HOST-PLANT RESISTANCE AND RESPONSE TO SELECTION IN SORGHUM TO HEAD BUGS *(Eurystylus oldi.* **Poppius)**

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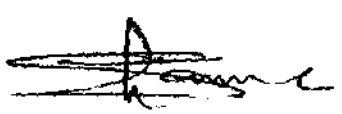
DECLARATION

I hereby declare that the work presented in this dissertation is original and a documentation of my research findings. No part of this dissertation has previously been submitted for a degree or any other qualification. References made to published and unpublished literature have been duly acknowledged.



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CERTIFICATION

The dissertation entitled **"HOST-PLANT RESISTANCE AND RESPONSE TO SELECTION IN SORGHUM TO HEAD BUGS (*Eurystylus oldi*. Poppius)"** by **SHOWEMIMO, Francis Abayomi** meets the regulations governing the award of the degree of Doctor of Philosophy of Ahmadu Bello University, Zaria and is approved for its scientific contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to late Professor C.C. Nwasike who initiated this work but never saw the end of it.

Abayomi, Engr. Z.O. Ariori, Messrs. E.T.Ishola and B.Bamidele, Miss Folashade Onifade, Miss O. K. Soetan, Mrs. C. F. Arotiba and Mr. Ayoola Onifade.

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Finally, I thank God for 'drawing me out' for His glory.

ABSTRACT

Three resistant sorghum cultivars used as males were crossed to three susceptible sorghum cultivars used as females in a factorial mating system. The resultant nine F, hybrids were advanced to F_2 generation and screened for resistance by artificially infesting each sorghum panicle with 10 pairs of head bugs *(Eurystylus oldi* (Poppius)) using the 'no choice' head cage method. The best 10% of F_2 genotypes were advanced to F_3 and F_4 generations. The six parents, nine F,s, nine F_2s, 25 F_3 lines and 25 F_4 lines were evaluated for resistance to *E. oldi.* Randomized complete block design **(RCBD)** was used, while North Carolina design II was the breeding design used.

The analysis of variance revealed highly significant effects (P=0.01) among entries (non-segregating and segregating populations), crosses, F_2 generations, F_3 lines and F_4 lines for all the traits measured that is; number of head bugs, grain damage rating, floaters percentage, germination percentage, 1000-grain weight and grain yield. The parents also showed highly significant effect **(P=0.01)** for all the traits except grain yield.

Estimates of genetic component of variance O^2_A, O^2_D and $O^{2A/}D$ ratio revealed the preponderance of non-additive gene action for all the traits measured. High narrow-sense heritability estimates were recorded for all traits in F_4 lines, F_3 lines, F_2 generations and the F1S, except for number of head bugs (47.00%) in the F1. High narrow-sense heritability estimates were also recorded at F_2 generations, F_3 and F_4 lines for all the traits measured.

TABLE OF CONTENTS

PAGE

CONTENT i

Title page ii

Declaration iii

Certification iv

Dedication v

Acknowledgement vii

Abstract ix

Table of Contents xi

List of Table xiii

List of Appendices .....

CHAPTER ONE 1

1.0 INTRODUCTION .....

CHAPTER TWO 5

2.0 LITERATURE REVIEW 5

2.1 Classification and description of *E.oldi* (Poppius) 7

2.2 Biology, bionomics and bioecology of *E.oldi* (Poppius) 9

2.3 Damage to sorghum by *E.oldi* (Poppius) 9

2.3.1 Feeding Activities 10

2.3.2 Oviposition/Egg-laying activities 11

2.4 Estimates of genetic variance component .....

2.5 Heritability and genetic advance 13

2.6 Sources, mechanism and mode of resistance in sorghum to *E.oldi* (Poppius) 15

CHAPTER THREE

3.0 MATERIALS AND METHODS 17

3.1 Plant materials 17

3.2 Experimental layout 17

3.3 Observation 20

3.4 Pedigree of F_3 and F_4 lines 22

3.5 Statistical and genetic analysis 22

CHAPTER FOUR

4.0 RESULTS 28

CHAPTER FIVE

5.0 DISCUSSION 47

CHAPTER SIX

6.0 SUMMARY AND CONCLUSIONS 53

REFERENCES 56

APPENDICES 65

13. Analysis of variance showing degrees of freedom and mean squares for segregating populations of F_2 generations and resistant parents for all traits measured 40

14. Analysis of variance showing degrees of freedom and mean squares for F_3 lines and resistant parents for all traits measured 41

15. Analysis of variance showing degrees of freedom and mean squares for F_4 lines and resistant parents for all traits measured 42

16. Estimates of components of variance and heritability for all traits measured 43

17. Narrow-sense heritability estimates (%), expected genetic gain (ΔG) and percentage gain in parenthesis for F_2 generations, F_3 and F_4 lines for all traits measured 44

LIST OF APPENDICES

Page

Appendix

I. Diagramatic representation of the male and female adults and nymphs of *E.oldi* 65

II. Picture of the head cage on sorghum panicle 65

CHAPTER ONE

INTRODUCTION

Sorghum, commonly called 'Guinea corn' belongs to the family Graminea or Poaceae, and the genus *Sorghum* with about five cultivated species, the most prominent species is *bicolor*. The guinea and kafir race are commonly cultivated in West Africa especially in Northern Nigeria (House, 1985). Sorghum is the world's fifth ranking cereal grain with regards to production levels. Sorghum is mainly grown in the tropics and Semi-Arid Tropics (SAT). The grain is harvested in Asia and Africa for human consumption while in the Americas for animal feeds (Leuschner, 1985). Percentages of the world area and production of sorghum in 1986 are 82.7% and 60.5%, respectively (FAO, 1987; and Nagur, 1990). In Nigeria sorghum is mainly grown in the savannah agro-climatic zones (Obilana, 1981). Presently, the land area devoted to sorghum production in Nigeria is about 6 million hectares. Between 1992 and 1994, Nigeria produced 6.10 million tonnes of sorghum on 5.70 million hectares with an average yield of 1.07 t/ha (Nwasike, 1982; 1987; Obilana, 1983; FAO, 1987, and ICRISAT/FAO, 1996).

Sorghum is the staple food of millions of people in Africa and Asia where over 90% of sorghum produced are used for human consumption. It is prepared as foods and drinks including unleavened bread, leavened bread, thick porridge (tuwo), thin porridge ("ogi" or "akamu"), boiled or steam-cooked grains eaten with seasonings and spices, alcoholic (eg "burukutu", "pito") and non-alcoholic beverages ("kunu"). The leaves, stalks and grains are used as livestock feed and the stalks mainly for fencing, fuel, making mats, baskets,

huts and a variety of other uses (Curtis, 1965; Oyenuga, 1967; Doggett, 1970; Nwasike, 1982; Obilana, 1985, and Aluko and Olugbemi, 1990). According to Obilana (1985), Nwasike (1987), and Baidu-Forson and Ajayi (1995) sorghum has attained a high status industrially as agro-industrial raw material in the manufacture of bread, biscuits, cakes, wax, syrup, starch, beverage food, malt drinks, and for brewing.

Several factors militating against sorghum production have been identified. In addition to diseases, parasitic weeds, birds, poor soils, erratic rainfall and drought, there is the problem of insect pests. Insect pests are one of the major factors limiting sorghum production in West Africa (Nwanze, 1985). Over 150 insect species have been listed as pests or potential pests of sorghum (Seshu-Reddy and Davies, 1979; Jotwani *et al*, 1980). However, only a few of these insects are pests of economic importance and the major insect pests are stem borer (*Busseola fusca*.Fuller), shoot fly (*Atherigona soccata* Rondani), sorghum midge (*Stenodiplosis sorghicola* Coq), head bugs (*Eurstylus sp*, *Campylomma sp*, *Creontiades sp* and *Taylorilygus sp*), head caterpillars (*Helicoverpa armigera* Hubner, *Pyroderces sp*, *Eublema gayneri* Roths), grasshoppers and locusts (Anonymous, 1983; and Sharma *et al.*, 1992).

Mirid head bugs are important pests of sorghum in Asia and Africa. Species belonging to four genera (*Calocoris*, *Campylomma*, *Creontiades* and *Eurystylus*) are known to attack sorghum. In Western Africa, head bugs have gained importance in recent years with the introduction of early flowering cultivars with compact panicles. In Nigeria, six

species of mirid head bugs attack sorghum, of which *Eurystylus oldi* (Poppius) comprises almost 80% of the total population in 1982 (Anonymous, 1983; McFarlane, 1989). Between 1983 and 1989, McFarlane (1989) reported that *Eurystylus sp* and *Campylomma sp* accounted for 63% and 29%, respectively of total head bug population at Samaru. In a survey by Ajayi (1996) in Northern Nigeria, 81% of the 88 fields visited were infested by *E.oldi* and over 50% of the 532 panicles sampled had *E.oldi* with a mean population of 9.68 per panicle.

Head bugs damage spoils the grain quality by rendering the grain soft and starchy and therefore unfit for food preparation. Head bugs damage also leads to higher incidence of grain mould, resulting in poor seed germination and renders the grain unfit for human consumption (Sharma and Lopez, 1989, 1990, and 1991). Yield losses of up to 86% have been attributed to head bug damage (Ajayi and Tabo, 1995). Avoidable losses have been estimated to cost over Rs 900 million per annum in India, $550 million in the Semi-Arid Tropics, $80 million in Australia and $250 million in U.S.A (Leuschner and Sharma, 1983; ICRISAT, 1992; Ratnadass and Ajayi, 1995).

Considerable work has been done on various control methods such as chemical, biological, cultural, and the use of traditionally grown land races which are usually late and low yielding. These control methods have not been very effective because of variation in climatic conditions, cost of chemicals, and the reported reduction in head bugs damage is mainly due to escape rather than resistance (Ajayi and Tabo, 1995; Ratnadass *et al.*, 1995).

In other to minimize the high yield losses associated with *E.oldi* damage in sorghum, a major component of long lasting and affordable control package would be host-plant resistance, which is environmentally safe; has no adverse effect on producers and end users; is a boom to small scale farmers; does not require any technical skills and can be integrated with other control methods as a component of integrated pest management. It is in the light of this consideration that the research project is designed with the following objectives:

The objectives of this study are:

(a) To estimate genetic components of variance for the desired traits indicating resistance to *E.oldi*.

(b) To determine heritability and the gene action governing the inheritance of the desired resistance traits.

