GENETIC VARIABILITY FOR STEM BORER RESISTANCE IN TWO ADAPTED EARLY-MATURING MAIZE (*Zea mays* L.) POPULATIONS

BY

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ABSTRACT

Stem borers are among the major biotic stresses limiting the grain yield of maize, an important cereal crop in Africa. Breeding for multiple resistance to maize stem borers has been reported to be a promising method of control. Understanding the genetic variability of crop populations will help in improving them for pest resistance. Thus, genetic variability for dual resistance to two stem borer species were determined in a white (DMR ESR-W) and a yellow (DMR ESR-Y) maize populations to provide information required for improving their levels of resistance to the borers.

Two experiments were conducted. In Experiment 1, a set of 100 S_1 plants of DMR ESR-W were selected to produce 250 full-sib and half-sib progenies using the North Carolina Design II (NCD II) mating scheme. The progenies with six checks were evaluated under artificial infestation with two borer species (*Sesamia calamistis* and (*Eldana saccharina*) at Ibadan, and non-infested conditions at Ibadan and Ikenne in 2008 and 2009 using Randomized Incomplete Block Design with two replications. Experiment 2 was with DMR ESR-Y and the same methodology was used. In both experiments, days to 50% anthesis and silking, plant and ear height, plant and ear aspect, ear length and grain yield were measured. Resistance was measured according to levels of leaf feeding damage, dead heart, stalk breakage, cob damage and stem tunneling. Analyses of variance for NCD II were conducted to estimate genetic variances and Narrow-Sense Heritability (NSH). Correlation coefficients were determined and partitioned into direct and indirect effects. Predicted responses to selection were estimated to measure expected genetic gains. Correlated response was used to determine traits that could hasten selection progress. Tests of significance were conducted at $p < 0.05$.

Infestation significantly reduced plant height (6.0 -11.1%), ear length (20.9 - 25.6%) and grain yield (23.9 - 30.4%) in both maize populations. Additive variance was significant for grain yield and stalk breakage in DMR ESR-W, and for stalk breakage, cob damage and stem tunneling in DMR ESR-Y. Narrow-sense heritability was low to moderate, but low for damage parameters except stalk breakage (40.6%) in DMR ESR-W, and cob damage (40.1%) in DMR ESR-Y. Negative correlations exist between grain yield and increasing levels of stem borer damage, with genotypic correlation between grain yield and stem tunneling being the highest (-0.52*) in DMR ESR-Y. Stem tunneling and cob damage had high positive direct effects on grain yield reduction. Estimated genetic gain per generation was 4.0 - 6.1% (= 210kg/ha) for grain yield under infestation in DMR ESR-W, but low for damage parameters in both maize populations. Direct selection for individual trait gave better response than indirect selection through other traits.

The significant additive variances and moderate heritability estimates obtained for stalk breakage and cob damage indicate that the traits are heritable, therefore, improvement of the maize populations for stem borer resistance using these traits is feasible. Direct selection for grain yield is recommended in improving the maize populations. Stem tunneling and cob damage by the borers are major causes of grain yield reduction.

Keywords: Genetic variance, Stem borers, Plant resistance, Maize grain yield, Genetic gain

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CERTIFICATION

We certify that this research work was carried out by Mrs Qudrah Olaitan OLOYEDE-KAMIYO in the Department of Agronomy, University of Ibadan, under our supervision.

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DEDICATION

This work is dedicated to Almighty Allah (to Whom be all adorations), my Sustainer, and to my parents, Mr & Mrs A.A. Oloyede, who took care of my children throughout the period of this research work.

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CHAPTER 1

INTRODUCTION

Maize is the third most important cereal crop in the world after wheat and rice. It is one of the world's best adapted crops growing between latitude 58^{o}N and 40^{o}S of the equator. According to records summarized by Van Eijnatten (1965), maize originated from America and was reported for the first time in West Africa in 1498. Maize belongs to the family Poaceae. It tolerates a wide range of temperature (14-30^{0}C) and requires a minimum of 500mm rainfall during its growth period. Maize performs best on soils with a pH range of 5.5-8.0. Therefore, it grows well in the Northern Guinea Savanna zone of Nigeria where conditions for its cultivation are quite favourable. This zone is regarded as the 'corn belt' of Nigeria. Its diverse uses as human food, livestock feed, raw material for agro-based industries as well as its ease of cultivation either sole or with other crops places it at advantage over most other food crops in Nigeria. Furthermore, the bimodal rainfall pattern of Southern Nigeria permits the cultivation of the crop twice in a year.

World production of maize in 2007 was around 788 million tonnes, which was more than rice (~650 million tonnes) and wheat (~600 million tonnes) from 158.6 million hectares of land with an average yield of 4.97 t/ha. The United States of America produces almost half of the world's harvest (~42.5%). World maize production increased to 822.7 million tonnes in 2008 from a land area of 161 million hectares with an average yield of over 5.0 t/ha (FAO, 2009). However, grain yield of maize in most developing countries including Nigeria is rather low. Current average grain yield of maize across sub-Saharan Africa is 1.78 t/ha (FAO, 2009). In Nigeria, production has increased from 5 million tonnes in 1998 from a land area of about 3.9 million hectares to 7.5 million tonnes from a land area of 3.8 million hectares in 2008. There was a corresponding increase in average grain yield from 1.3 t/ha in 1998 to 2.0 t/ha in 2008 (FAO, 2009). This yield increase has been made possible by the adoption of improved varieties and agronomic practices. Nonetheless, the grain yield obtained is still far below those from some other regions of Africa. For instance, in 2008, production of maize was 12.7 million tonnes in South Africa from 2.8 million hectares of land with average grain yield of 4.5 t/ha (FAO, 2009). The reason adduced for this yield disparity is the low levels of resistance to the prevailing stresses (Ajala *et al*., 2001).

Four major stresses reduce the yield of maize across Africa. These are drought, low and declining soil nitrogen, *Striga* and insect pests. Drought and low nitrogen stresses are common in the Northern part of Nigeria and can be controlled by irrigation, and application of nitrogen fertilizer, respectively. *Striga*, a parasitic weed, can also be controlled by fertilizer application because it is prevalent in areas with poor soils. Insect pests, of which stem borers are the most widely distributed and most damaging, seriously affect a significant proportion of the 96 million hectares of maize in the developing countries (Pingali 2001; Pingali and Pandey, 2001). Stem borers are very difficult to control because different species of stem borers affect maize at different growth stages in different locations. They infest the crop from seedling stage to maturity.

Four stem borer species, *Sesamia calamistis*, the pink stem borer; *Eldana saccharina*, the sugarcane borer; *Busseola fusca*, the African stem borer and *Chilo partellus*, the spotted stem borer, are of economic importance to maize in Africa. *S. calamistis and E. saccharina* are the most damaging and most widespread in West Africa among these species (Bosque-Perez and Mareck, 1990; Polaszek 1998). *S. calamistis* and *B. fusca* attack maize at the early growth stage and their effects lead to damage due to leaf feeding, deadheart and stem tunneling. *E. saccharina* attacks maize plants at flowering stage resulting in cob damage. Yield loss due to stem borer attack was estimated to be 20-70% depending on the severity of the damage and the stage of plant development when attacked (Ajala *et al*., 2001). Total crop failure has also been reported in some instances (Girling, 1980; Bosque-Perez and Mareck, 1991; Gounou *et al*., 1994; Schulthess and Ajala, 1999). However, the levels of damage and yield loss differ among genotypes based on their level of susceptibility, tolerance or resistance (Ajala, 1994).

Various methods have been proposed for the control of borer attack on maize. These are cultural control methods which include residue management, early planting and intercropping; biological control and chemical control. According to Malvar *et al*. (1993), the extra-early and early maize varieties suffer less borer damage than the late and medium-maturing varieties. This is because the early-maize populations and the varieties planted early enough probably escaped the second brood of borers. Cultural control strategies work best when used in combination with other control measures and are rarely effective when used singly. Biological control often requires trained personnel as well as commitment of the farming community to support the establishment of biological control agents. Even with chemical control, Ampofo (1986) observed that treatment of maize plants with carbofuran, an insecticide, was effective against foliar damage but not against stem tunneling by *Chilo partellus*. Ande *et al.* (2010) reported that serial application of chemicals extracted from moss was effective, but was found tedious and impracticable. Therefore, breeding for host plant resistance has been suggested as the most promising approach for the control of stem borers. This is because it is cheap, compatible with other integrated pest management (IPM) methods and it is environmentally safe (Girling, 1980; Gracen, 1989).

The first step in an insect resistance breeding programme is to identify sources of resistance in a crop population. A thorough understanding of inheritance pattern of the damage parameters under consideration, as well as the mechanisms of resistance is necessary when designing a breeding programme. At IITA, some sources of resistance to *S. calamistis* and *E. saccharina* have been identified and used to generate TZBR maize populations (Kling and Bosque-Perez, 1995). Efforts have been made since mid 1980s by IITA in breeding stem borer resistant maize genotypes, leading to the development of three maize populations each with resistance to *Sesamia* and *Eldana*. These genotypes were named TZBR (Tropical Zea Borer Resistance), *Sesamia* 1, 2 and 3 and *Eldana* 1, 2, and 3. Breeding efforts had further led to the development of other varieties that are being used or promoted on-farm in the West African sub-region. On-farm trials conducted in southeastern Nigeria in 2001 revealed a highly significant increase in the number of marketable cobs obtained with the use of Amakama TZBR-W C_1, a stem borer resistant variety developed at IITA, when compared to a local variety in an intercrop planting (Ajala *et al*., 2001).

The best approach to a successful host plant resistance breeding programme is the development of varieties with multiple insect resistance (Smith *et al*., 1989; Wiseman and Davis 1990; and Mihm, 1995). For instance, stem borer attack is more severe in the forest ecologies of West and Central Africa. These areas also harbour an array of diseases such as ear rot, downy mildew and other foliar diseases. Thus, it is desirable to have an appreciable level of resistance to all pests and diseases in maize genotypes commonly grown in such ecologies. The improvement of adapted maize populations for resistance to prevailing stem borer species will further improve their use and stabilize yield in stem borer-endemic locations. This can only be achieved through a knowledge of the level of genetic variability for stem borer resistance in adapted maize populations. The type of gene action and magnitude of genetic variability in a crop population determine the breeding scheme to adopt and the extent of progress attainable. However, variability studies on combined resistance of maize to different species of stem borers are scanty in literature. This study therefore, aims at investigating the levels of genetic variability for resistance to both *Sesamia calamistis* and *Eldana saccharina* in two adapted maize populations which are already resistant to downy mildew and streak diseases of maize. This will facilitate genetic improvement of the maize populations for resistance to both borer species that are prevalent in West and Central Africa. The objectives of this study were therefore to:

i. determine the extent of genetic variability within each of the maize populations (DMR ESR-W and DMR ESR-Y) for resistance to the stem borers and other agronomic traits,

ii. identify the most important stem borer damage parameter(s) causing grain yield loss.

iii. investigate the type of gene action involved in the inheritance of combined resistance to both *S. calamistis* and *E. saccharina*,

iv. evaluate plant characters that optimize gains from breeding for stem borer resistance, and

v. predict gains from selection and determine correlated responses to selection for combined resistance to both *S. calamistis* and *E. saccharina*.

CHAPTER 2

LITERATURE REVIEW

2.1 Botany of maize

Maize (*Zea mays* L.) belongs to the grass family, Poaceae. Currently, there are five species included in the genus *Zea*. Species of *Zea* that have been examined largely have a chromosome number of 2n= 20, except for *Z. perennis* (perennial teosinte) with 2n= 40 (Tito *et al*., 1991; Ellneskog Staam *et al*., 2007). It is a monoecious and cross pollinated plant, so a natural population is heterogenous. The grain of maize is a caryopsis. Late varieties flower 55-56-days and mature in 115days, early-maturing varieties flower in 45-55 days and mature in 90days, while extra-early varieties mature in 80-85 days. However, environmental factors influence the length of various growth stages. Growth in maize is divided into seedling, vegetative, flowering and grain filling/maturity stages.

The seedling stage involves germination and emergence of plumule and radicle and development of seminal root which anchors the seedling and provides it with water. The vegetative growth stage involves development of stem, leaves and root. The stem consists of alternating nodes and internodes, several of which remain condensed underground forming the crown. Each leaf consists of the leaf sheath, leaf blade and the collar which marks the point of extension of the leaf blade from the stem. As the internodes elongate, a new leaf emerges from the whorl one every 3 days with a total of 16-23 leaves within the first 4-5 weeks of planting depending on the genotype and climate (Kling, 1996).

At flowering stage, ear shoots are initiated 6-8 nodes below the tassel and occur about one week after tassel initiation. A typical maize ear has 750-1000 ovules, each ovule with a silk which is receptive for pollen germination. During flowering, anthers break open at the tip in the mid-morning, resulting in pollen shed from the anther spikelet of the tassel. Maize is protandrous and so silks which emerge from the ear shoot 1-3 days after anthesis, receive pollen as soon as they emerge. Grain filling starts with blister appearance, followed by the milky stage when the kernels are filled with white and milky fluid. After this is the dough stage during which the white paste solidifies to starch. The ear is considered to be at physiological maturity when 75% of the kernels in the central part of the ear attain the black layer stage or when the milk line has disappeared (Kling, 1996).

Four major stresses reduce the yield of maize across Africa. These are weeds, low and declining soil nitrogen, drought and insect pests/diseases. Among insect pests of maize, stem borers are the most widely distributed and most damaging. Weeds especially the parasitic weed *Striga*, and low soil nitrogen pose serious stress at the early growth stage of maize. Drought becomes a serious stress especially at flowering and grain filling stages. However, stem borers affect different stages of growth of maize in different locations. They also undergo second brood especially on the late-maturing varieties which makes the damage to be severe.

2.2 Biology of Stem borers

Stem borers are the most important insect pests of maize. They belong to the Order Lepidoptera. Four stem borer species, *Sesamia calamistis* (Pink stem borer), *Eldana saccharina* (Sugarcane borer), *Busseola fusca* (African stem borer) and *Chilo partellus* (Spotted stem borer) are of economic importance to maize in Africa. The pink and the African stem borers belong to the family Noctuidae, sugarcane borer belongs to the family Pyralidae, while the spotted stem borer belongs to the Crambidae family. The life cycle of stem borer is divided into four stages: Egg, larva, pupa and adult stage.

The adults emerge from their pupae and mate in the usual moth fashion where the female releases a sex pheromone that attracts a male from downwind. Females are generally slightly larger than males. Adult *Eldana* lives for two weeks, during which each female lays 400–600 eggs in batches of 100 to 200. Females of the Noctuidae family usually mate on the night of emergence where they oviposit under the leaf sheaths of maize on 3 to 4 subsequent nights. Each female can lay up to 1000 eggs in a lifetime. Eggs are usually light yellow in color which later change to pink and then black. Eggs hatch about a week after being laid.

Soon after emergence from eggs, the larvae bite into the stem of maize through the leaf sheath and migrate to the whorl to feed. Young larvae are either creamy-white, dark brown or black in color. There are usually six larval instars although eight are possible in unfavorable conditions. Instars burrow into the stem and feed on the central stem tissues. Mature larvae can be up to 40 mm in length. Larvae mature in about 35-

42 days and pupate in the stem. Prior to pupating, each larva cuts a small hole in the stem from which the adult moth emerges. Larvae move on to new plants once the plants they have been feeding on die due to their feeding activities.

The final instar larvae spin cocoons round themselves inside the hollowed-out stem of the maize plant or in the tunnels they have made in the cob. They molt into pupae inside the cocoons and after 2-3 weeks, the adults emerge. Pupae are generally 25 mm in length and shiny yellow brown to dark brown in color. Males are usually smaller than females. The pink stem borer completes its life cycle in 6-8 weeks during the dry season, but it takes a longer time in the wet season. Usually, there are 2-3 generations during the growing season. Often, eggs from the second or third generation are laid around the ears being the fresh part at this period. The emerging larvae then cause extensive damage to young kernels before burrowing into the stalks. The life-cycle of the sugarcane borer lasts 2–3 months depending on the temperature.

2.3 Stem borers of cereals in Africa: distribution and damages done

The four species of stem borers, although they attack the same host plants, are found in different ecologies of Africa. *S. calamistis and E. saccharina* are the most damaging and widespread in West Africa out of these four species (Bosque-Perez and Mareck, 1990; Polaszek, 1998). *S. calamistis and E. saccharina* are predominant in Southern Republic of Benin (Kouame, 1995). *B. fusca* accounts for 95% of all the species found on maize in Cameroon, followed by *E. saccharina* (De Groote *et al.*, 2001). *B. fusca*, the African stem borer is mainly in the cooler and higher altitudes of West Kenya, while *C. partellus*, the spotted stem borer, is the most important in the warmer and lower areas of East Kenya (Mugo *et al.*, 2002; De Groote *et al.*, 2001). However, both *B. fusca* and *C. partellus* occur together in the mid-altitude region of Kenya (600-1200m above sea level) (De Groote *et al.*, 2001).

Three stem borer species are of particular importance in Nigeria. *B. fusca*, the African stem borer, is found predominantly in the wet areas of the mid-altitude, while *S. calamistis*, the pink stem borer, and *E. saccharina*, the sugarcane borer are found in all vegetation zones of Nigeria. *Sesamia calamistis* is predominant in the derived and Guinea savanna zone (corn belt). *Eldana saccharina* is distributed through Northern Nigeria and as far South as Latitude 7^{o}N (Ibadan) and most abundant in riverine provinces between Latitude 7^{o} and 10^{o}N (Usua, 1968). Its highest field population is towards the end of the second planting season (Shanover *et al*., 1991; Guonou *et al.*, 1994).

Reports of many workers (Usua, 1968; Girling, 1978; Kaufmann, 1983; Bosque-Perez and Mareck, 1990; Gounou *et al.*, 1994; Kouame, 1995; De Groote *et al*., 2001) on the distribution of stem borers in Africa showed that the development and distribution of these pests depend on many factors. These factors include climatic conditions, agronomic practices and host plants. Wild host plants of stem borers have been documented by various workers (Ingram, 1958; Bowden, 1976; Seshu Reddy, 1983; Khan *et al.,* 1997). The most important alternative hosts of the major stem borers when fresh maize is not available are reported to be cultivated sorghum, *Sorghum versicolour, sorghum arundinaceum,* Napier grass, *Pennisetum glaucum* and *Hyperrhenia rufa* (Kouame, 1995; Khan *et al*., 1997) as well as sugarcane and wheat. Although stem borers oviposit heavily on some grasses, only a few grasses are favourable for them to complete their life cycles (Huttler, 1996).

Both *B. fusca* and *S. calamistis* infest maize early in the life of the plant while *E. saccharina* is a later-infesting pest. *Busseola* and *Sesamia* lay their eggs on leaves of maize. As the eggs hatch, the larvae start feeding on the leaves causing leaf feeding damage. As the leaves unfurl, the larvae feed within the leaf whorls and cut through the meristematic tissue. The central leaves dry up to produce the "dead heart" symptom which results in the death of the plant. When all the leaves are completely opened and no longer offer protection for the larvae, they bore into the stem and chew the vascular tissues causing stem tunneling. The boring activities of the larvae hinder the normal flow of sap, leading to the disruption of physiological processes and cause stunted growth (Kouame, 1995). The tunneled stems become weakened resulting in lodging and stalk breakage under intense wind (Usua, 1968).

Eldana attacks maize plants at flowering stage where it lays its eggs under the leaf sheath. The emerged larvae find their way into the ear shoot being the fresh part at this stage and feed on the developing cobs causing cob damage. The larvae also feed on the stem tissues resulting in stem tunneling. The late-maturing plants experience second brood of borers, hence, the damage level is usually higher in the late season. *C. partellus* cause leaf lesions, delay in days to flowering, reduced plant height, ear number, and ear length (Ajala, 1994). Other symptom of borer damage is presence of entrance or exit holes on the stem. The overall effect of these damages is grain yield loss. Infestation by *Eldana* was reported to reduce yield up to 36% (Bosque-Perez and

Mareck, 1991), while 100% loss due to borer infestation has also been reported (Girling 1980; Bosque-Perez and Mareck 1991; Gounou *et al*., 1994, Schulthess and Ajala, 1999).

Opinions differ as to the most important stem borer damage parameter that contributes to grain yield loss. Starks and Doggett (1970), Mohyuddin and Attique (1978) and Pathak and Othieno (1990) reported that yield loss was mostly due to dead heart. Plant loss due to dead heart was reported to be up to 50% (Kaufmann, 1983; Bosque-Perez and Mareck, 1990). Ampofo (1986) reported that the most significant damage parameter that influence yield was foliar damage. Ajala and Saxena (1994) and Odiyi (2007) reported that stem tunneling was the most important contributing factor to yield loss caused by stem borer. Extent of damage may not be useful in predicting the level of reduction in vigour and consequent yield loss due to differences in tolerance level among genotype. However, vigour plays an important role in resistance mechanism to *C. partellus* (Ajala and Saxena, 1994).

2.4 Control measures against stem borer infestation

The prerequisite for successful control of stem borers is a clear understanding of the biology, ecology, behaviour of the pests and their natural enemies, and the interaction between them and the crop. Knowledge of the most vulnerable stage of the plant growth is as well important. Various control measures have been adopted which include cultural, chemical, biological and breeding for host plant resistance.

2.4.1 Cultural control of stem borers

Cultural measures of stem borers include crop rotation, early planting, intercropping, mulching and deep ploughing. Lawani (1982) in a review highlighted the complexity of effects of agronomic practices on stem borer populations. He reported that succulent and rapidly growing maize is more attractive to stem borers for oviposition. Use of high dose of fertilizer, especially nitrogen fertilizer makes maize plant succulent and more attractive to stem borers, while zero application of fertilizer makes them susceptible. Use of half dose of the required fertilizer level for maize was therefore recommended for the control of borers. Gebre-Amlak *et al*. (1989), using different planting times under natural infestation, reported positive correlation between crop losses and late planting. The late-maturing varieties experience the second brood of borers which feed on the ear leaf and the fresh ear causing cob damage.

Push-pull strategy is another cultural control method which involves the use of intercropping to trap the insects. In this system, maize is intercropped with plants that release odours (for example *Desmodium*) which repel ('push') adult moths out of the maize field, to trap crops (napier and sudan grass) outside the field that 'pull' adult moths. Echenzona (2007) observed that decreasing corn planting densities, significantly ($P<0.05$) and progressively increased the number of entry/exit holes on cornstalks by stem borers. Increase in the corn populations from 40 000 to 80 000 plants/ ha on the other hand, resulted in a significant ($P<0.05$) increase in stem lodging which could adversely affect the yield. Ransom (2005) explained that with high plant densities, there was less space for roots of individual plants to develop. This would eventually result in the roots usually being less extensive, leading to plants being poorly anchored. Widely spaced plants received more light and appeared more robust to nourish more larval populations than weaker and slender stands of densely populated plants.

2.4.2 Chemical control of stem borers

Chemical control can provide an effective means of pest management under severe infestation. However, chemical application is only effective if sprayed at or just before planting, or if pest scouting and monitoring has been successful prior to crop damage. However, as stem borers burrow into the stem, they are often protected from insecticide application and thus difficult to control by chemicals. Ampofo (1986) observed that carbofuran was effective for foliar damage but not for tunneling by maize stalk borer. Lawani (1982) in a review discussed extensively, the problems associated with chemical control of borers. The use of chemicals was reported to increase borer populations and also eliminate their natural enemies. Ande *et al.* (2010) reported that serial application of chemicals extracted from moss was effective, but was found tedious and impracticable. The residual effect and cost of chemicals also pose serious limitation to its use.

2.4.3 Biological control of stem borers

Biological control involves the use of natural enemies of the insects. *Sesamia* and *Eldana* are hosts of several natural enemy complexes in West Africa (Mohyuddin and Greathead, 1970; Polaszek and Kimani, 1990; Polaszek, 1992; Polaszek *et al.*, 1993). However most of the parasites reported seem to be poorly adapted to the cultivated host maize (Kouame, 1995). The parasites appear late in the second season of the year when the damage to crop is already over. Parasite of *Sesamia* is *Telenomus busseolae* in the Republic of Benin (Setamou and Schulthess, 1995). Pheromone and light traps can be used to trap adult moths. Pheromones are ectohormones secreted by insects for communication between species. Pheromone baited traps are used to detect the presence of insect pests and estimate their population density and subsequently used to trap them.

Push-pull strategy is another method used to trap the insects. It involves the behavioral manipulation of insect pests and their natural enemies via the integration of stimuli. This stimuli act to make the protected resource unattractive or unsuitable to the pests (push) while luring them toward an attractive source (pull) from where the pests are subsequently removed (Samantha *et al*., 2007). In practice, maize is intercropped with plants that release odours that repel ('push') adult moths out of the maize field to trap crops outside the field that 'pull' adult moths. Typically, desmodium will repel or push the insects, while napier and sudan grass are used as trap crops that pull the insects to themselves. They are important fodder crops that produce a gummy substance that traps moths and prevents over 80% of larvae from reaching adulthood (Samantha *et al*., 2007).

2.4.4 Use of host plant resistance against stem borers

Herzog and FonderBark (1985) defined host plant resistance (HPR) as plant’s inherent qualities that render it unsuitable as food, shelter or for oviposition for insect pests. Breeding for host plant resistance is compatible with other integrated pest management systems, cheap and environmentally safe. According to Wiseman (1985), resistance can be classified according to intensities as immunity, high, moderate and low resistance, or by types as vertical (specific) or horizontal (general) resistance (Van der Plank, 1963). An immune cultivar is one which a specific insect will not damage or use under any known condition. High resistance cultivars possess attributes that result in small or minor damage by a specific insect under a given set of conditions. Moderate or intermediate resistance may result from either a mixture of phenotypically high and low resistance plants or plants homozygous for resistance genes. The moderate resistance under a given environmental condition produces an intermediate level of injury (Wiseman, 1985). In vertical resistance, the level of resistance offered by a particular host cultivar is against a specific insect biotype. However, in horizontal resistance, the level of resistance offered is against all insect biotypes.

