INHERITANCE AND COMBINING ABILITY STUDIES ON GRAIN YIELD AND RESISTANCE TO MAIZE WEEVIL (*Sitophilus zeamais*, MOTSCHULSKY) AMONG EXTRA EARLY QUALITY PROTEIN MAIZE INBRED LINES

BY

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NOVEMBER, 2016

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SCHOOL OF GRADUATE STUDIES

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A Thesis Submitted to the Department of Crop and Soil Sciences, Faculty of Agriculture, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana in Partial Fulfilment of the Requirements for the Award of Degree of

MASTER OF PHILOSOPHY IN PLANT BREEDING

BY

SOLOMON AMISSAH

(BSc. AGRICULTURE)

NOVEMBER, 2016

DECLARATION

I hereby declare that, this work being presented as thesis, is the result of an original research done by myself and that it has neither in whole nor in part been presented for another degree elsewhere, except for the references to other people's work, which have been duly acknowledged and cited.

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ABSTRACT

The maize weevil is one of the most important storage pests of maize in Ghana and Africa as a whole. It causes damage from as low as 20% to as high as 100% in untreated varieties. Developing resistant varieties has been identified as an important and environmentally friendly aspect of the integrated pest management system. However, little is known about the genetic control of resistance to the maize weevil in Ghana. The main objective of this research was to understand the genetic control and heritability of resistance to the maize weevil. The specific objectives were to identify promising genotypes with resistance to the maize weevil. Five parents were crossed in a complete Diallel mating design to obtain 20 hybrids. The 25 genotypes were planted again with two local checks to obtain their seeds. The seeds obtained from these genotypes were subsequently used in the laboratory evaluation for the identification of resistance of the genotypes to the three regional collections of the maize weevils. The laboratory assessment identified parent TZEEQI 111 as the best parental line for resistance to the maize weevil. It exhibited highly significant and negative GCA effects for weevil progeny emergence, percentage weight loss, percentage grain damage and susceptibility index. It also exhibited a positive and significant GCA effect for Median development period. Hybrids TZEEQI 111 × TZEEQI 139, TZEEQI 111 × TZEEQI 12, TZEEQI 111 × TZEEQI 61 and TZEEQI 12 × TZEEQI 66 exhibited significant SCA effects. Heritability estimates revealed high narrow sense heritability for F_1 weevil progeny emergence, percentage grain damage and susceptibility index. These results suggest the presence of additive and non-additive gene action in the control of resistance to the maize weevil. Parental lines TZEEQI 111, TZEEQI 139 and TZEEQI 66 performed very well and as such should be considered when forming base population to initiate breeding programs for resistance to maize weevils.

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My sincere gratitude goes to my parents for the unflinching support they have always provided.

DEDICATION

This work is dedicated to my family, especially to Mr Moses Amissah and Mrs Comfort Dedaa Amissah for their love and motivation and to anyone who has made my education possible.

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CHAPTER ONE

1.0 INTRODUCTION

Maize (*Zea mays* L.) is cultivated extensively worldwide (FAOSTAT, 2014) and the highest ranked cereal in terms of grain yield per hectare in the world (M'mboyi *et al*., 2010). Worldwide production of maize in 2014 amounted to 2,039,153,437 tonnes (FAOSTAT, 2014). The United States of America is the highest producer of maize in the world (FAOSTAT, 2014). The top ten maize producing countries in Africa are South Africa, Nigeria, Ethiopia, Tanzania, Malawi, Kenya, Zambia, Uganda, Ghana and Mozambique (FAOSTAT, 2014). In sub-Saharan Africa, maize is the most important and the most widely cultivated staple food, occupying an area which is in excess of 33 million hectares annually (Macauley, 2015). An estimated yield of less than 1.8 t/ha is realized on farmers' fields in Africa as compared to the average worldwide yield of 5 t/ha (Macauley, 2015). Maize yield in Ghana on farmers' fields is estimated at 1.7 t/ha (MoFA, 2011).

Maize has several uses for different people all over the world including human food, livestock feed, and its use in several industrial products (Zunjare *et al*., 2015). About 66% of the maize produced worldwide is used in the livestock industry for the feeding of livestock, 25% for human consumption and 9% for industrial purposes (Verheye, 2010). In developing countries, however, over 50% of the maize produced is consumed as food by humans. In sub-Saharan Africa, maize production is so important that low maize production is frequently linked with famine and scarcity of food (Oppong, 2013).

Maize comprises approximately 10% protein, 72% starch, and 4% fat, contributing 365

Kcal/100 g of energy (Ranum *et al*., 2014). Maize also provides most of the vitamin B's but lacks vitamin B12 and vitamin C. It is also a good source of fibre. Maize is however lacking in two important amino acids, specifically tryptophan and lysine (Ngaboyisonga and Njoroge, 2014).

In Ghana, maize is the most important cereal (FAOSTAT, 2014). However, maize is produced predominantly by smallholder farmers in Ghana under rainfed conditions (Ragasa *et al*., 2013).

It is estimated that a greater part of the maize produced in West Africa yearly, is damaged in storage before reaching the consumer (Hell *et al*., 2000). It is also estimated that about $4 billion worth of maize grains is lost after harvest in sub-Saharan Africa each year (FAOSTAT, 2014). The greatest damage is caused by insects (Ukeh *et al*., 2012). Insects damage 15 to 50% of the total maize produced each year in developing countries (Suleiman *et al.*, 2015).

The maize weevil (*Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae)) together with the Larger grain borer (*Prostephanus truncatus* Horn (Coleoptera: Bostrychidae)) are the most important storage pests of maize (Derera *et al*., 2014). *Sitophilus zeamais* infestation commences on-field and continues into storage (Demissie *et al*., 2008). The maize weevil is reported to cause damage to untreated storage maize from trace levels to as high as 80% grain damage when conditions are favourable (Tefera *et al*., 2010).

The problem of protein deficiency in maize was solved with the development of maize fortified with Lysine and Tryptophan. Quality Protein Maize was introduced into Ghana with the development of Obatanpa (Asiedu *et al.*, 2001). Quality Protein Maize developed earlier had soft endosperm, chalky and dull kernel appearance and were susceptible to storage grain pests (Ignjatovic-Micic *et al.*, 2011). This situation was alleviated with the successful development of quality protein maize that was genetically improved and possessed hard endosperm (Vivek *et al*., 2008).

The maize weevil is controlled predominantly by the use of synthetic insecticides. However, increased public awareness and concern for environmental safety and health considerations are gradually making the use of these chemicals unpopular (Kanyamasoro *et al*., 2012). Hence the need to find alternative methods of controlling these insects. The use of resistant varieties provides a safer, more practical and economic method of controlling the maize weevil than any other control technique (Abebe *et al*., 2009). A number of factors, whether present alone or in combination with other factors confer resistance to maize. Some of these factors include kernel hardiness, good husk cover, kernel size and texture, starchy amylose content, phenolic content etc. (Gudrups *et al*., 2001).

However, little is known about the genetic control of resistance to the maize weevil and the mode of inheritance and how easily the resistance can be transferred to the next generation. The lack of knowledge on the genetic control of resistance to the maize weevil is hampering further improvement of Quality Protein Maize. The main objective of this study therefore was to understand the genetic control and heritability of resistance to the maize weevil.

The specific objectives of the study were to:

I. estimate the general combining ability (GCA) and specific combining ability (SCA) of the parental lines and their hybrids respectively, for yield and resistance to maize weevil

II. estimate mid-parent and better parent heterosis for resistance to maize weevil III.

estimate broad sense and narrow sense heritability of resistance to maize weevil

IV. identify promising genotypes with resistance to maize weevil.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin, Botany and production

Maize, a member of the Poaceae family is believed to have originated from central Mexico 7000 years ago (Ranum *et al*., 2014). Archeological findings suggest that maize was an important crop in the diet of the ancient Aztec Indian and Mayan civilizations as far back as 6000 BC (Acquaah, 2012). Also, according to the Vavilovian centres of crop origin, maize is from the Mesoamerican centre from where it was transformed into a better food and spread to different parts of the world (Verheye, 2010). It is believed that maize was introduced to Africa by the Portuguese and Arabs through exploration and later through the slave trade. It is the most widely cultivated cereal and the third most important cereal crop after wheat and rice (Suleiman *et al*., 2015). In terms of the quantity of maize produced in the world, the United States of America is the highest, followed by China mainland, Brazil, Argentina and Ukraine (FAOSTAT, 2014). In terms of the total maize production on continental basis, the Americas are by far the highest maize producing continent, followed by Asia, Europe, Africa and finally Oceania (FAOSTAT, 2014).

Maize is protandrous, monoecious, has a determinate growth habit and can grow to a height of about 15 feet (4.57 m) (Acquaah, 2012). Maize grows and gives significantly high yield in temperate, subtropical and tropical zones from sea level to high elevations (Abadassi, 2015), making maize a versatile crop. In Ghana, maize is the most important cereal crop produced and consumed by smallholder farmers throughout the country and the most important staple food crop, second only to cassava (Ragasa *et al*., 2013). About 1.7 t/ha of maize yield is realized on farmers' fields in Ghana as compared to an attainable yield of 6.0 t/ha (MoFA, 2011). Maize has adapted perfectly to the conditions in Ghana, and as such can grow in almost all Agroecological zones in the country. It has adapted so well that it is reckoned to have replaced pearl millet and sorghum which are considered staple food, especially in Northern Ghana (Adu *et al*., 2014). Maize provides a lot of advantages when eaten but has a major disadvantage, deficiency in the two essential amino acids (Tryptophan and Lysine) (Ranum *et al*., 2014), hence the introduction of Quality Protein Maize to help solve this problem.

2.2 Uses of maize

Maize is a very important crop the world over. However, the uses of maize vary from country to country and from culture to culture. In developed countries, only a small percentage of the maize produced serves as food, the majority of it being used for industrial purposes (Santos *et al*., 2006). About 85% of the maize produced in developed countries is used for animal feed (Qi *et al*., 2002). As a result of this, maize is mentioned as the king of the ingredients used in the formulation of feed (Qi *et al*., 2002). Maize can be used in the preparation of drinks, whether soft drinks or alcoholic ones. In 2011 alone, 40% of the maize produced by the United States of America was devoted to the production of ethanol (Wise, 2012). Maize also serves as a source of starch, fuel, paper, and many other products (Nelson, 2003).

In most developing countries including Ghana, maize serves as a major staple food which is eaten directly by the populace including farmers and farmer households, with the remainder being sold to generate income (Ragasa *et al*., 2013). Majority of the people in developing countries derive their quotidian calorie supplies from maize. Some of the popular dishes prepared from maize in Ghana include, banku, kenkey, Akple, Etsew, Tuo Zaafi and maize porridge which is popularly used in the weaning of babies.

2.3 Quality Protein Maize

The maize plant is a key source of calories in the diets of almost 230 million residents of developing countries and supplies almost 50% of the calories and protein consumed in eastern and southern Africa and 20% of the calories and protein consumed in West Africa (Prasanna *et al*., 2014). Such heavy dependence on maize as a protein source, puts people at risk since the nutritional value of maize, likened to other cereals and legumes is poor, due to the lack of two essential amino acids, namely tryptophan and lysine (IgnjatovicMicic *et al*., 2011). As a result, any maize centered diet which lacked the two essential amino acids was classified as protein deficient. Thus children feeding on maize diet lacking in these two essential amino acids were likely to develop diseases related to protein deficiency such as kwashiorkor (Vivek *et al*., 2008). Also, almost 32% and 20% of toddlers that are fed on diets made from this kind of maize are stunted and underweight, respectively due to protein undernourishment (Gupta *et al*., 2013). As a result, countries that rely on maize as their staple food and importantly for the weaning of their young children, especially the developing countries, needed maize fortified with the two essential amino acids (lysine and tryptophan) (Vivek *et al*., 2008). Thus the driving force for the development of Quality Protein Maize was to improve the nutritional value of the maize grain, specifically the protein content (Krivanek *et al*., 2007).

The development of Quality Protein Maize began with the detection of the opaque 2 (*o*2) mutation in maize and the documentations of its nutritional benefits by Mertz *et al.* (1964).

The opaque-2 (*o*2) mutation can almost double the lysine content of the endosperm of the normal maize when in the homozygous recessive state (Ignjatovic-Micic *et al*., 2011). Also maize grains that are homozygous for the *o*2 recessive allele have protein quality value equivalent to 90% of the protein of milk (Ignjatovic-Micic *et al*., 2008). There was thus a superior total amino acid balance and an augmented quality of the protein of the seed after the discovery of opaque-2 (*o*2) allele and its introgression into normal maize lines (Gupta *et al*., 2013). Ghana as a country also set up a quality protein maize (QPM) development programme in 1989 at the Crops Research Institute of Ghana which led to the development and release of Obatanpa, an open-pollinated variety which has been overwhelmingly accepted by farmers in the country (Asiedu *et al.*, 2001). However, Obatanpa is highly susceptible to maize weevil due to its high protein content.

2.4 Benefits of Quality Protein Maize Over Normal maize

Several studies conducted have shown that the Quality Protein Maize has 55% more tryptophan and 30% more lysine than the normal maize, clearly highlighting the superiority of the Quality Protein Maize to that of the normal maize (Scrimshaw, 2006). Quality Protein Maize can also help reduce the use of protein supplements in animal diets, thus reducing cost. Studies conducted in Ghana also revealed that young children fed with porridge made from Quality Protein Maize had reduced stunting and were healthier than young children fed on normal maize diet (Kostadinovic *et al*., 2011). Quality Protein Maize is also of benefit in animal production. In the case of animal production, synthetic supplements are employed to account for the limiting amounts of threonine, lysine and tryptophan when formulating the diets of the animals (Panda *et al*., 2010). Quality Protein Maize thus helps to reduce the amount of protein supplements bought to augment animal diet prepared using normal maize (Scrimshaw, 2006). Feed formulation is thus simplified when Quality Protein Maize is used.

2.5 Constraints to Maize Production

The maize plant is prone to a lot of problems in production including diseases, pests and drought (Kanyamasoro *et al*., 2012).

2.5.1 Diseases of Maize

Disease is a major problem limiting maize production. They are important because they can lead to a reduction in plants' ability to intercept solar radiation, reduced plant population, an elevated level of plant lodging which all culminate into reduced yield and worth of the grains (Iowa University Extension, 2009). The weather of a particular place strongly influences disease incidence and as such disease incidence is different for every year. There are several diseases affecting the maize plant with most of these diseases being caused by fungi, bacteria and viruses, with a few being caused by other organisms.