(c) To measure response to selection in F_2, F_3, and F_4 generations using estimate of genetic advance.

CHAPTER TWO

LITERATURE REVIEW

2.1 CLASSIFICATION AND DESCRIPTION OF *Eurystylus oldi* Poppius.

The classification of *Eurystylus oldi* (Poppius) is shown below according to Poppius (1912), Webb and Elgood (1955), Odhiambo (1958), and Seshu Reddy and Davies (1979).

Kingdom	-	Animalia
Sub-kingdom	-	Metazoa
Sub-grade	-	Encoelomata
Division	-	Shcizocoela
Sub-division	-	Annulata
Phylum	-	Arthropoda
Sub-phylum	-	Euarthropoda
Super-class	-	Mandibulata
Class	-	Insecta
Sub-class	-	Pterygota
Infra-class	-	Paraneoptera
Super-order	-	Hemipteroidea
Order	-	Hemiptera
Sub-order	-	Heteroptera
Family	-	Miridae
Sub-family	-	Mirinae

Tribe	-	Mirini
Genus	-	Eurystylus
Species	-	Oldi
Common name	-	Head bug

The entire body length of the male *E.oldi* is between 3.04-4.18mm. The body colour varies from yellow to reddish brown depending on the colour of the grains that are infested. The head, rostrum, antennae, scutellum and pronotum are usually yellow, while the legs are also yellow with brownish red spots on the femora (Odhiambo, 1958; Stonedahl, 1995). The male antennae have laterally compressed segments; the first segment is thick and shorter than the frontal length of the head and lateral margin of the pronotal disc. The second segment of the antenna is very thick at the apex, while the third and fourth segments are thin and weakly spindled shaped. The pronotum has straight, lateral margins and the calli are flat with posterior margins marked with a deep furrow. The scutellum is convex and punctured. The head is not pubescent but the hind femora is densely pubescent with black tubercles on the tibiae. The eyes are large and convex. The rostrum extends to the middle of the mesocoxa with the first segment reaching the middle of the probasisternum (Poppius, 1912; Odhiambo, 1958; Teetes, 1985, Ratnadass, 1991 and Beyo, 1996).

The head of the female *E.oldi* is shorter from the side and the antennal first segment is mote compressed laterally than that of the male. The basal margin of the pronotum is

sinnate and punctured. The female *E.oldi* is larger that the male, the entire body length is between 3.11-5.9mm. The female has a long chitinized ovipositor that is as long as the abdomen. The female abdomen has a vertical line. The female is usually paler in colour than the male, and the antennae and pronotum are yellow (Odhiamabo, 1958; Teetes, 1985; Stonedahl, 1995, and Beyo, 1996).

2.2 BIOLOGY, BIONOMICS AND BIOECOLOGY OF *E.oldi* (Poppius).

The biology and seasonal activity of head bugs attacking sorghum has not been adequately investigated. However, according to Ratnadass *et al.* (1993 and 1994), field and laboratory studies conducted in Mali and Nigeria on the biology and population dynamics of *E.oldi* show that the female insect inserts its eggs into developing sorghum grain at the milk or soft dough stage. The creamy white eggs hatch between 5-7 days, and there are 5 nymphal instars which last for about 6-11 days. The maximum longevity observed for a mated female was 18 days (Steck *et al.*, 1989; McFarlane, 1989; Doumbia, 1992; Ratnadass *et al.*, 1994). However, detailed studies carried out in ICRISAT, Nigeria in 1994 revealed that adult longevity was about 25.27 days for male and 21.68 for female, while the mean number of eggs laid/female was 248 $\pm$ 89, the maximum number being 517, similarly, hatching took place after an incubation period of between 4-12 days (ICRISAT, 1994 and Ratnadass *et al.*, 1994).

Several generations of *E.oldi* could be completed on the same crop in a single cropping season; up to 4 generations were recorded in Mali and in Nigeria (Ratnadass, 1993) with two peaks of infestation, late September and October. The life cycle from egg to adult is completed in 15 - 20 days. Adults probably survive on wild hosts, irrigated and post rainy season sorghum, mango tree, and pigeon pea (Ratnadass, 1993; Ajayi, 1997; Ajayi and Ajiboye, 1997). According to Hiremath (1995) most head bugs especially *C. angustatus* complete 16 generations in a year and it is active throughout the year.

The relative abundance and damage on sorghum plant is not the same all over its area of occurrence. *E.oldi* is predominantly present in West Africa where its increasing population in recent years constitutes a serious problem in sorghum production (Doumbia and Teetes, 1991). The insect population and damage under field condition is influenced to a large extent by the macro and micro-environment prevalent in the crop canopy. Maximum *E.oldi* activity has been recorded during the period of August - September and a smaller peak occurs during the period of March - April (Sharma, 1985). Bala-Subramania *et al.* (1979) reported that the population build up was negatively correlated with the number of rainy days and not influenced by temperature, sunshine, relative humidity and rainfall. However, maximum *E.oldi* incidence is normally observed during the second half of the rainy season. In a series of study on environmental factors affecting *E.oldi* infestation by Leuschner *et al.* (1985), Viana (1985), Sivakumar and Baidu-Forson (1995), it was reported that,

most panicle insect pests of sorghum and millet had population peaks corresponding with those of *E.oldi*. It was also reported that high humidity was essential for population build up and that the life cycles of most insect pests of sorghum and millet are linked to monomodal rainfall pattern of Semi-Arid Tropics. Ambient temperatures also influence the level of insect infestation.

2.3 DAMAGE TO SORGHUM BY *E.oldi* (Poppius).

Head bug damage is caused by both feeding and egg laying or oviposition activities in developing sorghum grains.

2.3.1 Feeding Activities:

The mirid head bugs (adults and nymphs) feed mainly by sucking sap from developing kernels (grains) and occasionally on other tender parts of the sorghum plant. Consequently, the developing grains remain unfilled, shriveled and, in severe infestation, the panicles become completely chaffy. The damage done during the early stages of grain development results in heavy loss, while later infestation results largely in quality loss. The damaged grains show distinct reddish-brown feeding punctures, and in cases of severe feeding, grains become completely tanned (Sharma and Lopez, 1989; Sharma *et al.*, 1992).

2.3.2 Oviposition/Egg-laying activities:-

The female adult head bug inserts its eggs inside the grains at the milk or soft dough stage. In a study at Samako, Mali, pre-oviposition period was 2-3 days in 1992 and 3 $\pm$ 1.7 days in 1993. The number of eggs laid in a single grain varied from 1 to 7 (Ratnadass *et al.*, 1995b). Eggs are detectable by their protruding tip (operculum). Hatching takes place after an incubation period of 4-12 days depending on the location and prevailing condition (Gahukar, 1991; Sharma *et al.*, 1992). The large number of hatched eggs into nymphs, their molting and developmental stages disturb grain filling, thereby leaving unacceptable colour on the grain (Ratnadass *et al.*, 1991 and 1995b).

In a series of report by Steck *et al.* (1989) ; Ratnadass *et al.* (1991); Ratnadass and Ajayi (1995), a combination of feeding and oviposition/egg-laying activities is more destructive to the developing grains than feeding or oviposition/egg-laying alone. Head bug damage to sorghum grain is closely associated with grain mould, and poor germination, and grains are not marketable or fetch low prices depending on the amount of damage. The effects of *E.oldi* feeding and oviposition/egg-laying activities are the physical removal of nutrients and water leading to shriveled grains and weight loss. The action of the salivary enzymes results in the breakdown of endosperm texture leading to floury (or loss of vitrosity) thus, resulting in low starch and protein content, but having high level of

amino acids (Natarajan and Babu, 1987; Sharma and Lopez, 1989; Gahukar, 1991; Sharma *et al.*, 1992 and Ratnadass *et al.*, 1993).

2.4 ESTIMATES OF GENETIC VARIANCE COMPONENT

Fisher (1918) partitioned genetic variance into additive, dominance and their interactions i.e additive x additive, additive x dominance and dominance x dominance (epistasis). Gene effects other than additive are called non-additive. These parameters provide the bases for selection and improvement of crop plants for resistance to insects. There is no available genetic information on the traits associated with *E.oldi* resistance/tolerance. Traits such as: grain colour, number of head bugs count, damage rating, floaters percentage, germination percentage, 1000-seed weight and grain yield are important in selecting sorghum resistant to *E.oldi* infestation. However, from the scanty information available, Ayyangar and Ayyar (1938) reported that loose panicle type was dominant (*pa*) over compact panicle in sorghum resistant to head bugs and head caterpillars. In another study by Vinall and Cron (1921), long glume was recessive to short glume, while Jowett (1968) reported that small or short glume was strongly but incompletely dominant with epistatic effects for head bug. Ayyangar and Ponnaiya (1941) revealed that glabrous glume was recessive to hairy glumes for sorghum resistant to head bug and midge.

In related research on insect resistance, sorghum midge resistance was reported to be quantitatively inherited and controlled by additive genes with some cytoplasmic effects (Widstrom *et al.*, 1984; Agrawal *et al.*, 1988). According to Patil and Thombre (1985) both additive and non-additive gene effects were important for midge resistance because estimates for general combining ability (GCA) and specific combining ability (SCA) variances were significant, but the GCA effect was more important than the SCA effect. Sharma *et al.* (1996) reported that glume length showed negative and significant GCA effect, while other morphological traits associated with resistance to midge need to be determined. Similarly, both additive and non-additive gene effects were important for inheritance of resistance to shoot fly in sorghum but predominantly by additive gene effects (Indra *et al.*, 1972; Nimbalkar and Bapat, 1992). On the contrary, Agrawal and Abraham (1985) reported that resistance to shoot fly was predominantly controlled by non-additive genes.

Information from other genetic studies not related to insects or disease resistance, revealed the significance of GCA and SCA variances for 1000-grain weight, although SCA estimates were of higher magnitude (Rao and Goud, 1977). In another study, Dabholkar *et al.* (1986) reported the importance of both additive and non-additive gene action for 1000-grain weight. While Govil and Murty (1980) revealed the presence of additive gene action for 1000-grain weight using 10 diverse sorghum lines and their 45 F_1 hybrids. On the other hand, Showemimo (1991)

reported non-additive gene action for 1000 grain weight in a 5 x 5 factorial mating design of 4 sets; with each set comprising of ten parental lines and thier 25 F_1 hybrids.