Resistance to insect pests can occur naturally in cultivated crops or can be developed through organized plant breeding. A number of factors affect pest resistance in plants which include biochemical, environmental and genetic factors, as well as the plant morphology. Resistance of maize to the first brood of European corn borer (*Ostrinia numbilalis)* for example, has been found to be due to the presence of a chemical, DIMBOA (2,4 dihydroxy-7-methoxyl-1,4 benzoxazin-3-one) (Klun *et al*., 1967). This chemical is formed as a result of enzymatic conversion of glucosides present in an uninjured corn plant. Increase and decrease in temperature, decrease in light intensity and increase in relative humidity cause loss of resistance (Kumar, 1984). New stem borer resistant maize populations have been developed at IITA through series of selections, for instance Ama TZBR-W C_1, TZBR syn-W C_1, TZBR *Sesamia* 1, TZBR *Eldana* 1,3 and 4 (Ajala *et al*., 2001). However in developing resistance to one pest, it is important to guard against the development of new pest biotypes or susceptibility to other pests, hence, breeding for multiple resistance is very essential.

2.4.4.1 Mechanisms of insect resistance

Painter (1951) classified mechanisms of resistance of maize to insect pests into antixenosis (preference-non preference), antibiosis and tolerance. Generally, one or more of these mechanisms may operate in a resistant cultivar. Preference-non preference is the mechanism employed by the plant to prevent insect pests from using them as food, shelter or for oviposition. Some plants have special features which make them less attractive to the insect. Some morphological features that confer resistance to stem borers are short and narrow stems, more layers of lignified tissue in stems and leaf sheaths, and a large number of silica cells.

Antibiosis is an adjunct to non-preference which refers to those adverse effects on the life of the insect as a result of using resistant host plant as food. Antibiosis mechanism can be detected by high mortality rate of early instar larvae as well as large number of malformed adult insects (Dahms, 1972). Antibiosis and non-preference mechanism have been identified in whorl stage of Mp 496 x Mp 701 and Mp 704 x Mp 705, in resistance to the Southwestern corn borer and European corn borer (Davis *et al*., 1998) and to Fall armyworm (Wiseman and Davis, 1990). Tolerance is the inherent genetic vigour on growth capacity of a resistant plant that gives it the ability to withstand or recover from insect damage. Tolerance however, has been reported to be advantageous as it does not affect beneficial insects adversely as does antibiosis (Smith, 1997). Counting of eggs of stem borers suggests preference, while estimate of damages combines preference, antibiotics and tolerance.

2.4.4.2 Breeding for resistance to insect pests

Understanding of the biology, feeding habit, as well as the injury afflicted by the insect is important in insect pest resistance studies. Maintenance of the insect population and plant varietal survey are also important. Inheritance of pest resistance may be controlled by a single major gene, two or three major genes, or by many minor genes. Immunity against a particular pest is rare in plants, and environmental factors have a marked influence on the levels of resistance. Therefore, levels of resistance have to be improved systematically over several cycles of selection. In breeding for insect resistance, it is necessary that a source of resistance gene is identified in a plant population.

Some sources of resistance to *S. calamistis* and *E. saccharina* have been identified at IITA and used to generate TZBR maize populations (Kling and Bosque-Perez, 1995). Efforts have been made since the mid-1980s by IITA in breeding stem borer resistant maize genotypes, leading to the development of three maize populations each with resistance to *Sesamia* and *Eldana*, respectively in the late 1980s. These genotypes were named TZBR (Tropical Zea Borer Resistance), *Sesamia* 1, 2 and 3 and *Eldana* 1, 2, and 3 (Ajala *et al*., 2001). However, only *Eldana* 3 remained from that era and it has been nominated for release in Nigeria (Ajala *et al*., 2009a). Breeding efforts have further led to the development of other varieties that are being used or promoted on-farm in Nigeria, for example, Ama TZBR-W (Ajala *et al*., 2001).

The durability of resistance to stem borer will be greater if there is recombination of genes for resistance through all possible cross-combinations of genotypes. This is because single gene resistance is known to be more vulnerable to the appearance of new virulent alleles in the pest. The concept of heritability and its estimate are also useful in the selection of superior individuals from a created gene pool and the utilization of selected individuals to generate superior varieties. In breeding for resistance to insect pests, quantities of resistance possessed by a plant must be heritable.

2.4.4.3 Inheritance of resistance to insect pests

Plant resistance to pests can be either qualitatively or quantitatively inherited. Resistance is determined by a genetic relationship between the plant and the pest in qualitative inheritance. Research has shown that such resistance follows a gene for gene relationship. According to Flor (1956), for each gene conferring specific resistance in the host, there is a matching gene in the pathogen which when present, gives it the ability to overcome the plant resistance. This gene in the pathogen is known as virulent gene (Kim, 1992). This form of resistance is specific or vertical resistance. However, because of the specificity, vertical resistance often breaks down with time as the virulent gene spreads in the population of the pest and overcomes the plant resistance. Quantitative resistance known as the horizontal or polygenic resistance is considered to be more stable than vertical resistance because it offers protection against more insect biotypes. Kim (1992) stated that it would be more difficult for a pest to overcome a number of minor genes in the host due to their number and interactions.

Resistance to leaf feeding damage by the Ear corn borer was found to be quantitative (Scott *et al*., 1964) with additive gene action being predominant. However, earlier reports suggested that it was qualitative with a maximum of three genes depending on the source of resistance. Resistance to *C. partellus* has been reported to be polygenic with both additive and non additive genes involved (Guthrie, 1989). Ajala (1992) reported resistance to both leaf feeding damage and stem tunneling by *C. partellus* to be predominantly additive with non-additive gene action also being important for stem tunneling. However, dead heart and tolerance were not controlled by either type of gene action. Kim *et al*. (2003) also reported that resistance to downy mildew was polygenic with both additive and non-additive gene action being important.

2.5 Genetic variability for resistance to stem borers

Knowledge of the level of genetic variability is a pre-requisite in initiating a population improvement programme for resistance to stem borers. It helps to identify the best breeding scheme to adopt and level of progress attainable in selection. The choice of an efficient breeding procedure requires information about the magnitude of several genetic parameters such as genetic variances, average level of dominance, heritability, genetic correlation between traits, genotype x environment interaction, responses and correlated responses to selection (Hallauer and Miranda, 1988). Several studies on genetic variability for resistance to different pests of maize abound in literature (Ajala, 1992; Pathak and Othieno, 1990; Ajala *et al.*, 1995a; Butron *et al.*, 1999; Butron *et al.*, 2006; Badu-Apraku *et al.*, 2007; Badu-Apraku, 2006). A genetic variability study in an Indian maize germplasm for resistance to two species of sorghum downy mildew led to identification of an inbred line that offered a high level of resistance to both species of downy mildew (Sudha *et al.*, 2004).

Various breeding strategies have been suggested for population improvement programmes. Comstock *et al.* (1949) proposed an inter-population recurrent selection method to improve the cross between two populations by exploiting both additive and non additive genetic effects in the population. Reciprocal recurrent selection method was used by Odiyi (2006) to improve two maize populations for combined resistance to two stem borer species. An intra-population recurrent selection program is important if only GCA effect is significant as reported by Butron *et al.* (1999). Intra-population method includes mass selection, half-sib selection, full sib selection and S_1 family selection. Jenkins (1940) and Hull (1945) proposed intra-population recurrent selection method based on evaluation of half-sib progenies. S_1 progeny selection is considered to be superior to other methods of recurrent selection for improvement of a population per se in the absence of overdominance. S_1 selection has been extensively used in increasing level of resistance in maize to various field stresses (Hallauer *et al.*, 1988). Ajala *et al.* (2003) reported that S_1 progeny selection was effective for improving maize populations for resistance to downy mildew infection.

Since the rate of inbreeding is low under recurrent selection, high genetic variability is maintained through avoidance of genetic drift (Hallauer, 1992). The genetic variance of a trait depends on the complement of genes segregating in the population, the effect of the alleles present and their frequencies. However, it has been well established theoretically that in the presence of directional dominance or epistasis, inbreeding does not necessarily reduce genetic variance and may actually increase it (Tachida and Cockerham, 1989; Cheverud and Routman, 1995, 1996; Wang *et al.*, 1998). Various mating designs have been developed to estimate genetic variances in maize.

2.6 Mating designs and their applications

Statistical methods that permit more accurate studies of quantitative characters have been developed. They include diallel analysis (Hayman 1954, Griffing 1956), generation mean analysis (Mather, 1949), Line x tester, and North Carolina Design I, II, and III mating schemes (NCD I, II, III) (Comstock and Robinson, 1948; 1952). Diallel crossing scheme and analysis have been developed for parents that range from inbred lines to broad genetic base varieties (Gilbert, 1958). A complete diallel includes all possible crosses of the parents. As the number of parents increases, the number of possible crosses increases such that the number of crosses to evaluate becomes unmanageable. Because of this, the number of parents used is generally small and this makes the estimates of additive and dominance variances to be biased (Kearsey and Pooni, 1996). Diallel crosses are usually performed on inbred lines. Generation mean analysis involves the use of generations and not development of progenies. It makes use of means instead of variances and this makes the error to be smaller, and it can estimate epistatic effects. The major disadvantages of generation mean analysis are that estimates of heritability cannot be obtained, genetic advances cannot be predicted, and there is problem of cancelling effects at various loci (Hallauer and Miranda, 1988). In line x tester analysis, progenies are developed from crosses between lines and several testers, which are usually broad based genotypes (Kempthorne, 1957). It provides information about general and specific combining ability of the parents and also helpful in estimating various types of gene effects.

The NCD I allows extensive sampling of S_o plants in a population and hence, it is the easiest for producing a large number of progenies in maize. NCD I also provide information on GCA for males and average dominance of genes as in diallel and NCD II. Estimate of additive and total genetic variance are obtained directly from the mean squares of analysis of variance, but dominance variance is obtained as the difference between females within males and the male component of variance. NCD II (Cross classified) is suitable when estimating components of variance of a reference population. A greater number of parents can be handled by subdividing parents into sets unlike in diallel analysis (Hallauer and Miranda, 1988). Two independent estimates of additive variance are available and an estimate of dominance variance is determined directly from the mean squares of analysis of variance. NCD II can also test for maternal effect. These give NCD II an advantage over NCD I. The NCD III has been used primarily in maize F_2 population to determine the effects of linkage on the estimates of additive and dominance variances as well as average level of dominance of genes affecting a trait of interest. Progenies are developed by backcrossing individual S_o plant of the F_2 population to both parents which are the two inbred lines used to produce the F_2 population.

All these statistical methods have been utilized in maize breeding to study inheritance pattern for resistance to various stresses. Badu-Apraku *et al*. (2007) utilized NCD I to study variability for *Striga* resistance in a maize population. Meseka *et al*. (2006) used NCD II to estimate genetic variances for some maize inbreds selected for drought tolerance under low nitrogen. Diallel analysis was used to study inheritance of some maize inbreds for resistance to downy mildew (Kim *et al.*, 2003) and *Chilo partellus* (Ajala, 1992). Odiyi (2006) utilized both line x tester and NCD II to study genetic variability for resistance to *Sesamia calamistis* and *Eldana saccharina* in two maize populations. Results from these studies indicated that both additive and dominance gene actions are responsible for different damage parameters.

2.7 Heritability and response to selection

Heritability describes the relative importance of heredity in determining the phenotypic value of a character (Falconer, 1989). Heritability could be in the narrow- or broad-sense. Narrow-sense heritability expresses the extent to which the phenotype of an individual is determined by the genes transmitted from the parent (Falconer, 1989). It determines the degree of resemblance between relatives and is therefore, of great importance in breeding programme. Broad-sense heritability on the other hand, was defined by Nyquist (1991) as the proportion of phenotypic variance that is due to all genetic effects. Hanson (1963) defined heritability in terms of response to selection as the fraction of the selection differential expected to be gained when selection is practiced on a defined reference unit. Heritability varies with environment and the type of progeny used whether half sib, full sib, or S_1 progeny, although homozygous individuals are more sensitive to environmental differences than the heterozygous individuals (Falconer, 1989).

Heritability estimates are useful for comparing gains from selection under different experimental designs. The information obtained combined with information about the relative costs of additional replications within each environment, additional years of evaluations and additional locations for evaluations can be used to design optimal breeding strategies (Milligan *et al*., 1990). High heritability alone is not enough to allow sufficient improvement in a selection program. High heritability should be accompanied by substantial amounts of genetic advance for adequate progress to be made from selection (Badu-Apraku, 2006).

Additive variance is the chief determinant of the observable genetic properties of a population and of response of the population to selection (Falconer, 1989). Predicted response differs with selection methods as well as different combinations of generations per cycle and parental control. Comstock (1964) concluded that in the absence of overdominance, inbred progeny selection is expected to be superior to other recurrent selection methods for improvement of a population *per se*. Odiyi (2006) recorded high expected genetic gain for grain yield under stem borer infested condition using full-sib method. Ajala *et al*. (2009b) working on FARZ 23 maize population compared S_1, half-sib and full-sib selection methods using two and three seasons to complete a cycle, and observed that S_1 selection using three generations per cycle gave largest predicted response for grain yield and ear number when compared with half- and full-sib selection methods. However, considering operational efficiency and gains from selection, full-sib selection method that utilizes two generations per cycle was reported to offer the best method for improving the population. Weyhrich *et al*. (1998) compared response to selection in BS11 maize population for seven different selection methods. He observed that selection programs in which index selection was practiced except modified ear to row were successful in improving the population *per se*. Gains from selection can be increased for any recurrent selection method by increasing the selection intensity (Sprague and Eberhart, 1977).

Rapid progress could be made from indirect selection of a trait using another trait. Rogers *et al*. (1977) observed that selection based on percentage root lodging, size of root system or degree of secondary root development would result in a population that root-lodge less readily under corn rootworm infestation. Rehn and Russell (1986) observed that selection for corn borer resistance caused reduction in total yield, stover weight and grain yield with no change in harvest index. Odiyi (2007) reported that selection for fewer days to silking would result in reduction in stem tunneling by 14% of the gain attainable from selecting for stem tunneling itself. Ajala *et al*. (2009b) while selecting for ear number through emergence percentage among half-sib families obtained 112% of the gain possible with direct selection for ear number. However, their results showed that direct selection for grain yield would be better than indirect selection through any other trait. Sandoya *et al.* (2010) also reported that selection for stem resistance to Mediterranean corn borer in a maize synthetic population EPS12 significantly modified other agronomic traits.

2.8 Selection indices

Selection index is an artificial selection method in which several useful traits are selected simultaneously. An index is essential to make an objective selection during evaluation due to the complex nature of interaction among plant genotypes and parameters. Selection can be made using weighted or weight-free selection index. A weight-free index called Rank Summation Index (RSI) was developed by Mulumba and Mock (1978). RSI is mostly employed for its simplicity of use. Ajala *et al.* (1995a) used RSI to select Kenya local open-pollinated maize for resistance to *Chilo partellus*. A weighted index called Base Index developed by Williams (1962) has also been used extensively. Odiyi (2006) used base index to select for population crosses with superior performance under stem borer infestation. Smith *et al.* (1981) compared Optimum Index (Smith-Hazel) that uses heritability as index weight and base index of Williams (1962) which uses economic weight as index weight (equal economic weight were used for all traits involved). They found that the predicted gain for each trait in both methods was extremely close.

The method that is expected to give the most rapid improvement of economic value however, is to apply the selection simultaneously to all the component characters together (multiple trait selection), giving appropriate weight to each (Falconer, 1989). Weyhrich *et al.* (1998) compared response to selection in BS11 maize population for seven different selection methods. They observed that selection programs in which index selection was practiced were successful in improving the population *per se.* However, since assigning weight to traits often poses problems, RSI, a weight-free index was recommended (Ajala *et al.*, 1993, 1995a, 2003; Ajala, 2010).

CHAPTER 3

MATERIALS AND METHODS

3.1 Source populations

Two tropically-adapted early maturing flint-dent maize populations, one yellow-grained (DMR ESR-Y) and the other white-grained (DMR ESR-W) were used in this study. Both populations are resistant to downy mildew and the maize streak virus diseases. They were developed from a cross between downy mildew resistance (DMR) source from the Philippines and TZSR (Tropical Zea Streak Resistance) from IITA (Fajemisin, 1985). The white population is adapted to the forest zone, while the yellow population is adapted to both the forest and savanna zone of Nigeria.

3.2 Generation of S_1 lines and development of progenies for evaluation

The two maize populations were planted in February, 2008 at IITA Breeding nursery, Ibadan. About 300 S_1 lines were generated from each of the populations. Thereafter, 100 S_1 lines with well-filled cobs and dent kernel characteristics were selected from each population. These were used to generate both full- and half-sib progenies using the North Carolina Design II (NCD II) mating scheme of Comstock and Robinson (1952). The NCD II mating scheme was adopted because greater number of parents could be handled by subdividing parents into sets unlike in diallel analysis. Also, two independent estimates of additive variance (a measure of GCA) are available and estimate of dominance variance (SCA) is determined directly from the mean squares of analysis of variance unlike in the NCD I. The selected S_1 lines from each population were grouped into 10 sets, each set containing 10 lines of which five were designated as male parents and the remaining five as females (Table 3.1). Each male line was crossed to all the five females in a set. Consequently, five groups of half-sib and 25 full-sib families were produced within a set (Table 3.2) giving a total of 250 progenies generated across all sets in each population. However, only 225 progenies were obtained for the white population (DMR ESR-W) due to a problem of flowering date synchrony between males and females in one set.

Table 3.1. Crossing scheme on the field for each of the two maize populations using the North Carolina Design II

	Selected lines									
Set	Males					Females				
1	1	2	3	4	5	6	7	8	9	10
2	11	12	13	14	15	16	17	18	19	20
3	21	22	23	24	25	26	27	28	29	30
4	31	32	33	34	35	36	37	38	39	40
5	41	42	43	44	45	46	47	48	49	50
6	51	52	53	54	55	56	57	58	59	60
7	61	62	63	64	65	66	67	68	69	70
8	71	72	73	74	75	76	77	78	79	80
9	81	82	83	84	85	86	87	88	89	90
10	91	92	93	94	95	96	97	98	99	100

Table 3.2. Procedure for crossing the S_1 lines using Set 1 as example

♀ \ ♂	1	2	3	4	5
6	1x6	2x6	3x6	4x6	5x6
7	1x7	2x7	3x7	4x7	5x7
8	1x8	2x8	3x8	4x8	5x8
9	1x9	2x9	3x9	4x9	5x9
10	1x10	2x10	3x10	4x10	5x10

♂ Male ♀ Female

3.3 Evaluation of the maize progenies for combined resistance to *Sesamia calamistis* and *Eldana saccharina*

The 225 progenies of DMR ESR-W with three checks and 250 progenies of DMR ESR-Y with six checks were evaluated in 2008 and 2009. Evaluations were carried out at Ibadan (Lat.7^o 22'N, Long 03^o 58'E) in the derived savanna and Ikenne (Lat. 6^o 54'N, Long.03^o 42'E) in the humid forest of Nigeria (Fig. 3.1). The same method was used for evaluation of both maize populations.

3.3.1 Evaluation in Ibadan

Evaluations were carried out in two seasons: the first from August to November, 2008 and the second from May to August, 2009. A Randomized Incomplete Block Design with two replications was used. A plot was a single row of 7m length. Half plot technique was employed by dividing each row into two halves of 3m each, separated by 1m in the middle (Fig. 3.2). The first half was artificially infested with egg masses of *S. calamistis* and *E. Saccharina*, while the other half was left uninfested (control). Spacing was 0.75m between rows and 0.25m within row. Two seeds were planted per hole but thinned to one plant per hill at three weeks after planting (WAP) just before infestation. A maximum of 13 plants per plot was obtained resulting in a plant density of 53,333 plants/ha.

Infestation

Egg masses of the stem borer species reared on artificial diet in the laboratory (Plate 3.1) were used to infest each maize plant in the infested plots. An egg mass of *S. calamistis* containing 30-40 eggs at black head stage was inserted in-between the stem and leaf sheath at 3WAP (Plate 3.2), while the egg mass of *E. Saccharina* was inserted in-between the developing cob and the stem at flowering.

Agronomic practices

Weeds were controlled using pre-emergence spray of gramozone (276g/litre of Paraquat dichloride) and primextra (290g/litre of S-metolachlor, 370g/litre Atrazine and related compounds) a day after planting, each at the rate of 2.5 kg ai./ha (5 litres of commercial product/ha). One hand weeding was done at 4WAP and another herbicide spray at 8WAP, using only gramozone at the same rate. N.P.K. 15:15:15 was applied at 10 days after planting (DAP) at the rate of 30kgN/ha, while urea was applied at

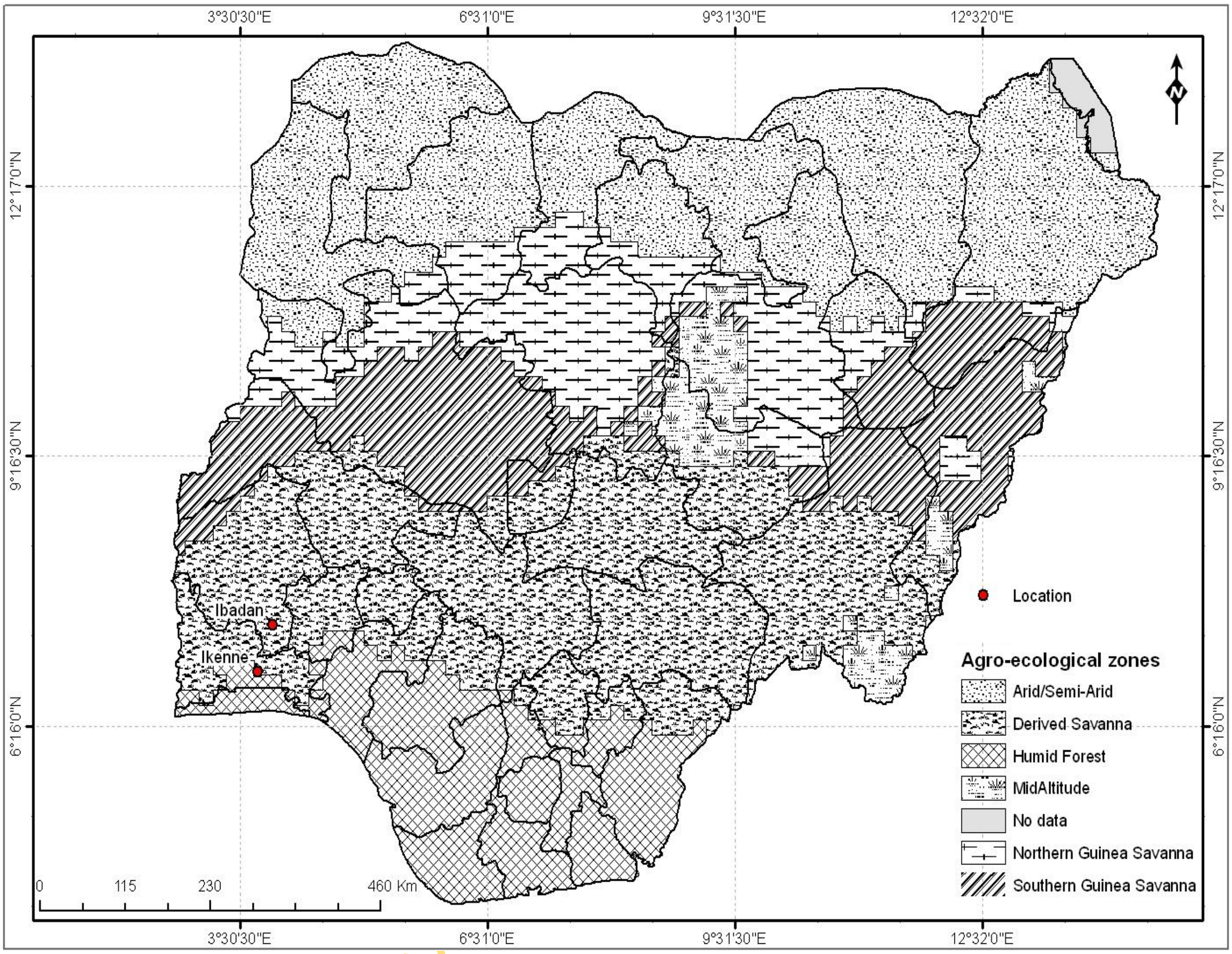

Fig. 3.1. Map of Nigeria states showing the study locations for evaluation of the maize progenies.

