.9	5.3	164.3	33

NS: Not Significantly Different at 5% probability levels; CV: Coefficient of variation

LSD: Least Significance Difference

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Mean	3.8	12.8	1.2	1.4
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	Ishiara National Cereals and Produce Board			
Store/stack	Larger grain borer	Weevil	Angoumois moth	Red flour beetle
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3B	7.3	41.2	0.8	20.7
3C	5.8	46.9	0.4	25.9
3D	12.6	41.8	0.3	26.9
4A	4.6	49.5	0.5	21.6
4B	6.2	43.0	0.0	17.3
Mean	6.7	45.6	0.5	22.4
LSD$_{(p\leq0.05)}$	NS	NS	0.9	6.3
CV %	102.9	5.3	164.3	33

NS: Not Significantly Different at 5% probability levels; CV: Coefficient of variation

LSD: Least Significance Difference

3.4.2. Stored product insect pests in the maize grain from farmers stores

From the agro-ecological zones sampled in the Eastern and North rift regions no significant differences in larger grain borer, weevils, anguomois moth and red flour beetle infestations were noted (Table 3.2). Samples collected from Eastern region had higher larger grain borer, maize weevil, angoumois moth and red flour beetle infestation than those samples collected from North Rift region. High levels of maize weevil infestation were noted in samples from Makueni agro-ecological zone lower midland zone three (LM3) for the Eastern region while agro-ecological zone upper midland zone four (UM4) and upper midland zone three (UM3) had the highest maize weevil infestation in North Rift region. Agro-ecological zone lower midland zone three (LM3) in Makueni had highest maize weevil infestation compared to all other agro-ecological zones. Samples collected from Kitui agro-ecological zone lower midland zone four (LM4) had the highest larger grain borer infestation while Machakos agro-ecological zone lower midland zone five (LM5) had the highest Angoumois grain moth infestation. The red flour beetle infestation was highest in agro-ecological zone lower midland zone four (LM4) in Kitui and Makueni in Eastern region while in North rift region agro-ecological zone upper midland zone four (UM4) had the highest Angoumois grain moth. Generally samples collected from the 0lower highland zones had high infestation of storage insect pests compared to the other agro-ecological zones in both regions.

Table 3.2: Storage insect pest species and their population in maize grain samples from Eastern and North Rift region in March to May 2009 in farmer stores (Mean number of storage insect pests per 100g)

Agro-ecological zones	Larger grain borer	Maize weevil	Angoumois moth	Red flour beetle
		Eastern Region		
Kitui LM4	4.8	17.4	0.3	0.6
Kitui LM5	4.3	10.3	0.1	0.1
Machakos LM4	3.3	16.6	6.6	0.2
Machakos LM5	0.3	15.0	15.7	0.1
Makueni LM3	3.8	20.4	10.8	0.5
Mean	3.4	15.9	6.7	0.3
$LSD_{(P\leq0.05)}$	NS	NS	NS	NS
CV%	34.0	42.0	30.0	23.0
		North Rift Region		
Uashi Gishu LH2	0.0	10.6	1.4	0.0
Uashi Gishu LH3	0.0	10.9	0.0	0.0
Uashi Gishu UM3	0.0	15.9	0.1	0.0
Uashi Gishu UM4	1.1	3.8	0.1	0.0
Kwanza LH2	0.5	8.9	1.6	0.0
Kwanza LH3	0.0	11.5	0.0	0.1
Kwanza UH3	0.0	14.4	0.1	0.0
Kwanza UM4	0.6	15.9	0.2	0.7
Mean	0.3	11.5	0.5	0.1
Mean	2.1	15.0	4.8	0.2
$LSD_{(P\leq0.05)AEZ}$	NS	NS	NS	NS
$LSD_{(P\leq0.05)\ Regions}$	1.5	NS	NS	NS
CV%	167.3	121.1	477.1	318.2

NS: Not Significantly Different at 5% probability levels; CV: Coefficient of variation.
LSD: Least Significance Difference; M. weevil: Maize weevil
UH: Upper Highland Zones; LH: Lower Highland Zones; LM: Lower Midland Zones; UM: Upper Midland Zones.

3.4.3. Stored product insect in whole grain and semi-processed maize samples sourced from farmer and trader stores in Eastern and North Rift region

Samples collected from Kitui had significantly ($P \leq 0.05$) higher larger grain borer infestation than all samples collected from trader stores (Table 3.3). Maize samples from Kwanza had significantly ($P \leq 0.05$) higher weevil infestation than all samples collected from trader stores. Maize samples collected from Makueni had significantly ($P \leq 0.05$) lower maize weevil infestation than all stores except Machakos and Kitui. Maize grain from Makueni had significantly ($P \leq 0.05$) higher red flour beetle infestation than all other traders stores, but Uashi-Ngishu traders stores did not have the red flour beetle infestation. No significant differences were noted in Anguomois infestation among all the traders stores (Table 3.3)

The semi processed maize grains collected from farmers in the agro-ecological zone lower midland zone four (LM4) in Machakos had significantly ($P \leq 0.05$) higher angoumois moth infestation than all farmers stores but there were no infestation of this pest were recorded in the Kitui LM4 amd the Makueni Lm5 ones. Samples collected in the agro-ecological zone lower midland zone four (LM4) in Kitui and the agro-ecological zone lower midland zone five (LM5) in Makueni did not have anguomois moth infestation and were not significantly different from samples in agro-ecological zone lower midland zone five (LM5) in Kitui (Table 3.3). No significant differences were noted in the larger grain borer, maize weevils and red flour beetle infestation among the farmers' processed maize (Table 3.3).