Some common foliar diseases of maize caused by fungi include Downy mildews, Common rust, Polysora rust, Tropical rust, Tar spot complex, Turcicum leaf blight, Maydis leaf blight, Anthracnose leaf blight, Yellow leaf blight, Curvularia leaf spot, Septoria leaf blotch, Macrospora leaf stripe. Other fungal diseases include Pythium stalk rot, Head smut, False head smut, Aspergillus ear rots, Common smut etc. Diseases commonly caused by bacteria include Bacterial stalk rot, Stewart's wilt, Bacterial leaf stripe (The CIMMYT Maize Program, 2004).

Viral diseases also include Maize lethal necrosis, Maize streak, Maize chlorotic dwarf, Maize chlorotic mottle, Maize dwarf mosaic, Maize mosaic, Maize stripe, Maize rough dwarf, Maize fine stripe, Maize bushy stunt, Corn stunt (Adebayo *et al.*, 2015). Diseases of maize in Ghana that are of importance include maize streak, smuts, rust and bacteria blight (Adu *et al.*, 2014).

2.5.2 Pests of Maize

The maize plant has a lot of pests both on the field and in storage. Pests of maize include insects, rodents, birds, microorganisms and to a lesser extent some ruminants. Common rodents that attack maize include the ground squirrel and the grasscutter. Insects are however by far the most important of the pests of maize, causing severe damage both on the field and in storage. 20 different species of insects are reported to attack maize grains in storage (Udo, 2011). Some common insects that infest maize grains in storage in Ghana include *Sitophilus zeamais* (Motschulsky), *Prostephanus truncatus* (Horn) (larger grain Borer), Rice weevil, *Sitophilus oryzae* (L.), Granary weevil, *Sitophilus granarius* (L.) and the lesser grain borer, *Rhyzopertha dominica* (F.) (Rajashekar *et al*., 2012). Others include the stem borers, cutworms, grasshoppers, and termites (Adu *et al*., 2014). The maize weevil has however assumed principal status as the most devastating insect pest in Ghana (Issa *et al*., 2011). This has become possible because of the warm and humid climate of the country which is suitable for the rapid growth and multiplication of the maize weevil (Cash, 2011).

2.5.3 Biology of *Sitophilus zeamais*

Sitophilus zeamais is ranked among insects causing the greatest damage in storage to maize grains in most parts of the tropics and sub-tropics (Danho *et al*., 2002). The activities of the pests are so destructive that damage ranging from 20 to 90% has been recorded in untreated maize (Issa *et al*., 2011). The head of the maize weevil is projected, forming a snout, with the snout accounting for one – third of the maize weevil's body (Smith, 2013). It is normally black or brown in colour, with length between 0.25 to 0.45 cm. The maize weevil thus has an average length of 3 mm (Siwale, 2007). It ranges in colour from dull red-brown to black, with the elytra having four reddish stains on it (Alleoni and Ferreira, 2006). It is a very vigorous flyer owing to the fact that it has well developed wings with additional prominent legs. The lifespan of the maize weevil varies with temperature.

Life cycle is longer in cooler areas compared to warmer environments (Cash, 2011). For instance, the life cycle of the maize weevil at 25°C is 37 days and that at 18°C is 110 days. *Sitophilus zeamais* infestation commences on-field and continues into storage. Infestation occurs when the adult female of the maize weevil creates a hole on the grain by chewing into the grain, laying its eggs and sealing the hole created with a waxy (gelatinous) secretion (Siwale, 2007). The white, elliptical shaped egg hatches into a larva and continues through the four moulting stages to adulthood in the grain. The development from egg to adult can take 21 days to 62 days for susceptible and resistant genotypes respectively. The conditions, thus favourable for the normal growth of the maize weevil are 25 ± 5ºC of temperature and 69 ± 6% of relative humidity (Tefera *et al*., 2010). The fact that it completes its life cycle faster in warmer areas and the ability to fly very well, coupled with the fact that the female weevil is capable of laying 400 eggs in its lifetime under favourable conditions account for their rapid increase in population and the ease with which it spreads, especially in the tropics (Cash, 2011).

2.5.4 Economic Importance of the Maize Weevil

The maize weevil is capable of destroying an entire grain which is sound and as such is considered as a prime storage pest (Kanyamasoro *et al*., 2012). It is responsible for causing losses well above 80% in untreated maize grains and 20% in treated grains (Abebe *et al*., 2009). The adults and larvae of the maize weevil are strong feeders and can thus cause severe physical damage to the maize grains (Kim and Kossou, 2003). The problem of maize weevils causing huge losses to stored maize is helped by the fact that most parts of Africa, specifically Ghana, have a warm humid climate which promotes a very high insect activity throughout the year (Baidoo *et al*., 2011). The more obvious consequence of the feeding of the maize weevil on the grains is reduction in weight of the grains due to burrowing of the female into the grain and the feeding activities of the offspring once it has hatched. Other consequences include reduced nutritional value, reduced germination percentage, reduced aesthetic value and a corresponding reduction in market value (Abebe *et al*., 2009).

Since maize weevils are internal feeders, their activities which include excretion in the grain, moulting and their dead bodies contaminate the grains which further reduces the commercial value of the grains (Sallam, 2005). The destruction of the maize grains by the weevil also poses threat to the health of the consumer. Their activities lead to the introduction of mycotoxins by moulds which normally develop on the grains at elevated relative humidity (Zunjare *et al*., 2015). The presence of aflatoxins in the diet can lead to illness when consumed in small quantities but can eventually lead to death when large amounts are ingested (Akowuah *et al*., 2015).

2.6 Control of the Maize Weevil

2.6.1 Synthetic pesticides

The first line of defence for most farmers in Ghana and many parts of Africa, when it comes to protecting maize grains from maize weevil infestation, is the use of synthetic chemicals (Chikukura *et al*., 2011). Pesticides serve as an important feature that ensures that farmers record increasing yield since their introduction in the 1950's. But there have been lots of concerns with regard to the use of synthetic pesticides in recent times (Pereira *et al*., 2009). Some common ones include the toxic effect on non-target organisms, pesticide residues found in food, high cost of some chemicals to the resource-poor farmer, unavailability of certain pesticide formulations to the rural farmers and insect resistance development to these insecticides (Mwololo *et al*., 2012). Abuse of these synthetic pesticides also leads to gradual reduction in reproduction potential of humans and eventually death (Saxena *et al*., 2014). Hence the continuous search for an alternative method which is safe to human health and does not lead to loss of biodiversity for the control of the maize weevil.

2.6.2 Botanicals

Botanicals are plant products or extracts that have lethal (insecticidal) effects as well as medicinal properties (Salako *et al*., 2008). The use of botanicals or phytochemicals have received much consideration and research in recent times because of the ever-increasing side effects of synthetic pesticides to human health. Botanicals have been in use for centuries, by peasant farmers in Africa and Asia but is gaining prominence in recent times as a non-toxic and cheap alternative to the synthetic pesticides (Issa, 2015). Other advantages of botanicals are that they are freely degradable even under situations of overdose. Most or all of them have no residual effects, and are locally available and easily accessible to the peasant farmer (Saxena *et al*., 2014).

Almost 2000 plant species have been identified worldwide to possess insecticidal properties. Among these, *Azadirachta indica* (Neem), *Vitellaria paradoxa* (Shea Tree), *Capsicum annuum* (Chilli pepper), *Citrus sinensis* (Sweet Orange), *Lippia multiflora* (Gambian tea bush), *Chamaecrista nigricens* (Black grain), *Combretum* spp. (bushwillows), *Khaya senegalensis* (African mahogany), *Ocimum americanum* (sweet basil), *Pterocarpus erinaceus* (barwood), *Synedrella nodiflora* (Nodeweed), *Pleiocapa* *mutica* (kanwene), *Securidaca longepedunculata* (violet tree), *Cassia sophera* (Sophera Senna), *Cymbopogon schoenanthus* (camel grass), *Mitragyna inermis* (yiela) have been used by farmers for the control of storage pests in Ghana (Belmain and Stevenson, 2001; Quattrocchi, 2012; Seidemann, 2005).

Neem and Pyrethrum have been extensively studied and are well exploited commercially for the control of storage pests (Dubey *et al*., 2008). There have also been several studies evaluating the effectiveness of some of these plants alone and their combinations in the control of storage pests. An experiment conducted by Issa *et al*. (2011a) showed that black pepper seed powder was the most effective in the control of maize weevil at a rate of 50 g/100 kg maize. They also found out that black pepper seed powder did not only cause death of the insects, but also prevented the feeding of the maize weevils.

In another study, cotton seed oil was reported to stabilize extracts of pyrethrum and thus increase the efficiency of the pyrethrum extracts when used to control the maize weevil (Wanyika *et al*., 2009).

Some problems however limit the use of botanicals in Africa and Ghana specifically. Botanicals, although mostly safe to humans and the environment as a whole, have different levels of efficacy and do not persist when applied (Isman, 2008). Botanicals do not persist because they break down easily in the presence of sunlight, air and moisture (Guleria and Tiku, 2009). This means that the botanical insecticides will have to be applied more frequently to be effective. More frequent application makes the use of botanical insecticides more expensive than synthetic pesticides (Guleria and Tiku, 2009).

Synthetic pesticides are very persistent and have known mode of action and level of efficacy.

2.6.3 Sanitation

Another effective, cheap and practical way of managing the maize weevil is observance of proper sanitations. Ensuring proper sanitation in the storage units before the introduction of new stock greatly reduces the need to use synthetic pesticides. Maintaining proper sanitation seeks to disrupt the developmental cycle of the maize weevil (Kasozi, 2013). Proper sanitation involves the removal of grains from the previous year's harvest, removal of any infested materials from the store room, fixing and sterilizing of floors, cracks and fractures in the storage unit (Jacobs and Calvin, 2001).

2.6.4 Hermetic control

Hermetic control system is a type of insect pest control method that basically seeks to reduce the concentration of oxygen in the container used while increasing the carbon dioxide concentration, eventually asphyxiating any insect pest present (Yakubu *et al.*, 2011). Silos are very important and common equipment necessary for the successful adoption of hermetic control method (Kasozi, 2013). Super grain bags have been developed as alternatives to the Silos to cater for the needs of resource-poor farmers in Africa and Asia who cannot afford the silos (De Groote *et al.*, 2013). In an experiment conducted in Ghana, the Triple layer bagging without pesticides was found to be an effective, cheap and environmentally friendly method of controlling the maize weevil (Anankware *et al*., 2012).

2.6.5 Biological control

The control of insect pests using biological agents is another method that is effective and gradually gaining popularity. This method is becoming popular because it hardly leaves any residues that are dangerous to the environment. They are actually natural enemies to pests that need control. Biological agents also continue to multiply and increase in numbers provided their hosts (pests) remain alive and the conditions are favourable for their survival (Flinn and Schöller, 1996). The idea behind the use of biological control is to inundate. Hence there is the need to know the exact time of release to allow the biological agents to outnumber the pests for effective control.

Some common biological agents for the control of insect pests include bacteria (*Bacillus thuringiensis*), parasitoids (*Theocolax elegans*), fungi (*Beauveria bassiana*), protozoa, and viruses (Flinn *et al*., 2006). Biological agents that have been used successfully for the control of the maize weevil include *Beuaveria* species specifically *Beuaveria bassiana*, and *Fusarium* species. *Fusarium verticolloides* has also been used for the control of weevil but its use is being discouraged because of the fact that it is pathogenic (Kasozi, 2013). Some of the known disadvantages of the biological control method is that there is the need for more information on the natural enemy and the host in order to know the exact time to synchronize the release of the natural agent. Biological agents have to be released early in order to rapidly outnumber the pests. Thus biological control is not advisable in pest outbreak conditions (Flinn and Schöller, 1996).

2.6.6 Host- plant resistance

In the protection of the maize grains from maize weevil attack, the plant itself is the first line of defence. The plant protects itself by employing physical barriers that restrict the feeding of the maize weevil (Kasozi, 2013). As an example, plants that possess very good husk cover are able to reduce field infestation by weevils to a greater extent. Good husk cover also discourages feeding by birds (Demissie *et al*., 2008). A maize plant has good husk cover when the husk covers the cob past the tip, and is very tight. However, most of the maize varieties in Africa lack very good husk cover, hence increase in maize weevil infestation (Abadassi, 2015). Maize plants with grains that possess hard kernel, bulky kernel size and a smooth grain texture are able to resist attack by the maize weevil (Gudrups *et al*., 2001).

Maize varieties resistant to the maize weevil have also been reported to possess phenolic acids in the pericarp and the aleurone layer (Demissie *et al*., 2015). Phenolic acids confer resistance in two ways; the first is through antibiosis due to the presence of phenolic acid amides which discourages the *S. zeamais* from using the grain for the purposes of feeding and oviposition (García-Lara *et al*., 2009) and secondly, through mechanical resistance. Maize grains reported to be resistant to the maize weevil have strong pericarps with high concentration of hydroxycinnamic acids (García-Lara *et al*., 2004). Host plant resistance can thus help to reduce maize weevil population drastically, at no apparent cost to the farmer. Plants that are however resistant to the maize weevil are not many (Derera *et al*., 2010). This has come to be the case because research works that have been conducted down the years have mostly not focused any attention on improving grain storage, but rather to increase yield, quality and tolerance to biotic and abiotic stresses (Demissie *et al*., 2008; Kanyamasoro *et al*., 2012).

Progress is finally being made in the identification, breeding and incorporation of maize resistant traits into elite genotypes (Derera *et al*., 2014). Maize weevil resistance has actually been reported by some scientists in their works conducted separately and under different conditions. Mwololo *et al*. (2012) in Kenya were able to identify two maize hybrids (CKPH08003 and BRAZ2451) that had good performance and were also resistant to the maize weevil. Tefera *et al.* (2013b) also identified CKPH08025 and CKPH08009 as hybrids that possess resistance to the maize weevil and the fact that they are also high yielding. There was also another report by Abebe *et al*. (2009) about the identification of BHQP-542 as a resistant variety among a total of 13 improved genotypes that were evaluated. It was identified as the genotype with the lowest index of susceptibility and was thus reported as resistant. Finally, work done by Kanyamasoro *et al*. (2012) in Uganda identified WL118-9 as a moderately resistant genotype with a susceptibility index of (SI=5.4) out of all the genotypes they tested.