Source : Geospatial laboratory, IITA, Ibadan (2008)

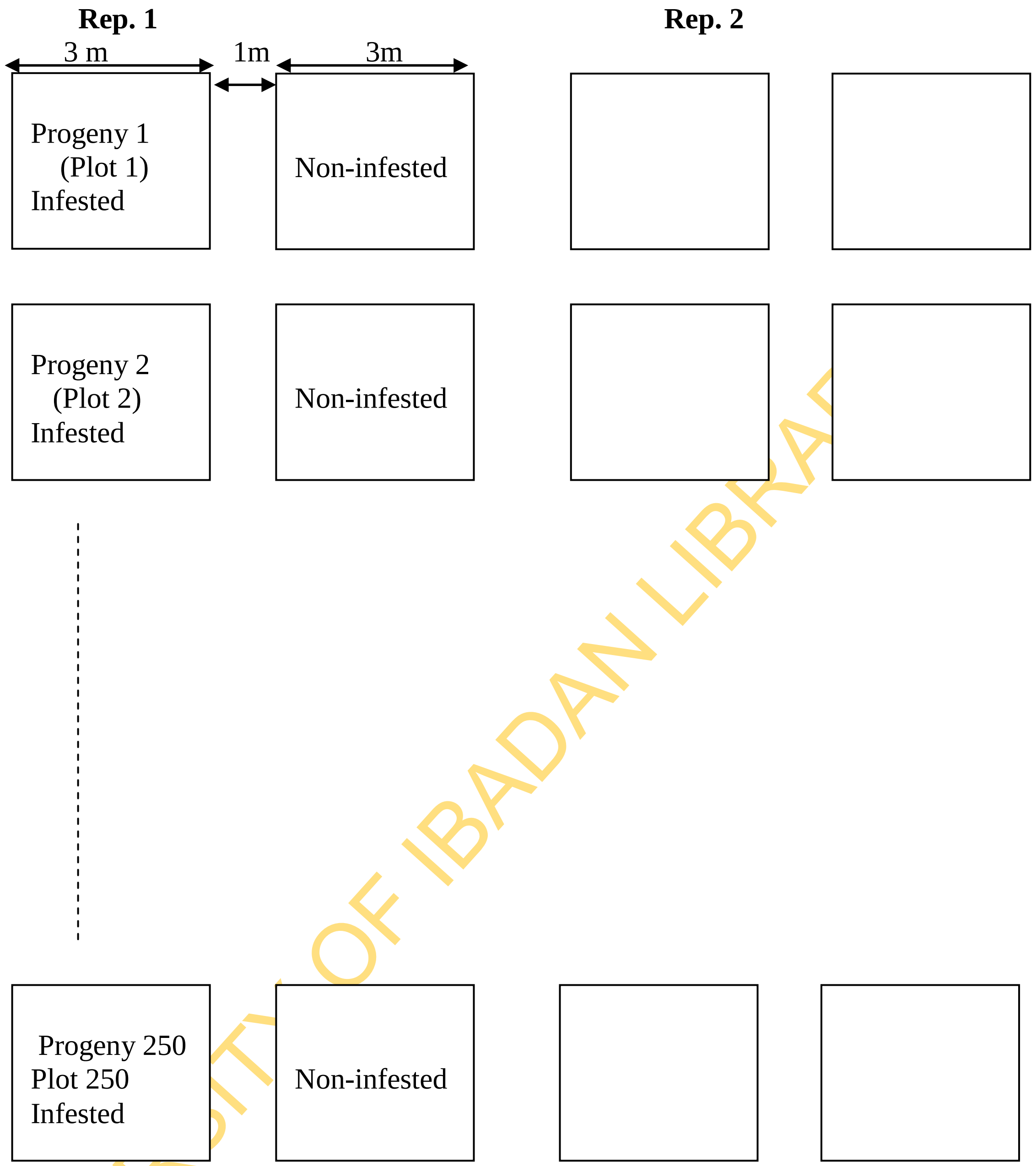

Fig. 3.2. Field layout for the evaluation of the maize progenies at Ibadan in 2008 and 2009.

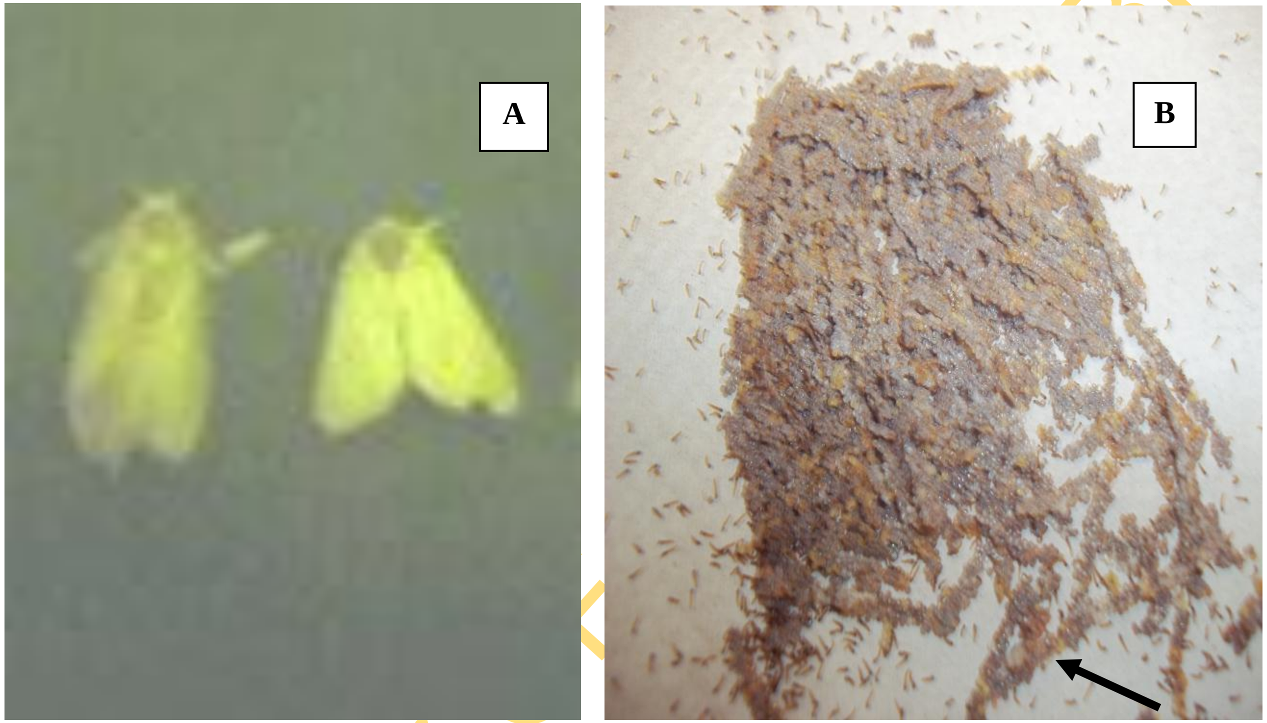

Plate 3.1. The stem borer species (A: *Eldana saccharina* left, *Sesamia calamistis* right) and egg mass of *Sesamia* (B) used for artificial infestation of the maize progenies.

Plate 3.2. Position of insertion of egg mass of *S. calamistis* on a 3 week-old maize plant.

6WAP at the same rate. Fields were irrigated as necessary.

Data collection

Agronomic traits assessed included plant stand, days to 50% pollen shed, days to 50% silking, plant aspect, plant and ear height, husk cover rating, stalk and root lodging, number of plants and ears at harvest, ear aspect, ear field weight, ear length and ear diameter in addition to grain moisture content. Damage parameters collected only on the infested plots were leaf feeding damage, dead heart, stalk breakage, cob damage count and stem tunneling.

Days to 50% pollen shed and 50% silking were determined as the number of days from planting to the day when half of the plants in a plot shed pollen and had silk extrusion, respectively. Plant aspect was rated per plot after anthesis on a scale of 1-9, 1- representing vigorous and appealing plants without lodging, leaf defoliation, nor disease symptoms and carrying their first ear at the middle of the plant, while 9 represents lodged, diseased and defoliated plants with their first ear closer to the soil surface or to the tassel. Data on plant and ear heights were collected on five competitive plants per plot. Husk cover was rated per plot on a scale of 1-9 based on the tightness of the tips of the husks, where 1 represents long and tight tip, and 9 for very short and loose tip. Ear aspect was rated per plot based on the neatness and filling of grains on the cobs on a scale of 1-9, 1 representing clean and well-filled ears, and 9 for ears with scanty and rotten or damaged grains. Ear length and diameter were taken on five representative cobs per plot using ruler and the average calculated. Ear length was taken from tip of the cob to the base, while the diameter was taken at the middle of the cob. Some quantities of maize were shelled from the harvested cobs per plot to determine grain moisture content which was done using Dickey-John moisture meter.

Leaf feeding damage was rated twice on the infested plots at 3 and 5 weeks after infestation (WAI) on a scale of 1-9 based on visual rating, with 1 representing 0-5% defoliation of the leaf area of the plants in a plot, and 9 for 80-100% defoliation of the entire leaf area. Stem tunneling was assessed on five competitive plants per plot after harvesting by splitting each plant stalk longitudinally and measuring the length tunneled by the insect larvae. The length was then expressed as percentage of the plant height. Other traits assessed are shown in Table 3.3.

Ears per plant was calculated by dividing the total number of ears at harvest by number of plants harvested per plot. Grain yield (t/ha) adjusted to 14% moisture

Table 3.3. Field data collected during evaluation of the maize progenies at Ibadan in 2008 and 2009

Traits	When	How	Unit of measurement
Plant stand	3WAP	number of plants per plot after thinning	number
Plant height	80 DAP	from ground level to the base of the tassel	centimetre
Ear height	80 DAP	from ground level to the node bearing the first ear	centimetre
Stalk lodging	82 DAP	plants that break below the first ear per plot expressed as percentage of plant stand	percentage
Root lodging	82 DAP	number of plants that lie completely flat on soil surface and/or are at angles less than 45° to the soil surface expressed as percentage of plant stand	percentage
Dead heart	4 WAI	number of plants with the growing points damaged in a plot expressed as percentage of plant stand	percentage
Stalk breakage	85 DAP	plants that break above first ear per plot expressed as percentage of plant stand	percentage
Cob damage	90 DAP	number of damaged cobs expressed as percentage of ears at harvest per plot	percentage
Ear field weight	90 DAP	weight of the cobs per plot using weighing balance	kilogramme

WAP: Weeks after planting, DAP: Days after planting, WAI: Weeks after infestation content, was calculated from ear field weight (FWT) per plot, assuming 80% shelling percentage as follows:

$$\text{Grain yield (t/ha)} = (\text{FWT (kg)}/ \text{ plot size } (m^2)) \times [(100- \text{Moisture Content}) \times 10,000 \times \text{SP}] /86 \times 1000$$

SP = Shelling percentage (weight of grain expressed as a percentage of ear weight).

Percentage yield reduction was estimated and adjusted by the extent of stem tunneling to obtain the level of tolerance of the progenies according to Ajala (1992).

$$\text{Tolerance} = \%\text{YLS} / \text{ST}$$

Where, ST = Stem tunneling (%)

%YLS= Grain yield reduction = (YNI-YI)/YNI *100

where, YNI = Yield of non-infested plot, YI=Yield of infested plot

3.3.2 Evaluation in Ikenne

Evaluations were carried out in two seasons: the first from September to December, 2008 and the second from June to September, 2009. The experiment was laid out in a Randomized Incomplete Block Design with two replications. Single-row plots each of 5m length were used. Spacing was 0.75m between rows and 0.25m within row. Two seeds were planted per hole but later thinned to one plant per hill at 3 weeks after planting (WAP) to obtain a maximum of 21 plants per row and a plant density of 53,333 plants/ha. Evaluation plots in both seasons in Ikenne were not artificially infested.

Agronomic practices

Weed control was similar to the one done in Ibadan. N.P.K 15:15:15 was applied at 10 days after planting (DAP) at the rate of 60kgN/ha and urea was applied at 6WAP also at the same rate. Fields were also irrigated as necessary.

Data collection

Only agronomic traits were assessed in Ikenne. They included plant stand, days to 50% pollen shed, days to 50% silking, plant aspect, plant and ear height, husk cover rating, stalk and root lodging, number of plants and ears at harvest, ear aspect, ear field weight and moisture content. Ears per plant and grain yield were also estimated as done in Ibadan.

3.4 Data analyses

Statistical analyses were conducted separately for the two maize populations. Data on dead heart, lodging, stalk breakage, cob damage and stem tunneling were normalized using arcsine transformation for statistical analysis. After analysing data for each of the locations, data were pooled over environments. Natural infestation by stem borers at Ibadan and Ikenne were low and not significant. Therefore, data under non-infested conditions at both locations were pooled and the means were compared with means of traits under infested condition in Ibadan using t-test. Analysis of variance for North Carolina Design II was performed using PROC GLM of SAS (Version 9.2). Random model was assumed for the analysis (entries, locations and seasons were assumed random). The statistical model of Comstock and Robinson (1952) for producing a number of set (n_1 x n_2 progenies) which are tested in a replicated trial was followed:

$$Y_{ijkln} = \mu + s_i + b_{ij} - m_{ik} + f_{il} + (mxf)_{jk,l} + e_{ijkln}$$

Where μ = general mean, s_i = the effect of ith set, b_{ij} = the effect of jth replication in ith set, m_{ik} = the effect of kth male in ith set, f_{il} = the effect of lth female in ith set, mxf)$_{jk,l}$ = the male x female effect in ith set, e_{ijkln} = the error associated with each observation.

Variance due to Entry was sub-divided into males (sets), females (sets), and female x male (sets). Variance due to Entry x Environment interaction was also partitioned into males/sets x environment, females/sets x environment, and males x females/sets x environment as shown in Table 3.4. Variances of ‘males within sets’ and ‘females within sets’ were tested with variances due to ‘environment x males in sets’ and ‘environment x females in sets’, respectively. Variances of ‘male x female within sets’ interaction, ‘environment x males in sets’ and ‘environment x females in sets’ interaction were tested by ‘environment x males x females in sets’ mean square. Environment x males x females within set was tested with error mean square. Sum of squares of ‘males in set’ and ‘females in set’ and their degrees of freedom were pooled to obtain a single mean square from which additive variance was estimated. Similarly, the ‘males in set x environment’ and ‘females in set x environment’ sum of squares

Table 3.4. Form of analysis of variance of the North Carolina Design II pooled over sets and over environments.

Sources of variance	Df	MS	EMS
Environment (E)	e-1		
Sets (S)	s-1		
S x E	(e-1)(s-1)		
Rep/S/E	es(r-1)		
Block (re)	re(b-1)		
Entry (G)	(g-1)		
Males/S	s(m-1)	MS_M	$\sigma^2 + r\sigma^2_{MFE} + fr\sigma^2_{ME} + re\sigma^2_{MF} + ref\sigma^2_{M}$
Females/S	s(f-1)	MS_F	$\sigma^2 + r\sigma^2_{MFE} + mr\sigma^2_{FE} + re\sigma^2_{MF} + rme\sigma^2_{F}$
Male x Female/S	s(m-1)(f-1)	MS_{MF}	$\sigma^2 + r\sigma^2_{MFE} + re\sigma^2_{MF}$
G x E	(g-1)(e-1)		
E x Males/S	s(m-1)(e-1)	MS_{EM}	$\sigma^2 + r\sigma^2_{MFE} + fr\sigma^2_{ME}$
E x Females/S	s(f-1)(e-1)	MS_{EF}	$\sigma^2 + r\sigma^2_{MFE} + mr\sigma^2_{FE}$
E x Males x Females/S	s(m-1)(f-1)(e-1)	MS_{EMF}	$\sigma^2 + r\sigma^2_{MFE}$
Pooled error	es(r-1)(mf-1)	MS_E	σ^2
Total	es(rmf-1)		

r: replicate**,** b: block**,** m -number of males, f: number of female, MS: Mean square, σ^2: error variance, $\sigma^2_{MFE:}$ variance due to environment x males x females in sets, σ^2_{FE}: variance of environment x females in sets, σ^2_{ME}: variance of environment x male in set, $\sigma^2_{MF:}$ variance of males x females in sets interaction, , σ^2_{M}: variance of males within sets, σ^2_{F}: variance of females within set and their degrees of freedom were pooled to obtain a single mean square from which the 'additive x environment' interaction variance was estimated according to Hallauer and Miranda (1988).

Additive genetic variance (σ^2_a), dominance variance (σ^2_d) and their interactions with the environment were estimated from the mean squares for ANOVA as follows:

$\sigma^2_m = (MS_M - MS_{MF} - MS_{ME} + MS_{EMF})/ref,$

$\sigma^2_a = 4\ \sigma^2_m = 4\ \sigma^2 f$

$\sigma^2_{mf\,=}\ (MS_{MF} - MS_{EMF})/re = 1/4\ \sigma^2_{d,}$

$\sigma^2_d = 4\ \sigma^2_{mf}$

$\sigma^2_{me} = (MS_{ME} - MS_{EMF})/\ rf,$

$\sigma^2_{ae} = 4\ \sigma^2_{me,}$

$\sigma^2_{mfe} = (MS_{EMF} - MS_E)/r,$

$\sigma^2_{de} = 4\ \sigma^2_{mfe},$

$\sigma^2_e = MS_E/er$

where, MS_M, MS_{MF}, MS_{ME}, MS_{EMF} are mean squares of pooled male and female, 'male x female', 'pooled (male and female) x environment' and 'male x female x environment', respectively, e = environment, r = replicate, σ^2_{ae} = additive x environment interaction variance, σ^2_{de} = variance due to 'dominance x environment' interaction, σ^2_e = environmental variance.

Degree of dominance was also estimated as:

$$\sigma^2_{d}/\ \sigma^2_{a}.$$

The standard errors of variance estimates and the narrow-sense heritability estimates were calculated as described by Hallauer and Miranda, (1988). Narrow-sense heritability (h^2) was estimated as follows:

$$h^2 = 4\ \sigma^2 m/\ [\sigma^2/er + 4\sigma^2_{me}/e + 4\sigma^2_{mfe}/e + 4\sigma^2_{mf} + 4\sigma^2_m]$$

Phenotypic and genotypic correlation coefficients between pair of traits were computed using variance-covariance matrix and estimates of genetic and phenotypic variances as described by Falconer (1996). Correlation was considered significant at 5% level of probability when the value of its coefficient is more than twice the standard error value, and at 1% level of probability when the value is more than thrice the standard error value. Genotypic correlation was calculated as follows:

$$r_G = \sigma_{G(X,Y)}/\sqrt{\sigma^2_{G(X)},\sigma^2_{G(Y)}}$$

where r_G is genotypic correlation between traits X and Y, $\sigma_{G(X,Y)}$ is genotypic covariance between trait X and Y, $\sigma^2_{G(X)}$ is genotypic variance of trait X, $\sigma^2_{G(Y)}$ is genotypic variance of trait Y.

Response to selection was determined using the formula:

$$\Delta G = i.c.\sigma_{ph}.h^2 \qquad \text{(Hallauer and Miranda, 1988)}$$

where i = standardized selection differential often referred to as K, c = parental control, σ_{ph} = phenotypic standard deviation (square root of phenotypic variance), h^2 = narrow-sense heritability estimate for the trait under consideration.

Predicted responses were expressed as percentage of means for each trait to estimate percentage genetic gains (Gains/generation %). Gains/season or generation was obtained by dividing gains/cycle by number of seasons used to complete a cycle.

Correlated response to selection was calculated as described by Kearsey and Pooni (1996) as:

$$CR_{y(x)} = i_x.h_x.h_y.r_{gx,y}.\ \sigma_{py}$$

where i_x = selection intensity (standardized selection differential) of trait *x;* h_x and h_y = square root of heritability estimate of trait *x* and *y*, respectively; $r_{gx,y}$ = genotypic correlation between trait *x* and *y* ; σ_{py} = Phenotypic standard deviation of trait *y*.

Correlated response was expressed as a percentage of predicted response for each of the traits studied.

Path coefficient analysis was used to partition correlation into direct and indirect effects using grain yield reduction as dependent variable. The partial regression coefficient gave the direct effect, while indirect effect was calculated as product of correlation and the path coefficient (partial regression coefficient) of each trait. The sum of direct and indirect effects of each trait gave the total correlation.

Rank Summation Index (RSI) of Mulumba and Mock (1978) was used to rank the progenies using five traits: plant aspect, leaf feeding damage, stem tunneling, tolerance and grain yield. This was done by ranking the selected traits for each progeny in order of preference and the ranks summed up to obtain an index as:

$$RSI_1 = \sum a_1 + b_1 \ldots\ldots\ldots + n_1$$

Where a_1 = rank of mean of trait “a” of progeny 1, b_1 = rank of mean of trait “b” of progeny 1, n_1 = rank of mean of trait “n” of progeny 1.

Progeny with the lowest index was rated as the best, while progeny with the highest index was rated as the worst. The top 10% progenies were considered for further recombination. The RSI values were also normalized using log transformation and subjected to ANOVA to estimate expected genetic gains from selection.

CHAPTER 4

RESULTS

4.1 Performance of progenies of DMR ESR-W and DMR ESR-Y maize populations under stem borer infested and non-infested conditions

Means, coefficients of variation (CV) and ranges of agronomic traits under infested condition (IC) and non-infested condition (NIC) for the white (DMR ESR-W) and yellow (DMR ESR-Y) maize populations are shown in Tables 4.1 and 4.2, respectively, and Tables 4.3 and 4.4, respectively, for the damage parameters. Ratings of plant and ear aspects were poor under IC (5-6) in both maize populations. Stalk lodging was more pronounced than root lodging under both conditions in DMR ESR-W (Table 4.1). Proportion of dead heart was low in both populations being 2% for the white and 0.4% for the yellow, but values obtained for other damage parameters were high. For instance, leaf feeding damage rating at 3 weeks after infestation (WAI) was 5.3 for DMR ESR-W (Table 4.3) and 4.7 for the DMR ESR-Y maize population (Table 4.4). Leaf feeding damage rating was higher at 3 WAI than at 5 WAI in DMR ESR-W. Stalk breakage and cob damage were also high, up to 25% and 31% for the white, and 20% and 44% for the yellow maize population, respectively. Percentage of stem tunneling was higher in DMR ESR-W (15.9%) than in DMR ESR-Y (4.4%). There were wide ranges for most of the traits measured in both maize populations. CV was also moderate for most of the traits except for traits expressed as percentages such as dead heart, stalk breakage, cob damage and stem tunneling (Table 4.4), where the standard error of means were also large.

Plant height, ear length and diameter, ears per plant and grain yield were significantly reduced ($p < 0.05$) under IC in both maize populations (Table 4.5). However, there was no significant reduction in days to 50% pollen shed under IC and NICs in both maize populations. Reduction in plant height ranged from 6.0 to 11.1% and ear length from 20.9 to 25.6% (Table 4.5). Days to silking and plant height were significantly reduced only in DMR ESR-Y. Mean grain yield of 3.5 t/ha was realized in DMR ESR-W under IC while 4.6 t/ha was realized under NIC, giving a mean grain yield reduction of 23.9%. On the other hand, mean grain yield of 3.2 t/ha was realized

Table 4.1. Mean ± S.E and ranges of agronomic traits for progenies of DMR ESR-W maize population evaluated under stem borer infested condition at Ibadan and non-infested conditions at Ibadan and Ikenne in 2008 and 2009.

Traits	Infested			Non-infested		
	Mean ± S.E	CV (%)	Range	*Mean ±S.E	CV (%)	Range
Days to pollen shed	49.6 ± 1.22	3.5	45.1 - 57.0	50.0 ± 1.11	3.1	47.0 - 56.0
Days to silking	50.0 ± 1.34	3.8	46.2 - 56.5	51.0 ± 1.20	3.3	47.0 - 57.0
Plant aspect	5.3 ± 0.80	21.3	3.0 - 7.0	3.1 ± 0.48	22.1	1.9 - 4.7
Plant height (cm)	144.6 ± 8.09	7.9	112.4 - 177.3	162.6 ± 9.66	8.4	137.8 - 183.8
Ear height (cm)	73.6 ± 6.59	12.7	49.8 - 93.9	75.2 ± 6.92	13.0	62.0 - 91.5
Husk cover rating	3.5 ± 0.57	22.6	1.7 - 5.9	3.5 ± 0.61	25.0	2.0 - 5.5
Root lodging (%)	4.0 ± 7.23	256.9	0 - 16.9	4.9 ± 6.29	183.0	0 - 18.1
Stalk lodging (%)	9.8 ± 9.53	137.0	0 - 50.8	10.1 ± 7.83	109.3	0.1 - 33.3
Ear aspect	5.6 ± 0.64	16.1	3.9 - 7.5	3.7 ± 0.51	19.5	2.7 - 5.5
Ear length (cm)	9.6 ± 0.64	9.4	6.1- 12.6	12.9 ± 0.91	10.0	9.9 - 15.3
Ear diameter (cm)	3.2 ± 0.14	6.2	2.7 - 3.9	4.3 ± 0.19	6.2	3.5 - 4.8
Ears per plant	0.8 ± 0.09	17.3	0.5 - 1.1	1.0 ± 0.11	16.3	0.7 - 1.3
Grain Yield (t/ha)	3.5 ± 0.60	24.3	1.7 - 5.2	4.6 ± 0.79	24.5	1.6 - 6.3

S.E: Standard error, CV: Coefficient of variation

* Data for non-infested plots at Ibadan and Ikenne were pooled because natural infestation by stem borers at both locations were low and not significant.

Table 4.2. Mean ± S.E and ranges of agronomic traits for progenies of DMR ESR-Y maize population evaluated under stem borer infested condition at Ibadan and non-infested conditions at Ibadan and Ikenne in 2008 and 2009.

Traits	Infested			Non-infested		
	Mean ± S.E	CV (%)	Range	*Mean ± S.E	CV (%)	Range
Days to pollen shed	48.8 ± 0.99	2.9	46.0 - 54.0	50.0 ± 0.99	2.8	47.0 - 55.0
Days to silking	49.8 ± 0.95	2.7	46.0 - 55.0	51.3 ± 1.02	2.8	48.0 - 56.0
Plant aspect	4.5 ± 0.73	23.0	3.1 - 6.4	3.1 ± 0.43	19.9	1.8 - 4.1
Plant height (cm)	175.4 ± 8.28	6.7	146.7 - 204.5	186.6 ± 10.46	7.9	155.9 - 214.5
Ear height (cm)	89.6 ± 5.65	8.9	66.7 - 114.7	93.6 ± 7.21	10.9	73.3 - 112.7
Husk cover rating	3.3 ± 0.58	24.7	1.4 - 6.2	3.3 ± 0.63	26.6	1.8 - 5.9
Root lodging (%)	5.4 ± 6.41	167.6	0 - 38.9	6.6 ± 6.40	137.8	0 - 39.2
Stalk lodging (%)	4.8 ± 6.62	196.3	0 - 51.5	8.3 ± 6.51	111.4	0.1 - 27.9
Ear aspect	5.3 ± 0.87	23.1	3.5 - 7.3	3.8 ± 0.60	22.3	2.6 - 5.1
Ear length (cm)	11.0 ± 0.63	8.1	7.5 - 13.3	13.9 ± 0.85	8.6	10.7 - 15.8
Ear diameter (cm)	3.4 ± 0.18	7.4	2.8 - 3.7	4.2 ± 0.22	7.3	3.5 - 4.8
Ears per plant	0.7 ± 0.09	16.9	0.5 - 1.0	0.9 ± 0.10	15.5	0.8 - 1.2
Grain Yield (t/ha)	3.2 ± 0.61	27.0	1.9 - 5.5	4.6 ± 0.93	28.4	3.2 - 8.3

S.E: Standard error, CV: Coefficient of variation

* Data for non-infested plots at Ibadan and Ikenne were pooled because natural infestation by stem borers at both locations were low and not significant.

Table 4.3. Mean ± S.E and ranges of damage parameters for progenies of DMR ESR-W maize population evaluated under stem borer infested condition at Ibadan in 2008 and 2009.