Semi-processed maize grains collected from traders in Kitui had significantly ($P \leq 0.05$) higher larger grain borer infestation than all other trader stores and there was no infestation of this pest in the Makueni zone. No significant differences in maize weevils, anguomois moth and red flour beetle infestation were noted among the samples collected from trader stores. (Table 3.3)

Semi-processed maize collected from traders had higher mean larger grain borer than those from farmers. Maize weevil infestation in the whole maize grain was higher in the samples collected from traders. Angoumois moth infestation was higher in the whole maize grain samples collected from farmers than those in semi-processed maize from farmers, traders and whole maize grain from traders. Semi-processed maize collected from traders had higher red flour beetle infestation than whole maize grain collected from farmers and traders (Table 3.3).

Table 3.3: Storage insect pest species and their population in grain samples from farmers and traders in Eastern region and North Rift regions March to May 2009 (Mean number of storage insects in 100g)

Regions	Larger grain borer	Weevil	Angoumois moth	Red flour beetle
		Whole grain from traders		
Kitui	1.2	10.8	2.3	0.7
Kwanza	1.0	33.6	0.0	0.2
Machakos	0.3	18.3	0.2	0.4
Makueni	1.0	10.5	0.1	1.4
Uashi Gishu	0.3	21.9	0.2	0.0
Mean	0.8	18.9	0.6	0.6
LSD$_{(P\leq0.05)}$	1.2	10.0	NS	0.7
CV%	261.9	90.0	563.4	200.1
		Semi processed grain from farmers		
Kitui LM4	2.1	10.2	0.0	0.9
Kitui LM5	0.5	15.5	0.3	2.3
Machakos LM4	3.1	3.2	2.4	1.0
Makueni LM3	0.1	23.8	1.7	0.0
Makueni LM5	0.0	1.5	0.0	0.0
Mean	1.4	10.6	0.9	0.8
LSD$_{(P\leq0.05)}$	NS	NS	1.93	NS
CV%	142.5	155.1	133.4	197.5
		Semi processed grain from traders		
Kitui	5.4	24.8	1.2	1.5
Machakos	3.6	8.2	1.6	0.1
Makueni	0.0	27.4	2.9	1.5
Mean	3.0	16.8	1.9	0.9
LSD$_{(P\leq0.05)}$	3.3	NS	NS	NS
CV%	161.9	140.1	359.1	220.4

NS: Not Significantly Different at 5% probability levels; CV: Coefficient of variation.

LSD: Least Significance Difference

LM: Lower Midland Zones

3.5. Discussion

The survey results demonstrated that various insect pests coexist in farm stores, trader stores and National Cereals and Produce Board stores in Eastern and North Rift region and these include maize weevil, larger grain borer, angoumois grain moth and red flour beetle. Findings show that the main insect pest found in all stores in the surveyed regions is maize weevils *Sitophilus zeamais*. High prevalence of the larger grain borer was in Eastern region. The findings are in agreement with the survey study conducted by De Lima (1979). The findings show that insect pest infestation is high in Eastern province and this can be attributed to the importation of maize from Tanzania and other areas like Taita taveta as a result of crop failure that is experienced in the area due to unreliable and inadequate rainfall in the area. High levels of larger grain borer were evident in Eastern region. Larger grain borer was accidentally introduced into East Africa through Tanzania thus interact. In Kenya larger grain borer was introduced through Taita taveta in 1983 (Meilkle, 2001).

Importation could be an avenue for pest spread. Importation of maize was evident in the area from trader stores who had sourced their maize from Tanzania and the National Cereals and Produce Board store specifically Kitui where there maize had come from South Africa. The maize from South Africa had the highest insect pest infestation compared to the local maize indicating that importation of maize can be a potential spread of stored product insect pests. The rise and drop in population of insect pest in different Agro-Ecological Zones can be attributed to changes in weather; storage condition and the type of control measures taken against the storage insect pest where by farmers control the pests once they notice an increase population of the pests (Esayas *et al.,* 2007). Farmers stores had high insect infestation compared to the traders stores. This can be attributed to the build up of storage insect pests in the farmer stores unlike in traders stores where the produce is always moving out of the store and they do not store the produce for long for the pests to build up to large numbers. Infestation by the red flour beetle was high in the samples with high infestation of maize weevil or the larger grain borer. This is because the red flour beetle is a secondary pest and attacks the already infested produce (Gwinner *et al.,* 1996). The study showed that the grain from Eastern region had higher levels of infestation with storage pests. This can be attributed to higher temperatures that are optimal for the development of the storage insect pests. Consequently it is recommended that the government should come up with enforcement measures on the importation rules and regulations in order to reduce the storage insect pest infestation and spread in the country.

CHAPTER FOUR

SUSCEPTIBILITY OF LOCALLY GROWN MAIZE VARIETIES TO MAIZE WEEVIL (*Sitophilus zeamais Motsch*) and ANGOUMOIS GRAIN MOTH (*Sitotroga cerealla)*