2.7 Maize storage and weevil infestation

Conventionally, maize in Ghana is stored in cribs outside of the farmers' house mostly when not dehusked. Maize can also be dehusked and shelled, but when in this form, they are stored in sacks or other suitable containers (Adu *et al*., 2014). Research is also being conducted on the use and efficiency of the Triple layer bagging method. The Triple layer bag is made up of light and transparent polyethylene bags which are used to line the jute bags. Thus, it has double layer of the polyethylene bags which is then used as an insert for the jute bag. Apart from the fact that these bags are cheap and thus can be afforded by the local farmer, it also has the advantage of killing storage pests including the maize weevil (Anankware *et al*., 2012). Silos are also very important storage facilities for maize. They are also excellent in serving as hermetic control systems and thus restricting the activities of the maize weevils (De Groote *et al*., 2013).

The state of the grains also influences storage. Maize grains with elevated moisture content will have more attacks from weevils than grains that are effectively dried to moisture contents that are equal or less than 11% (Tefera *et al*., 2011). Another factor that influences weevil activity in storage is husk cover. Although this practice is not feasible with respect to commercial farming, undehusked cobs stand a better chance against weevil attack than dehusked or shelled grains. Other factors that affect the populations of the weevils in storage and to a greater extent their level of destruction include temperature and relative humidity (Ileleji *et al*., 2007).

2.8 Resistance mechanisms

Resistance mechanisms in plants are presented in three main groupings; Antibiosis, Antixenosis and Tolerance (Smith and Clement, 2012).

Antibiosis is in play when the plant affects the insect negatively in such a way that it disturbs the insect's oviposition, reproduction and growth in general. Antibiosis can be morphological or through chemical means (Meihls *et al*., 2012). Volatiles from plants can also act as attractants to enemies that control the insect pests. Morphological presentation of antibiosis can be in the form of lignin content and husk cover (husk firmness) (Meihls *et al*., 2012).

Antixenosis is when the plant is not attractive to the insect in such a way that it delays the usage of the plant for oviposition and reproduction or the complete avoidance of the plant for both oviposition and reproduction (Mikami *et al*., 2012). Plant physical characteristics such as waxes, thickness of tissue, colour of grain, shape of grain etc. demonstrate antixenosis (Meihls *et al*., 2012).

Tolerance is when the plant produces appreciable yield despite supporting an insect population. The plant suffers injury from the activities of the maize weevils, but can still produce very good yield (Smith and Clement, 2012).

2.9 Resistance breeding against *S. zeamais*

Resistance breeding involves identification of grains possessing traits of interest and the screening of these genotypes to identify whether the traits are present or absent. After screening, genotypes could be either susceptible, moderately susceptible, moderately resistant, and resistant. Parameters that will help a breeder identify a resistant variety comprise hardiness of the grain, weight of the grain after infestation, damage suffered by the grain after infestation, adult mortality, median development time, time taken for F_1 weevil emergence, good husk cover, pericarp thickness, grain size, number of F_1 progeny that emerged (Abadassi, 2015; Demissie *et al*., 2008). Several researchers have reported the strong link between these parameters mentioned above and weevil resistance in maize (Abebe *et al*., 2009; García-Lara *et al*., 2004; Siwale *et al*., 2009).

Three different methods have been developed for the successful screening of maize to determine resistance. These methods were developed by Dobie (1974), Urrelo *et al.*

(1990) and Derera *et al*. (2010). Dobie's method utilizes time to 50% emergence (Median Development Period) and the entire F_1 offspring emergence to calculate resistance or susceptibility (Kanyamasoro *et al*., 2012). The value obtained is compared to a scale of 1 to 13. Dobie's method is generally regarded as laborious since it requires the determination of sex of the weevils to be used in the experiment. The procedure thus requires great experience and skill, making it a difficult endeavour to pursue especially for new researchers (Derera *et al*., 2010).

The other two methods are modifications of Dobie's method. The method by Urrelo *et al*. (1990) is also not very popular since it takes a longer time than Dobie's method to achieve the same results (Gudrups *et al*., 2001).

The protocol developed by Derera *et al*. (2010) is gradually gaining popularity and is generally recommended for quick screening of maize genotypes for resistance to the maize weevil because it requires a shorter time (45–56 days) to achieve the desired results as compared to that of Dobie which requires at least 90 days for screening and does not involve sex determination. Based on these parameters and protocols, some scientists have been able to screen and isolate genotypes that possess some level of resistance to maize weevil infestation. As an example, García-Lara *et al*. (2004) discovered high amounts of phenolic acids as well as other chemical compounds in the pericarp of the maize grains which was linked to grain hardiness and thus conferring some level of resistance. After the identification of genotypes with maize weevil resistance traits, the next step is how these traits can be passed on to the next generation. The successful transfer of resistance from parents to the hybrids is however stalled due to inability of inbred lines to effectively transfer useful traits to hybrids (Dari *et al*., 2010). The correlation for weevil resistance can be strengthened by crossing parents that are both resistant and thus increasing the level of resistance in the hybrid produced (Dhliwayo and Pixley, 2003). Studies by GarcíaLara *et al*. (2009) revealed that parents that were susceptible to the maize weevil possessed genes for resistance. This result establishes the need to know about the gene action involved in weevil resistance with specific attention to additive gene action in the development of weevil resistant genotypes.

2.10 Genetic control for resistance to the maize weevil

The term combining ability refers to the situation when it is a researcher's interest to find out the performance of parents in hybrid combination (Griffing, 1956). General combining ability and specific combining ability are two important terms that come to mind when dealing with combining ability. General combining ability (GCA) can be defined as the mean performance of a parental line in hybrid combination. When some hybrids actually perform better or worse than what is expected of them with respect to the mean performance of the parental lines used, then we are dealing with specific combining ability (SCA) (Kasozi, 2013).

The importance of determining the combining ability of a particular genotype is that it helps the breeder determine the particular breeding technique that will help improve the genotype (Makumbi *et al*., 2011). Hence General combing ability is important because its occurrence is linked with additive gene action while Specific combining ability is important because it is linked with non-additive gene action, which could either be dominance or epistatic gene action. In the light of this, several works done by researchers around the world, have highlighted the importance of General combing ability and

Specific combining ability and its related gene action in the selection of appropriate breeding methods for the introgression of maize weevil resistance into elite cultivars (Bello and Olaoye, 2009). In the research conducted by Abakemal *et al*. (2011) in Ethiopia, it was realized that resistance to the maize weevil was due mainly to additive gene action with non-additive gene action contributing only a small proportion. This is similar to work done by Kanyamasoro *et al*. (2012) who discovered that additive gene action was more significant in maize weevil resistance than non-additive gene action. However, additive, non-additive and maternal properties were significant in determining resistance to the maize weevil in the hybrids that were screened by Kim and Kossou (2003).

This result is similar to the outcome of the work done by Kasozi (2013) who also identified additive, non-additive and maternal effects as important factors conditioning resistance to maize weevils. Dari *et al*. (2010) also found out that, different gene actions were important for different parameters measured. For instance, additive gene action was more important than non-additive gene action for the total number of weevils that emerged and for total weight loss at the end of the experiment. Again, additive gene action was more essential than non-additive for kernel size and weight. They finally found out that when it came to kernel hardiness, additive and non-additive gene action both had the same level of importance. These results indicate that weevil resistance exists, and even though weevil resistance in maize is an intricate trait, advancement is possible.

2.11 Mating Designs

Breeders mate or cross plants mainly to gain knowledge and understanding about genetic control of a particular trait being studied. It also serves as a means to generate base population when starting a project or breeding programme (Acquaah, 2012). There are several mating designs that are chosen based on the breeder's objective and expected outcome. Some of the well-known mating designs include Biparental mating design, North Carolina I mating design, North Carolina II mating design and the Diallel mating design.

Diallel crosses involve the crossing of parents in all combinations which includes reciprocals and the selfs. The most significant mating design for estimating General combing ability (GCA) and Specific combining ability (SCA) is the Diallel mating design. The Diallel mating design also provides more valuable information about the population than the other mating designs (Acquaah, 2012).

CHAPTER THREE

3.0 MATERIALS AND METHODS

The experiment was in two parts. The first part was the field evaluation and the second part was the laboratory evaluation for weevil resistance.

3.1 Field evaluation

3.1.1 Experimental site

The field evaluation was undertaken at the Finatrade Field of the Animal Science Department of the Faculty of Agriculture, Kwame Nkrumah University of Science and Technology (KNUST)-Ghana: lat. 6.40^o, long. 1.37^o, 300 meters above sea level (masl) with 1400 mm of rainfall annually. The type of soil on the field is the haplic Alisols.

3.1.2 Genotypes used

Five inbred lines, TZEEQI – 12, TZEEQI – 61, TZEEQI – 66, TZEEQI – 111, TZEEQI – 139 were obtained from the International Institute of Tropical Agriculture (IITA). These inbred lines were chosen for their quality protein and high yield. The inbred lines were planted on the field and later crossed using a complete diallel mating design to obtain 20 hybrids and five parental lines.

Table 3.1: Origin and pedigree of the parental lines

Entry	Name	Pedigree
1	TZEEQI – 61	TZEE-W POP x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC2S5 (7) 4/9-3/8-1/3
2	TZEEQI – 12	TZEE-W Pop x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC1S5 (7) 10-10-10-10

3	TZEEQI - 111	TZEE-W Pop x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC2S5 (7) 6/9-8/8-2/3
4	TZEEQI - 139	TZEE-W POP x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC2S5 (7) 8/9-5/7-3/5
5	TZEEQI - 66	TZEE-W POP x 1368 STR S7 Inb 40 x Pool 15 SR QPM BC2S5 (7) 4/9-4/8-4/6

Source: International Institute of Tropical Agriculture

Table 3.2: Diallel crossing of the five inbred lines

	TZEEQI – 61	**TZEEQI – 12**	**TZEEQI – 111**	**TZEEQI – 139**	**TZEEQI – 66**
TZEEQI – 61	61 × 61	12× 61	111× 61	139 × 61	66 × 61
TZEEQI – 12	61 × 12	12 × 12	111 × 12	139 × 12	66 × 12
TZEEQI – 111	61 × 111	12 × 111	111 × 111	139 × 111	66 × 111
TZEEQI – 139	61 × 139	12 × 139	111 × 139	139 × 139	66 × 139
TZEEQI – 66	61 × 66	12 × 66	111 × 66	139 × 66	66 × 66

61 = TZEEQI – 61, 12 = TZEEQI – 12, 111 = TZEEQI – 111, 139 = TZEEQI – 139, 66 = TZEEQI – 66

Seeds of the 20 hybrids and five parental lines were harvested and planted again in the second season in a Randomized Complete Block Design. The hybrids were randomized separately from their parental lines. The seeds were planted on the Finatrade field with two seeds per hill and spaced at 75 cm by 40 cm. There were two rows per plot. The number of plants on each row were 25, making a total of 50 plants per plot. The area of a plot was 7.5 m^2, as such the number of plants on a per hectare basis will be 66,667 plants. Two checks, namely Abontem and Dodzi were included, with the former being a Quality Protein Maize which is known to be susceptible to the maize weevil and the latter being a normal maize variety, also known to be moderately resistant to the maize weevil. The checks were obtained from the Crops Research Institute of the Council for Scientific and Industrial Research (CSIR-CRI), Fumesua, Ghana. All agronomic practices necessary for maize production were duly followed.

3.1.3 Calculation for yield

Cobs were harvested at physiological maturity, dehusked and subsequently weighed to obtain the field weight. The cobs were then pooled together according to their respective genotypes. Samples were taken from each of the genotypes and the moisture content recorded by means of a moisture tester (John Deere). The remainder of the grains was sundried to a uniform moisture content. The grains were transported to the laboratory and kept in a freezer in preparation for the laboratory work.

Grain yield was calculated as:

$$\text{Grain Yield (t/ha)} = \text{EWT} \times \frac{(100 - Gmoi)}{85} \times (10000 \times 0.80)$$

Where: EWT = Ear Weight,

Gmoi= Grain Moisture Content,

0.80 = Shelling Percentage

3.2 Laboratory evaluation

3.2.1 Experimental site

The laboratory experiment was conducted in the insect laboratory of the Faculty of Agriculture, KNUST, Kumasi.

Seeds of the 20 hybrids, five parental lines and the two checks were used for the laboratory experiment. The harvested seeds were first kept in a freezer for 14 days at a temperature of -20 ± 2°C to kill weevils or any other pests that might have accompanied the seeds from the field. The seeds were then removed and placed in glass jars and maintained at room temperature for one week for acclimatization to achieve uniform grain temperature and moisture content among all samples. The seeds were then dried to a moisture content of 11 – 12% before artificial infestation.

3.2.2 Culturing of Maize Weevils

A culture of *S. zeamais* was set up at the insect laboratory of the Entomology section of the Department of Crop and Soil Sciences of the Faculty of Agriculture, KNUST. For this, 250 g of Obatanpa, a susceptible maize variety was placed into 1 litre Kilner jars and each infested with 100 unsexed weevils. There were six of these cultures to ensure that there was enough weevil progeny for the actual artificial infestation. For each weevil collection, two cultures were setup. After oviposition for a period of 10 days, the adults were sieved off and the grains plus the eggs were put back into the Kilner jars. The setup was monitored for progeny emergence. Plate 1 shows the set-up of the culture of maize weevils.

Plate 1: Culturing of maize weevils in Kilner jars

3.2.3 Artificial infestation

The maize weevils were obtained from three regions of Ghana; namely, the Northern, Ashanti and Greater Accra Regions. Thirty grams each of the 25 genotypes plus the two checks were weighed and put in plastic containers (250 ml). Very large holes were created on the lids of each of the containers and later fitted with Muslin clothes to allow for ventilation. Each of the weevil collection was used on the 27 genotypes, and each replicated three times, giving 81 containers for each weevil collection. In all, there was a total of 243 containers. The experimental design employed was a 27 × 3 Factorial, arranged in a completely randomized design. Each of these containers containing 30 g of maize grains was inoculated with 10 unsexed seven – day old maize weevils. After an oviposition period of 10 days, the adult weevils were sieved out and the grains containing the eggs were put back into each of their respective containers. This was done to ensure that any weevil emerging was truly F_1 progeny emergence. The average temperature and relative humidity in the insect laboratory was measured with a HOBO data logger and was found to have 29°C of temperature and of 71% RH. Plate 2 shows the actual artificial infestation.

a **b**

Plates 2 (a, b): layout of laboratory cultures

The whole setup was monitored for new emergence of F_1 progeny. F_1 progeny emergence began 21 days after sieving out adult weevils. Grains in each container was sieved daily and the weevils that emerged were counted and recorded. This continued until no F_1 progeny was seen emerging from any of the containers. After this period, the number of F_1 progeny that emerged from each container was summed up to obtain their total numbers.