	Mean ± S.E	CV (%)	Range
Dead heart (%)	2.0 ± 5.30	366.4	0 - 27.8
Leaf feeding damage 3WAI	5.3 ± 0.86	23.1	3.1 - 6.9
Leaf feeding damage 5WAI	4.9 ± 0.75	21.6	3.0 - 6.9
Stalk breakage (%)	25.1 ± 12.14	68.5	0.8 - 59.7
Cob damage count (%)	30.6 ± 17.70	81.9	0 - 78.4
Stem tunneling (%)	15.9 ± 6.42	57.3	4.4 - 33.3

S.E: Standard error, CV: Coefficient of variation, WAI: Weeks after infestation

Table 4.4. Mean ± S.E and ranges of damage parameters for progenies of DMR ESR-Y maize population evaluated under stem borer infested condition at Ibadan in 2008 and 2009.

Traits	Mean ± S.E	CV (%)	Range
Dead heart (%)	0.4 ± 1.28	406.2	0 - 6.1
Leaf feeding damage 3WAI	4.7 ± 0.91	27.6	3.1- 6.5
Leaf feeding damage 5WAI	4.9 ± 0.91	26.2	3.6 - 6.6
Stalk breakage (%)	19.9 ± 10.75	76.5	0 - 56.9
Cob damage count (%)	43.9 ± 14.88	47.9	15.4 - 89.1
Stem tunneling (%)	4.4 ± 2.46	78.6	0.4- 9.9

S.E: Standard error, CV: Coefficient of variation, WAI: Weeks after infestation

Table 4.5. Percentage reduction in agronomic traits for DMR ESR-W and DMR ESR-Y progenies under infested condition (IC) at Ibadan and non-infested conditions (NIC) at Ibadan and Ikenne in 2008 and 2009.

	DMR ESR-W				DMR ESR-Y			
Traits	IC	+NIC	% reduction	Diff.	IC	+NIC	% reduction	Diff.
Days to 50% pollen shed	49.6	50.0	0.8	ns	48.8	50.0	2.4	ns
Days to silking	50.0	51.0	2.0	ns	49.8	51.3	2.9	*
Plant height (cm)	144.6	162.6	11.1	**	175.4	186.6	6.0	**
Ear height (cm)	73.6	75.2	2.1	ns	89.6	93.6	4.3	*
Ear length (cm)	9.6	12.9	25.6	**	11.0	13.9	20.9	**
Ear diameter (cm)	3.2	4.3	25.6	**	3.4	4.2	19.0	**
Ears per plant	0.8	1.0	20.0	**	0.7	0.9	22.2	**
Grain yield (t/ha)	3.5	4.6	23.9	**	3.2	4.6	30.4	**

Diff.: Difference, *, **: significant at 5% and 1% level of probability respectively, ns: not significant, n = 250.
Means of traits under infested and non-infested conditions were compared using t-test.
+ Data for non-infested plots at Ibadan and Ikenne were pooled because natural infestation by stem borers at both locations were low and not significant.

in DMR ESR-Y under IC and 4.6 t/ha under NIC, thus reflecting a relatively higher grain yield reduction of 30.4% when compared to the DMR ESR-W (Table 4.5). The damage symptoms are shown in Plate 4.1.

4.2. Variance estimates of progenies of DMR ESR-W and DMR ESR-Y maize populations

Additive variance was significantly larger than dominance variance for days to 50% silking, grain yield, ear length, stalk breakage, root lodging and number of ears per plant under IC in DMR ESR-W (Table 4.6). Dominance variance was significantly larger than additive variance for leaf feeding damage at 5WAI, cob damage and stem tunneling under IC. Both additive and dominance variances were significant for days to silking under IC in this maize population, although additive variance was larger (Table 4.6). Both additive and dominance variances were also significant for days to pollen shed, plant and ear height, and husk cover rating under IC in DMR ESR-W, but dominance variance was larger. Under NIC (Table 4.7), additive variance was significantly larger than dominance variance for ears per plant, ear height and stalk lodging. Both additive and dominance variances were significant for days to 50% pollen shed and silking, ear height and husk cover rating under NIC, although additive variance was larger. Both additive and dominance variances were also significant for plant height, plant aspect and grain yield under NIC, but dominance variance was larger.

Additive variance was significantly larger than dominance variance for ear aspect, ear length, root lodging, husk cover rating, stalk breakage and cob damage under IC in DMR ESR-Y (Table 4.8). Dominance variance was larger than additive variance for grain yield under IC in this maize population. Both additive and dominance variances were also significant for days to pollen shed and stem tunneling under IC in this maize population, although dominance variance was larger (Table 4.8). Both additive and dominance variances had equal effects on days to 50% silking under IC in DMR ESR-Y. Under NIC (Table 4.9), dominance variance was significantly larger than additive variance for stalk lodging, ear aspect and grain yield in this maize population. Both additive and dominance variances were significant for plant and ear height under both conditions in DMR ESR-Y, although additive variance was larger. Both additive and dominance variances were also significant for days to 50% pollen shed and silking, plant aspect, root lodging, ear length and ears per plant under NIC, although

Plate 4.1**.** Damage symptoms as shown on the maize plants on the infested plot. (A: Leaf feeding damage, B: Cob damage, C: Stem tunneling)

Table 4.6. Components of genetic variance* and narrow-sense heritability estimates of agronomic and damage parameters for progenies of DMR ESR-W under stem borer infested condition at Ibadan in 2008 and 2009.

Traits	σ^2a ± S.E	σ^2d ± S.E	σ^2ae	σ^2de	σ^2e	σ^2d/ σ^2a	σ^2ph	h^2 (%) ± S.E
Days to pollen shed	1.61 ± 0.46	2.17 ± 0.68	0.00	0.55	0.65	1.35	4.70	34.25 ± 0.13
Days to silking	2.18 ± 0.56	1.71 ± 0.75	-0.07	1.10	0.76	0.78	5.16	42.29 ± 0.15
Plant aspect	0.10 ± 0.08	0.12 ± 0.23	-0.11	0.47	0.27	1.20	0.67	15.53 ± 0.15
Plant height (cm)	59.83 ± 18.71	90.72 ± 26.53	9.42	12.73	25.29	1.52	186.92	32.01 ± 0.13
Ear height (cm)	29.90 ± 10.60	70.69 ± 16.85	5.04	-33.98	19.16	2.36	105.28	28.40 ± 0.14
Husk cover rating	0.43 ± 0.13	0.50 ± 0.15	0.12	0.12	0.14	1.16	1.20	36.20 ± 0.14
Root lodging (%)	0.003 ± 0.00	-0.01 ± 0.01	0.00	0.00	0.01	{-3.33}	0.01	39.04 ± 0.44
Stalk lodging (%)	-0.001 ± 0.00	0.01 ± 0.01	0.01	-0.03	0.01	{-10.00}	0.01	{-10.77±0.46}
Ear aspect	0.15 ± 0.08	-0.05 ± 0.17	0.01	0.62	0.19	{-0.52}	0.60	24.52 ± 0.17
Ear length (cm)	0.25 ± 0.09	0.20 ± 0.17	0.00	0.46	0.18	0.80	0.85	29.06 ± 0.14
Ear diameter (cm)	0.01 ± 0.01	0.01 ± 0.01	0.00	0.03	0.01	1.00	0.05	26.99 ± 0.14
Ears per plant	0.001 ± 0.00	-0.000 ± 0.00	0.002	0.001	0.001	0.00	0.01	18.30 ± 0.23
Grain Yield (t/ha)	0.15 ± 0.06	0.01 ± 0.12	-0.02	0.20	0.15	0.07	0.41	37.56 ± 0.19
Dead heart (%)	-0.000 ± 0.00	0.00 ± 0.00	0.00	0.00	0.01	0.00	0.00	{-23.26±0.46}
Leaf feeding damage 3WAI	0.01 ± 0.11	0.17 ± 0.21	0.12	-0.36	0.33	17.00	0.38	1.45 ± 0.28
Leaf feeding damage 5WAI	0.02 ± 0.12	2.21± 0.26	0.00	-2.49	0.32	110.50	1.31	1.75 ± 0.09
Stalk breakage (%)	0.01 ± 0.00	-0.02 ± 0.01	0.01	0.04	0.02	{-2.00}	0.03	40.59 ± 0.29
Cob damage count (%)	0.01 ± 0.01	0.23 ± 0.03	0.00	-0.23	0.04	23.00	0.16	6.36 ± 0.10
Stem tunneling (%)	-0.000 ± 0.00	0.002 ± 0.00	0.00	0.00	0.00	∞	0.002	{-6.01±0.31}

* σ^2a: additive variance; σ^2d: dominance variance; σ^2ae: additive x environment interaction variance
σ^2de: dominance x environment interaction variance; σ^2e: environmental variance; σ^2d/ σ^2a: degree of dominance
σ^2ph: phenotypic variance; h^2: narrow-sense heritability; S.E: standard error; WAI: Weeks after infestation
Values in parenthesis and variances with negative values were taken as zero

Table 4.7. Components of genetic variance* and narrow-sense heritability estimates of yield and other agronomic traits for progenies of DMR ESR-W under non-infested conditions at Ibadan and Ikenne in 2008 and 2009.

Traits	σ^2a ± S.E	σ^2d ± S.E	σ^2ae	σ^2de	σ^2e	σ^2d/ σ^2a	σ^2ph	h^2 (%) ± S.E
Days to pollen shed	1.92 ± 0.43	1.70 ± 0.36	0.16	0.96	0.26	0.89	4.16	46.08 ± 0.14
Days to silking	2.33 ± 0.48	1.35 ± 0.34	0.08	1.23	0.28	0.58	4.29	54.35 ± 0.16
Plant aspect	0.09 ± 0.03	0.22 ± 0.05	0.04	-0.06	0.06	2.44	0.36	24.12 ± 0.13
Plant height (cm)	63.44 ± 16.80	74.87 ± 20.49	1.24	58.95	19.09	1.18	172.44	36.79 ± 0.13
Ear height (cm)	29.36 ± 7.50	18.49 ± 8.01	4.00	18.19	9.99	0.63	63.38	46.32 ± 0.16
Husk cover rating	0.45 ± 0.10	0.37 ± 0.10	0.07	0.17	0.09	0.82	0.97	46.20 ± 0.15
Root lodging (%)	-0.000 ± 0.00	0.003 ± 0.00	0.00	0.00	0.00	∞	0.01	{-1.40 ± 0.17}
Stalk lodging (%)	0.001± 0.00	-0.01 ± 0.00	0.00	0.01	0.01	{-10.00}	0.00	42.42 ± 0.55
Ear aspect	0.04 ± 0.02	0.09 ± 0.05	0.09	0.17	0.06	2.25	0.26	17.15 ± 0.15
Ear length (cm)	0.22 ± 0.12	0.35 ± 0.31	-0.11	0.14	0.40	1.56	0.99	22.52 ± 0.16
Ear diameter (cm)	0.003 ± 0.01	0.04 ± 0.02	0.01	0.02	0.02	13.33	0.08	4.30 ± 0.13
Ears per plant	0.002 ± 0.00	0.001 ± 0.00	0.00	0.02	0.00	0.50	0.01	18.15 ± 0.15
Grain Yield (t/ha)	0.17 ± 0.08	0.57 ± 0.14	0.07	0.11	0.14	3.35	0.93	18.55 ± 0.11

* σ^2a: additive variance; σ^2d: dominance variance; σ^2ae: additive x environment interaction variance
σ^2de: dominance x environment interaction variance; σ^2e: environmental variance; σ^2d/ σ^2a: degree of dominance
σ^2ph: phenotypic variance; h^2: narrow-sense heritability; S.E: standard error
Values in parenthesis and variances with negative values were taken as zero

Table 4.8. Components of genetic variance* and narrow-sense heritability estimates of agronomic and damage parameters for progenies of DMR ESR-Y under stem borer infested condition at Ibadan in 2008 and 2009.

Traits	σ^2a ± S.E	σ^2d ± S.E	σ^2ae	σ^2de	σ^2e	σ^2d/σ^2a	σ^2ph	h^2 (%) ± S.E
Days to pollen shed	1.16 ± 0.31	1.86 ± 0.40	0.01	-0.87	0.47	1.60	3.06	37.97 ± 0.14
Days to silking	1.25 ± 0.31	1.25 ± 0.39	-0.07	0.13	0.43	1.00	2.96	42.37 ± 0.15
Plant aspect	0.04 ± 0.08	0.06 ± 0.17	0.11	0.21	0.24	1.50	0.50	7.57 ± 0.20
Plant height (cm)	98.93 ± 26.57	78.52 ± 26.49	24.48	-6.09	31.81	0.79	218.46	45.28 ± 0.17
Ear height (cm)	62.60 ± 14.23	37.29 ± 12.13	5.68	-2.89	14.37	0.60	115.66	54.13 ± 0.17
Husk cover rating	0.61 ± 0.16	-0.02 ± 0.11	0.26	0.11	0.16	{-0.03}	0.95	64.93 ± 0.23
Root lodging (%)	0.002 ± 0.00	0.00 ± 0.00	0.00	0.01	0.01	0.00	0.01	19.46 ± 0.20
Stalk lodging (%)	0.00 ± 0.00	0.01 ± 0.01	0.00	0.00	0.01	∞	0.02	2.00 ± 0.18
Ear aspect	0.18 ± 0.08	-0.11 ± 0.19	0.08	-0.08	0.32	{-0.61}	0.39	46.03 ± 0.33
Ear length (cm)	0.24 ± 0.10	0.12 ± 0.15	0.07	0.19	0.19	0.50	0.69	35.43 ± 0.18
Ear diameter (cm)	0.01 ± 0.01	0.02 ± 0.01	0.00	-0.03	0.01	2.00	0.04	34.98 ± 0.19
Ears per plant	0.000 ± 0.00	-0.000 ± 0.00	0.00	0.00	0.00	0.00	0.01	3.55 ± 0.27
Grain Yield (t/ha)	0.06 ± 0.06	0.28 ± 0.15	-0.02	0.24	0.17	4.37	0.62	10.47 ± 0.12
Dead heart (%)	0.000 ± 0.00	-0.000 ± 0.00	0.00	0.00	0.00	0.00	0.00	4.09 ± 0.17
Leaf feeding damage 3WAI	0.01 ± 0.10	-0.20 ± 0.25	0.00	0.28	0.39	{-20.00}	0.34	3.80 ± 0.34
Leaf feeding damage 5WAI	0.02 ± 0.09	-0.40 ± 0.26	-0.10	0.65	0.38	{-20.00}	0.27	6.72 ± 0.39
Stalk breakage (%)	0.01 ± 0.00	0.01 ± 0.01	0.00	0.02	0.01	1.00	0.05	26.18 ± 0.15
Cob damage count (%)	0.01 ± 0.00	-0.01 ± 0.01	0.00	0.01	0.02	{-1.00}	0.02	40.10 ± 0.29
Stem tunneling (%)	0.002 ± 0.00	0.003 ± 0.00	0.00	0.00	0.00	1.50	0.00	8.12 ± 0.18

* σ^2a: additive variance; σ^2d: dominance variance; σ^2ae: additive x environment interaction variance
σ^2de: dominance x environment interaction variance; σ^2e: environmental variance; σ^2d/σ^2a: degree of dominance
σ^2ph: phenotypic variance; h^2: narrow-sense heritability; S.E: standard error; WAI: Weeks after infestation
Values in parenthesis and variances with negative values were taken as zero

Table 4.9. Components of genetic variance* and narrow-sense heritability estimates of yield and other agronomic traits for progenies of DMR ESR-Y under non-infested conditions at Ibadan and Ikenne in 2008 and 2009.

Traits	σ^2a ± S.E	σ^2d ± S.E	σ^2ae	σ^2de	σ^2e	$\sigma^2d/\ \sigma^2a$	σ^2ph	h^2 (%) ± S.E
Days to pollen shed	1.58 ± 0.36	1.78 ± 0.31	0.19	0.30	0.21	1.13	3.70	42.84 ± 0.14
Days to silking	1.40 ± 0.33	1.53 ± 0.30	0.16	0.84	0.22	1.09	3.40	41.21 ± 0.13
Plant aspect	0.08 ± 0.03	0.19 ± 0.04	0.07	-0.11	0.05	2.38	0.30	25.53 ± 0.13
Plant height (cm)	83.68 ± 19.82	61.30 ± 16.69	18.39	-22.72	21.72	0.73	165.62	50.52 ± 0.17
Ear height (cm)	48.27 ± 11.27	34.65 ± 8.43	15.82	-28.84	11.27	0.72	90.94	53.08 ± 0.17
Husk cover rating	0.75 ± 0.15	0.31 ± 0.08	0.13	0.13	0.09	0.41	1.22	61.47 ± 0.18
Root lodging (%)	0.001 ± 0.00	0.003 ± 0.00	0.00	0.01	0.00	3.00	0.01	13.24 ± 0.15
Stalk lodging (%)	-0.002 ± 0.00	0.01 ± 0.00	0.01	0.00	0.00	{-5.00}	0.01	{-17.34 ± 0.15}
Ear aspect	0.06 ± 0.04	0.21± 0.07	0.09	0.16	0.08	3.50	0.42	13.99 ± 0.12
Ear length (cm)	0.30 ± 0.14	0.54 ± 0.29	0.04	0.23	0.18	1.80	1.16	25.72 ± 0.17
Ear diameter (cm)	0.02 ± 0.01	0.01 ± 0.01	0.01	-0.01	0.01	0.50	0.04	49.60 ± 0.29
Ears per plant	0.001 ± 0.00	0.002 ± 0.00	0.00	0.01	0.00	2.00	0.01	9.14 ± 0.17
Grain Yield (t/ha)	0.13 ± 0.08	0.64 ± 0.16	0.07	0.08	0.18	4.92	0.97	12.90 ± 0.11

* σ^2a: additive variance; σ^2d: dominance variance; σ^2ae: additive x environment interaction variance
σ^2de: dominance x environment interaction variance; σ^2e: environmental variance; $\sigma^2d/\ \sigma^2a$: degree of dominance
σ^2ph: phenotypic variance; h^2: narrow-sense heritability; S.E: standard error
Values in parenthesis and variances with negative values were taken as zero

dominance variance was larger (Table 4.9). None of the gene actions was important for dead heart in both maize populations.

Environmental variances were larger than their corresponding genetic variances for plant aspect, root lodging, ear aspect and leaf feeding damage at 3WAI under IC in DMR ESR-W (Table 4.6). They were however larger for plant aspect, root lodging, ear aspect, leaf feeding damage and cob damage under IC in DMR ESR-Y (Table 4.8). Environmental variances were lower than estimates of genetic variances for nearly all traits under NIC in both maize populations. Estimate of ‘additive x environment’ interaction component of variance was lower than ‘dominance x environment’ interaction variance for most of the traits measured under both conditions in the maize populations.

Degree of dominance (σ^2d/σ^2a) was above unity for some traits under both conditions in the maize populations. Ratios with negative values were equated to zero. Partial dominance was observed in days to 50% silking, ear length, and grain yield under IC in DMR ESR-W (Table 4.6). No dominance was observed for root and stalk lodging, ear aspect, ears per plant and stalk breakage under IC in this maize population. Complete dominance was observed for ear diameter, while overdominance was observed in other traits under IC in DMR ESR-W (Table 4.6). Under NIC in DMR ESR-W (Table 4.7), partial dominance was observed in days to 50% pollen shed and silking, ear height, husk cover rating and ears per plant; no dominance was observed in stalk lodging, while overdominance was observed in other traits. In DMR ESR-Y under IC (Table 4.8), partial dominance was observed for plant and ear height and ear length; complete dominance was observed for days to 50% silking and stalk breakage, while overdominance was observed in days to pollen shed, plant aspect, ear diameter, grain yield and stem tunneling. Under NIC (Table 4.9), partial dominance was observed in plant and ear height, husk cover rating and ear diameter, no dominance in stalk lodging, while overdominance was observed in other traits. The ratio was exceptionally high for leaf feeding damage and cob damage under IC, and ear diameter under NIC in DMR ESR-W. It was also very high for stalk lodging and stem tunneling under IC, and grain yield under NIC in DMR ESR-Y. Highest error and phenotypic variance were obtained in plant height and lowest in dead heart in both maize populations.

Narrow-sense heritability estimates were low to moderate in both maize populations. It ranged from 1.45 % for leaf feeding damage at 3WAI to 42.29% for days to 50% silking under IC in DMR ESR-W. Heritability estimate for grain yield under IC in this maize population was 37.56%. Stalk breakage had the highest heritability estimate of 40.59% in DMR ESR-W among damage parameters (Table 4.6). Under NIC in this maize population, the estimate ranged from 4.30% for ear diameter to 54.35% for days to 50% silking (Table 4.7). In DMR ESR-Y, heritability estimates ranged from 2.00% for stalk lodging to 64.93% for husk cover rating under IC (Table 4.8). The estimate was rather lower for grain yield under IC in DMR ESR-Y (10.47%) than in DMR ESR-W. Cob damage had the highest estimate of 40.10% among damage parameters in this maize population. Heritability estimates ranged from 9.14% for ears per plant to 61.47% for husk cover rating under NIC in DMR ESR-Y (Table 4.9). Heritability estimates were higher under NIC than under IC except in some instances where additive variances were much smaller than dominance variance under NIC. Leaf feeding damage at 3WAI had the least heritability estimate in both maize populations among damage parameters.

4.3. Mean square estimates for progenies of DMR ESR-W and DMR ESR-Y maize populations

Significant entry effects were observed at Ibadan in 2008 and 2009 for all agronomic traits except ear aspect and number of ears per plant under IC for progenies of DMR ESR-W (Table 4.10). A breakdown of mean squares for Entries in DMR ESR-W revealed that ‘male in set’ and ‘female in set’ mean squares (a measure of GCA) were larger than mean squares for ‘male x female’ interaction (a measure of SCA) for most traits under IC. Both GCA and SCA were significant for days to 50% silking, plant and ear height and husk cover rating under IC in this maize population (Table 4.10). GCA male was significant for plant aspect, while both GCA male and GCA female were significant for ear length and grain yield under IC. GCA female was slightly larger than GCA male for most of the traits measured under IC in DMR ESR-W. Mean squares for Environment x Entry interaction were significant for husk cover rating, ear aspect and ear length under IC (Table 4.10). Leaf feeding damage at 5WAI, stalk breakage and cob damage showed significant entry effects for progenies of DMR ESR-W among damage parameters (Table 4.11). However, all agronomic traits showed highly significant entry effects in DMR ESR-W population under NIC, with both GCA and SCA being important except for ear length and number of ears per plant (Table 4.12).

Table 4.10. Mean squares from ANOVA of agronomic traits for progenies of DMR ESR-W evaluated under stem borer infested condition at Ibadan in 2008 and 2009.

Source	Df	Days to silking (days)	Plant aspect (1-9)	Plant height (cm)	Ear height (cm)	Husk cover (1-9)	Ear aspect	Ear length (cm)	Ears/ plant (no.)	Grain yield (t/ha)
Environment (E)	1	923.18**	31.58**	27517.65**	2113.58**	58.31**	0.47	157.37**	1.36**	140.44**
Set (S)	8	19.39**	3.34**	1286.35**	586.97**	1.98**	2.67**	5.29**	0.04*	2.96**
E x S	8	3.61	3.51**	132.69	63.22	0.09	1.60*	1.75**	0.03	1.54**
Rep (E x S)	18	3.16	1.07	91.53	71.15	0.70	0.46	0.39	0.01	0.45
Entry	224	9.42**	1.54*	319.28**	187.52**	2.03**	1.33	1.58**	0.02	0.96**
Male (S)	36	12.47**	1.54**	456.68**	271.76**	3.06**	1.63	2.08**	0.03	1.25**
Female (S)	36	19.58**	1.78	585.23**	313.10**	4.14**	1.89	2.67**	0.03	1.61**
Male x Female (S)	144	5.28**	1.42	198.26**	130.32**	1.13**	1.01	1.13	0.02	0.72
E x Entry	224	3.49	1.22	112.47	63.63	0.72*	1.07**	0.90*	0.02	0.67
E x Male (S)	36	3.52	0.71	139.37	81.54	0.86	1.02	0.82	0.02	0.54
E x Female (S)	36	3.29	1.33	122.83	62.94	1.01*	1.14	1.05	0.02	0.76
E x Male x Female (S)	144	3.58	1.30	107.54	59.63	0.64	1.06**	0.93*	0.02	0.71
Error	432	3.03	1.07	101.17	76.62	0.57	0.76	0.70	0.02	0.60

*, **: Significant at P = 0.05 and 0.01, respectively, df : degree of freedom
(1-9): 1- Excellent, 9- Poor

Table 4.11. Mean squares from ANOVA of damage parameters for progenies of DMR ESR-W evaluated under stem borer infested condition at Ibadan in 2008 and 2009.

Source	df	Deadheart (%)	Leaf feeding damage 3 WAI (1-9)	Leaf feeding damage 5 WAI (1-9)	Stalk breakage (%)	Cob damage (%)	Stem tunneling (%)
Environment (E)	1	0.11*	147.20**	0.00	3.67**	0.24	0.08*
Set (S)	8	0.02	1.26	2.41	0.22**	0.32*	0.04**
E x S	8	0.02	1.12	0.03	0.04	0.04	0.01
Rep (E x S)	18	0.03	0.72	0.51	0.07	0.13	0.01
Entry	224	0.02	1.43	2.35**	0.09*	0.28**	0.02
Male (S)	36	0.01	2.20	2.10**	0.12	0.21**	0.02
Female (S)	36	0.02	1.06	2.60**	0.16*	0.41**	0.02
Male x Female (S)	144	0.02	1.31	2.23**	0.06	0.26**	0.02
E x Entry	224	0.02	1.27	0.02	0.09**	0.03	0.01
E x Male (S)	36	0.02	1.41	0.03	0.11	0.03	0.02
E x Female (S)	36	0.03	1.46	0.03	0.10	0.03	0.01
E x Male x Female (S)	144	0.02	1.15	0.02	0.08*	0.03	0.01
Error	432	0.02	1.33	1.27	0.07	0.14	0.02

*, **: Significant at P = 0.05 and 0.01, respectively, df : degree of freedom , WAI: Weeks after infestation
(1-9): 1- Excellent, 9- Poor

Table 4.12. Mean squares from ANOVA of agronomic traits for progenies of DMR ESR-W evaluated under non-infested conditions at Ibadan and Ikenne in 2008 and 2009.