4.1. Abstract

Storage insect pests of maize cause direct and quality losses especially in small scale production. Although fumigants and synthetic insecticides are available, there is global concern about their negative effects on environmental and toxic residues on food products. Therefore, alternative management strategies such as the use of resistant varieties are required. The objective of this study was to determine the susceptibility of maize varieties to maize weevil (*Sitophilus zeamais* Motsch) and Angoumois grain moth. Sixteen maize varieties were screened for resistance to the maize weevil (*Sitophilus zeamais* Motsch) in the laboratory and field over two growing seasons. Field experiments were set up at two diverse ecological sites and after harvest, grain samples were incubated for two months and insect pests that emerged were counted and identified to species level. In addition insect free and undamaged samples of each maize variety were infested with unsexed four-week old weevils and left at ambient conditions for three months. The percentage grain damage, seed weight loss and number of F1 progeny were determined. There were significant varietal differences in infestation by the maize weevil and the angoumois grain moth. Varieties DK 8031and H513 had the highest maize weevil infestation of up to 32 insects per 100 grams while variety Katumani had the least infestation. Inbred lineCKPH080020 had the lowest index of susceptibility of 2.3, longer median development time of 38.8, lower number of F1 progeny of 9.5 insects after three months was thus considered resistant. Variety DK 8031 was most susceptible with median development time of 22 days, 124 F1 weevil progeny after three months and index of susceptibility of 8.5 had shorter median development time. An increase in

the F1 progeny resulted in increased seed damage and seed weight loss. Resistance in some of the varieties tested could be incorporated in local popular variety through breeding programmes and the resistant varieties could be further evaluated for possible release to farmers.

4.2. Introduction

The global post harvest grain losses caused by insect damage and other bioagents range from 10% to 40% (Raja *et al.,* 2001; Papachristos and Stamopoulos, 2002). Reduction of storage losses would improve household food security and income generating opportunities. Stored products are attacked by insect pests which cause quantitative and qualitative losses (Rajendran, 2002). Post harvest losses by storage insect pests such as the maize weevil (*Sitophilus zeamais)* continues to pose a major problem in Africa (Markham *et al.*, 1994) where it is a major insect pest of stored maize and grain products (Obeng-ofori and Amiteye, 2005).

Insect pest damage to stored grains results in major economic losses in Kenya where small scale farmers contribute 75% of the overall maize production. Grain production falls below demand and much of the grain produced is lost to storage insect pests. Weevil damage results directly in reduced grain weight and may also reduce future maize production for farmers who plant saved grain as seed (Pingali and Pandey, 2001). Weevil damage predisposes maize to infection by *Aspergilus flavus* and aflatoxin contamination, consequently posing a health risk (Smalley, 1998). Therefore, weevil resistant maize varieties would be a valuable component of the integrated pest management of the maize weevil. This study sought to evaluate the popular maize varieties grown in different agro ecological zones in Kenya for their susceptibility to the maize weevil (*Sitophilus zeamais).*

4.3. Materials and methods

4.3.1. Determination of infestation by storage insect pests under field conditions

Field experiments were conducted over two growing seasons during the 2008/2009 short rains and 2009 long rains seasons at Kenya Agricultural Research Institute (KARI) Mwea and Waruhiu Agricultural Training Centre. Seeds of sixteen varieties namely H513, Duma 43, DK 803, DHO1, DHO2, DHO4, Panner 77, Panner 7m-19, Panner 4M, Panner 67/5243, H516, KCB, H614D, Pioneer 3253 and Katumani composite were bought from the local seed companies and agrochemical dealers (Table 4.1).

Land was ploughed and harrowed to a moderate seed bed tilth and each variety was planted in 5m × 6.75m plots at a spacing of 75cm between rows and 30cm within rows. The plots were separated by 1m paths and each variety was replicated thrice. The experiment was arranged in a randomized complete block design and the three blocks were separated by 1.5m paths. Planting was done at onset of rains at the rate of two seeds per hill. Fertilizer (N.P.K 20:20:0) was applied at planting at the rate of 25 N kg/ha and 25 kg P_2O_5 /Ha. The plants were thinned to one plant per hill two weeks after emergence and hand weeding was done twice at two weeks after emergence and just before flowering. At flowering, the crop was top dressed with 25 N kg/ha CAN. At physiological maturity each variety was harvested separately and packed in brown khaki paper bags until evaluated for insect pest infestation.

The harvested grain from the three replicates of each variety was bulked and sample of 400 g per variety in each site was obtained and insects separated using a 3 mm sieve. Any storage pest present was collected for identification. Sub samples of 100 g of each variety was put in plastic jars and incubated on wooden shelves for two months at ambient conditions of 20-30^{0}C and 75-80% relative humidity. Each variety was replicated four times and the experiment was laid out in a randomized complete block design. The emerging pests were separated by sieving the maize across a 3 mm sieve. The adult insect were counted and identified to species level according to Haines (1991).

Table 4.1: Characteristics of maize varieties used in the study

Variety	Year of release	Optimal production altitude range	Months to maturity	Grain Yield(t/ha)
H513	1995	1200- 1600	4 - 5	6 – 8
H515	2000	1200- 1500	4 - 5	6 – 8
H516	2001	1200- 1500	4 - 5	7 – 9
H614D	1986	1500-2100	6 - 9	8 – 10
Duma 43	2004	800-1800	4 - 5	6 – 7
DK 8031	2003	900-1700	4 -4.7	6 – 8
DHO1	1995	900-1400	3 - 4	4 – 6
DHO2	1995	900-1400	3 - 4	4 – 6
DHO4	2001	900-1500	3 - 4	5 – 6
Panner 77	2008	800-1600	3 - 4	4 – 6
Panner 7M	2008	900-1500	3 - 4	4 – 6
Panner 4M	2008	900-1500	3 - 4	4 – 6
Panner 67	2001	800-1600	4 - 5	5 – 6
PHB 3253	1995	800-1800	4 - 5	7 – 9
KCB	1967	900-1350	3 - 4	3 – 5
Katumani	1967	900-1350	3 - 4	3 – 5

Source: Kenya Plant Health Inspectorate Service, 2009: National Crop Variety List.