3.3 Data collection

The following data were taken in the course of the laboratory evaluation.

3.3.1 Percentage mortality

Ten days after artificial infestation, the adult weevils were sieved out of each container. The number of dead and live adult weevils were recorded for each genotype (including the local checks).

Dead weevil was determined by pricking the weevil several times with camel hair brush. When there was no coordinated movement from the weevil, it was recorded as dead. The number of weevils found dead for each genotype was used to calculate percentage mortality.

3.3.2 F_1 weevil emergence

This parameter involves obtaining the total number of weevils emerging from each genotype at the end of the experiment.

3.3.3 Median Development Period (MDP)

This is the time to 50% emergence of the F_1 weevil progeny (Kanyamasoro *et al*., 2012). This was calculated as the number of days from day 5 of the period of oviposition to the time when 50% of the F_1 progeny emerged.

3.3.4 Percentage weight loss

After F_1 weevil emergence had ceased, the total number of grains in each container was counted and recorded. The number and weight of grains with or without holes were also recorded. Weight loss was calculated with the formula by Gwinner *et al*. (1996).

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

Where

Wu = Weight of undamaged seeds,

Nu = Number of undamaged seeds,

Wd = Weight of damaged seeds, and

Nd = Number of damaged seeds

3.3.5 Susceptibility index

Susceptibility index was also computed as:

$$\text{Index of susceptibility} = \frac{\text{Log}_e\ (\text{total number of } F_1 \text{ progeny emerged}) \times 100}{(median\ development\ period)}$$

Where: $\mathbf{F_1}$ = total number of adults emerged and, $\mathbf{Log_e}$ = Natural logarithm.

After calculation, the genotypes were classified based on the susceptibility indices obtained according to the scale of Dobie as 1.0 – 4.0 = resistant, 4.1 – 7.0 = moderately resistant, 7.1 – 10.0 = moderately susceptible, 10.1 – 13.0 = susceptible, and ≥ 13.1 = highly susceptible.

3.4 Analysis of data

Data collected was analyzed using the SAS statistical software version 9.1 (GLM). Thus, GCA and SCA were estimated for the five parental lines. Baker's ratio was used to determine the importance of the general combining ability (GCA), and the specific combining ability (SCA) (2GCA/2GCA+SCA) (Baker, 1978). General combining ability (GCA) is considered to be important in predicting progeny performance when the ratio approaches unity (Baker, 1978).

Some laboratory data analyzed included the quantity of adult *Sitophilus zeamais* dead, F_1 *Sitophilus zeamais* emergence, median development time, grain weight loss, and grain damaged, for the purpose of identifying weevil resistance. Field data including yield, plant height, ear height and husk cover were also analyzed by subjecting the data to general linear modeling (GLM) using the SAS statistical software version 9.1. Differences between means were separated using least significant differences at a probability level of 5%.

3.4.1 Grouping genotypes

Genotypes were grouped based on their response to the weevil resistance parameters measured, namely F_1 weevil progeny emergence, percentage grain damage, percentage grain weight loss, median development time (MDP), and susceptibility index.

3.5 Heritability estimates.

Heritability in the narrow sense for percentage adult mortality, F_1 weevil progeny emergence, median development period, percentage grain weight loss, percentage grain damage and Susceptibility index were calculated using the relation:

$$\frac{Va}{Vp} \times 100$$

Where Va= additive genetic variance and Vp= phenotypic variance.

3.6 Estimation of Heterosis

Estimates of mid – parent heterosis and better parent heterosis were determined for each hybrid.

Mid - parent heterosis = $\left(\frac{F_1 - MP}{MP}\right) \times 100$

Where: F_1 = the mean performance of the hybrid

MP = the average performance of the two parents that produced the hybrid

Better Parent Heterosis = $\left(\frac{F_1 - BP}{BP}\right) \times 100$

Where: F_1 = the mean performance of the hybrid

BP = The parent with the highest mean performance

CHAPTER FOUR

4.0 RESULTS

4.1 Yield parameters and agronomic performance of genotypes

Analysis of variance of results obtained on yield parameters are presented in Table 4.1. There were significant differences among genotypes for ear height ($p \leq 0.05$), hundred grain weight ($p \leq 0.05$) and husk cover ($p \leq 0.01$). Yield and plant height however did not produce any significant differences among the genotypes tested. The contribution of general combining ability effect was significant (p≤ 0.01) for ear height, hundred grain weight and husk cover but not for yield and plant height.

Table 4.1: Mean square for yield (t/ha), plant height (cm), ear height (cm), one hundred seed weight (g) and husk cover (%).

		Mean Squares				
Source	**DF**	**Yield (t/ha)**	**Plant height (cm)**	**Ear height (cm)**	**HUNGWT (g)**	**HuskC (%)**
Genotype	24	3.82	486.63	201.56*	10.41*	0.60**
GCA	4	5.90	667.31	583.54**	22.14**	0.94**
SCA	10	3.97	599.67	199.94	9.67	0.31
REC	10	2.84	301.33	50.40	6.47	0.75**
Error		3.64	338.58	113.89	5.81	0.25
GMean		4.75	94.12	46.32	13.11	2.15
CV%		40.17	19.55	23.04	18.39	23.04
GCA/SCA		1.49	1.11	2.92	2.29	3.06
CHECK1(A)		4.39	104.90	53.33	15.43	2.00
CHECK2(D)		5.54	114.20	67.20	18.74	2.07

* = P≤ 0.05, ** = P≤ 0.01, *** = P≤ 0.001. CHECK 1(A)= Abontem, CHECK 2(D)= Dodzi.

GCA was significant for ear height, hundred grain weight and husk cover all at a probability level of 1%.

The mean performance of genotypes in relation to ear height, hundred grain weight and husk cover are shown in Table 4.2. Hybrid 15 (TZEEQI - 139 × TZEEQI - 111) was the best genotype for both ear height and hundred grain weight (Table 4.2). However, it performed poorly in the aspect of husk cover, with a mean husk cover below both local checks. Hybrid 4 (TZEEQI - 61 × TZEEQI - 66) was the best genotype with respect to husk cover.

S5 (TZEEQ1 66) was the highest among the inbred lines for ear height. The strongest performance of the inbred lines was in husk cover where four out of the five inbred lines were among the ten best genotypes, presented in the respective order as S1= TZEEQI 61, S2= TZEEQI 12, S5= TZEEQI 66, S3= TZEEQI 111. Husk cover is an important agronomic parameter that helps reduce weevil infestation on the field.

Table 4.2: Mean performance of genotypes for ear height, hundred seed weight and husk cover.

Genotypes	Ear height (cm)	Hundred grain weight (g)	Husk cover (%)
H1	34.03	12.54	2.07
H2	53.17	12.96	2.00
H3	43.63	12.56	2.73
H4	39.97	10.39	3.13
H5	35.63	10.29	2.67
H6	45.23	10.92	2.00
H7	56.47	15.09	1.40
H8	46.43	15.79	1.67
H9	58.37	14.98	2.07
H10	39.23	9.35	2.80
H11	51.17	13.52	1.80
H12	50.67	13.30	2.53
H13	50.43	14.40	1.60
H14	50.52	12.58	2.00
H15	59.73	16.11	1.80
H16	51.40	14.70	1.67
H17	37.67	13.14	2.07
H18	44.63	13.84	2.20
H19	59.50	15.10	1.67
H20	46.03	13.92	2.07
S1	28.13	12.01	2.73
S2	37.13	10.98	2.67
S3	44.67	10.75	2.20
S4	46.80	15.02	1.93

S5	47.37	13.38	2.40
LSD (0.05)	3.50	0.79	0.16
MEAN	46.32	13.11	2.15

4.2 Response of the maize genotypes to *S. zeamais.*

Their mean square values indicate that environmental influence was only significant for percentage adult mortality (Table 4.3).

Table 4.3: Mean squares of *S. zeamais* resistance parameters for 25 genotypes and two local checks.

SOURCE	DF	Mean Squares					
		% MORTALITY	F_1	MDP	%WL	%GD	DIS
Regional collections (R)	2	0.08*	0.04	11.53	0.01	0.01	2.69
Genotype (G)	24	0.04	0.24***	19.76*	0.01**	0.04**	18.98***
G*R	48	0.04*	0.09	11.46	0.01	0.02	4.64
Error		0.03	0.10	12.38	0.01	0.02	4.86
GMean		5.87	52.41	33.65	4.79	26.69	11.27
CV%		82.01	19.48	10.46	35.92	26.50	19.56
CHECK 1(A)		0.00	26.67	35.00	3.17	18.44	8.17
CHECK 2(D)		10.00	26.33	34.56	2.35	23.54	8.60

* = P≤ 0.05, ** = P≤ 0.01, *** = P≤ 0.001. CHECK1(A)= Abontem. F_1= F_1 weevil progeny emergence, MDP= Median Development Period, % WL= percentage weight loss, % GD= percentage grain damage, DIS= susceptibility index. CHECK 1(A)= Abontem, CHECK 2(D)= Dodzi.

Genotype was significant for F_1 Progeny emergence (P≤ 0.001), median development period (P≤0.05), percentage grain weight loss (P≤ 0.01), percentage grain damage (P≤ 0.01) and susceptibility index (P≤ 0.001). General combining ability was significant for Median development period (P≤ 0.001), F_1 weevil progeny emergence (P≤ 0.001), percentage grain damage (P≤ 0.001) and Susceptibility index (P≤ 0.001). Both percentage adult mortality and percentage grain weight loss had significant Specific combining ability at 5% probability level. Genotype × weevil collection interactions were significant for percentage adult mortality (P≤ 0.05). Reciprocal crosses were significant for percentage weight loss alone.

There were significant variations in five of the weevil resistance parameters measured among the genotypes tested (Table 4.4). The differences measured among the genotypes for the five parameters confirm the presence of resistance mechanisms among the genotypes tested.

Inbred line S2 (TZEEQI 12) had the highest mean percentage adult weevil mortality (16.67). It performed better than all the hybrids, the two local checks inclusive. Hybrid H17 (TZEEQI 66 × TZEEQI 61) had the lowest mean percentage adult weevil mortality (1.11).

The mean square values for F_1 progeny emergence reveals that there were significant differences among the genotypes for this weevil resistance parameter. Hybrid H15 (TZEEQI 139 × TZEEQI 111) was the best genotype, supporting the lowest number of F_1 weevils (23) but not significantly different from the two local checks. Inbred line S3 (TZEEQI 111) was the best inbred line and the sixth best genotype in terms of supporting fewer F_1 weevil progeny (42). Hybrid H17 (TZEEQI 66 × TZEEQI 61) was the worst genotype for F_1 weevil progeny emergence. It recorded the highest mean number of F_1 progeny (73). It was significantly lower than the two local checks and the genotype mean.

Table 4.4: Mean performance of twenty hybrids and five inbred lines as affected by the six weevil resistance parameters.

Genotype	% Mort	F_1	MDP	%WL	%GD	DIS	Score
H1	6.67	68.33	32.00	3.45	31.16	12.97	-
H2	4.44	47.44	33.11	4.16	23.08	11.60	-

	H3	6.67	49.33	32.56	5.44	27.55	11.53	-
	H4	3.33	70.67	31.33	4.63	36.71	13.53	-
	H5	3.33	63.56	33.22	3.60	25.63	12.23	-
	H6	3.33	36.67	32.56	4.54	19.19	10.38	-
	H7	4.44	42.67	34.89	4.60	27.52	9.48	+
	H8	8.89	43.89	34.00	3.10	21.21	11.06	-
	H9	3.33	61.56	32.44	13.31	27.24	12.34	-
	H10	2.22	70.11	32.78	3.87	28.26	12.64	-
	H11	13.33	37.11	37.22	4.21	19.89	9.60	+
	H12	7.78	51.11	36.00	4.51	25.17	10.46	-
	H13	4.44	60.33	33.78	7.15	32.62	12.09	-
	H14	4.44	41.78	34.22	4.13	22.06	10.68	-
	H15	6.67	22.89	36.06	3.10	15.79	8.08	+
	H16	7.78	62.22	33.44	4.55	31.02	12.19	-
	H17	1.11	72.89	31.78	5.79	38.45	13.42	-
	H18	2.22	51.67	33.78	5.30	28.35	11.57	-
	H19	7.78	31.44	35.33	3.92	22.04	8.84	+
	H20	7.78	46.44	33.78	4.32	27.70	10.92	-
	S1	7.78	71.11	31.44	3.33	32.16	13.23	-
	S2	16.67	58.44	33.11	5.99	33.35	11.27	-
	S3	2.22	42.22	35.00	3.14	19.87	9.62	+
	S4	6.67	48.44	33.89	5.05	24.60	10.14	-
	S5	3.33	58.00	33.56	4.33	26.65	11.97	-
CHECK 1		0.00	26.67	35.00	3.17	18.44	8.17	+
CHECK 2		10.00	26.33	34.56	2.35	23.54	8.60	+
LSD (0.05)		2.52	7.25	0.65	0.97	2.90	0.47	
MEAN		5.87	52.41	33.65	4.79	26.69	11.27	

F_1= F_1 weevil progeny emergence, MDP= Median Development Period, % WL= percentage weight loss, % GD= percentage grain damage, DIS= susceptibility index, + = resistant, - = susceptible.

For median development period, hybrid H11 (TZEEQI 111 × TZEEQI 139) had the highest Median development period for the maize weevil. Its mean value of 37 was significantly higher than all the other genotypes tested. The best inbred line for median development period was S3 (TZEEQI 111). It ranked as the fifth best genotype out of the genotypes tested. Hybrid H4 (TZEEQI 61 × TZEEQI 66) produced the lowest median development period among all the genotypes (31). It had a significantly lower median development mean value than the two local checks and the genotype mean.

Percentage grain weight loss ranged from 3.1% for hybrids H8 (TZEEQI 12 × TZEEQI 66) and H15 (TZEEQI 139 × TZEEQI 111) to 13.31% exhibited by H9 (TZEEQI 111 × TZEEQI 61). The mean value for the best hybrids did not differ significantly from those of the local checks. Inbred line S3 (TZEEQI 111) was the best inbred line for percentage grain weight loss, placing third for the overall ranking of genotypes for percentage weight loss (Table 4.4). The mean percentage weight loss for inbred line S3 (TZEEQI 111) did not differ significantly from those recorded by the first two hybrids in the ranking and that of the two local checks.