Source	Df	Days to silking (days)	Plant aspect (1-9)	Plant height (cm)	Ear height (cm)	Husk cover (1-9)	Ear aspect (1-9)	Ear length (cm)	Ears/ plant (no.)	Grain yield (t/ha)
Environment (E)	3	2591.01**	5.42**	100862.81**	44047.65**	18.01**	150.83**	299.71**	1.57**	646.90**
Set (S)	8	29.62**	1.77**	2361.70**	789.43**	4.50**	3.56**	10.16**	0.10**	4.88**
E x S	24	4.60**	0.68	241.08*	99.59	1.30**	0.58	1.43	0.05**	1.15
Rep (E x S)	36	3.13	0.53	121.64	70.60	0.84	0.31	1.45	0.03	1.06
Entry	224	14.64**	1.23**	578.15**	239.44**	3.33**	1.01**	2.38**	0.04*	2.95**
Male (S)	36	26.58**	1.34**	887.38**	484.87**	5.84**	1.32**	3.34**	0.04**	3.29**
Female (S)	36	31.57**	2.29**	1051.44**	374.23**	6.57**	1.49*	2.43	0.05	5.08**
Male x Female (S)	144	5.57**	0.86**	331.93**	125.98**	1.56**	0.74*	2.04	0.03	2.29**
E x Entry	672	2.91**	0.44	180.77*	89.68	0.88**	0.64**	1.62	0.03**	1.18*
E x Male (S)	108	3.15	0.43	181.46	108.93	1.06*	0.62	1.40	0.02	1.09
E x Female (S)	108	3.03	0.61**	189.14	89.03	0.89	0.93**	1.43	0.03	1.56*
E x Male x Female (S)	216	2.88**	0.42	182.20*	88.99	0.81	0.56*	1.69	0.03**	1.15
Error	864	2.27	0.45	152.72	79.90	0.73	0.47	1.62	0.02	1.09

*, **: Significant at P = 0.05 and 0.01, respectively, df : degree of freedom
(1-9): 1- Excellent, 9- Poor

Mean squares for Environment x Entry interaction was significant for most traits under NIC in this maize population with the exception of plant aspect, ear height and ear length.

Similarly, under IC in DMR ESR-Y (Table 4.13), highly significant entry effects were observed at Ibadan in both seasons for all agronomic traits with the exception of plant aspect and number of ears per plant. A breakdown of mean squares for Entries in this population revealed that mean squares for male, female and 'male x female in set' interaction were important for days to silking, plant and ear height under IC. Both GCA male and SCA were significant for grain yield. Mean squares for Environment x Entry interaction were significant for plant aspect, plant height, ear length and husk cover rating under IC in DMR ESR-Y (Table 4.13), and for dead heart, stalk breakage and stem tunneling among damage parameters (Table 4.14). Stalk breakage, cob damage and stem tunneling showed significant entry effects among damage parameters in this maize population, with GCA being significant for stalk breakage and cob damage, while both GCA and SCA were significant for stem tunneling (Table 4.14). However, all agronomic traits showed highly significant entry effects in DMR ESR-Y population under NIC, with both GCA and SCA being important except for number of ears per plant (Table 4.15). GCA male was slightly higher than GCA female for most of the traits assessed under both conditions in this maize population. Mean squares for Environment x Entry interaction were significant for most of the traits in DMR ESR-Y under NIC except ear length and grain yield (Table 4.15). Environment had highly significant effect on almost all traits measured under both conditions in the maize populations.

GCA had significant effect on grain yield under IC, while both GCA and SCA had significant effect on grain yield under NIC in DMR ESR-W. However, partitioning sum of squares of Entries showed that GCA accounted for 50.0% and 47.9% of the total variation among entries for grain yield under IC and NIC, respectively in DMR ESR-W (Appendix 11). Among damage parameters, GCA accounted for 38.4% of the total variation for leaf feeding damage at 3WAI, 29.8% for dead heart, 53.0% for stalk breakage, 37.6% for cob damage and 35.1% for stem tunneling in DMR ESR-W (Appendix 12 & 13). However, in DMR ESR-Y, GCA accounted for 38.6% of the total variation among entries for grain yield under IC and 43.2% under NIC in DMR ESR-Y (Appendix 14). GCA accounted for 34.2% of the total variation for leaf feeding damage at 3WAI, 34.8% for dead heart, 48.7% for stalk

Table 4.13. Mean squares from ANOVA of agronomic traits for progenies of DMR ESR-Y evaluated under stem borer infested condition at Ibadan in 2008 and 2009.

Source	df	Days to silking (days)	Plant aspect (1-9)	Plant height (cm)	Ear height (cm)	Husk cover (1-9)	Ear aspect	Ear length (cm)	Ears/ plant (no.)	Grain yield (t/ha)
Environment (E)	1	119.17**	0.30	450096.30**	100917.17**	37.59**	87.01**	873.85**	17.50**	1319.23**
Set (S)	9	17.44**	2.17*	3400.96**	2086.82**	10.90**	3.03**	6.74**	0.03	2.03**
E x S	9	1.37	2.00*	644.26**	249.48**	3.19**	2.93*	1.22	0.02	0.79
Rep (E x S)	20	1.57	1.00	97.29	87.59	0.42	1.96	0.49	0.02	0.78
Entry	249	5.17**	1.30	400.25**	211.82**	1.98**	1.51*	1.41**	0.02	1.16**
Male (S)	40	7.01**	1.72	772.40**	409.33**	4.74**	2.71*	2.84**	0.02	1.36**
Female (S)	40	11.22**	1.44	744.74**	431.74**	4.07**	1.71	1.90*	0.02	1.31
Male x Female (S)	160	3.02**	1.13	202.73**	93.34**	0.69	1.13	0.99	0.02	1.06*
E x Entry	249	1.74	1.15*	142.47**	61.83	0.94**	1.33	0.94*	0.02	0.78
E x Male (S)	40	1.51	1.04	209.79**	70.76	1.31**	1.50	1.09	0.02	0.61
E x Female (S)	40	1.69	1.62*	161.06	69.71	1.40**	1.38	0.98	0.02	0.85
E x Male x Female (S)	160	1.77	1.06	124.21	56.05	0.71	1.24	0.87	0.02	0.78
Error	480	1.70	0.96	127.26	57.49	0.65	1.28	0.77	0.02	0.66

*, **: Significant at P = 0.05 and 0.01, respectively, df : degree of freedom
(1-9): 1- Excellent, 9- Poor

Table 4.14. Mean squares from ANOVA of damage parameters for progenies of DMR ESR-Y evaluated under stem borer infested condition at Ibadan in 2008 and 2009.

Source	df	Deadheart (%)	Leaf feeding damage 3 WAI (1-9)	Leaf feeding damage 5 WAI (1-9)	Stalk breakage (%)	Cob damage (%)	Stem tunneling (%)
Environment (E)	1	0.14**	108.64**	113.90**	1.28**	4.39**	0.08**
Set (S)	9	0.01*	1.72	3.81**	0.08	0.18**	0.01
E x S	9	0.01**	4.91**	4.97**	0.07	0.06	0.01
Rep (E x S)	20	0.01*	4.05**	2.31	0.06	0.04	0.01
Entry	249	0.004	1.53	1.42	0.09**	0.07*	0.01**
Male (S)	40	0.005	1.32	1.40	0.14**	0.12*	0.01
Female (S)	40	0.004	1.78	1.16	0.13**	0.10	0.01*
Male x Female (S)	160	0.004	1.49	1.44	0.07	0.06	0.01**
E x Entry	249	0.004**	1.73	1.75	0.06*	0.07	0.01*
E x Male (S)	40	0.01	1.62	1.51	0.06	0.07	0.01*
E x Female (S)	40	0.004	1.75	1.65	0.06	0.08	0.01
E x Male x Female (S)	160	0.005**	1.69	1.84	0.06	0.07	0.01
Error	480	0.003	1.55	1.51	0.05	0.06	0.01

*, **: Significant at P = 0.05 and 0.01, respectively, df : degree of freedom,
WAI: Weeks after infestation, (1-9): 1- Excellent, 9- Poor

Table 4.15. Mean squares from ANOVA of agronomic traits for progenies of DMR ESR-Y maize population evaluated under non-infested conditions at Ibadan and Ikenne in 2008 and 2009.

Source	df	Days to silking (days)	Plant aspect (1-9)	Plant height (cm)	Ear height (cm)	Husk cover (1-9)	Ear aspect (1-9)	Ear length (cm)	Ears/ plant (no.)	Grain yield (t/ha)
Environment (E)	3	2696.66**	28.42**	126866.61**	62845.33**	73.25**	312.85**	1903.81**	4.65**	1767.92**
Set (S)	9	23.60**	1.50**	6130.93**	3791.43**	15.65**	2.52**	11.30**	0.04*	5.36**
E x S	27	2.58	0.32	273.60*	231.03**	2.63**	1.18**	3.01*	0.04**	2.07
Rep (E x S)	40	2.75*	0.22	160.08	73.65	0.81	0.58	0.59	0.02	1.30
Entry	249	10.32**	1.03**	604.49**	327.62**	4.12**	1.45**	2.62**	0.03*	3.05**
Male (S)	40	15.63**	1.56**	1217.20**	673.75**	10.25**	1.99**	4.25**	0.04	2.43*
Female (S)	40	23.65**	1.73**	1118.30**	660.90**	8.23**	1.93**	3.16**	0.04	5.83**
Male x Female (S)	160	5.24**	0.70**	285.01**	145.06**	1.43**	1.16**	2.10*	0.03*	2.71**
E x Entry	747	2.32**	0.38**	179.19*	90.68**	0.93**	0.82**	1.62	0.02**	1.48
E x Male (S)	120	2.72	0.52**	249.40**	122.09**	1.14**	0.86	1.85	0.03	1.55
E x Female (S)	120	2.46	0.45**	167.39	108.53**	1.15**	1.05**	1.50	0.03	1.66
E x Male x Female (S)	480	2.19**	0.32	162.41	75.76	0.81	0.73	1.56	0.02	1.44
Error	960	1.77	0.37	173.77	90.18	0.74	0.65	1.45	0.02	1.40

*, **: Significant at p = 0.05 and 0.01, respectively, d.f: degree of freedom
(1-9): 1- Excellent, 9- Poor

breakage, 47.7% for cob damage and 42.2% for stem tunneling in this maize population (Appendix 15 & 16).

4.4. Correlation among traits for progenies of DMR ESR-W and DMR ESR-Y maize populations

There were positive and significant correlations between days to 50% pollen shed and silking (rp = 0.85**, rg = 0.89**) and plant and ear height (rp = 0.73**, rg = 0.69**) under IC in DMR ESR-W (Table 4.16). Genotypic correlations between plant and ear aspect, and plant height and ear length were also high and positive. The correlation between ears per plant and ear aspect was positive and highly significant under IC (rp = 0.42**, rg = 0.88**) in DMR ESR-W. Ears per plant had negative and significant correlations with plant and ear height. Ear length had negative and highly significant correlations with ears per plant and ear aspect, but positive relationship with plant and ear height and husk cover rating under IC in DMR ESR-W (Table 4.16). Correlations between grain yield and damage parameters in DMR ESR-W were negative except for leaf feeding damage (Table 4.16). However, the phenotypic correlation coefficients were low. Genotypic correlation between grain yield and stalk breakage was the highest among damage parameters (-0.47*) in this maize population. None of the damage parameters had significant phenotypic correlation with grain yield.

Stem tunneling had negative relationship with most agronomic traits in both maize populations. It had significant genotypic correlations with ear length (-0.66*), plant height (-0.75**) and ear height (-0.58**) in DMR ESR-W (Table 4.16). However, stem tunneling had positive relationship with plant and ear aspect. Ears per plant had negative and significant genotypic correlations with stalk breakage and stem tunneling. Stalk breakage also had positive and significant correlations with plant aspect (rp = 0.08*, rg = 0.89*) in this maize population. Leaf feeding damage had positive and significant correlation with husk cover rating (rp = 0.51*, rg = 0.13*) (Table 4.16). A positive relationship exists among damage parameters, for instance leaf feeding damage had significant genotypic correlation with stem tunneling (rg = 0.62*) in DMR ESR-W. Stem tunneling had positive and significant phenotypic correlations with stalk breakage (0.09*) and cob damage (0.12*) in DMR ESR-W, but their corresponding genotypic correlations were not significant (Table 4.16).

Table 4.16. Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients of 14 traits for progenies of DMR ESR-W maize population evaluated under stem borer infested condition at Ibadan in 2008 and 2009.

Traits	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Days to pollen shed		0.89**	0.11	0.16	-0.19	-0.56*	-0.25*	-0.30*	0.52**	-0.35*	-0.64*	0.06	-0.64**	-0.09
2 Days to silking	0.85**		0.23*	0.20	-0.17	-0.52*	-0.24	-0.36*	0.44*	-0.04	-0.50	0.08	-0.59**	-0.51*
3 Plant height (cm)	-0.10*	-0.05		0.69**	-0.12	-0.68*	-0.35**	-0.64**	0.36*	-0.75**	0.49*	0.50**	0.03	0.20
4 Ear height (cm)	-0.19**	-0.19**	0.73**		0.12	-0.87*	-0.35*	-0.46*	0.28*	-0.58**	-0.15	0.53**	0.26*	0.25
5 Husk cover rating	-0.14**	-0.14**	0.04	0.11*		0.48*	0.01	0.27*	-0.21	-0.10	0.14	0.38**	0.16	0.51*
6 Plant aspect	-0.03	0.00	-0.24**	-0.19**	0.07*		0.91**	0.92*	-0.97**	0.82*	0.89*	-0.24	-0.09	-0.75*
7 Ears per plant	0.05	0.11*	-0.22**	-0.26**	-0.07	0.30**		0.88**	0.42*	-0.75**	-0.84*	-0.42**	0.15	0.01
8 Ear aspect	0.06	0.06	-0.21**	-0.23**	0.03	0.19**	0.42**		-0.67*	0.76*	0.13	-0.59*	0.83**	-0.44*
9 Grain Yield (t/ha)	-0.08*	-0.15**	0.30**	0.35**	0.06	-0.38**	0.41**	-0.34**		-0.29	-0.47*	0.36*	-0.11	0.38
10 Stem tunneling (%)	-0.10*	-0.08*	-0.12*	-0.01	-0.02	0.01	0.06*	0.14**	-0.01		0.27	-0.66*	0.26	0.62*
11 Stalk breakage (%)	-0.10*	-0.08*	0.02	0.01	-0.02	0.08*	0.14**	0.10*	-0.06	0.09*		-0.30	0.68*	0.23
12 Ear length (cm)	-0.11*	-0.14**	0.29**	0.36**	0.19**	-0.16**	-0.39**	-0.34**	0.37**	-0.06	-0.03		-0.01	0.63*
13 Cob damage (%)	-0.03	-0.02	-0.11*	-0.10*	0.05	0.03	0.02	0.26**	-0.05	0.12*	0.08*	-0.11*		0.31
14 Leaf feeding damage 3WAI	-0.19*	-0.21**	-0.04	0.09*	0.13*	0.18**	-0.02	0.01	0.04	0.09*	0.09*	-0.03	0.09*	

*, **: Significantly different from zero at 0.05 and 0.01 levels of probability, respectively.

Under NIC in DMR ESR-W (Table 4.17), positive and significant correlations were observed between days to 50% pollen shed and silking (rp = 0.90**, rg = 0.97**) and plant and ear height (rp = 0.73**, rg = 0.83**). Grain yield had positive genotypic correlations with days to pollen shed, days to silking, and plant and ear height under both conditions in DMR ESR-W. However, the phenotypic correlations between grain yield and days to 50% pollen shed and silking were negative. Grain yield had positive and significant correlations with ears per plant (rp = 0.49**, rg = 0.57**) and ear length (rp = 0.32**, rg = 0.51**) under NIC in DMR ESR-W. Negative correlations were obtained between ears per plant and plant and ear aspect under NIC. However, ears per plant had positive and significant correlations with plant and ear height (Table 4.17).

Similarly, under IC in DMR ESR-Y (Table 4.18), there were positive and significant correlations between days to 50% pollen shed and silking (rp = 0.84**, rg = 0.91**) and plant and ear height (rp = 0.74**, rg = 0.76**). Ears per plant had negative genotypic correlations with plant and ear height, but positive phenotypic correlations under IC. Under both IC and NIC, ears per plant had negative genotypic correlations with plant and ear aspect, while ear length also had negative correlation with plant aspect. Ear length had negative genotypic correlations with plant and ear height, but positive phenotypic correlations under both conditions. Plant and ear aspect had negative and significant correlations with plant and ear height under both conditions in the maize populations, but positive correlations with husk cover rating. Genotypic correlation was highest between grain yield and stem tunneling (-0.52*) among damage parameters in DMR ESR-Y (Table 4.18). There were highly significant phenotypic correlations between grain yield and cob damage (-0.24**), stem tunneling (-0.15**) and leaf feeding damage (-0.18**) in this maize population. Leaf feeding damage had positive and significant phenotypic correlation with plant aspect in both maize populations. Negative relationship exists between cob damage and ear length in both maize populations, but it was significant only in DMR ESR-Y (rp = -0.15**, rg = -0.33**). The correlation between plant height and stalk breakage was positive and significant in DMR ESR-Y under IC. Positive relationship exists among damage parameters in both maize populations except in few cases.

The phenotypic correlation between grain yield and days to 50% pollen shed was positive and not significant under NIC in DMR ESR-Y (Table 4.19). Ears per plant had positive correlations with plant and ear height under NIC. Days to 50% pollen

Table 4.17. Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients of agronomic traits for progenies of DMR ESR-W maize population evaluated under non-infested conditions at Ibadan and Ikenne in 2008 and 2009.

Traits	1	2	3	4	5	6	7	8	9	10
1 Days to pollen shed		0.97**	0.27**	0.32**	-0.24*	-0.47**	0.26*	-0.09	0.07*	-0.04
2 Days to silking	0.90**		0.31**	0.33**	-0.20*	-0.42**	0.16	-0.04	0.39**	-0.08
3 Plant height (cm)	-0.06*	-0.06*		0.83**	-0.19*	-0.60**	0.34*	-0.47**	0.42**	0.36*
4 Ear height (cm)	-0.09*	-0.12**	0.73**		-0.03	-0.69**	0.35*	-0.27*	0.43**	0.38*
5 Husk cover rating	-0.16**	-0.13**	-0.03	0.04		0.25*	-0.45*	0.42**	-0.33**	0.10
6 Plant aspect	-0.08*	-0.09**	-0.22**	-0.23**	0.08*		-0.52*	0.60**	-0.76**	-0.34*
7 Ears per plant	-0.03	-0.05*	0.14**	0.15**	-0.05	-0.14**		-0.11	0.57**	0.06
8 Ear aspect	0.07*	0.10**	-0.14**	-0.12**	0.09**	0.14**	-0.07*		-0.90**	-0.69**
9 Grain yield (t/ha)	-0.02	-0.06	0.26**	0.27**	-0.07*	-0.28**	0.49**	-0.43**		0.51**
10 Ear length (cm)	-0.14**	-0.17**	0.13**	0.15**	0.11*	-0.10*	0.03	-0.25**	0.32**	

*, **: Significantly different from zero at 0.05 and 0.01 levels of probability, respectively.

Table 4.18. Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients of 14 traits for progenies of DMR ESR-Y maize population evaluated under stem borer infested condition at Ibadan in 2008 and 2009.

Traits	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Days to pollen shed		0.91**	0.07	0.16*	-0.01	-0.20*	0.12	-0.73**	0.49**	-0.32*	-0.15*	0.10	-0.03	†
2 Days to silking	0.84**		0.11	0.20*	0.08	-0.09	0.74*	-0.34*	0.42*	-0.07	-0.18*	0.11	0.07	†
3 Plant height (cm)	-0.16**	-0.20**		0.76**	-0.21*	-0.54*	-0.37*	0.38*	0.40*	-0.03	0.36*	-0.05	0.30	†
4 Ear height (cm)	-0.02	-0.10*	0.74**		-0.34**	-0.48*	-0.12	-0.23*	0.20*	-0.12	0.38**	-0.24*	-0.07	†
5 Husk cover rating	-0.11*	-0.04	-0.04	-0.08*		0.23	-0.24	0.89*	-0.18	-0.21	0.05	-0.02	0.75*	†
6 Plant aspect	-0.03	0.01	-0.21**	-0.15**	0.09*		-0.81*	0.90*	-0.89*	0.51*	-0.36	-0.36	-0.36	†
7 Ears per plant	-0.11**	-0.14**	0.04	0.04	-0.03	-0.24**		-0.26	0.95**	-0.34	-0.01	0.06	-0.40	†
8 Ear aspect	0.00	0.08*	-0.17**	-0.18**	0.11**	0.25**	0.02		-0.98*	0.70*	-0.07	†	0.91*	†
9 Grain Yield (t/ha)	-0.04	-0.08*	0.32**	0.20**	-0.03	-0.37**	0.48**	-0.39**		-0.52*	0.15	0.20	-0.03	†
10 Stem tunneling (%)	-0.18**	-0.11*	0.01	0.01	0.07	0.13**	-0.07	0.22**	-0.15**		-0.20	-0.11	-0.10	†
11 Stalk breakage (%)	-0.08*	-0.10*	0.09*	0.11*	-0.02	0.00	0.05	-0.02	-0.04	0.05		-0.28	0.35**	†
12 Ear length (cm)	-0.14**	-0.14**	0.18**	0.10*	0.12**	-0.14**	0.08*	-0.32**	0.33**	0.05	-0.07*		-0.33**	†
13 Cob damage (%)	-0.01	-0.04	-0.06*	-0.05	0.08*	-0.36*	-0.11*	0.33**	-0.18**	0.06*	0.08*	-0.15**		†
14 Leaf feeding damage 3WAI	0.10*	-0.09	-0.09	-0.01	0.02	0.26*	-0.09*	0.13**	-0.18**	0.12*	0.07	-0.05	0.15*	

*, **: Significantly different from zero at 0.05 and 0.01 levels of probability, respectively.
† Not estimated due to negative genetic variance

Table 4.19. Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients of agronomic traits for progenies of DMR ESR-Y maize population evaluated under non-infested conditions at Ibadan and Ikenne in 2008 and 2009.

Traits	1	2	3	4	5	6	7	8	9	10
1 Days to pollen shed		0.96**	0.23*	0.33**	-0.05	-0.13	-0.07	-0.43**	0.58**	-0.10
2 Days to silking	0.91**		0.19*	0.26**	0.04	-0.14	-0.02	-0.38**	0.59**	-0.02
3 Plant height (cm)	-0.09*	-0.13**		0.80**	-0.26**	-0.42**	0.11	-0.19	0.20*	-0.13
4 Ear height (cm)	-0.01	-0.10**	0.72**		-0.29**	-0.34**	0.17	-0.30*	0.25*	-0.23*
5 Husk cover rating	-0.06*	-0.03	-0.08*	-0.09*		0.53**	0.17	0.55**	-0.21*	0.07
6 Plant aspect	-0.04	-0.02	-0.21**	-0.17**	0.22**		-0.26	0.43**	-0.42**	-0.13
7 Ears per plant	-0.07*	-0.08**	0.12**	0.09**	0.00	-0.13**		-0.31	0.54**	0.31
8 Ear aspect	-0.02	0.03	-0.13**	-0.14**	0.17**	0.15**	-0.06*		-0.63**	0.08
9 Grain Yield (t/ha)	0.03	-0.02	0.20**	0.18**	-0.02	-0.20**	0.55**	-0.37**		-0.14
10 Ear length (cm)	-0.25**	-0.27**	0.18**	0.15**	0.17**	-0.06*	0.07*	-0.26**	0.23**	

*, **: Significantly different from zero at 0.05 and 0.01 levels of probability, respectively.

shed and silking had negative and significant correlations with most agronomic traits under both conditions in the maize populations except in few cases. For instance, days to 50% pollen shed and silking had positive genotypic correlations with plant and ear height and grain yield, but the phenotypic correlations were negative under both conditions in the maize populations. Strong positive correlation exists between ears per plant and grain yield under both conditions in the maize populations, while grain yield had negative and highly significant correlation with plant and ear aspect. Positive and highly significant relationship was observed between cob damage and ear aspect in both maize populations. Days to 50% pollen shed and silking had negative and significant correlations with most damage parameters in both maize populations. Generally, phenotypic correlations were lower than their corresponding genotypic correlations for all traits assessed under both conditions in the maize populations.

4.5. Predicted and correlated responses in DMR ESR-W and DMR ESR-Y maize populations

Estimates of predicted response to selection for the traits measured in DMR ESR-W, using three seasons and a modification of two seasons per cycle with a parental control of one, are shown in Table 4.20. Expected gains per generation ranged from -0.02% for stem tunneling to 6.65% for husk cover rating, using three seasons per cycle. For the flowering traits, expected gain was 1.13% in days to silking, while for growth parameters, higher gain is expected in ear height (2.32%) than in plant height (1.78%). Results of yield and yield components revealed that maximum gain of 4.03% is expected in grain yield. However, with the modification of two seasons per cycle, a better gain of 6.05% is feasible, which would result in grain yield increase of about 210kg/ha per generation. Ear length would give a gain of 2.46%, while ears per plant would give a gain of 2.01% with the modification. There would be a reduction of 0.50% and 0.03% per generation in dead heart and stem tunneling, respectively, when two seasons are used for a cycle. Rank Summation Index (RSI) gave a better response (0.26%) with the modification, than when each of the damage parameters was selected singly, except for dead heart.

Expected gains from selection in DMR ESR-Y ranged from 0.04% for RSI to 11.13% for husk cover rating using three seasons per cycle (Table 4.21). A gain of 0.86% per generation is feasible for days to 50% silking. Higher gain

Table 4.20. Predicted responses to selection of DMR ESR-W maize population at 10% selection intensity (i =1.76) under stem borer infested condition at Ibadan in 2008 and 2009.