Although grain yield is a complex trait, Spivakov (1988) reported additive gene effect for this trait and GCA variance was found to be significant. In another study, Palanisamy and Subramanian (1986) showed the importance of GCA variance for this trait. Indi and Goud (1981) reported that grain yield was under non-additive gene influence and found over dominance effect for this trait. Tomeau *et al.* (1972) pointed out that additive and dominance gene effects were of comparable importance in controlling grain yield. Goyal and Joshi (1984) recorded dominance effect for grain yield. The findings of Desai *et al.* (1980), Desai and Kukadia (1985), Kimbeng (1990), Showemimo (1991), Showemimo and Nwasike (1996) also revealed the importance of non-additive gene action for grain yield.

2.5 HERITABILITY AND GENETIC ADVANCE

There is a lot of scope for genetic studies on inheritance of morphological traits or factors of resistance to insects, especially head bugs in sorghum, but little or no information is available. In related research on other major insect pests of sorghum, resistance to shoot fly, sorghum midge and spotted stem borer was quantitatively inherited (Rana and Murty, 1971; Indra *et al.*, 1972; Widstorn *et al.*, 1984; Agrawal *et al.*, 1988; Nimbalakar and Bapat, 1992). High broad sense

heritability (52-82%) for resistance to sorghum shoot fly has been reported (Sharma *et al.*, 1977). High broad sense heritability and genetic advance for glossy leaf in shoot fly resistance in sorghum was reported by Jeewad (1993).

In non-insect resistance studies, Spivakov (1988) reported that grain yield and yield component showed high heritability estimates. In another study, narrow-sense heritability estimate was found to be 90% for 1000-grain weight and up to 76% for head length (Jan-Orn, 1973). High narrow-sense heritability estimates were obtained for 1000 grain weight and very low for grain yield (Kimbeng, 1990; Showemimo, 1991).

Abu-el-Gasim and Kambal (1975) reported genetic advance expectations from selecting the top 5% of a sorghum population. They obtained 65.5% for 1000 grain weight and 92.8% for grain yield per plant. Obilana and El-Rouby (1980) reported a gain of 38.4% and 40.4% for grain yield in B composite and Y composite, respectively, with 5% selection intensity. Lukhele and Obilana (1984) reported an expected increase of 3.33 cm, 2.82 heads, 1.92 gm and 25.57 grains for plant height,head number, 1000-grain weight and number of grains per head, respectively, using 10% selection intensity. Improvement in grain yield through selection of the best 10% of F_2 to F_4 derived lines in wheat out yielded random selection by 19 to 53% for one cross and 5 to 23% for the second cross. However, the responses to

selection in the derived lines were better than those from random selection (Whan *et al.*, 1982).

2.6 SOURCES, MECHANISM AND MODE OF RESISTANCE IN SORGHUM TO *E.oldi*. Poppius.

The International Sorghum Head Bug Nurseries (ISHBN) of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Asia Centre, India, consist of sorghum lines that have been screened under natural and artificial head bug infestation. Some of these lines have been found to be highly resistant while others are moderately resistant under different environments and levels of infestation (Sharma and Lopez, 1992). Thirty one head bug resistant varieties (HBVS) from ICRISAT, Asia Centre India, including selected entries from 1989 and 1990 ISHBN lines were evaluated at Bagauda, Kano, Nigeria, under natural and artificial head bug infestations. In the latter case, the head cage technique developed by Sharma *et al.* (1992) was used. From these nurseries, some resistant lines and varieties had been identified, namely: Malisor 84-7, IS 20368, IS 17645, IS 17610, IS 20747, IS 20638, etc. (Sharma *et al.*, 1992; 1994; Ratnadass and Ajayi, 1995; Ajayi, 1996, 1997).

Non-preference feeding is one of the components of resistance to head bugs. The lines, IS 20740, IS 20368, IS 17645, IS 23748 and Malisor 84-7 have been found to habour fewer head bugs. Damage rating under natural infestation varied from 1.2 to 2.1, and under

artificial infestation, damage rating varied from 1.7 to 3.2, while 1000-grain weight varied between 15.7 and 22.6g. Similarly, their floaters percentage ranged between 41 and 63.4% while germination percentage varied between 30 and 77% (Sharma and Lopez, 1990; Sharma *et al.*, 1994; Ratnadass *et al.*, 1995a; Ajayi, 1996, 1997). Days to glume opening, longer glume, hard corneous grains, low water: carbohydrate ratio in the grain, faster grain filling, and quicker ripening contribute towards resistance (Toure *et al.*, 1992; Sharma *et al.*, 1994). Head bug resistance in Malisor 84-7 seems to be related to endosperm hardening rather than free phenolic compounds or tanin content, and it was suggested that grain hardening was due to the endosperm rather than the pericarp (Fliedel *et al.*, 1993).

There are limited documented studies on the mode of inheritance of resistance to *E.oldi*. However, in a report by Ratnadass *et al.* (1995a), the mode of inheritance in Malisor 84-7 was found to be recessive in nature, without maternal effects. Factors that govern the inheritance of resistance are apparently related to endosperm characteristics. The genetics followed the classical rules of diploidy and it was also reported that the hardening pattern of the endosperm could be controlled by diploid cells of the plant rather than triploid cells (Fliedel *et al.*, 1993; Sharma *et al.*, 1995; Ratnadass *et al.*, 1995a).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Plant materials used

Three resistant and three susceptible cultivars were used in 1995 to make crosses by hand emasculation. The resistant cultivars were used as male parents while the susceptible once were used as females. Factorial mating design was used to produce 9 F_1 hybrids. The mating design corresponded to the North Carolina Design II of Comstock and Robinson (1952) which was used in the analysis of the data obtained. The description of the parental materials is presented in Table 1.

3.2 Experimental Layout:

Crosses were made in 1995 growing season in the Research Farm of the Institute for Agricultural Research, Samaru, Zaria. Three resistant and three susceptible parents were crossed in a factorial mating system to produce 9 F_1 hybrids by hand emasculation (Table 2). A total of 9 F_1 populations were produced with a minimum of 100 seeds per hybrid. The seeds of each hybrid were preserved in an air tight drum containing a tablet of Phostoxin till 1995 irrigation season. During the 1995 irrigation season, about half of each F_1 hybrid seeds were sown and advanced to F_2 generations by selfing. The F_2 seeds were planted 2 to 3 weeks after infestor rows were planted in the 1996 raining season. Selection of resistant lines was done at the F_2 generation since maximum segregation is observed at the F_2 generation. Screening and selection were done by artificially infesting

each sorghum head at 50% flowering or half anthesis stage with 10 pairs of *E.oldi* (Poppius) adults using the "No choice" method of head cages as recommended by Sharma *et al.* (1992) (Appendices 2). The selection criteria were based on desired resistance traits (See section 3.3 under observations).

Table 1: **Description of Parents**

Parent	New Code	Origin	Agronomic Characteristics	Reaction to *E.oldi* (Poppius)
IS 17610	HRhb 94001	ICRISAT	Tall (3.0m) medium to late maturing, cream coloured grains with loose head and over 60% glume coverage.	Resistant (R_1)
IS 20368	HRhb 94002	ICRISAT	Medium height (1.85m), slender stalk, medium maturing, cream coloured grains with semi-compact head and about 70% glume coverage.	Resistant (R_2)
Malisor 84 - 7	HRhb 94003	Inst. d'Economie Rurale, (IER) Bamako Mali.	Medium maturing semi-dwarf, slender stalk, cream grain colour with loose head and over 80% glume coverage.	Resistant (R_3)
SAMSORG 3 (KSV4)	HRhb 94001S	Inst. for Agric. Res. (IAR), Samaru, Nigeria.	Early maturing semi-dwarf, medium height, cream coloured grain semi-compact head, high yielding with about 50% glume coverage.	Susceptible (S_1)
Nagawhite	HRhb 94002S	Ghana	Medium maturing, tall with semi-compact head, white, bold and large grains, high yielding, less than 50% glume coverage.	Susceptible (S_2)
ICSV112	HRhb 94003S	ICRISAT	Late maturing, medium height, compact head with cream coloured grains.	Susceptible (S_3)

Table 2: Cross Combinations

Female	Male		
	R_1	R_2	R_3
S_1	S_1R_1	S_1R_2	S_1R_3
S_2	S_2R_1	S_2R_2	S_2R_3
S_3	S_3R_1	S_3R_2	S_3R_3

Adult head bugs were collected in a transparent polyethylene bag from sorghum panicles at soft to hard dough stage from the infestor rows by covering each panicle with a polyethylene bag, slanting a bit carefully not to break the stalk, then tapping the panicle to collect the head bugs. Male and female adult head bugs were then separated (Appendix I). Ten pairs of adult head bugs (i.e. male and female) were released into each cage of the test materials and the cage cloth was tied (Appendix II). After 20 days of infestation, cotton wool was soaked in chloroform, and placed in the polyethylene bags. The bags were then used to cover the head cages and panicles for about 10 minutes to immobilize the insects. The total number of head bugs in each head cage was counted.

A minimum of 250 plants were screened per population. The best 10% of the F_2 resistant lines were advanced to F_3 in the 1996 irrigation season, on a head per row basis. The 25 F_3 lines from the 9 crosses were advanced to F_4 generations during the 1997 raining season and evaluated along with the 6 parents, 9 F_1s, 9 F_2s and 25 F_3 lines. Therefore, six parents, 9 F_1s, 9 F_2s, 25 F_3 and 25 F_4 lines were evaluated by artificially introducing 10 pairs of *E.oldi* (Poppius) per panicle under no choice condition in the 1997 rainy season.

The experimental design was randomized complete block design with three replications. The plot size was 2 rows each, 5m long with 0.75m and 0.25m inter and intra row spacings, respectively. Five seeds/hill were planted and later thinned

down to two seedlings per stand two weeks after sowing, during which missing hills were compensated for, by transplanting to give a population of 40 plants per row, resulting in 88,888 plants per hectare.

Prior to ridging and sowing, 32kg/ha of P_2O_5 as single superphosphate fertilizer was applied as basal dressing. Split application of nitrogen fertilizer (urea) was done. The first 32kg/ha was basal, while 30kg/ha was applied, 3 weeks after thinning as top dressing. A mixture of gramoxone and sorghoprim A was sprayed as pre-emergence herbicide. Weeds were controlled afterwards by hoe weeding at 3 weeks and 6 weeks after sowing. Vertox 85 was sprayed to control stem borer.