Mean percentage grain damage showed that the genotype with the least mean percentage grain damage was hybrid H15 (TZEEQI 139 × TZEEQI 111) with a mean of 15.79%. It recorded a significantly lower grain damage than any of the other genotypes tested. Inbred line S3 (TZEEQI 111) recorded the lowest grain damage when the inbred lines were ranked. In the overall ranking of the twenty–five genotypes, S3 (TZEEQI 111) was the genotype with the third lowest percentage grain damage recorded (19.87%). Hybrid H17 (TZEEQI 66 × TZEEQI 61) recorded the highest percentage grain damage (38.45) among all the genotypes tested. It produced a significantly higher percentage grain damage than both checks.

Results for Susceptibility index indicated that hybrid H15 (TZEEQI 139 × TZEEQI 111) had the lowest susceptibility index. It had a significantly lower susceptibility index compared to the remaining twenty-four genotypes. It was however not significantly different from the two local checks. Inbred line S3 (TZEEQI 111) remained the best inbred line for Susceptibility index. In the overall ranking for the best genotype in terms of susceptibility index, inbred line S3 was the fifth. Hybrid H4 (TZEEQI 61 × TZEEQI 66) recorded the highest susceptibility index with a mean value of 13.53.

4.3 Classification of genotypes into groups based on the resistant parameters

Mean square values for the 20 hybrids and five inbred lines for some of the resistance parameters were employed in the classification of the genotypes into either resistant or susceptible classes.

4.3.1 Index of susceptibility

Classification of genotypes tested can be done based on the Dobie index of susceptibility. Based on this scale, none of the 25 genotypes was found to be resistant or moderately resistant (Figure 4.2). However, 20% of the genotypes belonged to the moderately susceptible class, 68% as susceptible and 12% as highly susceptible.

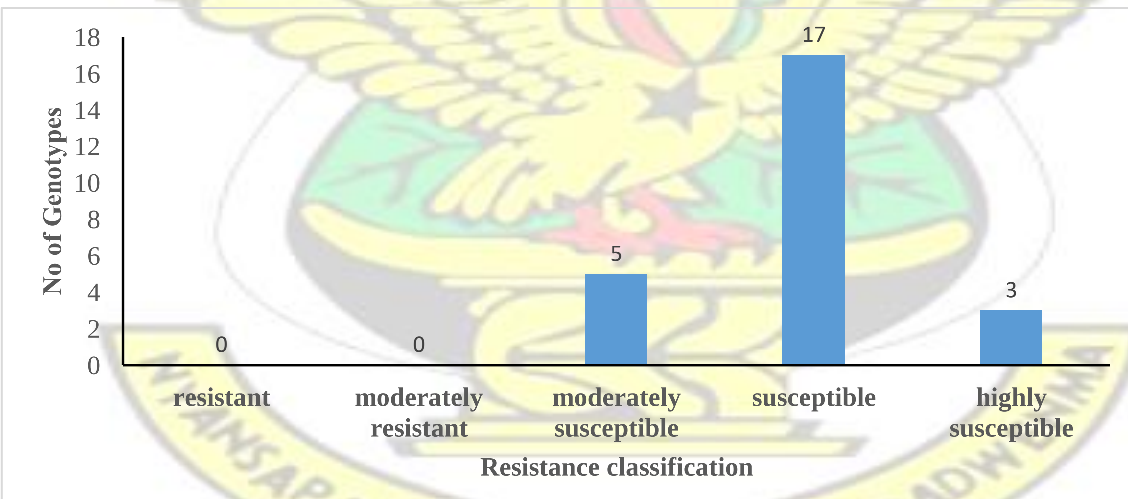

Figure 4.1: Resistance classification of 25 genotypes based on Dobie's index of susceptibility.

4.4 Genetic variation

The mean square values for percentage adult mortality reveal that SCA, genotype x weevil collection interaction and SCA × weevil collection interaction were significant ($p \leq 0.05$)

(Table 4.5). Calculation of the contribution of GCA and SCA to determine their relevance in percentage adult mortality indicated that GCA effects only contributed 15% while SCA effects contributed 85% of the genotype sum of squares.

The mean square values for F_1 weevil emergence also showed that genotype and GCA were significant at 0.1%. The evaluation of the influence of genetic effects governing F_1 weevil progeny emergence revealed that GCA effects contributed 75% while SCA effects contributed to 25%.

The mean squares for median development period revealed that genotype ($p \leq 0.05$) and GCA effects ($p \leq 0.001$) were significant. Concerning the determination of genetic effects that govern median development period, it was realized that GCA effects accounted for 65% while SCA effects accounted for 35% of the genotype sum of squares.

Table 4.5: Mean squares for weevil resistance parameters across the three regional collections.

		Mean Squares					
Source	**DF**	**% Mortality**	**F_1**	**MDP**	**% WL**	**% GD**	**DIS**
Regional Collections (R)	2	0.08*	0.04	11.53	0.01	0.01	2.69
Genotype (G)	24	0.04	0.24***	19.76*	0.01**	0.04**	18.98***
GCA	4	0.02	0.90***	72.10***	0.01	0.14***	77.48***
SCA	10	0.06*	0.08	15.85	0.01*	0.02	7.93
G*R	48	0.04*	0.09	11.46	0.01	0.02	4.64
REC	10	0.02	0.12	2.74	0.01*	0.02	6.63
GCA*R	8	0.04	0.09	9.05	0.01	0.03	4.64
SCA*R	20	0.05*	0.11	8.07	0.01*	0.02	3.85
REC*R	20	0.04	0.06	15.81	0.00	0.01	3.01
Error		0.03	0.10	12.38	0.01	0.02	4.86

GMean	5.87	52.41	33.65	4.79	26.69	11.27
CV%	82.01	19.48	10.46	35.92	26.50	19.56
GCA/SCA	0.37	10.26	4.54	0.66	7.48	9.77
CHECK 1(A)	0.00	26.67	35.00	3.17	18.44	8.17
CHECK 2(D)	10.00	26.33	34.56	2.35	23.54	8.60

* = P≤ 0.05, ** = P≤ 0.01, *** = P≤ 0.001. F_1= F_1 weevil progeny emergence, MDP= Median Development Period, % WL= percentage weight loss, % GD= percentage grain damage, DIS= Susceptibility index, R= regional collection, CHECK1(A)= Abontem, CHECK2(D)= Dodzi, GCA= general combining ability and SCA= specific combining ability.

Examining the mean square values for percentage grain weight loss revealed that genotype (p≤ 0.01), SCA effects (p≤ 0.05), reciprocal crosses (p≤ 0.05) and SCA × weevil collection interaction were significant. Figure 4.3 shows the contribution of GCA and SCA to the control of the weevil resistant parameters. Upon examination of the influence of genetic components to the control of percentage grain weight loss, it was realized that GCA effects contributed 11% while SCA effects contributed to 89% of the genotype sum of squares.

For percentage grain damage, the mean square values show that GCA effect was highly significant (p≤ 0.001). Genotype effect was also significant (p≤ 0.01). The proportion of genotype sum of squares that reveal the relevance of genetic effects towards the governance of percent grain damage was 69% for GCA and 31% for SCA.

Mean square values for Susceptibility index show that genotype and GCA effects were highly significant (p≤ 0.001). The contribution of GCA and SCA which shows the genetic effect that was important in the control of Susceptibility index revealed that GCA contributed 80% while SCA contributed 20%.

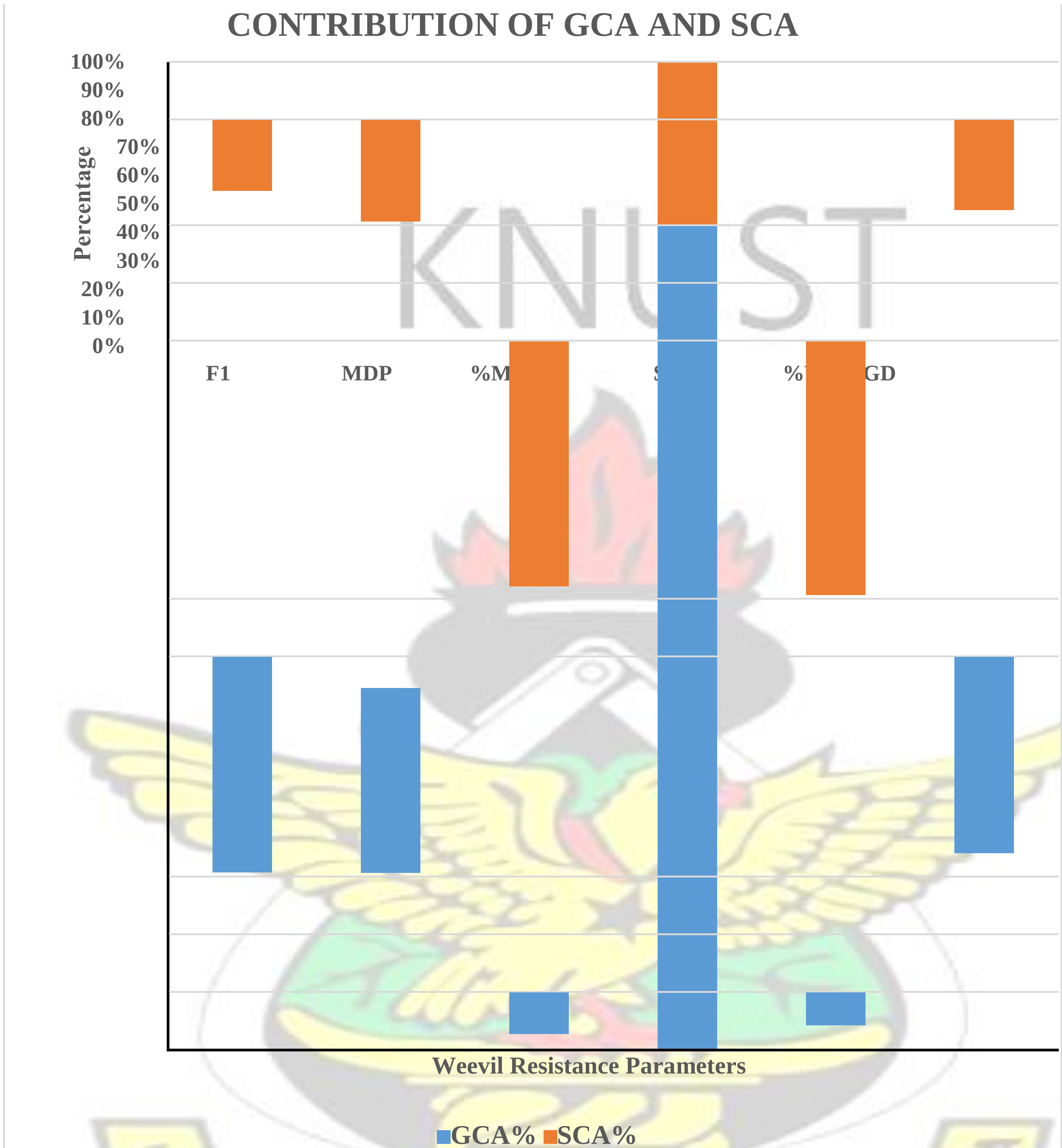

Figure 4.2: Mean contribution of GCA and SCA to the governance of each of the six weevil resistance parameters studied.

4.4.1 General combining ability estimates

Estimates of GCA effects for percentage adult mortality reveal that there was no significant effect for GCA (Table 4.6). For F_1 progeny emergence, P1 (TZEEQI 61) displayed a highly significant and positive GCA effects ($p \leq 0.001$). P3(TZEEQI 111) and

P4 (TZEEQI 139) displayed negative and significant GCA effects at 0.1% and 1% respectively for the same parameter. With regards to Median development period, P1 (TZEEQI 61) produced a highly significant and negative GCA effect (p≤ 0.001) while P3 (TZEEQI 111) and P4 (TZEEQI 139) produced significant and positive GCA effects at probability levels of 1% and 5%, respectively. Percentage grain weight loss did not produce any significant GCA effect. Estimates of GCA for percentage grain damage showed that P1 (TZEEQI 61) produced a highly significant (p≤ 0.001) and positive GCA effect while P3 (TZEEQI 111) displayed a highly significant (p≤ 0.001) and negative GCA effect. P1 (TZEEQI) displayed a highly significant and positive GCA effect for Susceptibility index (p≤ 0.001) while P3 (TZEEQI 111) and P4 (TZEEQI 139) exhibited highly significant (p≤ 0.001) and negative GCA effects for the same weevil resistance parameter.

Table 4.6: General combining ability effects for the six weevil resistance parameters

Parents	% Mortality	F_1	MDP	% WL	% GD	DIS
TZEEQI 61	-0.98	11.22***	-1.34***	0.63	3.98***	0.01***
TZEEQI 12	1.02	1.14	-0.28	-0.30	0.32	0.00
TZEEQI 111	-0.53	-8.14***	0.90**	-0.01	-4.65***	-0.01***
TZEEQI 139	1.02	-6.45**	0.72 *	0.00	-1.36	-0.01***
TZEEQI 66	-0.53	2.22	0.00	-0.32	1.70	0.00
SE (gi)	1.09	3.15	0.28	0.42	1.26	0.00
SE (gi - gj)	1.73	4.97	0.45	0.66	1.99	0.00

* = P≤ 0.05, ** = P≤ 0.01, *** = P≤ 0.001; F_1 = F_1 progeny emerged, MDP = median development period, DIS = Susceptibility index, % WL = percentage grain weight loss, % GD = percentage grain damage.

4.4.2 Specific combining ability estimates

The results for SCA for percentage adult mortality revealed that P2 × P5 (TZEEQI 12 ×

TZEEQI 66) had a significant (P≤0.01) and negative SCA effect while its reciprocal cross was positive but was however not significant (Table 4.7). P3 × P4 (TZEEQI 111 × TZEEQI 139) had a significant (P≤0.05) and positive SCA effect while its reciprocal cross, though positive, was not significant. P3 × P4 (TZEEQI 111 × TZEEQI 139) exhibited a significant and positive (P≤0.05) SCA effect for median development period while its reciprocal cross was also positive but not significant.