Season	Gain per Cycle	G/Gen.	G/Gen. (%)	Gain per Cycle	G/Gen.	G/Gen. (%)	Gain per Cycle	G/Gen.	G/Gen. (%)	Gain per Cycle	G/Gen.	G/Gen. (%)
	Days to pollen shed			Days to silking			Plant aspect (1-9)			Plant height (cm)		
3	1.31	0.44	0.88	1.69	0.56	1.13	0.22	0.07	1.41	7.70	2.57	1.78
2	1.31	0.65	1.32	1.69	0.85	1.69	0.22	0.11	2.11	7.70	3.85	2.66
	Ear height (cm)			Husk cover rating (1-9)			Stalk lodging (%)			Ear aspect (1-9)		
3	5.13	1.71	2.32	0.70	0.23	6.65	-0.02	-0.01	-0.07	0.33	0.11	1.99
2	5.13	2.56	3.48	0.70	0.35	9.97	-0.02	-0.01	-0.10	0.33	0.17	2.98
	Ear length (cm)			Ear diameter (cm)			Ears per plant (no.)			Grain Yield (t/ha)		
3	0.47	0.16	1.64	0.11	0.04	1.11	0.03	0.01	1.34	0.42	0.14	4.03
2	0.47	0.24	2.46	0.11	0.05	1.66	0.03	0.02	2.01	0.42	0.21	6.05
	Dead heart (%)			Leaf feeding damage 3WAI			Leaf feeding damage 5WAI			Stalk breakage (%)		
3	-0.02	-0.01	-0.35	0.02	0.01	0.10	0.04	0.01	0.24	0.10	0.04	0.16
2	-0.02	-0.01	-0.50	0.02	0.01	0.15	0.04	0.02	0.36	0.10	0.06	0.25
	Cob damage count (%)			Stem tunneling (%)			RSI					
3	0.04	0.01	0.05	-0.01	-0.003	-0.02	0.04	0.01	0.18			
2	0.04	0.02	0.07	-0.01	-0.01	-0.03	0.04	0.02	0.26			

G/Gen.: Gain/Generation, WAI: Weeks after infestation
1: Excellent 9: Poor, RSI: Rank Summation Index

Table 4.21. Predicted responses to selection of DMR ESR-Y maize population at 10% selection intensity (i = 1.76) under stem borer infested condition at Ibadan in 2008 and 2009.

Season	Gain per Cycle	G/Gen.	G/Gen. (%)	Gain per Cycle	G/Gen.	G/Gen. (%)	Gain per Cycle	G/Gen.	G/Gen. (%)	Gain per Cycle	G/Gen.	G/Gen. (%)
	Days to pollen shed			Days to silking			Plant aspect (1-9)			Plant height (cm)		
3	1.17	0.39	0.80	1.28	0.43	0.86	0.09	0.03	0.70	11.78	3.92	2.24
2	1.17	0.58	1.20	1.28	0.64	1.29	0.09	0.05	1.05	11.78	5.89	3.36
	Ear height (cm)			Husk cover rating (1-9)			Stalk lodging (%)			Ear aspect (1-9)		
3	10.25	3.42	3.81	1.11	0.37	11.13	0.01	0.003	0.06	0.50	0.17	3.14
2	10.25	5.12	5.72	1.11	0.56	16.17	0.01	0.01	0.10	0.50	0.25	4.71
	Ear length (cm)			Ear diameter (cm)			Ears per plant (no.)			Grain Yield (t/ha)		
3	0.52	0.17	1.56	0.12	0.04	1.18	0.01	0.003	0.43	0.15	0.05	1.51
2	0.52	0.26	2.34	0.12	0.06	1.77	0.01	0.01	0.71	0.15	0.07	2.27
	Dead heart (%)			Leaf feeding damage 3WAI			Leaf feeding damage 5WAI			Stalk breakage (%)		
3	0.003	0.001	0.25	0.04	0.01	0.28	0.06	0.02	0.42	0.10	0.03	0.17
2	0.003	0.002	0.50	0.04	0.02	0.42	0.06	0.03	0.63	0.10	0.05	0.26
	Cob damage count (%)			Stem tunneling (%)			RSI					
3	0.10	0.04	0.08	0.01	0.003	0.07	0.01	0.003	0.04			
2	0.10	0.05	0.12	0.01	0.01	0.11	0.01	0.01	0.06			

G/Gen.: Gain/Generation, WAI: Weeks after infestation
1: Excellent 9: Poor, RSI: Rank Summation Index

is expected in ear height (3.81%) than plant height (2.24%) in this population, but with the modification of two seasons/cycle, a gain of 5.72% is expected in ear height. Ear length gave the highest expected gain (2.34%) among yield and yield components with the modification. This was followed by grain yield with gains of 2.27% which resulted in a lower yield increase of about 73kg/ha per generation when compared to DMR ESR-W. RSI gave a lower expected gain (0.06%) in this population when compared to DMR ESR-W with the modification of two seasons per cycle. However, this is still better than selecting each of the damage parameters singly because RSI was constructed from lower levels of stem borer damages and increased yield. Therefore, negative responses or much lower values are expected for the damage parameters, but positive responses were obtained in this maize population. The modification of two seasons per cycle would give better gains per generation in both maize populations.

Correlated responses to selection expressed as percentage of expected gains for the traits measured in DMR ESR-W (Table 4.22) showed that indirect selection for some traits would be effective. Example of such instance is in selecting plant aspect through ear height which would give a gain of 119.64%, a little above the gain attainable with direct selection for plant aspect itself. Selection for plant aspect, ears per plant and cob damage would also be effective through stalk breakage. Selection for plant aspect would also reduce leaf feeding damage (-193.07%). Direct selection for grain yield would be better than indirect selection through any other trait. On the other hand, correlated responses to selection in DMR ESR-Y (Table 4.23) showed that direct selection for most of the traits would be better. An example of a situation where indirect selection might be more effective is in selecting for ear aspect through husk cover rating which would give a gain of 120.18% of the gain attainable through direct selection for ear aspect. Also, selection for ears per plant through days to 50% silking would give gains of 159.73%. However, direct selection for grain yield would also be more effective than indirect selection through any other trait in this maize population.

4.6. Contribution of agronomic and damage parameters to grain yield reduction in DMR ESR-Y maize population evaluated under stem borer infestation

Correlation coefficients of traits that had significant relationship with grain yield in DMR ESR-Y were further partitioned into direct and indirect effects using path analysis with grain yield reduction as the dependent variable.

Table 4.22. Correlated responses (expressed as percentage of expected gain) to selection of 14 traits for DMR ESR-W maize population evaluated under stem borer infested condition at Ibadan in 2008 and 2009.

Trait	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Grain Yield (t/ha)	100.00	54.32	41.48	39.01	32.19	-158.15	-84.00	18.46	41.06	-21.33	152.13	-79.75	-29.92	-134.04
2 Days to pollen shed	50.04	100.00	80.13	11.38	17.57	-84.57	-35.92	-36.72	6.54	-18.43	-34.41	-72.74	-166.25	-15.06
3 Days to silking	47.05	98.66	100.00	26.44	24.40	-87.26	-47.89	-39.17	9.68	-18.32	-216.64	-63.15	-170.30	-76.97
4 Plant height (cm)	33.49	10.61	20.02	100.00	73.24	-99.28	-74.07	-49.70	52.65	-11.25	73.55	53.84	7.53	-50.95
5 Ear height (cm)	24.54	14.53	16.40	65.01	100.00	119.64	-50.15	-46.81	52.57	10.60	87.03	-15.53	61.50	-31.54
6 Plant aspect	-64.80	-37.62	-31.53	-47.38	-64.32	100.00	80.62	98.90	-17.60	31.35	-193.07	76.54	-15.74	72.00
7 Ear aspect	-54.56	-25.32	-27.42	-56.03	-42.73	127.78	100.00	109.36	-54.36	22.16	-104.70	12.50	182.42	96.34
8 Ears per plant	-64.72	-18.23	-15.79	-26.47	-28.09	110.39	77.01	100.00	-33.44	0.71	2.79	-69.79	28.48	-30.82
9 Ear length (cm)	31.91	5.51	6.63	47.66	53.60	-33.39	-65.06	-56.82	100.00	33.95	221.84	-31.41	-2.39	-37.45
10 Husk cover rating	-20.78	-19.49	-15.74	-12.77	13.54	74.53	33.23	1.51	42.55	100.00	200.44	16.36	42.73	40.25
11 Leaf feeding damage 3WAI	7.52	-1.85	-9.45	4.24	5.65	-23.31	-10.72	0.30	14.12	11.41	100.00	5.38	16.73	7.44
12 Stalk breakage (%)	-70.19	-69.50	-49.01	55.19	-17.93	164.41	16.94	-134.31	-35.57	14.78	95.72	100.00	282.78	-21.31
13 Cob damage (%)	4.98	-27.51	-22.89	1.34	12.30	-5.86	42.82	9.49	-0.47	6.69	51.56	33.31	100.00	-7.14
14 RSI	-53.48	-6.52	-27.08	-23.68	-16.51	70.10	59.49	-26.89	-19.23	16.49	59.98	-9.66	-18.68	100.00

Negative signs indicate that the traits affect each other in opposite direction

Table 4.23. Correlated responses (expressed as percentage of expected gain) to selection of 14 traits for DMR ESR-Y maize population evaluated under stem borer infested condition at Ibadan in 2008 and 2009.

Trait	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Grain yield (t/ha)	100.00	25.71	20.93	4.81	8.79	-109.56	-47.29	101.94	10.83	-7.25	-53.37	9.77	-1.53	-13.89
2 Days to pollen shed	90.26	100.00	86.35	6.41	-13.39	-46.89	-67.09	24.52	10.31	-0.77	-62.54	-18.61	-2.91	-124.35
3 Days to silking	81.73	96.05	100.00	0.97	17.69	-22.29	-33.01	159.73	11.98	6.48	-14.45	-23.59	7.18	-64.28
4 Plant height (cm)	20.12	7.64	1.04	100.00	69.48	-138.25	38.14	-82.56	-5.63	-17.60	-6.40	48.78	31.82	-14.45
5 Ear height (cm)	43.99	-19.09	22.66	83.09	100.00	-134.36	-25.24	-29.28	-29.55	-31.15	-28.00	56.30	-8.12	-50.55
6 Plant aspect	-73.20	-8.92	3.81	-22.08	-17.94	100.00	41.03	-73.90	-16.58	7.88	44.51	-19.94	-15.61	-73.25
7 Ear aspect	-198.76	-80.31	-35.52	38.31	-21.20	258.12	100.00	-224.98	†	84.49	150.64	-9.56	106.94	†
8 Ears per plant	53.51	3.67	21.47	-10.36	-3.07	-58.06	-7.31	100.00	1.89	-5.63	-20.32	-0.38	-11.88	-53.40
9 Ear length (cm)	35.59	9.65	10.08	-4.42	-19.41	-81.53	†	11.84	100.00	-1.48	-20.77	-33.56	-30.96	-97.12
10 Husk cover rating	-43.36	-1.31	9.93	-25.14	-37.22	70.51	120.18	-64.13	-2.70	100.00	-53.67	8.11	95.25	24.22
11 Stem tunneling (%)	-44.30	-3.23	-1.32	-5.08	20.13	56.37	29.75	-32.13	-5.25	-7.45	100.00	-12.05	-4.49	1.22
12 Stalk breakage (%)	22.94	-12.44	-14.18	27.37	26.42	-70.08	-5.34	-1.70	-23.98	3.19	-34.08	100.00	28.23	-90.08
13 Cob damage (%)	-5.68	-3.08	6.83	28.23	-6.02	-86.73	94.44	-84.00	-34.97	59.14	-20.09	44.63	100.00	40.79
14 RSI	-5.26	-13.42	-6.24	-1.31	-3.83	-41.53	†	-38.53	-11.20	1.53	0.56	-14.54	4.16	100.00

† Not estimated due to absence of genetic correlation between traits concerned
Negative signs indicate that the traits affect each other in opposite direction

Plant height showed the strongest negative direct effect (-0.246) among agronomic traits, followed by plant aspect (-0.072) and ears per plant (-0.020) (Table 4.24). Other agronomic traits exerted positive effects on grain yield loss. Stem tunneling had the strongest positive direct effect (0.105) among damage parameters, followed by cob damage (0.036). Stalk breakage exerted negative effect on yield loss. Plant height had the highest positive indirect effect through ear height (0.203) and the highest positive total indirect effect (0.194). However, ear height had highest negative indirect effect via plant height (-0.187) with the highest negative total indirect effect (-0.221). Stem tunneling and leaf feeding damage had highest negative indirect effect through plant aspect with coefficient of -0.012 and -0.021, respectively. Stem tunneling and leaf feeding damage had negative total indirect effects. The total indirect effect of cob damage on grain yield loss accounted for 32.1% of the total correlation between cob damage and grain yield reduction, while total indirect effect of stem tunneling accounted for 11.6% of total correlation.

When effects of only the damage parameters on yield loss were considered, stem tunneling was consistently the most important trait causing yield loss (Table 4.25) with direct effect of 0.094 followed by cob damage (0.033). Stalk breakage exerted negative direct effect (-0.174). Cob damage acting via stem tunneling had highest indirect effect on yield reduction (0.008), while stem tunneling also had highest indirect effect through cob damage (0.003). Stem tunneling and leaf feeding damage had negative total indirect effect, while cob damage and stalk breakage had positive total indirect effect.

4.7. Ranking of progenies of DMR ESR-W and DMR ESR-Y maize populations for selection purposes.

The top 10% of the progenies evaluated were considered for recombination to improve the maize populations. The ranking of DMR ESR-W progenies showing the top 10% selection is presented in Table 4.26. Entry 145 (cross 70 x 64) ranked the best with index of 76. It was good in all the selection criteria, although it ranked 31 in its level of tunneling. The selected entries in this population comprised of a combination of progenies from six sets. Parents 5 and 73 were good combiners in their respective sets. Entry 195 (80 x 74) ranked the best in DMR ESR-Y (Table 4.27) with index of 137. It was good in the selection criteria, although it ranked 53 in its level of tolerance. The selected entries comprised of combination of progenies from all the sets. Parents 5

Table 4.24. Path coefficient analysis showing the direct effect (bold on diagonal) and indirect effect (off-diagonal) of agronomic and damage parameters on grain yield reduction in DMR ESR-Y maize population under stem borer infestation at Ibadan in 2008 and 2009.

	Indirect effect via												
Traits	1	2	3	4	5	6	7	8	9	10	11	C	I
1 Days to 50% silking	**0.027**	0.021	0.001	0.002	0.000	-0.003	-0.001	0.001	-0.010	0.000	0.045	0.083	0.057
2 Plant height (cm)	-0.002	**-0.246**	0.203	0.022	-0.001	-0.007	0.006	0.000	0.001	-0.001	-0.027	-0.052	0.194
3 Ear height (cm)	0.000	-0.187	**0.268**	0.018	-0.001	-0.010	0.001	-0.001	-0.004	-0.001	-0.037	0.047	-0.221
4 Plant aspect	-0.001	0.076	-0.068	**-0.072**	0.006	0.015	-0.007	0.001	0.017	0.005	-0.002	-0.030	0.042
5 Ears per plant	0.000	-0.010	0.011	0.022	**-0.020**	-0.005	0.004	-0.005	-0.015	-0.002	0.003	-0.017	0.003
6 Ear aspect	-0.001	0.035	-0.050	-0.020	0.002	**0.051**	-0.010	0.010	0.025	0.003	-0.006	0.038	-0.013
7 Ear length (cm)	-0.001	-0.034	0.005	0.012	-0.002	-0.012	**0.041**	-0.005	0.006	-0.003	0.016	0.024	-0.017
8 Cob damage (%)	0.001	-0.002	-0.004	-0.001	0.003	0.015	-0.005	**0.036**	0.009	0.001	0.000	0.053	0.017
9 Stem tunneling (%)	-0.003	-0.003	-0.010	-0.012	0.003	0.012	0.003	0.003	**0.105**	0.000	-0.005	0.095	-0.011
10 Leaf feeding damage 3WAI	0.001	0.014	-0.019	-0.021	0.002	0.010	-0.006	0.002	0.000	**0.017**	-0.013	-0.014	-0.031
11 Stalk breakage (%)	-0.006	-0.035	0.053	-0.001	0.000	0.002	-0.003	0.000	0.003	0.001	**-0.189**	-0.176	0.013

C: Total correlation, I: Total indirect effect

Table 4.25. Path coefficient analysis showing the direct effect (bold on diagonal) and indirect effect (off-diagonal) of damage parameters on grain yield reduction in DMR ESR-Y maize population under stem borer infestation at Ibadan in 2008 and 2009.

Traits	Indirect effect via					
	1	2	3	4	C	I
1 Cob damage (%)	**0.033**	0.008	0.000	0.000	0.041	0.008
2 Stem tunneling (%)	0.003	**0.094**	0.000	-0.004	0.092	-0.001
3 Leaf feeding damage 3WAI	0.002	0.000	**0.005**	-0.012	-0.005	-0.009
4 Stalk breakage (%)	0.000	0.002	0.000	**-0.174**	-0.172	0.003

C: Total correlation, I: Total indirect effect

Table 4.26. Ranking of the performance of DMR ESR-W progenies showing the top 10% selection.

S/N	Entry	Cross	Plant aspect (1- 9)	Rank	Leaf feeding (1- 9)	Rank	Grain yield (t/ha)	Rank	Stem tunneling (%)	Rank	Tole-rance	Rank	RSI
1	145	70 x 64	4	16	4	17	5	7	11	31	0	5	76
2	176	86 x 81	5	37	5	78	4	27	12	41	2	44	227
3	17	7 x 4	4	2	4	4	5	6	13	72	4	157	241
4	174	79 x 75	4	5	4	25	5	2	5	3	NE	224	259
5	114	49 x 43	5	35	5	57	4	13	18	158	0	9	272
6	134	69 x 62	4	6	5	115	5	5	15	104	2	46	276
7	1	6 x 1	4	15	5	112	4	14	12	48	3	104	293
8	206	96 x 92	5	84	4	5	4	36	17	135	1	35	295
9	144	69 x 64	5	76	3	1	3	153	12	52	1	16	298
10	23	8 x 5	5	40	5	128	4	53	10	17	2	61	299
11	72	27 x 25	5	28	4	10	4	101	15	111	2	49	299
12	164	79 x 73	4	24	5	106	4	15	11	39	3	116	300
13	118	48 x 44	4	20	4	22	4	63	15	102	2	95	302
14	220	100 x 94	5	50	5	36	4	94	16	124	0	1	305
15	125	50 x 45	3	1	5	118	5	4	14	84	3	100	307
16	181	86 x 82	4	9	5	53	4	35	14	85	3	126	308
17	71	26 x 25	5	46	4	15	5	3	12	51	6	196	311
18	166	76 x 74	5	112	4	3	4	22	17	149	1	29	315
19	21	6 x 5	4	7	5	50	3	140	14	96	1	34	327
20	24	9 x 5	4	3	5	73	4	48	12	44	4	160	328
21	165	80 x 73	4	8	5	68	5	9	17	144	3	103	332
22	14	9 x 3	5	106	4	11	4	20	21	189	0	8	334
23	163	78 x 73	4	11	5	54	4	19	19	171	2	80	335

NE: not estimated because of negative yield loss, RSI: Rank Summation Index

Table 4.27. Ranking of the performance of DMR ESR-Y progenies showing the top 10% selection.

S/N	Entry	Cross	Plant aspect (1- 9)	Rank	Leaf feeding damage (1-9)	Rank	Grain yield (t/ha)	Rank	Stem tunneling (%)	Rank	Tolerance	Rank	Rank Summation Index (RSI)
1	195	80 x 74	4	21	4	21	4	28	2	14	3	53	137
2	125	50 x 45	3	1	4	9	4	18	3	30	4	84	142
3	6	6 x 2	4	32	3	5	4	9	2	21	5	126	193
4	21	6 x 5	3	5	4	51	5	1	1	8	5	129	194
5	234	99 x 92	3	10	5	185	5	4	0	1	1	10	210
6	22	7 x 5	4	14	4	88	5	3	4	71	3	41	217
7	42	17 x 14	3	6	4	83	4	17	2	18	5	93	217
8	51	26 x 21	4	54	4	41	4	23	4	99	3	54	271
9	25	10 x 5	4	15	4	23	3	86	2	19	5	133	276
10	179	79 x 71	3	3	4	93	4	39	4	114	2	29	278
11	147	57 x 55	3	7	4	7	3	98	4	116	3	57	285
12	250	100 x 95	4	12	4	18	4	7	5	168	4	90	295
13	18	8 x 4	4	101	5	135	4	19	3	33	1	13	301
14	76	36 x 31	4	53	4	22	4	21	5	176	3	43	315
15	226	96 x 91	4	24	4	56	4	25	4	73	6	137	315
16	97	37 x 35	4	34	4	75	4	6	4	86	5	117	318
17	26	16 x 11	3	4	4	25	4	14	4	105	7	174	322
18	112	47 x 43	4	75	4	42	4	41	4	87	4	81	326
19	54	29 x 21	4	85	4	73	3	93	3	59	2	26	336
20	169	69 x 64	4	91	4	76	4	15	5	157	2	27	366
21	58	28 x 22	4	83	3	2	4	65	5	179	3	40	369
22	123	48 x 45	4	79	4	57	4	43	5	153	3	38	370
23	205	90 x 81	4	89	4	86	4	16	2	28	6	158	377
24	37	17 x 13	3	2	5	152	4	13	6	208	0	3	378
25	20	10 x 4	4	116	4	54	4	27	4	97	4	89	383

and 45 were good combiners in their respective sets in this maize population.

CHAPTER 5

DISCUSSION

Knowledge of the genetic variability of any breeding population is important in crop improvement. It helps to determine the most effective breeding scheme to adopt and the limits of selection. The wide ranges for most agronomic and damage parameters indicate that moderate levels of variability exist in both maize populations for resistance to stem borers. Significant reductions were recorded in the maize populations for plant height, grain yield, ear length and diameter, and ears per plant under stem borer infestation. When maize is infested, the photosynthetic capacity is reduced and the vascular tissues are destroyed as the larvae feed on the leaves and bore into the stem. These lead to stunted growth, weakening of the stalk, poor ear shoot development and eventually grain yield reduction. The significant reduction in plant height, ear length and diameter, and grain yield under stem borer infestation was also observed by Ajala (1994) for *Chilo partellus*. Percentage yield reduction recorded in this study falls within the range of losses recorded by previous workers (Ajala *et al.*, 2001; De Groote *et al*., 2001; Odiyi, 2006) for various stem borer species.

The low values recorded for dead heart in this study suggest limited migration of larvae of the pink stem borer, *S. calamistis* to the meristematic region. It is also an indication that the pink stem borers rarely cause dead heart. Dead heart occurs when the feeding larvae migrate to the meristematic region, thus damaging the growing point which eventually leads to death of the maize plant attacked. Coefficients of variation (CVs) were high, especially for the damage parameters. A similar observation was reported by Odiyi (2006) under stem borer infestation and by Badu-Apraku *et al.* (2005) under drought stress. These results suggest that high CVs are associated with stress conditions. In addition, CVs for secondary traits are also higher than those measured directly (Ajala *et al.*, 2009b). Data on dead heart, stalk breakage and stem tunneling were expressed in percentages, and therefore had high CVs.

Estimates of genetic variances revealed that dominance variance was significantly larger than additive variance for most of the damage parameters in DMR ESR-W except stalk breakage, but additive variance was significantly larger for grain yield.

Grain yield and stalk breakage being controlled by additive gene action under infestation in DMR ESR-W, and the moderate narrow-sense heritability estimates obtained for these traits indicate that the traits are under genetic control and that progress will be made in advanced generations for improved grain yield and stem borer resistance. This is also confirmed by the high expected gain/generation for grain yield in this maize population. However, in DMR ESR-Y, additive variance was significantly higher than dominance variance for stalk breakage and cob damage, while additive variance was also significant for stem tunneling, although dominance variance was larger. This indicates that moderate levels of genetic variability exist in this maize population for combined resistance to the borers, and that improvement for resistance is feasible. Dominance variance was higher than additive variance for grain yield in DMR ESR-Y with a low narrow-sense heritability estimate. The low heritability for grain yield in this maize population was not unconnected with the large dominance gene effect on this trait, as well as the high environmental variance. It therefore suggests that progress will be slow in improving this maize population for high grain yield. The low expected gain/generation for grain yield in this population also confirms this. An explanation for build-up of dominance variance was given by Badu-Apraku *et al*. (2007) that in the presence of overdominance, both favourable and unfavourable alleles are retained in the population. As a result, gene frequency moves towards equilibrium. The genetic variance resulting from their segregation contributes to the dominance variance components.

Low narrow-sense heritability estimates obtained in the present study for most damage parameters in both maize populations agreed with the observation made by Odiyi (2006). The low heritability indicates that progress will be slow in improving the maize populations for resistance to stem borers. However, better improvement is expected in DMR ESR-W from direct selection for grain yield under stem borer infestation. Heritability varies with characters, population structure, environmental conditions under which the individuals are subjected and the way the phenotype is measured. Therefore, a change in any one of this will affect heritability (Falconer, 1989). Environmental variance is dependent on the conditions of management. Hence, more variable conditions will reduce heritability, while more uniform conditions will increase it. Heritability could be made larger by reducing environmental variation (Falconer, 1989). Low heritability estimates have been reported by some workers under varying field stresses (Ajala, 1992; Kim, 1994; Berner *et al.*, 1996, Odiyi, 2006 and Badu-Apraku, 2006). Negative heritability estimates for traits such as stalk lodging, dead heart and stem tunneling in DMR ESR-W is as a result of the negative additive variances for these traits.

In the present study, higher additive to dominance variance obtained for leaf feeding damage and dominance gene action controlling stem tunneling, with dead heart not being controlled by either type of gene actions in DMR ESR-Y are in agreement with the findings of Ajala (1992). Dominance gene action controlling leaf feeding damage in DMR ESR-W was also reported by Odiyi (2006) for TZBR Comp 1. Both additive and dominance gene action controlling various damage parameters in both maize populations is consistent with earlier studies by Ortega *et al.* (1980), Guthrie (1989) and Ajala (1992). This suggests that breeding schemes that take advantage of both additive and non-additive gene actions, such as S_1 family selection, full-sib selection and testcross evaluation should be adopted in the improvement of both maize populations for combined resistance to the borers. Theoretically, variances should not be negative, but negative variance obtained for some traits measured in this study is due to their computation from expected mean squares. Negative variances result from sampling error in the production of progenies for evaluation, experimental error, or combination of both in estimating a quantity that has either zero or small positive value (Robinson *et al*., 1955, Gouesnard and Gallais, 1992).