3.3 Observations

Data were collected on 5 randomly selected plants and the following measurements were made:

1. Head bug count: Total number of *E.oldi* on 5 panicles was counted.
2. Grain damage rating: Head bug damage rating was evaluated at maturity on a 1 - 9 scale (Sharma *et al.*, 1992) in which:

   1 = All grains fully developed with a few feeding punctures;

   2 = Grains fully developed, with feeding punctures;

   3 = Grains showing slight tanning or browning;

   4 = Most grains with feeding punctures and a few showing slight shriveling;

5 = Grains showing slight shriveling and browning;

6 = Grains showing more than 50% shriveling and turning brown or tanned;

7 = Most of the grains highly shriveled with dark brown colouration;

8 = Grains highly shriveled and slightly visible outside the glumes; and

9 = Most of the grains highly shriveled and slightly visible outside the glume.

3. 1000-grain weight (g): The weight of 1000 grains from the 5 randomly tagged, caged and infested panicles in each replication after threshing measured to the nearest 0.1 g.

4. Floaters percentage (%): 1000 grains from the infested panicles in each replication were counted. Moisture content overnight (12hrs) was equilibrated at 37^{0}C. Sodium nitrate solution was prepared to a specific density of 1.31 in a 500ml beaker. The 1000 grain sample was placed in the beaker containing the sodium nitrate solution. Number of grains floating on the surface was counted and expressed as a percentage of the total number of grains.

5. Germination percentage (%): 100 grains were counted from the infested panicles and placed in a water-soaked filter paper in a Petri dish at room temperature in the laboratory. Grains with radicle and plumule emergence after 72hrs were counted and expressed as a percentage of the total number of grains.

6. Grain yield (kg/ha): The weight of threshed grains in kg/ha was recorded.

3.4 Pedigree of the F_3 and F_4 lines:

Each of the F_3 lines that were advanced to F_4 generations were code named based on the year the crosses were made, the order of the cross (which eventually points to their parents) and the selected resistant line. e.g. HRhb 95001-4 as in Table 10.

HR:- Host Resistance

hb:- Head bug (*E.oldi*)

95:- 1995 the year the crosses were made

001:- The first cross made.

-4 (dash 4):- Selected resistant line from the best 10% lines.

3.5 Statistical Analysis:

A randomized complete block design with three replications was used. The statistical model used for the analysis of variance (ANOVA) and expected mean square (EMS) was based on the following linear model:

$Y_{ijk} = \mu + M_i + F_j + (M \times F)_{ij} + R_k + E_{ijk}$ (Singh and Chaudhary, 1985).

Where:

Y_{ijk} is the kth observation on i x j^{th} progeny;

μ is the general mean;

M_i is the effect of ith male;

F_j is the effect of jth female;

$(M \times F)_{ij}$ is the interaction effect;

R_k is the effect of kth replication and

E_{ijk} is the error associated with each observation.

Therefore, the analysis of variance was as follows (Table 3- 7):

Table 3: Form of the analysis of variance and expected mean squares.

Source of Variation	*Degree of freedom (D.F)*	*Mean Squares (MS)*	*Expected Mean Squares (EMS)*
Replications	(r-1) = 2	MS_r	
Males	(m-1) = 2	MS_m	$\sigma^2_e + r\sigma^2_{mf} + rf\sigma^2_m$
Females	(f-1) = 2	MS_f	$\sigma^2_e + r\sigma^2_{mf} + rm\sigma^2_e$
Males x Females	(m-1)(f-1) = 4	MS_{mf}	$\sigma^2_e + r\sigma^2_{mf}$
Error	(mf-1)(r-1) = 16	MS_e	σ^2_e
Total mfr-1	26		

Table 4: Form of the analysis of variance for the non-segregating populations

Source of variation	D.F	MS
Replications	(r-1) = 2	MS_r
Entries	(e-1) = 14	MS_{en}
Parents	(p-1) = 5	MS_p
Hybrids	(h-1) = 8	MS_h
Parents vs Hybrids	(n-1) = 1	MS_n
Error (r-1)	(r-1)(e-1) = 28	MS_e

Table 5: Form of the analysis of variance for the F_2 Populations

Source of variation	(D.F)	MS	EMS
Replications	(r-1) = 2	MS_r	
Entries	(e-1) = 11	MS_{en}	
Resistant Parents	(Pa-1) = 2	MS_{pa}	
F_2 Populations	(Po-1) = 8	MS_{po}	$\sigma^2_e + r\sigma^2_{po}$
P_a vs P_o	(a-1) = 1	MS_a	
Error	(r-1)(e-1) = 22	MS_e	σ^2_e

Table 6: Form of the analysis of variance for F_3 lines.

Source of variation	d.f	MS	EMS
Replication	(r-1) = 2	MS_r	
Entries	(e-1) = 27	MS_{en}	
Resistant Parents	(Pa-1) = 2	MS_{pa}	
F_3 lines	(Po-1) = 24	MS_{po}	$\sigma^2_e + \sigma^2_{po}$
P_a vs P_o	(a-1) = 1	MS_a	
Error	(r-1)(e-1) = 54	MS_e	σ^2_e

Table 7: Form of the analysis of variance for the F_4 lines.

Source of variation	D.F	MS	EMS
Replication	(r-1) = 2	MS_r	
Entries	(e-1) = 27	MS_{en}	
Resistant Parents	(Pa-1) = 2	MS_{pa}	
F_4 lines	(Po-1) = 24	MS_{po}	$\sigma^2_e + r\sigma^2_{po}$
P_a vs P_o	(a-1) = 1	MS_a	
Error	(r-1)(e-1) = 54	MS_e	σ^2_e

In this analysis, males and females express the general combining ability (Tables 3 and 4) while males x females interaction expresses the specific combining ability. The genetic component of variance was estimated using the expected mean squares according to Kempthorne (1957) as used by Singh and Chaudhary (1985):

$$\sigma^2 m = \frac{Ms_m - Ms_{mxf}}{rf} = Cov\ H.S(males) = \frac{1}{4}\sigma^2_A = \sigma^2_{g\ c\ a.m}$$

$$\sigma^2_f = \frac{Ms_f - Ms_{mxf}}{rm} = Cov\ H.S(females)\ \ \frac{1}{4}\sigma^2_A = \sigma^2_{g\ c\ a.f}$$

$$\sigma^2_{mxf} = \frac{Ms_{mxf} - Ms_e}{r} = Cov(f.s) - 2Cov(H.S) = \frac{1}{4}\sigma^2_D = \sigma^2_{s\ c\ a}$$

$$N.B:\ \sigma^2_m = \sigma^{2\sim}_f = \frac{1}{4}\sigma^2_A;\ \ \sigma^2_m + \sigma^2_f = \frac{1}{2}\sigma^2_A;\ \ \sigma^2_{mxf} = \frac{1}{4}\sigma^2_D;$$

$$\sigma^2_m + \sigma^2_f + \sigma^2_{mxf} = \sigma^2_G \ assuming\ no\ epistasis$$

$$\therefore\ \sigma^2_A = 4\sigma^2_m = 4\sigma^2_f;\ \ \sigma^2_D = 4\sigma^2_{mxf}$$

Where;

MS_m = Mean square males

MS_f = Mean Square females

MS_{mxf} = Males x Females interaction mean square

MS_e = Error Mean Square

r = Number of replications; r = 3

m = Number of males, m = 3

f = Number of females, f = 3

A = Additive gene effect

D = Dominance gene effect

G = Genotypic variance

The average additive genetic variance ($\sigma^2_A{}'$) was estimated thus:

$$\sigma^2_A{}' = \text{Cov(H.S) Average} = \frac{1}{r\,(2mf-m-f)} \left[\frac{(F-1)MS_f + (M-1)MS_m}{(m+f-2)} \right] - MS_{mxf}$$

Narrow sense heritability was estimated using Grafius *et al.* (1952) formula as used by Showemimo (1991):

$$h^2 = \frac{\sigma^2_f + \sigma^2_m}{\sigma^2_f + \sigma^2_m + \sigma^2_{mxf} + \sigma^2_{e/r}}$$

Where;

h^2 = Heritability estimates

σ^2_f = Female component of genetic variance

σ^2_m = Male component of genetic variance

σ^2_{mxf} = Male x Female interaction genetic variance

σ^2_e = Error variance

r = Replication

Narrow sense heritability estimates for derived lines of progenies were estimated using the expected means square, was calculated using Frey and Horner (1955) formula as recommended by Obilana and Fakorede (1981):

$$h^2 = \frac{\sigma^2_s}{\sigma^2_s + \sigma^2_{e/r}}$$

Where;

h^2 = Heritability estimate

σ^2_s = Selected lines component of genetic variance (σ^2P_o in Tables 5, 6 and 7)

σ^2_e = Error variance

r = Number of replications

Genetic advance (ΔG) was estimated using the method proposed by Obilana and Fakorede (1981); Singh and Chaudhary (1985):

$$\Delta G = K.\sigma_{ph}H$$

Where;

ΔG = Expected or predicted genetic gain from selection

K = Selection intensity = 10% in this study, i.e. K = 1.75 and

H = Heritability estimates of the selected lines or progenies.

Finally, significant differences between the means of resistance and susceptible parents, F_1 hybrids, F_2 populations, F_3 lines and F_4 lines to *Eurystylus oldi* were estimated by the Duncan's New Multiple Range Test (DNMRT) as described by Obi (1986).

CHAPTER FOUR

RESULTS

Mean performances, grand means, standard errors and coefficient of variations of parents and their F_1 hybrids for the six traits studied are presented in Tables 8a and 8b. The results indicated definite differential reactions between the resistant and susceptible parents to *E.oldi* infestation. The differences as measured by Duncan's New Multiple Range Test (DNMRT) were significant. The resistant parents had fewer *E.oldi*, lower damage rating, and floaters percentage compared to the susceptible parents. The highest germination percentage (95.3%) and heaviest 1000-grain weight (19.60g) were recorded for the resistant parent HRhb 94001 (R_1). However, the grain yield for both resistant and susceptible parents were not statistically different. The highest coefficient of variation (CV) was recorded for grain yield (23.30%) while the lowest was 4.8% for germination percentage for the parents. The lowest standard error (SE $\pm$) for the parents was obtained for damage rating ($\pm$ 0.29), and the highest ($\pm$ 139.20) was obtained for grain yield. The grand mean for the number of *E.oldi* (365), damage rating (3.24) and floaters percentage (77.9%) of F_1 hybrids were lower than those for their parents, while the grand mean for grain yield, 1000-grain weight and germination percentage were higher for F_1 hybrids than for their parents. The F_1 hybrids had coefficient of variations for grain yield, 1000-grain weight and germination percentage of 17.0%, 10.50% and 3.90%, respectively which were lower than those for their parents.