H- Hybrid; DH- Dryland hybrid; KCB- Katumani Composite B; DK- Dekalb

4.3.2. Determination of the susceptibility of maize varieties to weevil under laboratory conditions

4.3.2.1. Rearing and multiplication of maize weevil

Maize weevils (*Sitophilus zeamais)* were multiplied on Makueni composite at 20-30^{0}C temperature and 75-80% relative humidity in plastic jars as described by Wright et al., (1989) and Bekele *et al.,* (1996). The maize was first disinfested by heating in an oven for 4 hours at 40^{0}C and two hundred unsexed adult weevils were placed in one litre plastic jars containing 500 g of maize. The top of the jars were covered with cheese cloth, fastened with rubber bands and the jars were then placed on trays with Petri dishes containing small amount of water to avoid contamination of the cultures by mites. The samples were incubated for 42 days when the emerging adults were removed by sieving and kept in separate jars.

4.3.2.2. Inoculation and susceptibility assessment

Maize grain samples from the field experiment were placed in glass jars and disinfected by placing in an oven at 40^{0}C for 4 hours. The grain was then cleaned by sieving using a 25-mesh screen to attain grains of approximately equal size and grains with discolouration or mechanical damage were removed. A hundred grams of each maize variety were placed in 500 g plastic honey jars with ventilated lids lined with whatmans No.1 filter paper. Each jar was inoculated with 50 active, four week old unsexed adult weevils and the jars were sealed and then placed on laboratory benches. Each variety was replicated four times and experiment laid out in a randomized complete block design. The adult maize weevils were allowed a seven day oviposition period before being removed (Derera *et al.,* 2001) and the grain was then incubated for three months. Variety 614D was used as the susceptible check while inbred line CKPH08002 was the resistant check which was obtained from the National Agricultural Research

Laboratories, Kenya agricultural Research Institute. Control samples consisted of seeds of each variety without weevil inoculation but kept under similar conditions.

Data collected included on adult mortality, number of F1 progeny, seed damage, seed weight loss, median development and index of susceptibility. Adult mortality was assessed 7 days after introduction of weevils by removing all the adult weevils and counting the live and dead insects. The number of F1 progeny was determined starting at 38 days from oviposition period by examining the seeds after every 2 days. The emerging F1 progeny insects were removed and counted for each jar on each assessment period (Nwana and Akibi-betts, 1982). Seed damage and weight loss were determined by sorting out the grains into damaged and undamaged portions and weighing each lot to the nearest 0.1 gram. Seed damage was based on presence or absence of holes and tunnels on the grain. Seed damage was expressed as a proportion of the total number of seeds sampled. Seed weight loss was determined by the count and weigh method according to Gwinner et al. (1996) as follows:

$$\text{Seed weight loss (\%)} = \frac{(Wu \times Nd)-(Wd \times Nu) \times 100}{Wu(Nd+Nu)}$$

Where, Wu = weight of undamaged seeds, Nu = Number of undamaged seeds, Wd = weight of damaged seeds, and Nd = Number of damaged seeds.

The median development time was calculated as the time (days) from the middle of the seven day oviposition period to the emergence of 50% of the F1 progeny (Dobie, 1977). The index of susceptibility was calculated according to Dobie (1974) as follows:

$$\text{Index of susceptibility} = \frac{(\log_e \times \text{total number of F1 progeny emerged}) \times 100}{\text{Median development time}}$$

Log_e =Logarithim exponential

The susceptibility index (Dobie, 1974), ranges from 0 to 11, where 0-3= resistant, 4-7= moderately resistant, 8-10= susceptible and ≥11= highly susceptible.

4.3.3 Data analysis

All data was subjected to analysis of variance (ANOVA) using Genstat statistical package (Lawes Agricultural Trust, Rothamsted Experimental Station, 2006, version 9). Means were separated using Fisher's Least Significant Difference test (LSD) at 5% probability level.

4.4. Results

4.4.1. Storage insect pests infesting maize varieties under field conditions

The insect pests found on the grain were maize weevils and anguomois moth. During the 2008 short rains in Mwea, variety Panner 67 had significantly ($P \leq 0.05$) higher maize weevil infestation in comparison to all the other varieties except DHO4 and pioneer 3253. Varieties DK 8031, DHO2, H515 and Katumani did not have maize weevil infestation (Table 4.2). However, they were not significantly different from H513, Duma 43, DHO1, Panner 77, Panner 7M, Panner 4M, H516, KCB and H614D (Table 4.2). During the 2009 long rains in Mwea, DK 8031 variety had significantly ($P \leq 0.05$) higher weevil infestation than all the other varieties. Grain grown at Waruhiu no significance differences in weevil infestation were noted among the varieties during the two seasons (Table 4.2)

During the 2008 short rains in Mwea, variety H614D had significantly ($P \leq 0.05$) higher Angoumois moth infestation than all the varieties. Varieties KCB had significantly higher number of angoumois moth than H513, Duma 43, DK 8031,DHO1, DHO2, DHO4, Panner 77, Panner 7M, Panner 4M, Panner 67, H515, H516, Pioneer 3253 and katumani. In waruhiu variety Panner 4M had significantly ($P \leq 0.05$) higher Angoumois grain moth infestation than all the other varieties. Varieties H513, DK 8031, DHO2, DHO4 Panner 7M, Panner 67, H515, H516, KCB, Pioneer 3253 and Katumani did not have Anguomois moth infestation but were not significantly different from Duma 43, DHO1,Panner 77, H614D (Table 4.2)