Table 4.7: Specific combining ability effects for the six weevil resistance parameters

Parents	% Mortality	F_1	MDP	% WL	% GD	DIS
P1*P2	-0.91	1.17	0.58	-1.59	-2.60	0.00
P1*P3	-0.47	-1.00	-0.43	3.32***	-0.86	0.00
P1*P4	-0.36	-2.35	0.13	0.87	0.77	0.00
P1*P5	-6.00	9.67	-1.23	2.82	7.70	0.01
P2*P3	-3.58	7.97	-1.60*	-0.28	1.37	0.01**
P2*P4	-3.47	-4.89	0.47	0.05	-0.86	0.00
P2*P5	-9.56**	-11.74	0.49	-1.78	-9.95*	0.00
P3*P4	3.64*	-7.83	1.37*	-1.14	-2.85	-0.01
P3*P5	5.56	-11.30	1.56	1.39	-2.62	-0.01
P4*P5	2.67	-2.78	0.44	-0.29	1.70	0.00
P2*P1	1.67	2.39	-0.61	-0.07	2.76	0.00
P3*P1	0.56	-7.06	0.33	-4.58***	-2.08	0.00
P3*P2	0.56	-16.72**	-0.11	0.34	-4.53	-0.01*
P4*P1	1.11	-5.50	-0.61	-0.85	-2.54	0.00
P4*P2	0.00	0.44	0.33	0.41	2.73	-0.01
P4*P3	3.33	7.11	0.58	0.56	2.05	0.01
P5*P1	1.11	-1.11	-0.22	-0.58	-0.87	0.00
P5*P2	3.33	-3.89	0.11	-1.10	-3.57	0.00
P5*P3	0.00	9.83	0.33	0.29	1.57	0.01
P5*P4	0.00	7.89	-0.17	0.11	1.66	0.01
SE (Sij)	2.43	5.03	0.55	0.92	2.38	0.00
SE (Sij - Skl)	1.15	1.15	1.15	1.15	1.15	1.15

* = P≤ 0.05, ** = P≤ 0.01, *** = P≤ 0.001; F_1 = F_1 weevils emerged, MDP = median development period, DIS = Susceptibility index, % WL = percentage grain weight loss, % GD = percentage grain damage, P = parent.

For percentage grain weight loss, the estimates revealed that P1 × P3 (TZEEQI 61 × TZEEQI 111) had a highly significant (P≤0.001) and positive SCA effect while its reciprocal cross also had a highly significant and negative SCA effect (P≤0.001). SCA estimates for percentage grain damage showed that only one main cross, P2 × P5

(TZEEQI 12 × TZEEQI 66) produced a significant (P≤0.05) and negative SCA effect. Its reciprocal cross was negative but not significant. Values for Susceptibility index indicated that estimate for P2 × P3 (TZEEQI 12 × TZEEQI 111) were significant (P≤0.01) and positive while the reciprocal cross also showed a significant (P≤0.05) and negative SCA effect.

4.4.3 Estimates of heritability

Heritability for yield was very low, below 10%. The estimates of heritability for the other yield parameters were moderately high (Table 4.8).

Table 4.8: Heritability estimates for yield parameters

	Genetic parameter			
Traits	**σ^2g**	**σ^2e**	**σ^2p**	**H^2**
YIELD	0.06	1.21	1.27	4.71
PLHT	49.35	112.86	162.21	30.42
EHT	29.23	37.96	67.19	43.50
HUSKC	0.12	0.08	0.20	58.69
HUNGWT	1.54	1.94	3.47	44.23

EHT= ear height, PLHT= plant height, HUSKC= husk cover and HUNGWT= hundred grain weight

Estimates of heritability in the narrow sense for percentage adult mortality, F_1 weevil progeny emergence, median development period, percentage weight loss, percentage grain damage and the Dobie index of susceptibility are presented in Table 4.9.

Table 4.9: Variance components for the estimation of broad sense and narrow sense heritability for the six weevil resistance parameters measured.

Traits	Genetic parameter							
	σ^2gca	σ^2sca	σ^2e	σ^2A	σ^2D	h^2	H^2	BR
% Mort	0.67	1.21	0.03	1.34	1.21	35.01	66.58	0.53
F_1	5.73	0.75	0.10	11.45	0.75	62.51	66.61	0.94
MDP	3.22	1.96	12.38	6.44	1.96	43.90	57.29	0.77
% WL	0.94	1.07	0.01	1.87	1.07	42.36	66.64	0.64
% GD	3.55	0.99	0.02	7.11	0.99	58.48	66.65	0.88
DIS	6.47	2.06	4.86	12.94	2.06	55.51	64.35	0.95

% Mort = percentage adult mortality; F_1 = F_1 progeny emergence; %WL= % weight loss; % GD= % grain damage; Susceptibility index; σ^2_{gca} = variance of general combining ability; σ^2_{sca} = variance of specific combining ability; σ^2_A = additive variance; σ^2_D = dominance variance; σ^2_e = error variance; h^2= narrow sense heritability; H= broad sense heritability; BR=baker's ratio.

The genetic variances of the six weevil resistance parameters indicate that genetic variances with respect to F_1 progeny emergence, percentage adult mortality, percentage weight loss, median development, percentage grain damage and Susceptibility index were moderately large compared to their environment variances. As a result, their estimates of heritability were also moderately high, ranging from 35.01 to 62.51%.

4.5 Relationship among parameters tested

The six weevil resistance parameters were compared to each other to find out how one parameter relates to another.

Table 4.10 shows the relationship that exists between the six weevil resistance parameters and how each one influences the other. There is a significant ($P \leq 0.05$) negative relationship between F_1 progeny emergence and percentage adult weevil mortality. There exists a highly significant and positive relationship (P≤0.001) between F_1 weevil progeny emergence and Susceptibility index, F_1 progeny emergence and percentage weight loss and F_1 progeny emergence and percentage grain damage.

Table 4.10: Correlations among the six weevil resistance parameters

	F_1	**% Mort**	**DIS**	**%WL**	**DAMAGE**
% MORT	-0.14*				
SI	0.82***	-0.13			
% WL	0.38***	0.04	0.30***		
DAMAGE	0.86***	-0.00	0.73***	0.53***	
MDP	-0.06	-0.01	-0.41***	-0.01	-0.05

* = P≤ 0.05, ** = P≤ 0.01, *** = P≤ 0.001, respectively; F_1 = F_1 weevils emerged, MDP = median development period, DIS = Susceptibility index, % WL = percentage grain weight loss, % GD = percentage grain damage.

A highly significant (P≤0.001) relationship (P≤0.001) also existed between Susceptibility index and percentage grain weight loss and Susceptibility index with percentage grain damage. Susceptibility index and Median development period produced a highly significant and negative relationship.

There was also a highly significant positive relationship (P≤0.001) between percentage weight loss and percentage grain damage.

4.6. Estimates of Mid Parent and High Parent Heterosis.

Estimates of mid parent heterosis revealed that out of the six weevil resistance parameters studied, only percentage grain weight loss showed significant heterosis. The estimates of mid parent heterosis for percentage grain weight loss are presented in Table 4.11. The results show that out of the twenty hybrids, only Hybrid H9 (TZEEQI 111 × TZZEQI 61) had significant heterosis (P≤ 0.01). The other nineteen hybrids did not exhibit significant heterosis.

Estimates for better parent heterosis showed an increase in the number of hybrids exhibiting significance (Tables 4.12, 4.13 and 4.14). Percentage adult mortality, percentage weight loss, and Susceptibility index all had hybrids that showed significance.

Table 4.11: Estimates of Mid parent heterosis for percentage weight loss

PERCENTAGE GRAIN WEIGHT LOSS				
F_1	**F_1 MEAN**	**Parent 1**	**Parent 2**	**Mid – Parent Heterosis**
H1	3.45	3.33	5.99	-25.97
H2	4.16	3.33	3.14	28.59
H3	5.44	3.33	5.05	29.83
H4	4.63	3.33	4.33	20.89
H5	3.60	5.99	3.33	-22.75
H6	4.54	5.99	3.14	-0.55
H7	4.60	5.99	5.05	-16.67
H8	3.10	5.99	4.33	-39.92
H9	13.31	3.14	3.33	311.44**
H10	3.87	3.14	5.99	-15.22
H11	4.21	3.14	5.05	2.81
H12	4.51	3.14	4.33	20.75
H13	7.15	5.05	3.33	70.64
H14	4.13	5.05	5.99	-25.18
H15	3.10	5.05	3.14	-24.29
H16	4.55	5.05	4.33	-2.99
H17	5.79	4.33	3.33	51.18
H18	5.30	4.33	5.99	2.71
H19	3.92	4.33	3.14	4.95
H20	4.32	4.33	5.05	-7.89

* = P≤ 0.05, ** = P≤ 0.01, *** = P≤ 0.001.

For percentage adult mortality, the hybrids that showed significant heterosis (P≤ 0.05) were H5 (TZEEQI 12 × TZEEQI 61), H6 (TZEEQI 12 × TZEEQI 111), H10 (TZEEQI 111 × TZEEQI 12) and H18 (TZEEQI 66 × TZEEQI 12).

Table 4.12: Estimates of better parent heterosis for percentage adult mortality

F₁	PERCENTAGE MORTALITY			
	F_1 MEAN	Parent 1	Parent 2	Better Parent Heterosis
H1	6.67	7.78	16.67	-59.99
H2	4.44	7.78	2.22	-42.93
H3	6.67	7.78	6.67	-14.27
H4	3.33	7.78	3.33	-57.20
H5	3.33	16.67	7.78	-80.02*
H6	3.33	16.67	2.22	-80.02*
H7	4.44	16.67	6.67	-73.37
H8	8.89	16.67	3.33	-46.67
H9	3.33	2.22	7.78	-57.20
H10	2.22	2.22	16.67	-86.68*
H11	13.33	2.22	6.67	99.85
H12	7.78	2.22	3.33	133.63
H13	4.44	6.67	7.78	-42.93
H14	4.44	6.67	16.67	-73.37
H15	6.67	6.67	2.22	0.00
H16	7.78	6.67	3.33	16.64
H17	1.11	3.33	7.78	-85.73
H18	2.22	3.33	16.67	-86.68*
H19	7.78	3.33	2.22	133.63
H20	7.78	3.33	6.67	16.64

* = P≤ 0.05, ** = P≤ 0.01, *** = P≤ 0.001.

Percentage grain weight loss had only hybrid H9 (TZEEQI 111 × TZEEQI 61) exhibiting significant heterosis (P≤0.01). All the other hybrids were not significantly different from each other.

Table 4.13: Estimates of better parent heterosis for percentage weight loss

	PERCENTAGE GRAIN WEIGHT LOSS			
F_1	F_1 MEAN	Parent 1	Parent 2	Better Parent Heterosis

H1	3.45	3.33	5.99	-42.40
H2	4.16	3.33	3.14	24.92
H3	5.44	3.33	5.05	7.72
H4	4.63	3.33	4.33	6.93
H5	3.60	5.99	3.33	-39.90
H6	4.54	5.99	3.14	-24.21
H7	4.60	5.99	5.05	-23.21
H8	3.10	5.99	4.33	-48.25
H9	13.31	3.14	3.33	299.70**
H10	3.87	3.14	5.99	-35.40
H11	4.21	3.14	5.05	-16.63
H12	4.51	3.14	4.33	4.16
H13	7.15	5.05	3.33	41.60
H14	4.13	5.05	5.99	-31.10
H15	3.10	5.05	3.14	-38.61
H16	4.55	5.05	4.33	-9.90
H17	5.79	4.33	3.33	33.72
H18	5.30	4.33	5.99	-11.52
H19	3.92	4.33	3.14	-9.47
H20	4.32	4.33	5.05	-14.46

* = P≤ 0.05, ** = P≤ 0.01, *** = P≤ 0.001.

For Susceptibility index, hybrid H19 (TZEEQI 66 × TZEEQI 111) was the only hybrid that displayed significant heterosis (P≤0.05). The other hybrids were not significant.

Table 4.14: Estimates of better parent heterosis for Susceptibility index

INDEX OF SUSCEPTIBILITY				
DIS	**F1**	**Parent 1**	**Parent 2**	**Better Parent Heterosis**
H1	12.97	13.23	11.27	-1.97
H2	11.60	13.23	9.62	-12.32
H3	11.53	13.23	10.14	-12.85
H4	13.53	13.23	11.97	2.27
H5	12.23	11.27	13.23	-7.56
H6	10.38	11.27	9.62	-7.90
H7	9.48	11.27	10.14	-15.88
H8	11.06	11.27	11.97	-7.60
H9	12.34	9.62	13.23	-6.73
H10	12.64	9.62	11.27	12.16
H11	9.60	9.62	10.14	-5.33
H12	10.46	9.62	11.97	-12.62
H13	12.09	10.14	13.23	-8.62
H14	10.68	10.14	11.27	-5.24
H15	8.08	10.14	9.62	-20.32
H16	12.19	10.14	11.97	1.84
H17	13.42	11.97	13.23	1.44
H18	11.57	11.97	11.27	-3.34
H19	8.84	11.97	9.62	-26.15
H20	10.92	11.97	10.14	-8.77

* = P≤ 0.05, ** = P≤ 0.01, *** = P≤ 0.001.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Field evaluation

Mean square values for yield showed that the yield of the genotypes did not differ significantly from each other. The yields of H11 (TZEEQI 111 × TZEEQI 139), H16 (TZEEQI 139 × TZEEQI 66), H10 (TZEEQI 111 × TZEEQI 12), H15 (TZEEQI 139 × TZEEQI 111), and H14 (TZEEQI 139 × TZEEQI 12) were higher than the two local checks used. Hybrid H15 (TZEEQI 139 × TZEEQI 111) had the highest ear height, however, it was lower than the second local check (Dodzi).

Mean square values with respect to husk cover showed that there were significant differences among the 25 genotypes for husk cover. This is important since this variation helps discriminate genotypes and thus helps select genotypes that will help reduce field infestation of weevils. Demissie *et al*. (2008) reported that husk tightness and husk tip extension were the two most important parameters needed for the successful reduction of weevil infestation on the field. The best five genotype in this aspect were H4 (TZEEQI 61 × TZEEQI 66), H10 (TZEEQI 111 × TZEEQI 12), H3 (TZEEQI 61 × TZEEQI 139), S1 (TZEEQI 61) and H5 (TZEEQI 12 × TZEEQI 61). The worst genotype in terms of husk cover was H7 (TZEEQI 12 × TZEEQI 139).

Significant differences in genotype for hundred grain weight shows that variation exist among the genotypes with respect to their grain weight. Hybrid H15 (TZEEQI 139 × TZEEQI 111) had the heaviest grains but was similar to H8 (TZEEQI 12 × TZEEQI 66).