Table 8a: Mean performance of parents for all traits measured

Generations	Number of head bugs/5 panicles	Damage Rating[1]	Floaters Percentage	Germination percentage	1000 grain weight (g)	Grain yield (kg/ha)
Parents						
1. Resistant R^2_1 (HRhb 94001)	217b[3]	1.7d	66.8c	95.3a	19.60a	817a
2. Resistant R_2 (HRhb 94002)	218b	2.5cd	72.8bc	80.0b	15.97b	808a
3. Resistant R_3 (HRhb 94003)	221b	3.2c	82.5ab	84.7b	15.27b	686a
1. Susceptible S_1 (HRhb 94001S)	920a	5.2b	97.9a	65.0c	9.30c	716a
2. Susceptible S_2 (HRhb 94002S)	961a	6.5b	91.1a	55.3d	8.97c	694a
3. Susceptible S_3 (HRhb 94003S)	900a	6.7a	98.7a	51.3d	8.93c	664a
Grand mean	573	4.3	85.0	71.9	13.01	731
Standard Error (SE $\pm$)	51.8	0.29	5.59	2.8	1.43	139.20
Coefficient of Variation (CV%)	11.1	8.30	8.10	4.8	13.5	23.30

1. On a scale of 1 - 9 where 1 = no head bug damage and 9 = severe head bug damage.
2. Code R_1, R_2 and R_3, S_1, S_2 and S_3 see table 1 and 2
3. Means followed by the same letters within each column are not significantly different at the 0.05 level of probability as determined by Duncan's New Multiple Range Test (DNMRT).

Table 8b: Mean performance of F_1 hybrids for all traits measured

Generation	Number of head bugs/5 panicles	Damage Rating[1]	Floaters Percentage	Germination percentage	1000 grain weight (g)	Grain yield (kg/ha)
F_1 hybrids						
1. $S_1 \times R_1$[2]	610a	1.8c	76.6ab	95.7a	21.30a	1261a
2. $S_2 \times R_1$	244cd	1.4c	88.7a	97.7a	19.43a	723cd
3. $S_3 \times R_1$	454b	5.9a	95.5a	83.3b	16.77ab	738cd
4. $S_1 \times R_2$	318bc	3.6b	88.2a	94.0a	21.20a	983b
5. $S_2 \times R_2$	350bc	2.3bc	71.5b	93.3a	14.80b	793bc
6. $S_3 \times R_2$	267bc	3.2b	90.2a	86.3ab	20.20a	901b
7. $S_1 \times R_3$	330bc	2.2c	29.6d	94.3a	20.33a	913b
8. $S_2 \times R_3$	180d	2.3bc	62.7bc	96.7a	16.17ab	754bc
9. $S_3 \times R_3$	533a	6.0a	98.3a	65.7c	12.30c	625bc
Grand mean	365	3.24	77.9	89.7	18.06	855
Standard Error (SE ±)	75.4	0.48	6.59	2.87	1.55	118
CV (%)	25.30	18.20	10.40	3.90	10.50	17.0

1. On a scale of 1 - 9 where 1 = no head bug damage and 9 = severe head bug damage.
2. Code R_1, R_2 and R_3, S_1, S_2 and S_3 see table 1 and 2
3. Means followed by the same letters within each column are not significantly different at the 0.05 level of probability as determined by Duncan's New Multiple Range Test (DNMRT).

The mean performance of the F_2 generation for all the traits studied is presented in Table 9. Distinct differential reaction to *E.oldi* infestation was obtained. The cross S_3 x R_2 (HRhb 94003S x HRhb 94002) had the highest number (950) of *E.oldi* with a high floaters percentage (91.4%), and a reasonable grain yield of 982kg/ha. The cross S_1 x R_1 (HRhb 94001S x HRhb 94001) had the highest grain yield (1164kg/ha), high 1000-grain weight (20.60g), the highest germination percentage (97.7%), few *E.oldi* (281), and low grain damage rating (1.8). The lowest coefficient of variation (C.V. %) was 4.2% for germination percentage and highest 15.9% for grain yield in F_2 generations. Comparatively, grand mean, standard error of a mean, and coefficient of variation in F_2 generation are higher than F_1 hybrid for germination percentage only (Tables 8 and 9).

The mean performances of F_3 and F_4 lines are shown in Tables 10 and 11, respectively. Slight significant differences occurred among the 25 F_3 lines and among the 25 F_4 lines. In Table 10, the HRhb 95001-4, HRhb 95004-1, HRhb 95003-1, HRhb 95004-4 and HRhb 95002-9 performed better for the six traits of resistance to *E.oldi*. The HRhb 95009-13 was the poorest with 810 *E.oldi*/5 panicles, grain damage rating of 6.5, and 99.3% floaters percentage which were all above their grand mean. Also, germination percentage (69.3%), 1000-grain weight 14.17g and grain yield 531.0kg/ha were low.

Table 9: Mean performance of F_2 generations for all traits measured

F_2 Population	Number of head bugs/5 panicles	Damage Rating[1]	Floaters percentage	Germination percentage	1000 grain weight (g)	Grain yield (kg/ha)
1. $S_1 \times R_1$	281de[2]	1.8cd	86.9a	97.67a	20.60a	1164a
2. $S_2 \times R_1$	505b	2.4c	94.5a	93.67a	18.83a	718bc
3. $S_3 \times R_1$	617b	5.1b	98.6a	83.00c	15.23ab	680cd
4. $S_1 \times R_2$	435c	2.2c	89.1a	91.33a	20.70a	1031a
5. $S_2 \times R_2$	278e	2.1c	78.1ab	95.67a	17.23ab	801ab
6. $S_3 \times R_2$	950a	4.8b	91.4a	91.67a	18.10a	982a
7. $S_1 \times R_3$	619b	1.5d	69.2bc	96.67a	20.77a	894ab
8. $S_2 \times R_3$	389cd	1.3d	59.3c	94.67a	16.10ab	630cd
9. $S_3 \times R_3$	597b	5.8a	97.7a	74.33d	12.47c	613d
Grand mean	519	3.00	85.0	90.96ab	17.78	835
SE $\pm$	52.9	0.30	5.38	3.13	1.31	108.1
CV%	12.5	12.2	7.8	4.2	9.0	15.9

1. On a scale of 1 - 9 where 1 = no head bug damage and 9 = severe head bug damage.

2. Means followed by the same letters within each column are not significantly different at the 0.05 level of probability as determined by Duncan's New Multiple Range Test.

Table 10: Mean performance of F_3 lines for all traits measured.

F_3 line	Number of head bug/5 panicles	Damage Rating[1]	Floaters percentage	Germination percentage	1000 grain weight (g)	Grain yield (kg/ha)
*HRhb 95001 - 4	288e	2.7de	53.0d	95.7a	20.10a	984.00a
HRhb 95001 - 7	239f	5.4ab	72.0c	98.0a	14.03c	708.3bc
HRhb 95001 - 12	329e	3.1d	84.8ab	91.3a	15.23bc	673.0c
HRhb 95002 - 1	264ef	2.2e	63.4d	96.0a	16.23bc	667.7c
HRHb 95002 - 7	260ef	2.0e	62.4d	97.3a	17.80ab	772.7b
HRhb 95002 - 9	249ef	2.3e	39.3f	93.0a	19.03a	888.7a
HRhb 95002 - 11	271e	2.9de	94.9a	91.3a	15.30bc	585.0cde
HRhb 95003 - 1	389d	5.1b	59.4d	91.3a	19.03a	920.3a
HRhb 95003 - 6	459c	4.6b	92.9a	91.0a	10.47bc	826.0ab
HRhb 95003 - 12	614b	4.5bc	98.6a	70.3c	11.57cd	518.0de
HRhb 95003 - 16	509bc	6.0a	6.0a	61.3cd	12.00bc	506.7de
HRhb 95004 - 1	282e	2.2e	95.5a	91.0a	22.00a	996.3a
HRhb 95004 - 4	465c	2.8de	88.1abb	88.7a	19.70a	898.3a
HRhb 95005 - 2	403cd	2.1e	87.0ab	97.0a	15.77bc	657.3cd
HRhb 95005 - 3	265ef	2.5de	93.4a	93.0a	17.47ab	633.0cd
HRhb 95005 - 4	302e	1.9e	63.5cd	97.3a	19.47a	828.7ab
HRhb 95006 - 4	333de	4.2bc	95.1a	47.0e	10.07de	545.7d
HRhb 95006 - 5	250ef	4.0bc	97.0a	63.7cd	17.37ab	707.7b
HRhb 95007 - 1	298e	1.6e	82.4b	74.3c	9.37e	522.3d
HRhb 95007 - 4	551b	2.2e	93.8a	96.7a	19.37a	800.0ab
HRhb 95008 - 5	247ef	3.6cd	73.2c	85.7ab	17.10ab	758.ob
HRhb 95008 - 10	321e	2.2b	83.7b	86.3ab	18.27a	881.0a
HRhb 95009 - 12	324e	5.0b	93.7a	88.3a	12.67b	696.01c
HRhb 95009 - 13	810a	6.5a	99.3a	69.3c	14.17b	531.0d
HRhb 95009 - 21	303e	6.4a	98.9a	57.0d	8.90e	476.3e
Grand mean	361	3.5	82.6	83.8	16.25	719.4
SE ±	22.80	0.35	3.5	4.45	1.67	55.97
CV (%)	7.7	12.1	5.2	6.5	12.6	9.5

* HRhb 95001 - 4: HR - Host Resistant; hb - head bug; 95-1995 the year crosses were made; 001 - the first cross and - 1 (dash one) - selected resistant line.

1. On a scale of 1 - 9 where 1 = no head bug damage and 9 = severe head bug damage. Means within column followed by the same letter(s) are not significantly different at 5% level of probability as determined by Duncan's New Multiple Range Test.

Table 11: Mean Performance of F_4 lines for all traits Measured.