Environmental variance was higher than genetic variance for leaf feeding damage at 3WAI and dead heart in DMR ESR-W, with high degree of dominance. Environmental variance was also higher than genetic variance estimates for leaf feeding damage in DMR ESR-Y. This implies that environment has a strong influence on expression of this trait, hence, leaf feeding damage alone is not a reliable selection criterion for stem borer resistance. Environmental variance should be reduced as much as possible in genetic studies through careful management or proper design of experiments (Falconer, 1989). Average degree of dominance being above unity for some traits in both populations suggests overdominance at some loci for genes affecting these traits. When there is overdominance with respect to a desired character or combination of characters, then inbreeding and crossing can achieve what selection is not able to (Falconer, 1989).

The significant mean squares for Entries for leaf feeding damage at 5WAI, stalk breakage and cob damage in DMR ESR-W, and stalk breakage, cob damage and stem tunneling in DMR ESR-Y are indications of a considerable level of genetic variability in both maize populations for combined resistance to the borers. GCA female being larger than GCA male for some traits under infestation in DMR ESR-W suggests the presence of maternal effects on these traits, although Hallauer and Miranda (1988) stated that maternal effect is not important in maize. The larger percentage sum of squares due to SCA than that due to GCA for grain yield in DMR ESR-Y indicates that non-additive gene action is important in the inheritance of grain yield under stem borer infestation in this maize population. This agrees with the larger dominance variance to additive variance for grain yield in DMR ESR-Y. The high importance of both GCA and SCA obtained in the present study for stem tunneling in DMR ESR-Y was also observed by Ajala (1992) for *Chilo partellus*.

The significant mean squares obtained for only 'males in set' and 'females in set' for plant aspect, ear length, grain yield and stalk breakage in DMR ESR-W, as well as husk cover rating, ear aspect, ear length, stalk breakage and cob damage in DMR ESR-Y indicate that only additive effects were important for these traits. The significant mean squares for males, females and 'male x female in set' for leaf feeding damage at 5WAI and cob damage in DMR ESR-W, and stem tunneling in DMR ESR-Y, suggests that both additive and non-additive gene actions were important for the traits. However, dominance gene action was more important for leaf feeding damage at 5WAI and cob damage in DMR ESR-W. Absence of significant mean squares for Entry x Environment interaction in both maize populations for plant height, ear height, and grain yield is consistent with the study by Ajala *et al*. (1995b) on the spotted stem borer.

Some traits of economic importance such as grain yield have complex inheritance and may involve several related characters (Stuber and Moll, 1969). To improve pest resistance in a maize population, knowledge of the magnitude and direction of relationship between damage parameters and some other agronomic traits is important, as this can aid selection. Correlation between two unrelated traits may be due to pleiotropy or tight linkage existing between genes controlling them (Falconer, 1981). The degree of correlation arising from pleiotropy expresses the extent to which two characters are influenced by the same gene. Falconer (1989) stated that if the two characters have low heritability, then the phenotypic correlation is determined chiefly by environmental correlation, but if they have high heritability, then the genetic correlation is more important. The high narrow-sense heritability for days to 50% pollen shed and silking, and plant and ear heights contributed to the high genotypic correlations between these pairs of traits. The high correlation suggests that either trait of the pair could be selected with equal effect. Negative and significant correlation between plant height and plant aspect indicates that tall plants give poor plant appeal as such plants are prone to lodging. Husk cover rating having positive and significant correlations with plant aspect as well as ear aspect is expected since good husk cover is one of the criteria for rating good appealing plants. Also ears with tight husk cover tend to have better ear aspect rating, since tight husk cover offers protection to the ear against pests and rain. The negative and highly significant correlation between ear length and ears per plant under infestation in DMR ESR-W is an indication that the more the number of ears produced per plant, the shorter the length of the ear. It also indicates that the genes that increase number of ears per plant also decrease ear length.

The positive genotypic correlation between grain yield and plant height as well as days to silking indicates that genes that cause delay in flowering also increase plant height as well as grain yield. It therefore implies that tall and late-maturing plants have high grain yield. This agrees with the results of earlier studies under various field conditions by Hallauer and Miranda (1988), Holthaus and Lamkey (1995), Betran and Hallauer (1996) and Odiyi (2007), but contrasts results of studies by Borrero *et al*. (1995) and Silva *et al*. (2004). The high and positive correlations between grain yield and ears per plant, as well as plant and ear height indicate that grain yield is a function of many agronomic traits. The positive correlation between ears per plant and grain yield confirms the fact that if a maize plant produces more than one cob, the grain yield tends to increase, a known phenomenon, since yield is a function of cob number and weight.

Generally, negative correlations exist between grain yield and damage parameters in both maize populations, suggesting that reduced level of damage will increase grain yield. Similar observations were made by Ajala (1994), Ajala and Saxena (1994) and Gounou *et al*. (1994). The high negative genotypic correlation between grain yield and stem tunneling in DMR ESR-Y, as well as the significant additive variance for stem tunneling suggests its reliability as a selection criterion for improvement of grain yield and stem borer resistance in this maize population. This corroborates the findings of Ajala and Saxena (1994) and Odiyi (2007). In the present study, most damage parameters had negative and significant correlations with flowering, indicating better tolerance in late-flowering genotypes. This was also observed by Hudon and Chiang (1991) and Schulz *et al*. (1997) in a study involving first generation European corn borer, and Odiyi (2007) with *S. calamistis and E. saccharina.*

The negative genotypic correlations between stem tunneling and most agronomic traits except plant and ear aspect in both maize populations revealed that high levels of tunneling by stem borer larvae has adverse effects on overall growth of maize. When the stem is extensively tunneled, the vascular bundles are destroyed and the flow of nutrient from the source (root) to the sink (ear shoot) is disrupted. This leads to stunted growth, weakening of the stem, poor development of the ear shoot and poor plant appeal. This explains the negative correlation between stem tunneling and ears per plant. The negative and significant correlation between plant height and stem tunneling in DMR ESR-W suggests that tall plants are more resistant to stem tunneling, as was observed in DMR ESR-Y which is taller than the white, but with lower levels of stem tunneling. However, stem tunneling was reported in this study as a proportion of plant height and not as absolute values. Therefore, the taller the genotype, the lesser the percentage value to be obtained, even for the same extent of tunneling when compared with a shorter genotype. Reduced level of feeding damage on the vascular bundle could lead to reduction in levels of stunted growth caused by extensive damage, consequently leading to taller plants. This however contrasts the report of Sandoya *et al*. (2010) who observed positive and significant association between tunnel length and plant height. The positive correlation between stalk breakage and plant height supports the fact that tall plants are more susceptible to breakage. The positive correlation between stalk breakage and plant aspect indicates that broken stalks have poor plant appeal. The negative and significant correlation between cob damage and ear length suggests that damage to the developing cob by *Eldana* will reduce the ear length. The positive and highly significant correlation between cob damage and ear aspect is however expected since damaged cobs have poor ear appeal.

Some previous studies (Bosque-Perez and Mareck, 1991; Gounou *et al*., 1994; Kling and Bosque-Perez, 1995; Odiyi, 2006; Ajala *et al*., 2008) have reported on significant positive correlations between *Sesamia* and *Eldana* damage parameters. Hence, selecting for reduced levels of damage occasioned by one borer species may have positive impact on damage caused by the other species, resulting in greater progress in breeding for combined resistance to both borer species (Ajala *et al*., 2008). This explains the positive relationship observed among damage parameters in this study. The positive and significant correlation between stem tunneling and stalk breakage in the maize populations, although with low coefficients was also reported by Butron *et al.* (1999). The higher genotypic correlations for the traits measured relative to their corresponding phenotypic correlations is consistent with results of previous studies on variability for varying agronomic and damage parameters (Ajala and Saxena, 1994; Akanvou *et al.*, 1997; Silva *et al.*, 2004; Odiyi, 2007; Ajala *et al.*, 2009b).

Predicted response to selection usually suggests the extent of improvement that can be achieved in a particular crop population. Response differs with different selection methods, number of generations per cycle and parental control. Ajala *et al*. (2009b) working on FARZ 23 maize population observed that S_1 selection method with parental control of two and using three generations per cycle, gave the largest predicted response for grain yield and ear number when compared with half- and full-sib selection methods. The modification of using two seasons per cycle instead of three, will however be useful if a much higher gain is expected (Ajala *et al.*, 2009b). In this study, expected gains were generally low for the damage parameters in both maize populations. Reduction of 0.50% and 0.03% is expected in dead heart and stem tunneling, respectively in DMR ESR-W, while slight increase is expected in other damage parameters. This indicates that there will be slow progress from selection for resistance. Ajala *et al*. (2009a) on screening for resistance to stem borers however recorded 12% reduction in stalk breakage, 7% reduction in overall damage rating and yield increase of about 20% in S_1 progenies of TZBR Eldana 3 C_4. Grain yield increase of about 210 kg/ha is expected per generation in DMR ESR-W using two seasons to complete a cycle, which is similar to the gain obtained by Ajala *et al.* (2009b), but a much lower increase (73 kg/ha) is expected in DMR ESR-Y. This suggests that better improvement is expected in DMR ESR-W from direct selection for grain yield. Klenke *et al*. (1986) found that four selection cycles reduced damage by both first and second generation European corn borer, but decreased grain yield, suggesting that yield should be included in the selection criteria in a selection program. Other agronomic traits are also expected to improve with selection, except stalk lodging in DMR ESR-W. To improve rate of response in a selection program, higher heritability is desirable and this can be accomplished through reduction in environmental variation. To some extent, increase in selection intensity will also increase rate of response (Falconer, 1989).

Index selection has been reported to improve crop population (Rogers *et al.*, 1977; Weyhrich *et al.*, 1998; Ajala, 2010). Rogers *et al.* (1977) reported that a selection index combining both size of root system and secondary root development was more effective in reducing root lodging due to corn rootworms than using either criterion alone. Weyhrich *et al.* (1998) reported that all selection programmes in which index selection was practiced, were successful in improving BS11 maize population. Ajala (2010) also observed that response from Rank Summation Index (RSI) constructed from emergence index, days to 50% silking and plant stand at harvest, was much higher than when each of the three traits was selected singly in the improvement of three maize populations. Similarly in this study, RSI gave better response than when each trait was selected singly in DMR ESR-W maize population using the modification of two seasons/cycle. A lower expected gain (0.05%) was obtained for RSI in DMR ESR-Y when compared to DMR ESR-W with the modification of two seasons per cycle. However, this gain is still better than selecting each of the damage parameters singly because RSI was constructed from lower levels of stem borer damages and increased yield. Therefore, negative responses or much lower values are expected for the damage parameters, but positive responses were obtained in DMR ESR-Y. Nonetheless, predicted gains for single trait selection will only at best, be theoretical. The actual difference between the performance of the original population (C_o) and final cycle of selection will reveal the actual gain for traits of interest (Ajala *et al*., 2010). RSI has been reported to be a recommended index due to its simplicity of use and for being weight-free (Ajala *et al*., 1995a; Ajala *et al*., 2003; Ajala, 2010).

Correlated response suggests that it might sometimes be possible to achieve more rapid progress under selection for a secondary trait than from selection for the desired trait itself (Falconer, 1989). Indirect selection for a trait will only be successful if the secondary character has substantially higher heritability and genetic correlation (Falconer, 1989). This is reflected in the relationship between grain yield and plant aspect, where selection for grain yield would improve plant aspect in both maize populations. Similar response was observed between plant aspect and stalk breakage in DMR ESR-W with high genotypic correlation. Selection for increased grain yield would improve number of ears per plant, but cause reduction in stem tunneling and cob damage in DMR ESR-Y. Selection for reduced stalk breakage is expected to result in slight increase in ear height in DMR ESR-W. Similar observation was made by Russell *et al*. (1979) for European corn borer.

Selection for resistance would increase days to 50% pollen shed and silking in this study. Selection for increased days to 50% silking would result in reduction in stem tunneling and stalk breakage in DMR ESR-Y. Similar observation was made by Odiyi (2007). In DMR ESR-W, selection for increased days to 50% silking would result in reduction in leaf feeding damage, stalk breakage and cob damage. This is due to the strong negative genotypic correlations existing between days to 50% silking and these traits. Sandoya *et al*. (2010) however reported that selection for resistance to Mediterranean Corn Borer (MCB) significantly reduced days to silking, plant and ear height, and 100-kernel weight, but seedling vigour was increased. Among damage parameters, selection for reduced stalk breakage in DMR ESR-W, as well as cob damage and stem tunneling in DMR ESR-Y is expected to improve grain yield. This is in agreement with the report of Sandoya *et al*. (2008) who observed that selection for resistance to MCB positively influenced grain yield, but contrasts the report of Novoa and Russell (1988), Butron *et al*. (2000) and Sheri *et al*. (2004). However, direct selection for grain yield would give better response than indirect selection through any other trait in both maize populations. This result is similar to those of Ajala *et al*. (2009b) and Hallauer and Miranda (1988). Direct selection for grain yield is therefore recommended as the most effective method for improving yield in these maize populations.

Opinions differ as to the most important stem borer damage parameter(s) that actually cause grain yield reduction in maize. Starks and Doggett (1970), Mohyuddin and Attique (1978), and Pathak and Othieno (1990) reported that grain yield loss by *Chilo partellus* was mostly due to dead heart. Plant loss due to dead heart was reported to be up to 50% (Kaufmann 1983; Bosque-Perez and Mareck, 1990). Ampofo (1986) reported that the most important parameter was foliar damage. Ajala and Saxena (1994) reported that stem tunneling was the factor that contributed most to grain yield loss by *Chilo partellus*. Odiyi (2007) also observed that stem tunneling was the most important factor contributing to grain yield reduction caused by *Sesamia calamistis* and *Eldana saccharina*. In this study, stem tunneling had relatively high positive direct effect on grain yield loss among damage parameters followed by cob damage. Tunneling by stem borer larvae affects the overall growth of maize resulting in serious yield loss. *Eldana* larvae feed on the developing cobs being the fresh part at the stage of its infestation, and cause extensive damage to the young kernels. This reduces the quantity and quality of grains, thus, leading to grain yield loss.

Leaf feeding damage reduces the photosynthetic capacity of the plant thereby limiting the amount of photosynthates translocated to other parts. This affects the plant growth at early stage. However, as the maize plant grows, the leaves become too strong for the larvae to chew. Consequently, the effect of leaf feeding damage becomes less prominent on the maize plant. This explains why leaf feeding damage rating at 5 weeks after infestation was lower than at 3 weeks after infestation in this study. Dead heart symptom was less prominent in both populations suggesting limited migration of *Sesamia calamistis* to the growing point. It also shows that *Sesamia* rarely cause dead heart. Moreover, when a plant dies due to the effect of dead heart, the neighbouring plants within the plot maximize the available space, nutrient and water to grow and yield better, thus, compensating for the loss due to the dead plant. Consequently, stem tunneling and cob damage are the most important damage parameters causing grain yield loss by *Sesamia calamistis* and *Eldana saccharina*.

Plant height, plant aspect and ears per plant had negative direct effects on grain yield loss among agronomic traits in DMR ESR-Y. The negative effect of plant aspect on grain yield reduction will however not be considered, since it implies that good plant appeal will increase grain yield reduction. Plant vigour has been reported to play a positive role in plant resistance to stem borers (Ajala and Saxena, 1994). Therefore, plant height and ears per plant are the most important agronomic traits influencing grain yield reduction. This is similar to the result obtained by Ajala and Saxena (1994) with *Chilo partellus*. This indicates that grain yield reduction will be less on tall plants bearing more than one ear. The strong positive relationship between grain yield and plant height as well as ears per plant obtained in this study also supports this.

Considerable levels of genetic variability for combined resistance to both stem borer species exist in the maize populations, hence improvement can be made using S_1 or full-sib selection. Stem tunneling and cob damage being the most important damage parameters causing grain yield loss should be taken into consideration during selection for improved grain yield under stem borer infestation.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Stem borers are among the most difficult to control of all the stresses of maize on the field. This is because different species of stem borers affect maize at different stages of its growth in different locations. Stem borer attack is more severe in the forest ecologies which also harbour an array of foliar diseases like downy mildew and streak. Therefore, there is need for maize populations or varieties meant for these ecologies to have an appreciable level of resistance to all pests. No meaningful genetic improvement can be made in any crop population without knowledge of its genetic variability. This knowledge guides breeders on the most appropriate breeding scheme to adopt in the improvement, as well as the extent of progress attainable following selection. However, variability studies on combined resistance of maize to different species of stem borers in Africa are scanty in literature. This study was therefore carried out to: (i) determine the level of genetic variability for resistance to both *Sesamia calamistis* and *Eldana saccharina* and other agronomic traits in DMR ESR-W and DMR ESR-Y maize populations, (ii) identify the most important stem borer damage parameter(s) causing grain yield loss, (iii) investigate the type of gene action involved in the inheritance of combined resistance to both *S. calamistis* and *E. saccharina*, (iv) evaluate plant characters that optimize gains from breeding for stem borer resistance, and (v) predict gains from selection and determine correlated responses to selection for combined resistance to the borers.

The level of genetic variability in two adapted maize populations, Downy Mildew Resistance Early Streak Resistance White (DMR ESR-W) and Yellow (DMR ESR-Y) for combined resistance to two species of stem borer, *Sesamia calamistis* and *Eldana saccharina* was studied to facilitate their improvement. North Carolina Design II mating scheme was used to cross a set of 100 S_1 lines selected in each of the maize populations to generate 250 progenies each. These progenies were evaluated under artificial stem borer infested condition at Ibadan and non-infested condition at Ibadan and Ikenne in 2008 and 2009. The experiments were laid out in a

Randomized Incomplete Block Design with two replications at both locations. The results are summarized below:

1. There were significant reductions in plant height, ear length and diameter, ears per plant and grain yield under stem borer infestation with yield loss of 24-30% in the maize populations.
2. Yield reduction was higher in DMR ESR-Y (30.4%) than in DMR ESR-W maize population (23.9%) despite the lower level of damage in DMR ESR-Y indicating that DMR ESR-W is more tolerant to the borers than DMR ESR-Y.
3. The low proportion of dead heart relative to other damage parameters in both maize populations suggests limited migration of *Sesamia* larvae to the growing point of maize. It is also an indication that *Sesamia* rarely cause dead heart.
4. Combined resistance to both *S. calamistis* and *E. saccharina* is polygenic with both additive and dominance gene actions involved.
5. The wide ranges and significant additive variance for stalk breakage in DMR ESR-W, as well as stalk breakage, stem tunneling and cob damage in DMR ESR-Y, with low to moderate heritability estimates for these traits indicate that considerable levels of genetic variability exist in the maize populations for resistance to the borers.
6. Narrow-sense heritability estimates were low to moderate for the traits studied. They were, however, low for most damage parameters, suggesting slow progress from selection using these traits.
7. Negative correlations exist between grain yield and damage parameters, indicating that reduced level of damage by the borer species will increase grain yield. However, positive correlations exist among damage parameters.
8. The low expected genetic gains for damage parameters in both maize populations suggests slow progress from selection for resistance. However, the 6.05% (approximately 210kg/ha per generation) gain expected from selection for grain yield under infestation in DMR ESR-W using 2 seasons per cycle indicates that better progress is expected from direct selection for grain yield in this maize population.
9. Direct selection for grain yield under stem borer infestation would be better in both maize populations than indirect selection through any other trait.

10. Stem tunneling and cob damage are the damage parameters contributing most to grain yield loss.

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APPENDICES

Appendix 1. Rainfall data for Ibadan* and Ikenne** in 2008 and 2009

	Ibadan		Ikenne	
Month	2008	2009	2008	2009
		Mm		
January	0.00	10.05	3.60	23.30
February	0.00	33.75	10.00	46.60
March	99.85	24.60	126.50	49.90
April	133.10	174.90	29.40	171.00
May	164.10	186.15	117.70	167.30
June	208.60	181.55	242.70	234.60
July	248.90	159.95	290.00	215.60
August	122.85	41.35	97.40	92.00
September	292.35	154.80	354.60	139.50
October	115.80	115.90	71.10	186.20
November	0.10	32.55	0.00	17.50
December	7.90	0.00	18.00	0.00
Total	1393.55	1115.55	1361.00	1343.50

Source: * IITA, Ibadan (2010), ** I A R &T, Ikenne (2010)

Appendix 2. Temperature and Relative Humidity in Ibadan in 2008 and 2009

	2008			2009		
Month	Minimum	Maximum	Mean	Minimum	Maximum	Mean
……………………………………Temperature (^{o}C)…………………………………						
January	17.60	32.46	25.03	20.97	32.50	26.73
February	20.66	34.98	27.82	23.58	33.86	28.72
March	22.68	33.54	28.11	23.13	33.97	28.55
April	22.88	32.57	27.72	22.47	32.07	27.27
May	22.04	31.19	26.61	22.84	30.97	26.91
June	21.70	29.66	25.68	22.03	30.00	26.01
July	21.52	28.18	24.85	21.60	28.19	24.90
August	21.26	28.01	24.64	21.08	27.12	24.10
September	21.91	28.83	25.37	21.51	28.81	25.16
October	21.84	30.57	26.21	21.95	29.34	25.64
November	23.00	32.16	27.58	21.51	31.53	26.52
December	21.93	32.26	27.09	21.99	33.44	27.71
…………………………………Relative Humidity (%)………………………………						
January	28.97	79.55	54.26	33.68	87.35	60.52
February	24.90	90.52	57.71	40.54	91.71	66.13
March	43.00	92.13	67.56	42.35	90.42	66.39
April	49.70	93.73	71.72	51.53	88.97	70.25
May	55.16	92.13	73.65	55.58	88.45	72.02
June	61.60	91.93	76.77	56.33	87.67	72.00
July	64.61	92.39	78.50	63.23	87.00	75.11
August	63.23	89.48	76.35	67.87	89.00	78.44
September	63.53	93.33	78.43	62.57	92.33	77.45
October	55.45	92.55	74.00	59.74	92.06	75.90
November	41.07	92.77	66.92	42.13	88.83	65.48
December	35.35	89.23	62.29	29.90	92.45	61.18

Source: IITA, Ibadan (2010)

Appendix 3. Mean ± S.E and ranges for agronomic and damage parameters among progenies of DMR ESR-W evaluated under stem borer infested and non-infested conditions at Ibadan in 2008.

	Infested			Non-infested		
Traits	Mean±SE	CV (%)	Range	Mean±SE	CV (%)	Range
Days to pollen shed	48.97± 0.10	4.1	44.0-57.0	48.82 ±0.10	4.2	44.0-57.0
Days to silking	48.98 ±0.11	4.9	44.0-58.0	48.93 ±0.11	4.7	44.0-58.0
Plant height (cm)	138.84±0.70	10.6	84.2-183.2	156.75±0.75	10.1	106.0-202.8
Ear height (cm)	71.88 ± 0.57	16.7	30.0-104.2	73.38 ± 0.60	17.0	32.0-103.8
Root lodging (%)	3.42 ± 0.30	187.2	0.0-38.5	3.06 ± 0.28	192.5	0.0-33.3
Stalk lodging (%)	12.72 ± 0.66	108.5	0.0-72.7	13.24 ± 0.65	102.2	0.0-80.0
Husk cover rating	3.80 ± 0.05	26.7	2.0-7.0	3.66 ± 0.05	27.7	2.0-7.0
Plant aspect	3.67 ± 0.04	22.8	2.0-6.0	3.24 ± 0.04	25.2	2.0-6.0
Ears per plant	0.96 ± 0.01	17.0	0.2-1.7	0.98 ± 0.01	18.2	0.4-2.0
Ear aspect	5.84 ± 0.05	17.6	3.0-8.0	3.41 ± 0.04	23.0	2.0-6.0
Grain yield (t/ha)	3.09 ± 0.04	26.6	0.9-6.3	4.87 ± 0.06	27.8	1.3-10.0
Ear length (cm)	9.19 ± 0.05	12.0	3.8-13.4	12.29 ± 0.07	12.2	8.0- 15.9
Ear diameter (cm)	3.15 ± 0.01	6.9	1.8-4.1	4.20 ± 0.01	6.2	3.2- 5.0
Dead heart (%)	1.43 ± 0.19	284.3	0.0-30.8			
Stem tunneling (%)	16.43 ± 0.44	55.6	0.0-53.0			
Stalk breakage (%)	28.89 ± 0.89	64.7	0.0 -100.0			
Leaf feeding damage 3WAI	5.94 ± 0.06	21.6	2.0- 8.0			
Leaf feeding damage 5WAI	5.16 ± 0.05	22.3	2.0-8.0			
Cob damage (%)	29.66 ± 1.28	90.4	0.0-100.0			

Appendix 4. Mean ± S.E and ranges for agronomic and damage parameters among progenies of DMR ESR-W evaluated under stem borer infested and non-infested conditions at Ibadan in 2009.