The parental line with the heaviest grains was S4 (TZEEQI 139). H10 (TZEEQI 111 × TZEEQI 12) was the worst genotype when hundred grain weight was concerned.

5.2 Response to weevil infestation

The significant difference in environment for only percentage adult mortality suggests that there were variations in the genotypes responses to the three regional weevil collections. Thus, genotype performance was not the same across the weevils from the three regions. Significant SCA effects for adult mortality reveal that non-additive gene action was important in the control of adult mortality. However, the very high CV for percentage adult mortality suggests the variation could have come from other factors other than the genotype. Derera *et al*. (2010) suggested that poor handling of weevils during infestation can be attributed to the increase in mortality and not as a result of the genotypic effect. Thus, percentage adult mortality is not a good parameter for the measure of grain resistance to weevils.

The significant variation exhibited by the genotypes with respect to the F_1 progeny emergence, percent grain damage, percentage grain weight loss, median development period (MDP), and Susceptibility index (DIS) demonstrate the presence of resistance mechanisms among the 25 genotypes tested. The difference in genotypic response to weevil infestation has been reported in many studies that involve both quality protein maize and normal maize (Demissie *et al*., 2015; García-Lara *et al*., 2009). This is an interesting prospect since genetic variability implies that there is the possibility of introgressing weevil resistant traits into most of the elite germplasm of maize available. For effective breeding, García-Lara *et al*. (2009) suggested that scientists employ QTL mapping to identify QTLs associated with maize resistance for successful development of varieties that will be resistant to the maize weevil. Genotypic variation for percentage adult weevil mortality was not significant. This buttresses the fact that percentage adult mortality is a poor indicator of maize weevil resistance.

5.2.1 Genotypic performance

Mean square values that were significant for the 25 genotypes tested showed that the genotypes can be discriminated into classes based on their response to the weevil resistance parameters.

Results for F_1 progeny emergence showed that hybrid H15 (TZEEQI 139 × TZEEQI 111) was the best genotype. It was significantly better than the other genotypes tested. It thus supported the lowest number of F_1 progeny. The best parental line was S3 (TZEEQI 111). This trait is advantageous since high F_1 emergence is linked to elevated grain damage and weight loss (Abebe *et al.*, 2009). Thus, any genotype that supports a small amount of F_1 progeny is desirable. The genotype that supported the highest number of F_1 progeny was hybrid H17 (TZEEQI 66 × TZEEQI 61), and was consequently the worst genotype.

Mean square values for median development period also indicate that genotype H11 (TZEEQI 111 × TZEEQI 139) was the best genotype. This genotype was able to prolong the developmental time of the weevil. Median development period is an important parameter in weevil resistance studies because it is inversely proportional to F_1 progeny emergence. Longer median development period is thus a quality of genotype that exhibits resistance to the maize weevil (Goftishu and Belete, 2014). Hybrid 15 (TZEEQI 139 × 111) had the second longest median development period, thus explaining its fewer F_1

progeny. S3 (TZEEQI 111) was the best parental line and was thus good at prolonging the developmental time of the weevils. H4 (TZEEQI 61 × TZEEQI 66) had the shortest median development period, hence the worst genotype.

Percentage grain weight loss also assists to classify genotypes with respect to resistance. H8 (TZEEQI 12 × TZEEQI 66) was the best genotype in terms of percentage weight loss. Though it supported some number of F_1 progeny, weight reduction was not significant. H15 (TZEEQI 139 × TZEEQI 111) also performed extremely well in this aspect. Grain weight loss is an important parameter for determining resistance in maize grains since it reveals what the farmer is losing economically (Dari *et al*., 2010; Derera *et al*., 2014). S3 (TZEEQI 111) was the best parental line at reducing the extent of weight loss. The genotype that recorded the highest weight loss was H9 (TZEEQI 111 × TZEEQI 61).

Grain damage is another important parameter linked to weevil resistance. Tefera *et al*. (2013a) reported strong positive relationship between weight loss, F_1 emergence, median development period and grain damage. Data on percentage grain damage showed that H15 (TZEEQI 139 × TZEEQI 111) performed better than the other genotypes in reducing damage due to weevil activities. This result is possible because H15 (TZEEQI 139 × TZEEQI 111) supported fewer numbers of F_1 weevils which had a longer developmental time and as such had reduced weight loss. The best parental line was S3 (TZEEQI 111). It is a very good genotype to consider for future breeding work for weevil resistance since it helps reduce grain damage

Another important parameter for grouping genotypes into resistance classes is Susceptibility index. Comparing the performance of the genotypes to the scale used to discriminate among the genotypes, none of the genotypes was found to be resistant or moderately resistant. The genotypes were classified as moderately susceptible, susceptible, and highly susceptible. Nevertheless, Hybrid H15 (TZEEQI 139 × TZEEQI 111) performed remarkably and was significantly better than the other genotypes studied. It was significantly better than check 2 (Dodzi) but similar in performance to check 1 (Abontem). Hybrid 4 (TZEEQI 61 × TZEEQI 66) was the worst in terms of Susceptibility index and median development period. For F_1 weevil emergence and percentage grain damage, Hybrid H17 (TZEEQI 66 × TZEEQI 61) was the worst genotype.

5.2.2 Comparison of the six weevil resistance parameters

Results of relationship studies on the six weevil resistance parameters showed a significant and negative relationship between percentage adult weevil mortality and F_1 progeny emergence. This means that an increase in adult mortality will lead to a reduction in the F_1 progeny weevils.

There was a very high and positive relationship between F_1 emergence and Susceptibility index. This means that increasing F_1 progeny will lead to an increase in susceptibility index. The aim then, will be to reduce values recorded for these two parameters.

F_1 progeny emergence had a highly significant and positive relationship with percentage weight loss and percentage grain damage. Thus increasing F_1 progeny will increase grain weight loss and grain damage (Derera *et al.*, 2010).

The relationship between susceptibility index and median development period was highly significant and negative. This is in agreement with work done by (Goftishu and Belete,

2014) who also identified that the longer the median development time, the lower the susceptibility index. Longer median development period could be attributed to antibiosis. This could explain why the genotypes were able to slow down the development of the weevil.

Susceptibility index was however related to grain damage and weight loss in a highly significant and positive way. Increasing percentage weight loss and percentage grain damage implies an increase in susceptibility index. There was a highly significant and positive relationship between percentage weight loss and grain damage. Increasing damage to the kernels will in turn lead to an increase in weight loss of the grain due to the feeding activities of the maize weevil.

5.2.3 Estimates of combining ability

Significant GCA effects for ear height, hundred grain weight and husk cover, suggests that these weevil resistance parameters are controlled by additive gene action. The importance of additive gene action for husk cover suggests the ease with which selection can be performed for improvement. This is especially true for husk cover which has been identified as one of the yield parameters that is key to reducing weevil infestation on the field (Demissie *et al*., 2008). Significant reciprocal crosses for husk cover also suggests the importance of maternal effects. This implies that additive gene action and maternal effects are important in the control of husk cover.

There was significant GCA effects for F_1 progeny emergence, median development period, grain damage and Susceptibility index, suggesting the importance of additive gene action for these parameters. Selection for these parameters will be easy since additive gene action is in control. Non-additive gene action was important for adult mortality and grain weight loss because of the significant SCA effects. This suggests the importance of dominance effect or epistasis in the control of the traits. This implies that selection will be difficult for these traits due to the importance of dominance or epistasis. Genotype × regional weevil collections interaction was significant for only adult mortality. This implies that adult mortality was collection specific and as such the performance was different for each regional collection. Selection for improvement, will have to be done on weevil collection basis.

Significant SCA × weevil collection interaction for adult mortality and weight loss indicate variation in the performance of these parameters across the three regions. As such selection for genotypes that respond favourably to these parameters will have to be done on regional basis. Significant reciprocal cross for weight loss suggests the importance of maternal effects in the control of the parameter. These results corroborate the findings made by Kim and Kossou (2003) who reported the importance of additive, non – additive and maternal effects in the conditioning of resistance to the maize weevil.

GCA effects for F_1 progeny emergence showed that results for TZEEQI 111 ($p \leq 0.001$) and TZEEQI 139 ($p \leq 0.01$) were significant and negative. This result is desirable since it suggests that TZEEQI 111 and TZEEQI 139 are parents that help reduce F_1 progeny emergence.

TZEEQI 111 ($p \leq 0.01$) and TZEEQI 139 ($p \leq 0.05$) show significant and positive GCA for median development period. This means that these genotypes will help prolong the developmental period of the weevils. This is beneficial since the weevils will take a longer time to complete their life cycles and thus produce less progeny. Parent TZEEQI 111 had a significant and negative GCA effect for grain damage ($p \leq 0.001$). TZEEQI 111 is thus important for reducing the amount of grain damage.

TZEEQI 111 and TZEEQI 139 were important for reducing Susceptibility index. They recorded significant and negative GCA effects. This is ideal since lower indices of susceptibility means resistance.

Specific combining ability (SCA) estimates for adult mortality reveal that hybrid TZEEQI 111 × TZEEQI 139 was the most desirable cross. It produced a significant ($p \leq 0.05$) and positive SCA value. This is ideal since this hybrid promotes increased adult weevil mortality which is linked to fewer F_1 weevil emergence. Hybrid TZEEQI 111 × TZEEQI 139 again showed a significant and positive SCA effect. It implies that the hybrid was ideal in the prolonging of the developmental period of insects.

Parent TZEEQI 111 × TZEEQI 12 was important for both F_1 progeny emergence and Susceptibility index. It produced a significant and negative SCA effect for F_1 progeny emergence ($p \leq 0.01$) and Susceptibility index ($p \leq 0.05$). This is important since the hybrid performance leads to a reduction in the F_1 progeny and Dobie's susceptibility index.

The SCA effect for TZEEQI 111 × TZEEQI 61 was significant and negative for weight loss ($p \leq 0.001$). The SCA effect reveal that the hybrid was ideal in the reduction of grain weight loss. The SCA value for TZEEQI 12 × TZEEQI 66 was significant and negative ($p \leq 0.05$). The hybrid is important because it reduces the level of grain damage suffered during infestation.

5.2.4 Heterosis

Estimates of mid – parent heterosis reveal that only percentage weight loss recorded significant heterosis. The results reveal that the heterosis recorded by Hybrid H9 (TZEEQI 111 × TZEEQI 61) was significant (P≤ 0.01). This means that the increase in performance of the hybrid was real and not due to chance.

Estimates of better parent heterosis also reveal that adult mortality, weight loss and Susceptibility index had hybrids exhibiting significant heterosis. Heterosis data on adult mortality show that hybrids H5 (TZEEQI 12 × TZEEQI 61), H6 (TZEEQI 12 × TZEEQI 111), H10 (TZEEQI 111 × TZEEQI 12) and H18 (TZEEQI 66 × TZEEQI 12) recorded significant heterosis (P≤ 0.01). This means that their hybrid vigor was not due to chance but real. For weight loss, hybrid H9 (TZEEQI 111 × TZEEQI 61) recorded significant better parent heterosis (P≤ 0.01). This confirms that the heterosis did not occur by chance.

Estimates of better parent heterosis for Susceptibility index show that hybrid H19 (TZEEQI 66 × TZEEQI 111) recorded the only significant heterosis. This implies that the vigor seen the hybrid did not occur by chance.

5.2.5 Heritability

Estimates of heritability for the yield parameters revealed that the heritability estimates were low for most of the parameters measured. The low estimate of heritability for yield reveal that it not heritable. Husk cover on the other hand, had a moderately high heritability estimate. This means that the performance of the genotypes, exhibited in the form of husk cover is heritable.

Narrow sense heritability estimates reveal that F_1 progeny emergence recorded high heritability (62.51%). F_1 progeny emergence also had a Baker's ratio approaching unity (0.94). This is an important finding since this result suggests the presence of additive gene action in the control of F_1 progeny emergence. This also means that selection based on this parameter will be effective. The same can be said of grain damage (58.48%) and Susceptibility index (55.51%). Grain damage and Susceptibility index both recorded moderately high narrow sense heritability estimates and very high Baker's ratio, 0.88 and 0.95 respectively. This suggests the importance of additive gene action in the conditioning of resistance in these two parameters. This indicates that these parameters can be inherited easily.

Adult mortality, median development period and weight loss recorded moderately low narrow sense heritability. Their Baker's ratios were however moderately high. This suggests the presence of both additive and non-additive gene action in the control of these traits. Additive gene action was however more important than non-additive gene action.

CHAPTER SIX

6.0 CONCLUSION

Significant GCA effects indicate the importance of additive gene action in the conditioning of resistance to the hybrids. The exhibition of significance for SCA suggests the importance of non-additive gene action for the control of weevil resistance. Comparing the contribution of GCA and SCA effects revealed that GCA effects were more important than SCA effects for F_1 weevil progeny emergence, Median development period, percentage grain damage and Susceptibility index. SCA effects were also found to be important for percentage adult mortality and percentage weight loss. Baker's ratio further confirmed the importance of additive gene action over non-additive gene action for the conditioning of resistance. Baker's ratio for F_1 weevil progeny emergence, percentage grain damage, and Susceptibility index were very high and close to unity, suggesting the strong presence of additive gene action for weevil resistance. Baker's ratio for percentage weight loss and percentage adult mortality was also moderately high and as such the slight significance of additive gene action in the transfer of resistance.

Significant mid-parent heterosis for H9 (TZEEQI 111 × TZEEQI 61) with regards to percentage weight loss suggests that it is a true hybrid and thus did not occur by chance. The hybrid will exhibit the same performance when the parents are crossed again. Significant better parent heterosis estimates for H5 (TZEEQI 12 X TZEEQI 61), H6 (TZEEQI 12 X TZEEQI 111), H10 (TZEEQI 111 X TZEEQI 12) and H18 (TZEEQI 66 X TZEEQI 12) with respect to adult mortality revealed that their performance was not due to chance. The heterosis was thus real and as such the performance exhibited is going to be repeated when the parents are crossed for each of these hybrids. Better parent heterosis for percentage weight loss revealed that H9 (TZEEQI 111 X TZEEQI 61) was again significant. Thus, the performance of the hybrid was real and not due to chance. The significant performance of H19 (TZEEQI 66 X TZEEQI 111) for susceptibility index shows that the better parent heterosis for this hybrid was not due to chance but real.

Low heritability estimates for most of the yield parameters reveal that they were not heritable. However, moderately high heritability estimate for husk cover meant that husk cover is heritable. Narrow sense heritability was high for F_1 weevil emergence, percentage grain damage and Susceptibility index. This meant that resistance to the maize weevil can be found in some of the genotypes tested and were heritable. Selection for resistance based on these parameters may not be difficult.