F_4 line	Number of head bugs/5 panicles	Damage rating[1]	Floaters percentage	Germination Percentage	1000 grain weight (g)	Grain yield (kg/ha)
HRhb 95001 - 4	289bcd	2.5cd	58.8d	92.3a	19.63a	1007.0a
HRhb 95001 - 7	271cd	3.2c	80.2c	97.7a	16.77bc	704.3b
HRhb 95001 - 12	254cd	3.0c	47.7e	93.7a	15.43c	675.3b
HRhb 95002 - 1	260cd	2.4d	64.2d	90.0a	17.33bc	670.7b
HRhb 95002 - 7	274cd	1.5e	82.3c	95.7a	18.13b	705.7b
HRhb 95002 - 9	270cd	3.1c	55.3de	98.3a	16.17bc	890.0a
HRhb 95002 - 11	272cd	2.4d	93.8a	92.7a	17.13bc	571.7c
HRhb 95003 - 1	276cd	3.1c	91.3ab	91.7a	19.17a	848.7ab
HRhb 95003 - 6	335bc	4.5ab	81.6c	92.0a	17.17bc	714.0b
HRhb 95003 - 12	416bc	3.2c	92.4a	75.3bc	16.23c	548.3c
HRhb 95003 - 16	520b	5.0a	98.8a	66.7c	12.07d	557.7c
HRhb 95004 - 1	433b	2.1d	73.8cd	76.0bc	22.57a	967.3a
HRhb 95004 - 4	474b	2.2d	65.4d	89.7a	18.13b	928.7a
HRhb 95005 - 2	442b	3.2c	94.0a	92.0a	15.27c	633.3bc
HRhb 95005 - 3	226d	3.2c	83.8c	96.7a	17.53bc	632.7bc
HRhb 95005 - 4	320c	1.5e	91.9ab	97.0a	18.13b	829.0ab
HRhb 95006 - 4	318c	1.6de	97.3a	66.0c	12.93cd	527.3c
HRhb 95006 - 5	357bc	2.5cd	96.3a	84.0ab	16.43be	736.0b
HRhb 95007 - 1	258cd	2.2d	88.4abc	74.7bc	14.73c	477.3d
HRhb 95007 - 4	221d	1.4e	98.0a	76.3a	21.73a	871.0ab
HRhb 95008 - 5	270cd	3.5c	66.7d	83.7ab	18.13bc	766.3b
HRhb 95008 - 10	744a	2.5cd	95.2a	73.3c	15.33c	884.7a
HRhb 95009 - 12	266cd	4.4b	99.3a	85.0ab	12.17d	628.0bc
HRhb 95009 - 13	338bc	4.7ab	96.7a	70.0c	10.70de	562.0c
HRhb 95009 - 21	254cd	5.6a	99.4a	54.0d	8.97e	488.3cd
Grand mean	334	3.1	84.9	85.0	16.32	713.1
SE $\pm$	37.55	0.26	2.74	4.71	1.55	49.3
CV (%)	13.8	10.2	3.9	6.8	11.7	8.5

1. On a scale of 1 - 9, where 1 = no head bug damage and 9 = severe head bug damage. Means within the same colum followed by the same letter(s) are not significantly different at 5% level of probability as determined by Duncans New Multiple Range Test.

The best line out of the 25 F_4 lines for the six traits was HRhb 95001-4 which had the lowest *E.oldi* population (289/5 panicles), grain damage rating of 2.5, floaters percentage of 58.8%, while germination percentage of 92.3%, 1000-grain weight of 19.63g, and grain yield of 1007kg/ha were all high, (Table 11). The grand mean, standard error and coefficient of variation (C.V. %) for both F_3 and F_4 lines were lower than those of F_2 generations, F_1 hybrids and their parents.

The analysis of variance for non-segregating populations, segregating populations of F_2 generations and resistant parents; F_3 lines and resistant parents; F_4 lines and resistant parents are presented in Tables 12a and 12b, 13, 14 and 15, respectively. The resuts in Table 12a, show highly significant effects ($P = 0.01$) among all entries and crosses for all the traits. The parents revealed highly significant effects ($P = 0.01$) for all traits except for grain yield. The males and females showed highly significant effects ($P = 0.01$) for grain damage rating and germination percentage, while the males also shoed significant effects ($P = 0.05$) for 1000-grain weight. The males x females interaction was highly significant ($P = 0.01$) for grain damage rating and germination percentage but significant ($P = 0.05$) for floaters percentage (Table 12b). The parents versus (vs) crosses and males vs females were highly significant ($P = 0.01$) for all the traits except grain yield. The parents vs crosses differed significantly ($P = 0.05$) for grain yield.

Table 12a: Analysis of variance showing degrees (d.f) of freedom and mean squares for non segregating populations for all traits measured.

Source of variation	d.f	Mean Squares					
		Number of head bugs/5 panicles	Grain damage Rating	Floaters percentage	Germination percentage	1000-grain weight (g)	Grain yield (kg/ha)
Replications	2	52264**	0.57	262.15*	20.82	11.76	5121
Entries	14	228886**	10.67**	1019.97**	746.50**	59.32**	77446**
Parents (P)	5	452831**	13.81**	525.48**	913.66**	62.40**	12897
F_1 hybrids (H)	8	59357**	8.54**	1389.57**	311.33**	30.40**	106793**
P vs H	1	465381**	12.03**	535.66**	3392.03**	275.43**	165416*
Error	28	6513	0.27	58.61	13.51	4.37	22907

*,** Significant at 5% and 1% level of probability, respectively.

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Table 12b: Analysis of variance showing degrees (d.f) of freedom and mean squares for non segregating populations of males and females for all traits measured.

Source of variation	d.f	Mean Squares					
		Number of head bugs/5 panicles	Grain damage Rating	Floaters percentage	Germination percentage	1000-grain weight (g)	Grain yield (kg/ha)
Replications	2	52264**	0.57	262.15*	20.82	11.76	5121
Males (M)	2	11	1.61**	188.54	185.33**	16.23*	16185
Females (F)	2	2983	1.93**	52.60	148.11**	0.12	2014
Males x Females	4	1220	1.21**	50.42*	103.21**	3.02	1961
M vs F	1	2258167**	62.0**	2145.13**	3901.40**	279.27**	28084
Error	16	4131	0.02	55.26	5.33	3.16	22867

*,** Significant at 5% and 1% level of probability, respectively.

The results in Table 13 shows highly significant effects (P = 0.01) among entries and F_2 populations for all the traits measured. The resistant parents showed highly significant effects (P=0.01) for all the traits except the number of *E.oldi* per 5 panicles and grain yield. The comparison between resistant parents and the F_2 generations (P_a vs P_o) showed highly significant effects for the number of *E.oldi*, grain damage rating, floaters percentage, and germination percentage. A Similar trend is shown in Table 14, where highly significant effects (P = 0.01) were recorded for all the traits measured among all entries and F_3 lines. Resistant parents showed highly significant effects (P = 0.01) for all traits except for the number of *E.oldi* and grain yield. The resistant parents compared to F_3 lines (P_a vs F_3 lines) differed significantly (P = 0.01) for the number of *E.old*, grain damage rating, and floaters percentage (Table 14). Similarly, the entries and F_4 lines showed highly significant effects (P = 0.01) for all the traits measured (Table 15). The resistant parents differed significantly (P=0.01) for grain damage rating, floaters percentage and germination percentage, and (P=0.05) for 1000-grain weight and grain yield. The resistant parents vs F_4 lines did not differ for germination percentage and 1000-grain weight, but differed significantly at P = 0.05 for grain yield, at P = 0.01 for the number of *E.oldi*, grain damage rating, and floaters percentage.

The estimate of male, female and males x females interaction component of variance is presented in Table 16. The male components of variance were larger in magnitude than the female components for all the traits except the number of *E.oldi* and grain damage rating. This further indicates the predominance of male variances over those for the females as already shown by their mean squares (Table 12). The males x females interaction components of variance were larger in magnitude than those of the males and females components for all the traits except floaters percentage and 1000-grain weight,

whereas the male component of variance was larger in magnitude than those of the females and males x females interaction components. The mean squares that were significantly different from zero should give significant estimates of genetic components of variance, since estimates of variance components are linear functions of their mean squares. Negative estimates of variance component were recorded for the number of *E.oldi* for males, and 1000-grain weight for females. Table 16 also shows the average additive (linear) gene effect (σ^2_A), which estimates the average general combining abilities (GCA), dominance gene effect (σ^2_D) which is quadratic and gives an estimate of specific combining ability (SCA), and the ratio of σ^2_A and σ^2_D that is σ^2_A/σ^2_D. There is a preponderance of dominance (σ^2_D) or non-additive gene effect over additive gene effect for all the traits measured (Table 16). This was evident from the large magnitude of σ^2_D compared to σ^2_A. It was further confirmed by the σ^2_A/σ^2_D ratio which was less than unity for all the traits studied as shown in Table 16.

Narrow-sense heritability estimates are also presented in Table 16. Narrow-sense heritability estimate of 47% was recorded for the number of *E.oldi*. High narrow-sense heritability estimate was recorded for 1000-grain weight, floaters percentage, germination percentage, grain damage rating and grain yield had heritability (narrow sense) estimates of (h^2) = 78.50%, 77.71%, 75.58%, 73.10% and 65.47%, respectively.

The narrow-sense heritability and expected genetic gain (ΔG), for F_2 generations, F_3 and F_4 lines for all the traits measured are presented in Table 17. High heritability estimates were recorded for all the traits measured at F_2 generations, F_3 lines and F_4 lines. The heritability estimate of the F_3 lines were higher than those of F_2 generation for all the traits measured except damage rating.

Table 13: Analysis of variance showing degrees (d.f) of freedom and mean squares for F_2 populations and resistant parents for all traits measured.

Source of variation	d.f	Mean squares					
		Number of head bugs /5 panicles	Grain damage rating	Floaters percentage	Germination percentage	1000-grain weight (g)	Grain yield (kg/ha)
Replications	2	12957	0.32	298.63**	27.03	0.57	75187*
Entries	11	150919**	7.11**	504.29**	170.81**	20.96**	87866**
Resistant Parents (P_a)	2	11	1.61**	188.54**	185.33**	16.23**	16185
Populations (P_o)	8	131292**	9.12**	545.33**	172.95**	24.17*8	113257**
P_a vs P_o	1	609752**	2.08**	807.43*8	124.59**	4.73	28097
Error	22	4133	0.10	49.00	14.66	2.80	13774

*, ** Significant at 5% and 1% level of probability, respectively.

Table 14: Analysis of variance showing degrees of freedom and mean squares for F_3 lines and resistant parents for all traits measured.