During the 2009 long rains in Mwea, Variety H515 had significantly ($P \leq 0.05$) higher Anguomois moth infestation than all the varieties except DHO4, Panner 77, Panner 4M and KCB. Varieties Duma 43, Panner 7M, Panner 67, Katumani did not have Anguomois moth infestation, however, they were not significantly different from H513, DK 8031, DHO1, DHO2, .H516, H614D, Pioneer 3253. In Waruhiu, variety Panner 4M had significantly ($P \leq 0.05$) higher Angoumois grain moth infestation than all varieties. (Table 4.2)

Variety and site interaction had significant ($P \leq 0.05$) effect on the Angoumois moth and the maize weevils during the 2008 short rains and 2009 long rains seasons respectively. During the long rains seasons, varieties KCB and H614D had significantly higher Angoumois moth infestation in Mwea than in Waruhiu and varieties DK8031 and H515 had significantly higher maize weevils' infestations in Mwea than those Waruhiu during the short rains 2008. In 2009 long rains in Mwea, variety H614D had the highest angoumois moth infestation and all other varieties except Duma 43, Panner 77, Panner 7M and KCB had no angoumois moth infestation. During the short rains, H515 had higher weevil infestation while Panner 67, H516, KCB and Katumani had no weevil infestation. In Waruhiu during the long rains, Panner 4M had higher Anguomois moth infestation while all other varieties except Duma 43, DHO1, Panner 77 and H614D had no Angoumois infestation. During the short rains, H513 had higher weevil infestation while Duma 43, DHO2, Panner 7M, H515, H516 and Katumani had no weevil infestation. Overall, the maize grown in Mwea had significantly higher maize weevil and angoumois moth infestations in the short rains and long rains season than the maize grown in Waruhiu (Table 4.2).

Table 4.2: Population levels of stored product insect pests in different maize varieties grown in Mwea and Waruhiu during the short rains and long rains 2009 (mean number of insect pest per100g of grain)

	Maize weevil				Angoumois moth			
	2008 short rains		2009 Long rains		2008 short rains		2009 Long rains	
Variety	Mwea	Waruhiu	Mwea	Waruhiu	Mwea	Waruhiu	Mwea	Waruhiu
H513	2.4	1.8	0.6	1.5	0.0	0.0	2.0	0.0
Duma 43	1.8	0.0	0.4	0.0	0.2	0.2	0.0	0.4
DK 8031	0.0	0.6	31.8	0.8	0.0	0.0	0.2	0.0
DHO1	2.2	0.2	0.2	0.4	0.0	2.2	2.0	2.0
DHO2	0.0	0.0	2.0	0.0	0.0	0.0	0.4	0.0
DHO4	7.8	1.6	0.6	1.8	0.0	0.0	5.2	0.0
Panner 77	0.4	0.4	2.4	0.3	1.8	0.8	6.6	1.2
Panner 7M-19	3.2	0.0	3.8	0.0	1.4	0.0	0.0	0.0
Panner 4M	0.4	0.4	0.4	0.5	0.0	7.4	3.0	5.6
Panner 67	11.6	1.0	0.0	1.1	0.0	0.0	0.0	0.0
H515	0.0	0.0	16.4	0.0	0.0	0.0	10.0	0.0
H516	1.8	0.0	0.0	0.0	0.0	0.0	0.2	0.0
KCB	1.2	0.6	0.0	0.4	6.6	0.0	7.2	0.0
H614D	1.4	1.4	1.8	1.2	9.2	0.6	0.8	0.9
Pioneer 3253	6.8	0.6	0.4	0.9	0.0	0.0	1.0	0.0
Katumani	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	2.6	0.54	3.8	0.56	1.2	0.7	2.4	0.6
LSD$_{(P\leq 0.05)}$ Variety	7.0	NS	5.8	NS	2.4	5	7.9	7.0
LSD$_{(P\leq 0.05)}$ Site	1.25		1.06		NS		1.6	
LSD$_{(P\leq 0.05)}$ Variety*site	NS		4.23		3.9		NS	
CV%	214.9	239.4	121.2	245.7	158.3	563.8	259.7	478.5

NS= Not Significantly Different at 5% probability levels; CV= Coefficient of variation.

LSD= Least Significance Difference

H- Hybrid; DH- Dryland hybrid; KCB- Katumani Composite B; DK- Dekalb

4.4.2. Susceptibility of maize varieties to the maize weevil under laboratory conditions

Evaluations using 2008 short rains harvest showed that, variety CKPH080020 had significantly ($P \leq 0.05$) longer median development time of 38.8 days than all the other varieties while variety DK 8031 had a significantly ($P \leq 0.05$) shorter median development time of 21 days than all the other varieties except H531, Duma 43, DHO4, Panner 4M, Panner 67 and Katumani (Table 4.3). Variety DK8031 had significantly ($P \leq 0.05$) higher F1 progeny of 123.5 weevils than all the other varieties except Duma 43 (91.8 weevils) while variety CKPH080020 had significantly ($P \leq 0.05$) lower F1 progeny of 9.5 weevils than all the other varieties except DHO1, DHO2, Panner 77, Panner 4M and Katumani. Varieties DHO2 and KCB had significantly ($P \leq 0.05$) higher adult mortality than all varieties except Panner 4M and Duma 41 while variety H515 did not have adult mortality and it was not significantly different from H513, Duma 43, DK8031, DHO1, Panner 7M, H516, H614D, Pioneer 3253 and Katumani (Table 4.3).