	Infested			Non-infested		
Traits	Mean±SE	CV (%)	Range	Mean±SE	CV (%)	Range
Days to pollen shed	50.22 ± 0.11	4.5	44.0- 62.0	50.13 ± 0.10	4.3	44.0- 59.0
Days to silking	51.04 ± 0.11	4.6	45.0- 64.0	50.75 ± 0.10	4.3	46.0- 59.0
Plant height (cm)	150.28 ± 0.67	9.4	73.8- 190.1	167.19 ± 0.77	9.7	100.0 -211.0
Ear height (cm)	75.20 ± 0.53	14.8	32.0- 110.6	74.56 ± 0.52	14.5	40.0- 111.0
Root lodging (%)	4.56 ± 0.61	282.7	0.0- 100.0	3.40 ± 0.42	261.4	0.0- 66.7
Stalk lodging (%)	7.05 ± 0.65	194.7	0.0- 100.0	4.82 ± 0.55	238.4	0.0-100.0
Husk cover rating	3.28 ± 0.05	33.3	1.0- 7.0	3.31 ± 0.05	33.4	1.0- 7.0
Plant aspect	3.46 ± 0.04	27.2	1.0- 8.0	2.96 ± 0.04	28.1	1.0- 7.0
Ears per plant	1.09 ± 0.02	29.9	0.4- 6.0	1.06 ± 0.01	21.1	0.4- 2.1
Ear aspect	5.81 ± 0.05	17.6	3.0- 4.6	3.53 ± 0.03	19.6	2.0- 8.0
Grain yield (t/ha)	4.02 ± 0.13	65.0	0.0- 9.5	5.82 ± 0.07	25.9	1.7- 10.6
Ear length (cm)	10.04 ± 0.06	11.9	3.8-13.5	13.51 ± 0.07	10.6	5.0- 17.6
Ear diameter (cm)	3.76 ± 0.31	7.4	2.0- 4.2	4.39 ± 0.02	7.9	2.2- 5.2
Dead heart (%)	2.47 ± 0.41	345.1	0.0- 100.0			
Stem tunneling (%)	15.11 ± 0.42	58.2	0.0- 52.0			
Stalk breakage (%)	20.82 ± 1.00	100.8	0.0- 100.0			
Leaf feeding damage 3WAI	5.11 ± 0.06	23.6	2.0- 8.0			
Leaf feeding damage 5WAI	5.19 ± 0.05	22.2	3.0- 8.6			
Cob damage (%)	30.77 ± 1.42	96.2	0.0- 100.0			

Appendix 5. Mean ± S.E and ranges for agronomic and damage parameters among progenies of DMR ESR-Y evaluated under stem borer infested and non-infested conditions at Ibadan in 2008.

	Infested			Non-infested		
Traits	Mean± SE	CV (%)	Range	Mean± SE	CV (%)	Range
Days to pollen shed	48.81 ±0.08	3.9	45.0- 59.0	48.88±0.09	4.0	45.0- 60.0
Days to silking	50.11 ±0.09	3.9	46.0 - 62.0	50.05±0.09	4.0	45.0- 62.0
Plant height (cm)	197.05±0.85	9.5	135.0-249.6	198.60±0.78	8.7	149.2- 240.0
Ear height (cm)	99.81 ± 0.61	13.5	49.0- 139.0	99.93±0.57	12.7	45.0- 135.0
Root lodging (%)	1.13 ± 0.18	362.6	0.0- 50.0	3.02±0.36	265.4	0.0- 100.0
Stalk lodging (%)	2.54 ± 0.26	223.9	0.0- 30.0	2.56±0.33	284.8	0.0-100.0
Husk cover rating	3.52 ± 0.06	39.3	1.0- 8.0	3.47±0.06	41.2	1.0-8.0
Plant aspect	4.51 ± 0.05	26.3	2.8- 8.4	2.73±0.03	23.6	1.0-5.0
Ears per plant	0.86± 0.01	17.6	0.4- 1.6	1.07±0.01	18.1	0.6-2.0
Ear aspect	5.10± 0.06	25.8	1.0- 8.0	3.68±0.05	29.0	1.0-8.0
Grain yield (t/ha)	4.37 ±0.05	26.2	1.8- 8.7	6.62±0.09	29.6	2.4- 8.3
Ear length (cm)	11.99± 0.05	8.9	8.1- 14.9	15.28± 0.07	9.5	8.0- 19.8
Ear diameter (cm)	3.58± 0.01	7.2	1.8- 4.3	4.45± 0.01	6.7	2.1- 5.3
Dead heart (%)	0.82± 0.12	339.0	0.0- 20.0			
Stem tunneling (%)	8.15± 0.22	58.9	0.0- 35.7			
Stem breakage (%)	22.46± 0.84	83.3	0.0- 100.0			
Leaf feeding damage 3WAI	4.35± 0.06	30.5	2.6- 9.0			
Leaf feeding damage 5WAI	4.57± 0.06	28.8	2.6- 9.0			
Cob damage (%)	38.80 ±1.13	64.7	0.0- 100.0			

Appendix 6. Mean ± S.E and ranges for agronomic and damage parameters among progenies of DMR ESR-Y evaluated under stem borer infested and non-infested conditions at Ibadan in 2009.

	Infested			Non-infested		
Traits	Mean±SE	CV (%)	Range	Mean±SE	CV (%)	Range
Days to pollen shed	48.68± 0.07	3.1	46.0- 58.0	48.62±0.07	3.1	45.0- 55.0
Days to silking	49.42± 0.07	3.0	46.0- 61.0	49.40±0.07	3.1	47.0- 58.0
Plant height (cm)	153.93± 0.70	10.0	93.6- 190.9	191.99±0.88	10.2	128.7- 244.0
Ear height (cm)	79.39± 0.46	12.8	51.2- 111.4	99.66±0.60	13.3	66.7- 140.0
Root lodging (%)	9.64± 0.61	141.1	0.0- 100.0	9.07±0.60	146.6	0.0- 100.0
Stalk lodging (%)	6.55± 0.49	167.0	0.0- 100.0	6.97±0.44	141.0	0.0- 66.7
Husk cover rating	3.13± 0.04	25.3	2.0- 7.0	3.09±0.03	24.0	2.0- 6.0
Plant aspect	4.47± 0.05	25.7	2.6- 9.0	3.25±0.04	24.4	2.0- 7.0
Ears per plant	0.60± 0.01	19.6	0.2- 0.9	0.84±0.01	20.8	0.2- 1.3
Ear aspect	5.78± 0.07	27.4	3.0- 9.0	4.02±0.06	30.7	1.0- 8.0
Grain yield (t/ha)	2.04± 0.04	42.4	0.3- 5.7	3.09±0.06	42.4	0.4- 8.5
Ear length (cm)	10.08± 0.05	11.8	4.0- 13.6	12.52± 0.07	12.1	6.6- 17.2
Ear diameter (cm)	3.21± 0.01	9.0	1.6 - 4.0	4.03± 0.02	9.5	2.0- 5.8
Dead heart (%)	0.08± 0.04	992.4	0.0- 9.1			
Stem tunneling (%)	0.74± 0.02	66.1	0.0- 3.1			
Stem breakage (%)	17.21± 0.70	91.0	0.0- 100.0			
Leaf feeding damage 3WAI	5.01± 0.07	30.1	3.0- 9.0			
Leaf feeding damage 5WAI	5.24± 0.07	28.4	3.0- 9.0			
Cob damage (%)	49.11± 1.06	47.8	0.0- 100.0			

Appendix 7. Mean ± S.E and ranges for agronomic traits among progenies of DMR ESR-W evaluated under non-infested condition at Ikenne in 2008 and 2009.

Traits	2008			2009		
	Mean±S.E	CV (%)	Range	Mean±S.E	CV (%)	Range
Days to pollen shed	52.70± 0.12	4.8	48.0- 62.0	49.26± 0.10	4.1	45.0 - 56.0
Days to silking	54.81± 0.13	5.0	50.0- 64.0	50.52 ± 0.09	3.9	46.0 - 57.0
Plant height (cm)	144.85± 1.11	15.9	50.0- 200.0	181.19 ± 0.72	8.3	120.0- 225.0
Ear height (cm)	64.00± 0.68	21.9	20.0- 105.0	88.82± 0.50	11.9	65.0 - 120.0
Root lodging (%)	10.55 ± 0.59	114.9	0.0- 100.0	2.33 ± 0.24	217.9	0.0 - 40.0
Stalk lodging (%)	16.97 ± 0.64	78.4	0.0- 100.0	5.64± 0.42	155.2	0.0 - 100.0
Husk cover rating	3.27 ± 0.06	37.0	1.0- 7.0	3.63 ± 0.05	23.4	2.0 - 7.0
Plant aspect	3.02 ± 0.04	26.1	2.0- 8.0	3.63 ± 0.05	23.4	2.0 - 8.0
Ears per plant	0.92 ± 0.01	18.6	0.1- 2.0	0.94 ± 0.01	11.7	0.1- 1.8
Ear aspect	4.59 ± 0.04	19.9	2.0- 7.0	3.22 ± 0.05	29.5	2.0 - 6.0
Grain yield (t/ha)	2.78 ± 0.06	44.5	0.1- 9.9	4.70 ± 0.05	21.9	1.2- 10.3

Appendix 8. Mean ± S.E and ranges for agronomic traits among progenies of DMR ESR-Y evaluated under non-infested condition at Ikenne in 2008 and 2009.

Traits	2008			2009		
	Mean±SE	CV (%)	Range	Mean±SE	CV (%)	Range
Days to pollen shed	52.63± 0.10	4.2	45.0- 61.0	49.84 ±0.08	3.5	45-55
Days to silking	54.68± 0.10	4.1	48.0- 63.0	51.21± 0.08	3.4	47.0- 56.0
Plant height (cm)	162.95± 0.90	12.2	90.0- 215.0	192.74± 0.78	9.0	105.0 - 230.0
Ear height (cm)	76.76±0.65	18.7	35.0- 115.0	98.05 ±0.51	11.6	45.0-130.0
Root lodging (%)	12.63±0.51	88.5	0.0- 100.0	1.36 ±0.21	334.8	0.0-50
Stalk lodging (%)	17.35±0.55	70.1	0.0- 100.0	6.29 ±0.43	154.5	0.0-100.0
Husk cover rating	2.93±0.05	36.0	1.0- 7.0	3.81± 0.06	36.8	2.0-8.0
Plant aspect	3.17±0.03	21.1	2.0- 6.0	3.18± 0.03	21.4	2.0-6.0
Ears per plant	0.91±0.01	15.5	0.4- 1.4	0.92± 0.01	12.0	0.5-1.3
Ear aspect	4.78±0.04	18.4	2.0- 8.0	2.83 ±0.04	28.2	1.0-7.0
Grain yield (t/ha)	2.91±0.05	37.2	0.1- 8.3	5.89 ±0.06	23.4	2.1-10.9

Appendix 9. Means of agronomic traits for DMR ESR-W and DMR ESR-Y progenies under infested condition (IC) at Ibadan and non-infested conditions (NIC) at Ibadan and Ikenne in 2008 and 2009

	DMR ESR-W			DMR ESR-Y		
	Ibadan		Ikenne	Ibadan		Ikenne
Traits	IC	NIC	NIC	IC	NIC	NIC
……………………………………………2008……………………………………………						
Days to 50% pollen shed	49.0	48.8	52.7	48.8	48.9	52.6
Days to silking	49.0	48.9	54.8	50.1	50.1	54.7
Plant height (cm)	138.8	156.7	144.9	197.1	198.6	163.0
Ear height (cm)	71.9	73.3	64.0	99.8	99.9	76.7
Ear length (cm)	9.2	12.3	11.0	12.0	15.3	13.5
Ear diameter (cm)	3.1	4.2	4.2	3.6	4.4	3.4
Ears per plant	1.0	1.0	0.9	0.9	1.1	0.9
Plant aspect	3.7	3.2	3.0	4.5	2.7	3.2
Ear aspect	5.8	3.4	4.6	5.1	3.7	4.8
Grain yield (t/ha)	3.1	4.9	2.8	4.4	6.6	2.9
……………………………………………2009…………………………………………...						
Days to 50% pollen shed	50.2	50.1	49.3	48.7	48.6	49.8
Days to silking	51.0	50.8	50.5	49.4	49.4	51.2
Plant height (cm)	150.3	167.2	181.2	154.0	192.0	192.7
Ear height (cm)	75.2	74.6	88.8	80.3	100.8	98.1
Ear length (cm)	10.1	13.4	13.3	10.1	12.5	15.5
Ear diameter (cm)	3.3	4.6	4.5	3.2	4.0	4.4
Ears per plant	1.1	1.1	1.0	0.6	0.8	0.9
Plant aspect	3.5	3.0	3.0	4.5	3.3	3.2
Ear aspect	5.8	3.5	3.2	5.8	4.0	2.8
Grain yield (t/ha)	3.9	5.9	4.7	2.0	3.1	5.9

Appendix 10. Comparison of means of agronomic traits for DMR ESR-W and DMR ESR-Y progenies under infested (IC) and non-infested conditions (NIC) at Ibadan during 2008 and 2009 seasons

	DMR ESR-W			DMR ESR-Y		
Trait	IC	NIC	Diff.	IC	NIC	Diff.
……………………………………….2008						
Days to 50% pollen shed	49.0	48.8	ns	48.8	48.9	ns
Days to silking	49.0	48.9	ns	50.1	50.1	ns
Plant height (cm)	138.8	156.7	**	197.1	198.6	ns
Ear height (cm)	71.9	73.3	ns	99.8	99.9	ns
Ear length (cm)	9.2	12.3	**	12.0	15.3	**
Ear diameter (cm)	3.1	4.2	**	3.6	4.4	**
Ears per plant	1.0	1.0	ns	0.9	1.1	**
Plant aspect	3.7	3.2	**	4.5	2.7	**
Ear aspect	5.8	3.4	**	5.1	3.7	**
Grain yield (t/ha)	3.1	4.9	**	4.4	6.6	**
……………………………………….2009						
Days to 50% pollen shed	50.2	50.1	ns	48.7	48.6	ns
Days to silking	51.0	50.8	ns	49.4	49.4	ns
Plant height (cm)	150.3	167.2	**	154.0	192.0	**
Ear height (cm)	75.2	74.6	ns	80.3	100.8	**
Ear length (cm)	10.1	13.4	**	10.1	12.5	**
Ear diameter (cm)	3.3	4.6	**	3.2	4.0	**
Ears per plant	1.1	1.1	ns	0.6	0.8	**
Plant aspect	3.5	3.0	**	4.5	3.3	**
Ear aspect	5.8	3.5	**	5.8	4.0	**
Grain yield (t/ha)	3.9	5.9	**	2.0	3.1	**

Diff.: Difference, *, **: significant at 5% and 1% level of probability respectively, ns: not significant
Means of traits under infested and non-infested conditions were compared using t-test.

Appendix 11. Analysis of variance for grain yield for progenies of DMR ESR-W under stem borer infested condition in Ibadan and non-infested condition at Ibadan and Ikenne in 2008 and 2009

Source	df	Sum of squares	Mean Square	F Value	Pr > F
			Infested condition		
Environment	1	140.44	140.44	232.15	<.0001
Set	8	23.67	2.96	4.89	<.0001
Rep (Env*Set)	16	7.28	0.45	0.75	0.7399
Entry	215	206.73	0.96	1.44	0.004
Male (Set)	36	44.95	1.25	2.31	0.007
Female (Set)	36	58.03	1.61	2.12	0.0134
Male*Female (Set)	143	102.96	0.72	1.02	0.4583
Env*Entry	213	142.27	0.67	1.1	0.2073
Env*Male (Set)	36	19.48	0.54	0.77	0.8242
Env*Female (Set)	36	27.37	0.76	1.07	0.3723
Env*Male*Female (Set)	141	99.75	0.71	1.17	0.1276
Error	346	209.32	0.60		
			Non-infested condition		
Environment	3	1940.69	646.90	593.44	<.0001
Set	8	39.05	4.88	4.48	<.0001
Rep (Env*Set)	32	33.80	1.06	0.97	0.5178
Entry	215	634.40	2.95	2.5	<.0001
Male (Set)	36	118.44	3.29	3.03	<.0001
Female (Set)	36	182.78	5.08	3.25	<.0001
Male*Female (Set)	143	327.29	2.29	2	<.0001
Env*Entry	631	743.33	1.18	1.08	0.1612
Env*Male (Set)	108	117.43	1.09	0.95	0.6244
Env*Female (Set)	108	168.95	1.56	1.36	0.017
Env*Male*Female (Set)	415	475.98	1.15	1.05	0.2798
Error	670	730.35	1.09		

df : degree of freedom

Appendix 12. Analysis of variance for leaf feeding damage and dead heart for progenies of DMR ESR-W under stem borer infested condition at Ibadan in 2008 and 2009

Source	df	Sum of squares	Mean Square	F Value	Pr > F
		Leaf feeding damage			
Environment	1	147.20	147.20	110.95	<.0001
Set	8	10.09	1.26	0.95	0.4749
Rep (Env*Set)	16	11.58	0.72	0.55	0.9216
Entry	215	306.51	1.43	1.12	0.2015
Male (Set)	36	79.16	2.20	1.56	0.0929
Female (Set)	36	38.14	1.06	0.73	0.8294
Male*Female (Set)	143	187.82	1.31	1.15	0.2082
Env*Entry	213	270.80	1.27	0.96	0.6317
Env*Male (Set)	36	50.69	1.41	1.23	0.1987
Env*Female (Set)	36	52.53	1.46	1.27	0.1618
Env*Male*Female (Set)	141	161.52	1.15	0.86	0.8435
Error	351	465.69	1.33		
		Dead heart (%)			
Environment	1	0.11	0.11	4.63	0.0321
Set	8	0.14	0.02	0.73	0.6666
Rep (Env*Set)	16	0.47	0.03	1.24	0.2358
Entry	215	4.45	0.02	0.86	0.8718
Male (Set)	36	0.52	0.01	0.67	0.8843
Female (Set)	36	0.81	0.02	0.88	0.6457
Male*Female (Set)	143	3.14	0.02	0.95	0.6197
Env*Entry	213	5.15	0.02	1.02	0.4427
Env*Male (Set)	36	0.78	0.02	0.94	0.5689
Env*Female (Set)	36	0.91	0.03	1.1	0.3405
Env*Male*Female (Set)	141	3.26	0.02	0.97	0.5761
Error	351	8.36	0.02		

df : degree of freedom

Appendix 13. Analysis of variance for stalk breakage, cob damage and stem tunneling for progenies of DMR ESR-W under stem borer infested condition at Ibadan in 2008 and 2009

Source	df	Sum of squares	Mean Square	F Value	Pr > F
		Stalk breakage (%)			
Environment	1	3.67	3.67	55.81	<.0001
Set	8	1.75	0.22	3.33	0.0011
Rep (Env*Set)	16	1.16	0.07	1.10	0.3521
Entry	215	19.00	0.09	0.95	0.0389
Male (Set)	36	4.24	0.12	1.09	0.4038
Female (Set)	36	5.86	0.16	1.63	0.0543
Male*Female (Set)	143	8.94	0.06	0.74	0.9643
Env*Entry	213	19.76	0.09	1.41	0.0023
Env*Male (Set)	36	3.90	0.11	1.28	0.1572
Env*Female (Set)	36	3.60	0.10	1.18	0.2451
Env*Male*Female (Set)	141	11.95	0.08	1.29	0.0333
Error	351	23.11	0.07		
		Cob damage (%)			
Environment	1	0.24	0.24	1.64	0.2007
Set	8	2.59	0.32	2.26	0.0231
Rep (Env*Set)	16	2.04	0.13	0.89	0.5819
Entry	215	60.76	0.28	9.37	<.0001
Male (Set)	36	7.49	0.21	6.44	<.0001
Female (Set)	36	14.78	0.41	15.1	<.0001
Male*Female (Set)	143	37.02	0.26	8.46	<.0001
Env*Entry	213	6.42	0.03	0.21	1
Env*Male (Set)	36	1.16	0.03	1.06	0.3983
Env*Female (Set)	36	0.98	0.03	0.89	0.6498
Env*Male*Female (Set)	141	4.31	0.03	0.21	1
Error	346	49.70	0.14		
		Stem tunneling (%)			
Environment	1	0.08	0.08	5.00	0.026
Set	8	0.34	0.04	2.78	0.0054
Rep (Env*Set)	16	0.14	0.01	0.56	0.9124
Entry	215	3.25	0.02	1.09	0.2717
Male (Set)	36	0.62	0.02	0.93	0.5811
Female (Set)	36	0.55	0.02	1.27	0.2384
Male*Female (Set)	143	2.15	0.02	1.14	0.2186
Env*Entry	213	2.96	0.01	0.92	0.7502
Env*Male (Set)	36	0.66	0.02	1.39	0.0896
Env*Female (Set)	36	0.43	0.01	0.91	0.6232
Env*Male*Female (Set)	141	1.86	0.01	0.87	0.8324
Error	349	5.29	0.02		

df : degree of freedom

Appendix 14. Analysis of variance for grain yield for progenies of DMR ESR-Y under stem borer infested condition in Ibadan and non-infested condition at Ibadan and Ikenne in 2008 and 2009

Source	df	Sum of squares	Mean Square	F Value	Pr > F
			Infested condition		
Environment	1	1319.23	1319.23	1986.60	<.0001
Set	9	18.26	2.03	3.05	0.0015
Rep (Env*Set)	18	14.04	0.78	1.17	0.279
Entry	240	279.26	1.16	1.49	0.001
Male (Set)	40	54.34	1.36	2.22	0.0067
Female (Set)	40	52.55	1.31	1.55	0.0846
Male*Female (Set)	160	170.31	1.06	1.36	0.0269
Env*Entry	237	184.71	0.78	1.17	0.0797
Env*Male (Set)	40	24.47	0.61	0.78	0.8176
Env*Female (Set)	40	33.87	0.85	1.08	0.3572
Env*Male*Female (Set)	157	122.86	0.78	1.18	0.1019
Error	412	273.59	0.66		
			Non-infested condition		
Environment	3	5303.80	1767.90	1262.20	<.0001
Set	9	48.21	5.36	3.82	<.0001
Rep (Env*Set)	36	46.69	1.30	0.93	0.5954
Entry	240	732.74	3.05	2.06	<.0001
Male (Set)	40	97.34	2.43	1.57	0.0329
Female (Set)	40	233.16	5.83	3.52	<.0001
Male*Female (Set)	160	434.04	2.71	1.88	<.0001
Env*Entry	713	1057.20	1.48	1.06	0.2153
Env*Male (Set)	120	186.28	1.55	1.08	0.2946
Env*Female (Set)	120	198.96	1.66	1.15	0.1575
Env*Male*Female (Set)	473	682.23	1.44	1.03	0.3569
Error	817	1144.30	1.40		

df: degree of freedom

Appendix 15. Analysis of variance for leaf feeding damage and dead heart for progenies of DMR ESR-Y under stem borer infested condition at Ibadan in 2008 and 2009

Source	df	Sum of squares	Mean Square	F Value	Pr > F
		Leaf feeding damage			
Environment	1	108.64	108.64	70.09	<.0001
Set	9	15.51	1.72	1.11	0.3531
Rep (Env*Set)	18	72.84	4.05	2.61	0.0004
Entry	240	368.29	1.53	0.89	0.8199
Male (Set)	40	52.89	1.32	0.81	0.74
Female (Set)	40	71.09	1.78	1.02	0.4813
Male*Female (Set)	160	238.36	1.49	0.88	0.7879
Env*Entry	238	411.16	1.73	1.11	0.1695
Env*Male (Set)	40	64.92	1.62	0.96	0.5452
Env*Female (Set)	40	70.03	1.75	1.04	0.4255
Env*Male*Female (Set)	158	267.23	1.69	1.09	0.2474
Error	414	641.74	1.55		
		Dead heart (%)			
Environment	1	0.14	0.14	45.18	<.0001
Set	9	0.06	0.01	2.07	0.0308
Rep (Env*Set)	18	0.10	0.01	1.70	0.0367
Entry	240	1.04	0.00	0.97	0.6073
Male (Set)	40	0.18	0.00	0.91	0.6198
Female (Set)	40	0.18	0.00	1.21	0.2788
Male*Female (Set)	160	0.68	0.00	0.95	0.6379
Env*Entry	238	1.07	0.00	1.41	0.0013
Env*Male (Set)	40	0.20	0.01	1.12	0.3045
Env*Female (Set)	40	0.15	0.00	0.83	0.7555
Env*Male*Female (Set)	158	0.71	0.00	1.42	0.0034
Error	414	1.32	0.00		

df : degree of freedom

Appendix 16. Analysis of variance for stalk breakage, cob damage and stem tunneling for progenies of DMR ESR-Y under stem borer infested condition at Ibadan in 2008 and 2009

Source	df	Sum of squares	Mean Square	F Value	Pr > F
		Stalk breakage (%)			
Environment	1	1.28	1.28	26.78	<.0001
Set	9	0.72	0.08	1.66	0.0968
Rep (Env*Set)	18	1.09	0.06	1.26	0.2096
Entry	240	22.48	0.09	1.57	0.0003
Male (Set)	40	5.60	0.14	2.43	0.0031
Female (Set)	40	5.28	0.13	2.09	0.0109
Male*Female (Set)	160	11.48	0.07	1.20	0.1261
Env*Entry	237	14.11	0.06	1.24	0.0287
Env*Male (Set)	40	2.31	0.06	0.97	0.5362
Env*Female (Set)	40	2.52	0.06	1.06	0.3953
Env*Male*Female (Set)	157	9.39	0.06	1.25	0.0441
Error	414	19.86	0.05		
		Cob damage (%)			
Environment	1	4.39	4.39	69.28	<.0001
Set	9	1.66	0.18	2.92	0.0023
Rep (Env*Set)	18	0.73	0.04	0.64	0.8649
Entry	240	17.65	0.07	0.99	0.0536
Male (Set)	40	4.71	0.12	1.70	0.0493
Female (Set)	40	4.04	0.10	1.24	0.2489
Male*Female (Set)	160	9.58	0.06	0.85	0.8475
Env*Entry	237	17.64	0.07	1.17	0.0786
Env*Male (Set)	40	2.78	0.07	0.99	0.503
Env*Female (Set)	40	3.25	0.08	1.15	0.2645
Env*Male*Female (Set)	157	11.06	0.07	1.11	0.2043
Error	412	26.10	0.06		
		Stem tunneling (%)			
Environment	1	0.08	0.08	12.05	0.0006
Set	9	0.06	0.01	0.99	0.444
Rep (Env*Set)	18	0.15	0.01	1.27	0.2004
Entry	240	2.18	0.01	1.56	0.0003
Male (Set)	40	0.49	0.01	1.40	0.1469
Female (Set)	40	0.43	0.01	1.75	0.0406
Male*Female (Set)	160	1.27	0.01	1.49	0.0065
Env*Entry	237	1.38	0.01	0.87	0.0501
Env*Male (Set)	40	0.35	0.01	1.65	0.0159
Env*Female (Set)	40	0.25	0.01	1.16	0.2596
Env*Male*Female (Set)	157	0.84	0.01	0.79	0.9551
Error	414	2.79	0.01		

df : degree of freedom