Source of variation	D.F	Mean Square					
		Number of head bugs /5 panicles	Damage rating	Floaters percentage	Germination percentage	1000 grain weight	Grain yield
Replications	2	7206**	0.24	168.90**	37.95	0.844	9472
Entries	27	57584**	6.65**	802.46**	590.86**	36.03**	67774**
Resistant Parents (P_a)	2	11	1.61**	188.54**	185.33**	16.23*	16185
F_3 Lines	24	57969.3**	6.95**	862.69**	646.60**	39.01**	74027**
P_a vs Lines	1	163485.9*	9.46**	584.72**	64.14	3.88	20879
Error	54	1209	0.17	25.79	27.75	4.07	5345

*, ** Significant at 5% and 1% level of probability respectively.

Table 15: Analysis of variance showing degrees of freedom and mean squares for F_4 lines and resistant parents for all traits measured

Source of variation	D.F	Mean Squares					
		Number of head bugs /5 panicles	Damage rating	Floaters percentage	Germination percentage	1000-grain weight	Grain yield
Replications	2	7723	0.01	170.38**	71.51	2.75	5254
Entries	27	40612**	4.18**	672.26**	407.99**	28.27**	66214**
Resistant Parents (P_a)	2	11	1.61**	188.54**	185.33**	16.23*	16185*
F_4 lines	24	41195**	4.42**	701.11**	442.58**	30.32**	72043**
P_a vs lines	1	107822**	3.43**	947.19**	23.03	3.133	26364*
Error	54	2377	0.01	19.00	31.30	3.66	4504

*, ** Significant at 5% and 1% level of proberbility respectively.

Table 16: Estimates of components of variance and narrow-sense heritability (%) for all traits measured.

Estimate	Number of head bugs/5 panicles	Grain damage rating	Floaters percentage	Germination percentage	1000-grain weight (g)	Grain yield (kg/ha)
σ^2_m	-134.333	0.044**	15.347	9.124**	1.468*	1580.444
σ^2_f	195.889	0.080**	0.242	4.989**	-o.322	5.889
σ^2_{mf}	1764.333	35.28**	2.73*	29.9**	0.45	6982
σ^2_A	10.472	0.016	1.949	1.764	0.227	198.291
σ^2_D	1764.333	35.28	2.73	29.9	0.45	6982
σ^2_A/σ^2_D	0.006	0.0005	0.714	0.059	0.504	0.028
h^2(ns)%	47.99	73.1	77.51	75.58	78.50	65.47

*, ** Significant at 5% and 1% level of probability respectively.

ns = narrow -sense, h^2 = heritability estimate.

Table 17: **Narrow - sense heritability estimates (%), expected genetic gain (ΔG) and percentage gain (in parentheses) for F_2 generations, F_3 lines, and F_4 lines for all traits measured.**

Generation	Traits											
	No of Head bugs/5 panicles		Grain damage rating		Floaters percentage		Germination percentage		1000-grain weight (g)		Grain weight (Kg/ha)	
	h^2(%)	ΔG	h^2(%)	ΔG	h^2(%)	ΔG	h^2(%)	ΔG	h^2(%)	ΔG	h^2(%)	ΔG
F_2 populations	98.96	627.50	99.64	5.27	97.09	49.64	97.25	22.38	96.28	8.28	96.10	565.97
F_3 lines	99.31	418.44	99.19	4.58	99.01	50.89	98.59	43.87	96.64	10.56	97.65	464.95
		(40.0%)		(46.5%)		(50.6%)		(66.2%)		(56.1%)		(45.1%)
F_4 lines	98.11	248.48	99.25	2.65	99.10	45.92	97.70	45.97	96.13	12.26	97.76	560.13
		(37.3%)		(36.7%)		(47.4%)		(51.2%)		(53.7%)		(54.6%)

h^2 = Narrow - sense heritability estimate
ΔG = Expected genetic gain.

The F_4 lines were slightly higher than F_3 lines for grain damage rating, floaters percentage and grain yield. Generally, the differences between narrow-sense heritability estimates of F_4 lines and F_3 lines for all the traits measured was less than 1, except for the number of *E.oldi*. The narrow-sense heritability estimates of F_2 generations was lower that those for F_3 lines and F_4 lines for all the traits except 1000-grain weight, grain damage rating and number of *E.oldi*.

The estimated or predicted genetic gain (ΔG) when the best 10% genotypes/lines were selected for resistance based on the six traits of *E.oldi* resistance are also presented in Table 17. The expected genetic gain from the F_2 generations to the F_3 lines and F_4 lines were quite different. A decrease in the number of *E.oldi* from 627.50 to 418.44 and 248.48 for F_2, F_3 and F_4, respectively; and grain damage rating of 5.27, 4.58 and 2.65, respectively; but an increase was recorded for floaters percentage (49.6%) from F_2 generation to F_3 lines of 50.6% and a decrease at F_4 lines of 45.9%. The germination percentage increase from 22.4% at F_2 generations to 43.9% at F_3 lines and 45.9% at F_4 lines. The 1000-grain weight increased from 8.3g at F_2 generations to 10.6g at F_3 lines to 12.3g at F_4 lines. There was a decrease in grain yield from 566.0kg/ha at the F_2 generations to 465.0kg/ha at F_3 lines, but a subsequent increase to 560.1kg/ha at F_4 lines. The comparison of F_4 lines vs F_3 lines, and F_3 lines vs F_2 generations is presented in percentages (Table 17) of their predictive genetic gain over the previous generation from which the selection was done. Genetic gains of 37.3%, 36.7% and 47.4% were recorded in F_4 lines from the F_3 lines for number of *E.oldi*, grain damage rating, and floaters percentage, respectively. Similarly, genetic gains of 40%, 46.5%, and 50.6% were recorded in F_3 lines compared to F_2 generations for number of *E.oldi*, grain damage rating, and floaters percentage, respectively.

An increase in genetic gains of 51.2%, 53.7%, and 54.6% occurred in F_4 lines over F_3 lines were recorded for germination percentage, 1000 grain weight and grain yield, respectively. The genetic gains in F_3 lines from F_2 generations were 66.2%, 56.1%, and 45.2% for germination percentage, 1000 grain weight and grain yield, respectively.

CHAPTER FIVE

DISCUSSION

The differential reaction of the parents showed a distinct response to *E.oldi* infestation, thus justifying their classification into resistant and susceptible cultivars. The resistant cultivars had fewer number of *E.oldi*, and the damage on these genotypes was low as indicated by the the low grain damage rating, the floaters percentage when compared to those recorded for susceptible genotypes. Their resistance was further confirmed by the high germination percentage, 1000-grain weight, and grain yield. The grain yields of the resistant parents were statistically the same with the susceptible parents. This is due to statistical limitation because a large experimental error was recorded and the C.V(%) was fairly high for this trait. However, statistical significance or non significance may not necessarily mean biological significance or non significance. Therefore, the statistical non-significant difference obtained from both resistant and susceptible parents for grain yield is not genetical, because the resistant parents performed better than the susceptible parents. It is evident in Table 8a, that the best resistant parent out yielded the best susceptible parent with over 100kg/ha of grain yield. The response of the F_1 hybrids to *E.oldi* infestation was not very distinct because they were non-segregating populations, thus, their reaction to *E.oldi* infestation could not be ascertained. Although, grain yield in the F_1 generations was better than in the F_2, F_3, and F_4 generations, this could be due to heterosis though not studied as part of the objectives of this research. The mean performance at the F_2 generations showed a distinct response to *E.oldi* infestation, mainly because the highest variability due to segregation is expected at this generation, a phenomenon which gives room for selection. The response to *E.oldi* infestation was not obvious at the F_3 and F_4 lines, although there was an appreciable percentage of segregation at these generations, especially at the F_3 generations. The low differential response observed at the F_3 and F_4

lines was mainly due to selection for resistance done at the F_2 generation. The low standard error and coefficient of variation obtained for F_3 and F_4 lines confirm the low response to *E.oldi* infestation. Similar observations were recorded by Beyo (1996) and Malgwi (1997) where they recorded low standard errors and coefficient of variations in evaluating *E.oldi* resistant cultivars. The lines HRhb 95001-4, HRhb 95004-1 and HRhb 95002-9 performed consistently well at the F_3 and F_4 generations as evidenced by their low number of *E.oldi*, grain damage rating, and floaters percentage, high germination percentage, heavier 1000-grain weight, and higher grain yield (Tables 10 and 11). Lines such as HRhb 95007-4, HRhb 95002-1, and HRhb 95002-7 performed fairly well at the F_3 and F_4 generation, while the worst genotypes for the six traits of resistance studied were HRhb 95009-21, HRhb 95009-13, and HRhb 95003-16. This is expected since an appreciable percentage of segregation still exists at the F_3 and F_4 generations.

The significant effects observed among entries and F_1 hybrids for all the traits (Table 12) indicated that an appreciable amount of genetic variation existed among them for the traits measured. Significant differences existed between the parents for all traits measured except grain yield thus confirming the non-significant response to *E.oldi* infestation in their mean grain yield (Table 8a and 8b). The highly significant values for male parents and female parents in (Table 12b) are responsible for the highly significant values obtained for their crosses. These results are in agreement with Jan-Orn (1973), Lukhele and Obilana (1984), and Showemimo and Nwasike (1996). These authors further stated that the amount of improvement that could be made through selection among the crosses depends on the amount of variation between the crosses and the intensity of selection applied. In this study, the F_2 generations, F_3, and F_4 lines differed significantly for all the traits measured (Tables 13, 14 and 15), thus confirming the existence of variability in the sorghum populations

subjected to *E.oldi* infestation. Similar variability in sorghum populations subjected to head bugs infestation had been reported (Ratnadass *et al.*, 1991; Sharma *et al.*, 1992; Sharma *et al.*, 1994; Ratnadass *et al.*, 1995; and Ajayi, 1997).