Evaluation using 2009 long rains harvest showed that, variety CKPH080020 had significantly ($P \leq 0.05$) longer Median Development Time (39.5 days) than all the other varieties except KCB and DHO1. On the other hand, variety DK 8031 had significantly ($P \leq 0.05$) shorter Median Development Time than all varieties except Duma 43, DHO4, Panner 4M and Panner 67. Variety DK8031 had significantly ($P \leq 0.05$) higher F1 progeny than all varieties while variety CKPH080020 had significantly ($P \leq 0.05$) lower F1 progeny than all varieties except KCB. Varieties KCB had significantly ($P \leq 0.05$) higher adult mortality than all varieties except Panner 67, DHO2 and Duma 41 while variety H516 had significantly ($P \leq 0.05$) lower adult mortality than all varieties except Pioneer 3253, H614D, H515, Panner 7M, DHO4, DHO1, DK8031, Duma 43 and H513 (Table 4.3)

Table 4.3: Adult mortality, median development time and F1 progeny of *Sitophilus zeamais* on maize varieties under laboratory infestation

	2008 Short rain			2009 Long rain		
Variety	MDT	F1 progeny	Adult mortality	MDT	F1 progeny	Adult mortality
H513	24.8	54.8	2.3	27.5	63	3.0
Duma 43	27.8	91.8	0.7	21.8	92.7	2.0
DK 8031	21.8	123.5	1.0	17.5	125.7	1.8
DHO1	32.8	30.8	3.8	34.8	33.2	4.8
DHO2	27.8	34.8	17.8	23.5	39.7	13.0
DHO4	24.5	56.5	1.0	22.0	68.5	3.0
Panner 77	29.0	40.8	9.8	29.8	51.2	5.8
Panner 7M-19	28.0	69.8	2.0	28.8	95.0	2.8
Panner 4M	23.5	35.8	11.5	21.5	58.7	10.0
Panner 67	23.0	89.5	10.8	22.3	69.7	10.8
H515	26.5	58.3	0.0	25.0	63.7	2.3
H516	29.8	64.5	0.5	27.8	69.7	1.5
KCB	33.5	20.0	17.8	36.0	17.0	14.5
H614D	22.5	47.0	1.3	22.0	52.2	2.5
Pioneer 3253	26.8	65.8	3.0	23.8	67.7	3.5
Katumani	23.0	45.0	6.5	24.3	32.5	6.5
Duma 41	28.3	55.8	13.5	26.8	59.5	13.5
CKPH080020	38.8	9.5	6.8	39.5	6.0	7.5
Mean	27.3	54.1	6.1	26.4	59.2	6.0
LSD$_{(P\leq 0.05)}$	3.9	32.5	6.7	5.7	25.6	4.0
CV%	10.0	42.0	77.0	15.3	30.5	47.2

NS= Not Significantly Different at 5% probability levels; CV= Coefficient of variation.

LSD= Least Significance Difference; MDT= Median Development Time (Days).

H- Hybrid; DH- Dryland hybrid; KCB- Katumani Composite B; DK- Dekalb

During the 2008 short rains season, variety DK8031 had significantly ($P \leq 0.05$) higher seed damage than all varieties while variety CKPH080020 had significantly ($P \leq 0.05$) lower seed damage than the other varieties except H513, DHO1.,DHO2, DHO4, Panner 4M,H515, H614 D, Katumani and Duma 41. Variety DK 8031 had significantly ($P \leq 0.05$) higher seed weight loss of 12.8% than the other varieties except Duma 43, Panner 7M, Panner 67, Pioneer 3253 while variety CKPH080020 had significantly ($P \leq 0.05$) lower seed weight loss of 0.5% than the other varieties except DHO1, DHO2, DHO4, Panner 77, Panner 4M, KCB, Katumani. Variety DK8031 had significantly ($P \leq 0.05$) higher index of susceptibility of 8.5 compared to all the other varieties except H513, Duma 43, Panner 67 and H614 while variety CKPH080020 had significantly ($P \leq 0.05$) lower index of susceptibility of 2.3 than the other varieties except KCB (Table 4.4).

During the long rains in 2009, variety DK8031 had significantly ($P \leq 0.05$) higher seed damage of 0.6 compared to the other varieties while variety CKPH080020 had significantly ($P \leq 0.05$) lower seed damage of 0.1 compared to the other varieties except DHO1, DHO2, Panner 4M, Panner 77, KCB, Katumani and Duma 41. Variety DK 8031 had significantly ($P \leq 0.05$) higher seed weight loss compared to the other varieties except Duma 43, Duma 41, Panner 67 while variety CKPH080020 had significantly ($P \leq 0.05$) lower seed weight loss than the other varieties except DHO1, DHO2, DHO4, Panner 77, Panner 4M, KCB, Katumani. Variety DK 8031 had significantly ($P \leq 0.05$) higher index of susceptibility compared to the other varieties except H513, Duma 43, Panner 67 and H614 while variety CKPH080020 had significantly ($P \leq 0.05$) lower index of susceptibility in comparison to the other varieties (Table 4.4).

Table 4.4: Grain damage and susceptibility rating of different maize varieties under laboratory infestation