Significant differences in the mean square values for five of the six weevil resistance parameters suggest the presence of variation in the performance of the 25 genotypes with respect to weevil resistance. The variation in performance showed that Hybrid 15 (TZEEQI 139 × TZEEQI 111) was the best genotype for F_1 progeny emergence, percentage grain damage and Susceptibility index. It was the second-best genotype for percentage weight loss and recorded the same mean value as the best genotype TZEEQI 12 × TZEEQI 66. Hybrid TZEEQI 139 × TZEEQI 111 also had very good yield, recording yield that was similar to the highest yielding genotype. Parent S3 (TZEEQI 111) was the best parental line. It performed better than all the other parents for all parameters measured.

6.1 RECOMMENDATION

Further studies should be carried out to understand genetic control mechanisms or basis for resistance to maize weevil.

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APPENDICES

Appendix 1: Mean squares for the weevil resistance parameters for the Greater Accra Region.

Source	DF	% Mortality	F_1	MDP	% WL	% GD	DIS
		Mean Squares					
Genotype	24	0.05*	0.13	23.24	0.01	0.03	8.44
GCA	4	0.04	0.38**	54.31*	0.00	0.05	29.44***
SCA	10	0.09**	0.10	17.16	0.01	0.03	5.20
REC	10	0.03	0.07	16.88	0.01	0.01	3.29
Error		129.28	580.14	21.17	34.22	162.37	5.08
Mean		6.53	49.17	33.99	5.35	26.65	11.13
CV%		84.64	19.13	13.54	46.02	28.27	20.25
CHECK1(A)		0.00	26.67	35.00	3.17	18.44	8.17
CHECK2(D)		10.00	26.33	34.56	2.35	23.54	8.60

*, **, *** indicate the value is significant at P≤0.05, P≤0.01 and P≤0.001, respectively. F_1= F_1 weevil progeny emergence, MDP= Median Development Period, % WL= percentage weight loss, % GD= percentage grain damage, DIS= Susceptibility index. CHECK1(A)= Abontem, CHECK2(D)= Dodzi.

Appendix 2: Mean squares for the weevil resistance parameters for the Ashanti Region.

		Mean Squares					
Source	**DF**	**% Mortality**	**F_1**	**MDP**	**% WL**	**% GD**	**DIS**
Genotype	24	0.05*	0.12	6.74	0.01*	0.01	7.86
GCA	4	0.05	0.21	16.15*	0.01	0.02	20.97**
SCA	10	0.05	0.10	7.53	0.01*	0.01	5.78
REC	10	0.05	0.10	2.19	0.01	143.31	0.014.70
Error		72.56	799.68	4.96	20.16		5.29
Mean		7.33	55.43	33.22	5.01	27.42	11.49
CV%		72.62	20.86	6.70	32.75	26.92	20.02
CHECK1(A)		0.00	26.67	35.00	3.17	18.44	8.17
CHECK2(D)		10.00	26.33	34.56	2.35	23.54	8.60

*, **, *** indicate the value is significant at P≤0.05, P≤0.01 and P≤0.001, respectively. F_1= F_1 weevil progeny emergence, MDP= Median Development Period, % WL= percentage weight loss, % GD= percentage grain damage, DIS= Susceptibility index. CHECK1(A)= Abontem, CHECK2(D)= Dodzi.

Appendix 3: General combining ability effects for the six weevil resistance parameters for the Ashanti Region

Source		Mean Squares				
	DF	**% Mortality**	**F_1**	**MDP**	**% WL**	**% GD**
Genotype	24	0.05*	0.11	6.74	0.01*	0.01
GCA	4	0.05	0.21	16.15*	0.01	0.02
SCA	10	0.05	0.10	7.53	0.01*	0.01
REC	10	0.05	0.10	2.19	0.01	0.01
Mean		7.33	55.43	33.22	5.01	27.42
CV%		72.62	20.86	6.70	32.75	26.92

*, **, *** indicate the value is significant at P≤0.05, P≤0.01 and P≤0.001, respectively; F_1 = F_1 weevils emerged, MDP = median development period, DIS = Susceptibility index, % WL = percentage grain weight loss, % GD = percentage grain damage.

Appendix 4: Mean squares for the weevil resistance parameters for the Northern Region

		Mean Squares					
Source	**DF**	**% Mortality**	**F_1**	**MDP**	**% WL**	**% GD**	**DIS**
Genotype	24	0.01	0.16*	12.70	0.01 ***	0.03*	9.95**
GCA	4	0.02	0.50 ***	19.74	0.01***	0.12***	36.35***
SCA	10	0.01	0.11	7.30	0.01***	0.01	4.66
REC	10	0.01	0.08	15.28	0.01**	0.01	4.67
Error		39.56	489.05	11.02	2.74	112.53	4.21
Mean		3.73	52.64	33.75	4.03	26.00	11.20
CV%		90.83	17.49	9.84	22.28	23.80	18.32
CHECK1(A)		0.00	26.67	35.00	3.17	18.44	8.17
CHECK2(D)		10.00	26.33	34.56	2.35	23.54	8.60

*, **, *** indicate the value is significant at P≤0.05, P≤0.01 and P≤0.001, respectively. F_1= F_1 weevil progeny emergence, MDP= Median Development Period, % WL= percentage weight loss, % GD= percentage grain damage, DIS= Susceptibility index. CHECK1 (A)= Abontem, CHECK2(D)= Dodzi.

Appendix 5: General combining ability effects for the six weevil resistance parameters in the Greater Accra Region

Parents	**% Mortality**	**F_1**	**MDP**	**% WL**	**% GD**	**DIS**
P1	-0.20	9.56 *	-1.65*	0.55	2.79	1.23**
P2	3.13	-3.11	-0.62	0.78	0.67	-0.12
P3	-2.20	5.94	1.75*	-0.19	-4.20*	-1.15**
P4	1.13	-6.81	0.95	-0.38	-2.67	-0.72
P5	-1.87	6.29	-0.42	-0.75	3.41	0.75*
SE (gi)	1.86	3.93	0.75	0.96	2.08	0.37
SE (gi - gj)	2.94	6.22	1.19	1.51	3.29	0.58

*, **, *** indicate the value is significant at P≤0.05, P≤0.01 and P≤0.001, respectively; F_1 = F_1 weevils emerged, MDP = median development period, DIS = Susceptibility index, % WL = percentage grain weight loss, % GD = percentage grain damage.

Appendix 6: parameters for the Greater Accra Region.

Parents	% Mortality	F_1	MDP	% WL	% GD	DIS
P1*P2	-6.13	-5.46	1.12	-3.98 *	-9.33*	-0.52
P1*P3	-2.47	-5.29	-1.58	3.00	-1.77	0.25
P1*P4	2.53	2.91	-0.45	0.75	2.36	0.29
P1*P5	-8.33	-9.57	-2.40	1.49	9.33	0.43
P2*P3	-5.80	18.54*	-2.28	-1.62	2.67	2.05**
P2*P4	-7.47	-1.43	0.52	-1.94	-4.06	-0.20
P2*P5	-28.33***	-8.40	0.80	-9.28*	-24.68**	-0.12
P3*P4	7.87*	-15.09	2.82	-1.10	-4.93	-1.49
P3*P5	4.67	1.77	3.33	1.99	4.37	0.31
P4*P5	8.00	-7.93	0.20	-2.30	-4.02	-0.70
P2*P1	-3.33	0.17	-0.17	-1.39	-1.77	0.30
P3*P1	-1.67	-8.17	-0.17	-6.54**	-0.28	-0.11
P3*P2	1.67	-25.00*	-0.83	0.02	-7.04	-1.12
P4*P1	3.33	-1.83	-0.17	-0.38	0.31	-0.28
P4*P2	3.33	-8.17	0.50	-0.30	-2.64	-1.08
P4*P3	0.00	-0.33	4.83**	-0.46	-2.07	-0.98
P5*P1	3.33	-7.17	-0.17	0.45	2.84	-0.28
P5*P2	3.33	-2.67	-0.33	-0.79	-1.69	0.01
SE (Sij)	3.83	8.11	1.55	1.97	4.29	0.76
SE (Sij - Skl)	5.08	10.77	2.06	2.62	5.70	1.01

*, **, *** indicate the value is significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively; F_1 = F_1 weevils emerged, MDP = median development period, DIS = Susceptibility index, % WL = percentage grain weight loss, % GD = percentage grain damage.

Appendix 7: Weekly rainfall pattern at the Finatrade field

	Relative humidity (%)	Rainfall (mm)
October	86.43	10.60
	86.00	4.71
	82.13	3.23
	85.00	3.40
Mean	**84.89**	**5.49**
November	87.71	2.07
	83.88	0.68
	86.00	0.24
	84.50	0.00
Mean	**85.52**	**0.75**
December	72.57	0.00
	71.38	0.00
	58.75	0.00
	50.50	0.00
Mean	**63.30**	**0.00**

Appendix 8: parameters for the Ashanti Region.

Parents	% Mortality	F_1	MDP	% WL	% GD	DIS
P1*P2	7.33*	12.16	-0.01	-0.99	2.81	0.32
P1*P3	-1.33	2.26	0.10	5.26***	-0.31	0.22
P1*P4	-3.33	5.83	0.90	1.28	5.16	0.71
P1*P5	-6.67	38.63*	-0.63	3.83	13.76	2.45
P2*P3	-6.00*	13.69	-1.23	0.14	4.46	1.68*
P2*P4	-3.00	-12.74	2.07**	0.43	-2.61	-0.76
P2*P5	3.00	-9.97	0.20	1.29	-1.81	0.18
P3*P4	5.00	-13.97	-1.06	-0.99	-4.35	-0.82
P3*P5	11.67*	-11.90	0.75	1.88	-5.16	-0.80
P4*P5	-1.33	-10.63	0.12	0.69	1.15	1.44
P2*P1	6.67	-0.83	-0.67	1.11	3.28	0.10
P3*P1	0.00	-8.67	0.00	-6.59***	-3.29	-0.41
P3*P2	0.00	-15.00	0.83	1.08	-2.85	-0.93
P4*P1	0.00	-5.33	-0.50	0.10	-2.14	-0.11
P4*P2	-1.67	4.67	-0.17	1.68	5.76	0.69
P4*P3	8.33*	18.83	0.75	1.37	6.89	2.04*
P5*P1	1.67	-6.33	0.17	-1.25	-4.23	-0.28
P5*P2	6.67	-11.17	-0.50	-0.53	-5.50	-0.61
P5*P3	-3.33	14.17	0.83	0.21	1.76	0.64
P5*P4	8.33*	9.67	-0.83	-0.11	0.92	1.13
SE (Sij)	2.87	9.52	0.75	1.51	4.03	0.77
SE (Sij - Skl)	3.81	12.65	1.00	2.01	5.35	1.03

*, **, *** indicate the value is significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively; F_1 = F_1 weevils emerged, MDP = median development period, DIS = Susceptibility index, % WL = percentage grain weight loss, % GD = percentage grain damage.

Appendix 9: Monthly temperature and relative humidity readings in the laboratory

	TEMPERATURE (°C)	RELATIVE HUMIDITY (%)
APRIL	30.17	68.60
MAY	28.88	70.97
JUNE	27.63	73.15

Specific combining ability effects for the six weevil resistance

JULY	27.83	72.08
AVERAGE	**28.63**	**71.20**

Appendix 10: General combining ability effects for the six weevil resistance parameters for the Northern Region

Parents	**% Mortality**	**F_1**	**MDP**	**% WL**	**% GD**	**DIS**
P1	0.27	16.43***	-1.35*	0.58	5.72**	1.63***
P2	1.60	4.96	0.29	-0.61*	0.58	0.03
P3	0.27	-18.44***	0.25	-0.90**	-8.68***	-1.35***
P4	-0.40	-6.27	0.82	0.42	-0.05	-0.55
P5	-1.73	3.33	0.01	0.51	2.43	0.23
SE (gi)	1.03	3.61	0.54	0.27	1.73	0.33
SE (gi - gj)	1.62	5.71	0.86	0.43	2.74	0.53

*, **, *** indicate the value is significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively; F_1 = F_1 weevils emerged, MDP = median development period, DIS = Susceptibility index, % WL = percentage grain weight loss, % GD = percentage grain damage.

Appendix 11: parameters for the Northern Region.

Parents	% Mortality	F_1	MDP	% WL	% GD	DIS
P1*P2	-3.93	-3.19	0.65	0.20	-1.28	-0.09
P1*P3	2.40	0.04	0.18	1.70**	-0.51	0.45
P1*P4	-0.27	-15.79*	-0.05	0.60	-5.22	-1.05
P1*P5	-3.00	-0.07	-0.67	3.14*	0.02	0.92
P2*P3	1.07	-8.33	-1.29	0.64	-3.02	-0.41
P2*P4	0.07	-0.49	-1.19	1.66**	4.09	-0.50
P2*P5	-3.33	-16.87	0.47	2.64*	-3.36	-0.62
P3*P4	-1.93	5.57	2.35*	-1.33*	0.74	0.24
P3*P5	0.33	-23.77	0.60	0.30	-7.07	-3.26*
P4*P5	1.33	10.23	1.00	0.72	7.96	0.16
P2*P1	1.67	7.83	-1.00	0.07	6.78	-0.09
P3*P1	3.33	-4.33	1.17	-0.61	-2.67	-0.58
P3*P2	0.00	-10.17	-0.33	-0.08	-3.72	-1.33
P4*P1	0.00	-9.33	-1.17	-2.28**	-5.78	-0.46
P4*P2	-1.67	4.83	0.67	-0.14	5.07	-1.41
P4*P3	1.67	2.83	-3.83**	0.77	1.33	1.22
P5*P1	-1.67	10.17	-0.67	-0.94	-1.21	0.72
P5*P2	0.00	2.17	1.17	-1.98**	-3.52	-0.16
P5*P3	1.67	8.00	2.00	0.50	2.69	0.93
P5*P4	-3.33	1.83	0.83	0.64	0.31	-0.27
SE (Sij)	2.12	7.44	1.12	0.56	3.57	0.69
SE (Sij - Skl)	2.81	9.89	1.48	0.74	4.74	0.92

*, **, *** indicate the value is significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively; F_1 = F_1 weevils emerged, MDP = median development period, DIS = Susceptibility index, % WL = percentage grain weight loss, % GD = percentage grain damage.

Specific combining ability effects for the six weevil resistance