	2008 short rains			2009 Long rains			
Variety	Seed damage	Weight loss (%)	Susceptibility index	Seed damage	Weight loss (%)	Susceptibility index	Susceptibility Rating
H513	0.3	3.1	7.1	0.4	3.3	7.5	S
Duma 43	0.5	8.7	8.0	0.5	9.6	8.0	S
DK 8031	0.5	12.8	8.5	0.6	13.1	8.5	S
DHO1	0.1	1.6	4.5	0.1	1.6	4.7	MR
DHO2	0.2	1.5	4.9	0.1	1.2	5.0	MR
DHO4	0.3	3.0	7.0	0.2	3.4	7.1	MR
Panner 77	0.2	1.1	5.1	0.1	0.6	5.3	MR
Panner 7M-19	0.4	6.5	6.8	0.3	9.7	7.0	MR
Panner 4M	0.2	1.6	6.7	0.2	1.7	6.8	MR
Panner 67	0.4	7.5	7.8	0.5	4.2	7.9	S
H515	0.3	3.7	6.5	0.3	4.9	6.6	MR
H516	0.3	4.2	6.0	0.3	3.5	6.0	MR
KCB	0.1	0.8	3.6	0.2	1.6	3.7	R
H614D	0.3	4.1	7.4	0.3	5.2	7.4	MR
Pioneer 3253	0.4	5.5	6.9	0.4	5.8	7.0	MR
Katumani	0.2	1.6	6.0	0.2	1.5	6.0	MR
Duma 41	0.3	1.4	6.1	0.4	2.3	6.1	MR
CKPH080020	0.08	0.5	2.4	0.1	0.4	2.3	R
Mean	0.3	3.8	6.2	0.3	4.3	6.3	
LSD$_{(P\leq 0.05)}$	0.2	3.9	1.3	0.2	2.9	1.2	
CV%	47.9	72.1	14.6	40.4	47	12.9	

NS= Not Significantly Different at 5% probability levels; CV= Coefficient of variation.

LSD= Least Significance Difference; MDT= Median Development Time (Days).

S=Susceptible; MR=moderately resistant; R=Resistant

H- Hybrid; DH- Dryland hybrid; KCB- Katumani Composite B; DK- Dekalb

4.5. Discussion

There were significant varietal differences among the maize varieties in the level of infestation by the maize weevil and Angoumois grain moth. These findings agree with observation of Demissie *et al.*, (2008b) and Caswell (1962) who reported that infestation of the maize weevil commences in the field. Field infestation studies by Tigar et al. (2004) found low presence of *Sitophilus zeamais* at initial harvest stage and higher levels of infestation after several months of storage. At harvest time all development stages of this insect are present. Adults emerge just before harvest and emergence continues for sometime thereafter (Giles and Ashman, 1971). In the field, the degree of infestation is mainly determined by the completeness of the husk covering the cob (Giles and Ashman, 1971). In the store, the number of the maize weevil present at any time will depend upon the initial population of the insect at harvest; the numbers of insects subsequently infesting the crop from elsewhere, and the rate of multiplication of the insects within the crop (Dobie 1974). The rate of multiplication of the insect depends upon temperature and moisture content of the maize (Makate, 2010). The presence of long tight husk is known to reduce field infestation of insect pests (Golob, 1984; Dansou, 2001). The maize grown in Mwea had higher numbers of maize weevils and Angoumois grain moth compared to those grown in Waruhiu. The difference in numbers of the different storage insect pests can be attributed to the difference in agro-ecological zones in the two sites

There were significant varietal differences in the susceptibility of maize varieties and the associated losses due to laboratory infestation by the maize weevil with respect to the index of susceptibility, F1 progeny, median development time, seed damage, and seed weight loss. The susceptibility index decreased with increase of the Median development time. However, the number of F1 progeny, seed damage, seed weight loss and index of susceptibility were positively related. These differences in the susceptibility of maize varieties indicate the inherent ability of particular varieties to resist maize weevil attack. From other studies resistance in stored maize to insect attack has been attributed to physical factors such as grain hardness, pericarp surface texture, nutritional factors such as amylase, lipid and protein content (Firoz *et al.,* 2007; Dobie, 1974) or non nutritional factors, especially phenolic compounds (Serratos *et al.,* 1987). Gudrups *et al.,* (2001) also reported that pericarp roughness was correlated with susceptibility. The role phenolics play in resistance formation in these surface tissues may be both related to structural components and antibiosis factors (Arnason *et al.,* 1993). For *Sitophilus oryzae* grain hardness has been reported as the main resistance parameter (Bamaiyi *et al.,* 2007). Out of the 17 maize varieties tested against the maize weevil in this study, only the inbred line CKPH080020 that was resistant. The remaining 16 varieties were moderately resistant to susceptible. The moderately resistant varieties were KCB, DHO1, DHO2, DHO4, Panner 77, Panner 7M, Panner 4M, H515, H516, Pioneer 3253, Katumani and Duma 41. Varieties DK8031, Duma 43, H513, Panner 67 and H614 were susceptible..

The adult weevil mortality did not have effect to the susceptibility index, seed damage, seed weight loss, F1 progeny and median development time. Dobie (1974) found that the overall rate of mortality of adult maize weevil on different maize varieties was generally low and concluded that there was no evidence of variation among the varieties in their effects upon the mortality of *Sitophilus zeamais.* Abraham (1991) also suggested that this parameter might not be a good indicator of susceptibility, because adult weevils were found to survive without food for more than ten days in the laboratory test. Relative longer developmental time was required on the resistant variety, CKPH080020 than on the moderately resistant varieties. Similary, weevils on varieties having a high index of susceptibility displayed reduced periods of the completion of development. Reduced survival and establishment reduces the insects populations and the resultant crop damage (Abebe *et al.,* 2009). Prolongation of development periods results in reduction of the number of generation in a season. According to Horbes (1988), the index of susceptibility is based on the assumption that the more the F1 progeny and the shorter the duration of the development, the more susceptible the seeds would be. Abraham (1991) indicated that the extent of damage during storage depends upon the number of emerging adults during each generation and the duration of each life cycle and seeds permitting more rapid and higher levels of adult emergence will be more seriously damaged. Several maize varieties including local races have been characterized as sources of resistances to maize weevil (Giga and Mazarura, 1991; Arnason *et al.,* 2004; Thanda *et al.,* 2005) and some sources of resistance have been incorporated into elite maize lines (CIMMYT, 2001).

Breeding for resistance to maize weevil seems to be the way to go for sustainable management of stored product pests in new maize varieties (George, 1992; Thanda *et al*., 2001). An ideal maize breeding programme should include the development of maize varieties able to resist insect attack for a long period in addition to varieties with high yield (Ashamo, 2001). Physical characteristics such as colour, kernel, hardness, testa, thickness and seed size influence the resistance to maize weevil (Ashamo, 2001). The use of resistant grain varieties can enhance the effectiveness of biological and chemical control methods against stored product insect pests (Scholler, 1998). Seed testa serves as a barrier to the penetration to the soft nutritious endosperm by insect pests, implying that the thicker types provide protection against insect degradation. Breeding for maize varieties with thick tester may be an effective method of mitigating maize weevil infestation (Lale and Kartey, 2006). Factors such as the presence of soluble phenolics and tannins may impart resistance (Ramputh *et al.,* 1999). The study showed that maize varieties commonly grown in Kenya differed in the level of susceptibility to storage insect pest. This resistance could be used in breeding programs to improve the popular but susceptible varieties. Farmers can also be advised to grow the less susceptible varieties.

CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1. General discussion

This study reveals that infestation of stored product insect pests can be from imported maize or may be from field infestations in farmers' fields. At harvest time, all development stages of maize weevil are present. Adults emerge just before harvest and emergence continues in storage. The presence of long tight husk is known to reduce field infestation of insect pests (Giles and Ashman, 1971). Maize weevil is a major stored product insect pest present almost in all agro-ecological zones. Larger grain borer was mostly found around the eastern region and this can be attributed to importation of maize from regions where the pest is prevalent. The extent of damage during storage depends upon the number of emerging adults during each generation and the duration of each life cycle. Hence seeds permitting more rapid and higher levels of adult emergence will be more seriously damaged. Host plant resistance should be incorporated in integrated pest management used for the control of maize weevil (Heinrich *et al.*, 2004). Host resistance should be included in the development of maize varieties. Several maize varieties including local races have been characterized as sources of resistance to maize weevil and some sources of resistance have been incorporated into maize varieties (Arnason *et al.*, 2004; Thanda *et al.*, 2005).

From the survey it revealed that Eastern region has high storage pest infestation than North Rift region. This can be attributed to the climating conditions of the region (Mutlu and Houndtondji, 1990), Eastern region has higher temperatures compared to the North Rift region which are favourable for the development of storage insect pests especially beetles; maize weevil and larger grain borer. The crop failure experienced in the Eastern region also contributes introduction of storage insect pests in the area because for them to meet the food deficit in the area they have to import maize from other areas and precaution may not be taken on any infestation present.

For the initial field infestation of storage insect pests, the maize grown in Mwea had higher numbers of maize weevils and Angoumois grain moth compared to those grown in Waruhiu. The difference in numbers of the different storage insect pests can be attributed to the difference in agro-ecological zones in the two sites. Mwea being an agro-ecological zone lower midland zone four (LM4) is characterized by higher temperatures compared to agro-ecological zone upper midland zone two (UM2) which has low temperature. Higher temperatures favour the development of maize weevils and Angoumois grain moth (Ileleji *et al.*, 2007).

The difference in susceptibility to maize weevil in the different maize varieties can be attributed to the difference in physical and chemical characteristics. These characteristics should be incorporated in breeding programmes for resistant variaties. Since moisture content increases susceptibility of maize to maize weevil, farmers should be trained on sun drying the grains to the right moisture content to reduce post harvest losses due to pest infestation.

5.2. Conclusions

Imported maize had high levels of infestation of storage pests especially the larger grain borer compared to the local maize. This implies that the increase in larger grain borer infestation in the country especially Eastern province can be attributed to the foreign maize which is imported in the area for food security due to crop failure in the area caused by drought.

This study has reaffirmed the fact that maize weevil infestation starts in the field and there are varieties which have some resistance to maize weevil infestation. Maize weevil is a major post-harvest pest of maize. It is necessary for factors which influence susceptibility to be elucidated so as to provide information to maize breeders. This will enable them to combine a high degree of resistance with good grain quality. The maize inbred line CKPH080020 which was identified as having resistance trait could be used to develop insect resistant varieties. Information generated by this work will help breeders to promote maize types with highest chances of adoption by farmers. In conclusion, if resistant maize varieties extend the developmental period of maize weevil, the post harvest loss incurred during storage of farm produce will be minimized to large extend. Those varieties with low index of susceptibility can be stored relatively for longer periods of time. Resistant varieties, therefore, can be utilized as an environmental friendly way to reduce damage by maize weevil (*Sitophilus zeamais)* under traditional storage conditions.

5.3. Recommendations

Based on the findings of this study, the following is recommended:

1. Studies to be carried out on the most appropriate integrated pest management options for the management of storage insect pests in Kenya.
2. Evaluation of maize varieties for susceptibility to other storage insect pests like larger grain borer, angoumois grain moth and red flour beetle.

3. Studies to be carried out to identify the factors which influence susceptibility and the information be provided to maize breeder
4. Studies on the role of different storage insect pests in the spread of *Aspergillus flavus* and associated aflatoxin contamination.
5. A study to be carried out to establish the percentage losses by the larger grain borer and maize weevils over a certain period farmers store their maize.
6. The government to put an importation regulation to reduce the spread of storage insect pests.
7. Maize varieties be developed that are resistant to storage insect pests incorporating host resistance in the new varieties.
8. Farmers to be educated on the best control measure to reduce the losses which they are facing from insect pests infesting their stored maize.

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