In Table 16 the male components were larger that the female components for all traits recorded except for number of *E.oldi* and grain damage rating. The preponderance of male components of variance over the female for floaters percentage, germination percentage, 1000-grain weight and grain yield implies that the male components of variance were more important in the expression of these traits in the hybrids. The female components of variance were, however more important in the expression of the number of *E.oldi* and grain damage rating in the hybrids. These results agree with those reported by Rana and Murty (1971), Palanisamy and Subramanian (1986), Spivakov (1988), and Sharma and Lopez (1991). Assuming, the absence of epistasis, the North Carolina mating design II of Comstock and Robinson (1952) makes it possible to calculate the estimates of genetic variances which indicate the presence of additive or non additive (dominance) variances for the traits measured. The partitioning of variance component estimates (Table 16) revealed the preponderance of dominance variance (σ^2_D) over the additive (σ^2_A) for all the traits measured, as evidenced by the σ^2_D values that were larger than those of σ^2_A. Therefore, dominance component of variance (σ^2_D) was genetically responsible for the expression of all the traits measured. The preponderance of dominance component of variance over the additive component was confirmed by the σ^2_A/σ^2_D ratio, where all the ratios obtained for the six traits were less than unity. Therefore, selecting superior plants types should be based on the dominance gene effect, since the degree of dominance was higher for total performance than for its individual component. The results obtained by Indra *et al.* (1972), Desai *et al.* (1980), Desai and Kukadia (1985), Kimbeng (1990), Nimbalkar and Bapat

(1992) in sorghum agree with those obtained in this study. Widstom *et al.* (1984) and Agrawal *et al.* (1988) obtained additive gene effect for the same traits in a study on sorghum midge resistance. Although, combining ability was not the focus of this study, however, from the component of variance, the specific combining ability assumes greater importance than general combining ability. Thus, selection procedures that give proper consideration to defined traits of *E.oldi* resistance become necessary.

Narrow-sense heritability measures the relative importance of the additive portion of the genetic variance that can be transmitted to the next generation of offspring. The moderate narrow-sense heritability estimate (h^2 = 47.00%) obtained for the number of *E.oldi* indicates that both additive and dominance gene effects control this trait. However, the high values of narrow-sense heritability estimate for the remaining traits (Table 16) indicate the presence of additive gene effects. Obilana and Fakorede (1981), in a critical review of heritability, stated that any trait that is strongly influenced by some environmental variations will have low heritability estimates; conversely, other traits that are not easily influenced by the environment or where the environments are controlled, the same traits will tend to have high heritability estimates. In related research on other major insect pests of sorghum, such as shoot fly, midge, and spotted stem borer, resistance traits are qualitatively inherited (Rana and Murty, 1971; Agrawal *et al.*, 1988; Nimbalkar and Bapat, 1992). Their findings agree with those reported in this study (Table 16 and 17). Similar reports on high heritability estimate in insect resistance breeding have been reported by Sharma *et al.* (1977) and Jeewad (1993) for sorghum shoot fly.

The reduction in the number of *E.oldi*, grain damage rating and floaters percentage from F_2 populations to F_3 lines and F_4 lines indicates that the fewer the number of *E.oldi*

the lower the damage rating and floaters percentage in any genotype or line and the easier their predictability towards *E.oldi* resistance. Also, the higher the germination percentage, 1000 grain weight and grain yield as the generation advances, the better the predictability of the lines towards *E.oldi* resistance. Similar results were reported by Abu-el-Gasim and Kambal (1975), and Obilana and El-Rouby (1980) for sorghum by selecting the top 5% in an improvement programme. Similarly, Whan *et al.* (1982), using the best 10% selection of F_2 to F_4 derived wheat lines, reported a high percentage in their response to selection. The high percentage genetic gain obtained in this study when selection is carried out in an early generation (F_2 generations) and advanced to F_3 and F_4 generations, is important if the genetic theory is correct, that the frequency of the best genotypes decreases rapidly with advancing generations (Shebeski, 1967; Shebeski and Evans, 1973). It follows that, when population size is constant as in this study, early generation populations of F_3 and F_4 lines will have greater potentials of *E.oldi* resistance and high grain yield as homozygosity is approached. Thus, favouring early generation selection to permit testing in many sites and years at an early stage. Thereby, shortening time, money, and space in the development of resistant materials to *E. oldi* with acceptable agronomic traits.

The negative component of variance obtained for the number of *E.oldi* in males and 1000-grain weight in females are considered low in this study. The negative estimate obtained in this study could have arisen from the mathematical implications of obtaining the estimates, since estimates of component of variance depend on the relative magnitude of the mean squares in the computation, which in turn depend on the degrees of freedom. In this study, the male x female interaction mean squares were of larger magnitude than those for males for the number of *E.oldi* and those for females for 1000 grain weight. Negative component of variance is not a new phenomenon in quantitative genetic studies, having been

reported in sorghum by Jan-Orn, 1973; Lukhele and Obilana, 1984; Showemimo, 1991. These earlier workers attributed negative estimates to sample size, assortative mating, deficiency in statistical and/or genetic model, experimental layout, linkage and estimates of actual zero values.

CHAPTER SIX

SUMMARY AND CONCLUSION

Three resistant male cultivars (genotypes) and three susceptible female cultivars (genotypes) were crossed, using the hand emasculation technique, in a factorial mating design, to produce 9 F_1 hybrids. The mating design corresponded to the North Carolina Design II which was used in the analysis of the data obtained. The F_1 hybrids were advanced to F_2 generations by selfing. Screening and selection were done at the F_2 generations by artificially infesting the sorghum panicles with 10 pairs of *E.oldi* using the "no choice" head cage method. A minimum of 250 plants were screened. The 10% of the genotypes, based on the parameters of *E.oldi* resistance, were advanced to the F_3 generations. Twenty five F_3 lines were advanced to the F_4 generations. The 6 parents, 9 F_1, 9 F_2, 25 F_3 lines and 25 F_4 lines were evaluated by artificially infesting them with 10 pairs of *E.oldi* under "no choice" head cage condition. The experimental design used was randomized complete block design with three replications.

The parental cultivars showed distinct response to *E.oldi* infestation, but the F_1 hybrids response to *E.oldi* was not very distinct. The mean performance of the F_2 generations showed a very distinct response. The low standard error and coefficient of variation for F_3 lines and F_4 lines confirmed the low differential response to *E.oldi* infestation. Three lines: HRhb 95001-4, HRhb 950004-1 and HRhb 95002-9 performed consistently well across the resistant traits at both the F_3 and F_4 generations. The HRhb 95007-4, HRhb 95002-1 and HRhb 95002-7 performed fairly well across the resistant traits measured at both F_3 and F_4 generations.

The entries, F_1 hybrids, F_2 populations, F_3 and F_4 lines differed significantly for all the traits measured. The parents also differed significantly for all the traits except grain yield.

There was a preponderance of male component of variance in the expression of all the traits except the number of *E.oldi* and grain damage rating. The male x female interaction component of variance were larger in magnitude than those of the male and female component of variance in all the traits except floaters percentage and 1000 grain weight, respectively, there by, explaining the negative estimate obtained in this study.

Evaluation of variance components revealed that all the traits were under the influence of non-additive gene effect, based on the fact that σ^2_D values were larger in magnitude than those for additive gene effect for all the traits measured. This was further confirmed by the σ^2_A/σ^2_D ratio, with all the values being less than unity, implying that selection should be based on dominance gene effect.

High narrow-sense heritability estimates were obtained as follows: number of *E.oldi* (47.00%), grain damage rating (73.10%), floaters percentage (77.51%), germination percentage (75.58%), 1000-grain weight (75.50%), and grain yield (65.47%) thus, these traits were highly inheritable. The narrow-sense heritability for F_2 generation was lower than that of F_3 and F_4 lines for all the traits except 1000-grain weight, grain damage rating and number of *E.oldi*. The difference between heritability estimates of F_3 lines and F_4 lines for all the traits measured were less than unity except for number of *E.oldi*. Thus, the heritability of these traits were highly transferable.

The reduction in number of *E.oldi*, damage rating and floaters percentage, with an increase in genetic gain for germination percentage, 1000-grain weight and grain yield obtained in this study, from screening and selection done at F_2, F_3 and F_4 generation for *E.oldi* resistance are achievable, thus, identifying resistant sorghum lines in early generations. The early selection of the best performing lines towards *E.oldi* resistance, based on the traits of resistance studied, is a significant achievement in head bug resistance study. Since this study is a pioneer research work on head bug resistance study in Nigeria.

The results obtained in this study indicate that all the traits studied were under non-additive gene effect, since dominance gene effect was more influential in all the traits measured. High narrow-sense heritability estimates were obtained for all the traits in all the generations evaluated. Similarly, high genetic advances were recorded. Based on the findings in this study, the lines: HRhb 95001-4, HRhb 95004-1 and HRhb 95002-9 that showed a high level of *E.oldi* resistance and good agronomic traits should be included in on-station testing for one or two years, before multilocational testing. They could then be recommended for farmer adoption. While the lines: HRhb 95007-4, HRhb 95002-1, and HRhb 95002-7 that performed fairly well across the resistant traits studied at the F_3 and F_4 generations should be included in a host-plant insect resistance breeding programme that will utilize their already known genetic potentials and genetic information of the desired resistance traits. Based on this study, early generation selection using pedigree breeding method is most suited in breeding for *E.oldi* resistance in sorghum.

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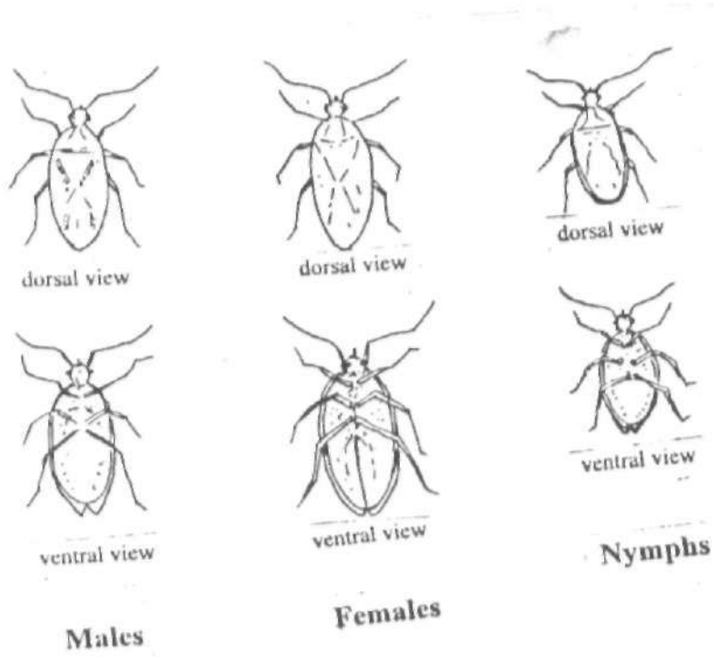
APPENDICES

APPENDIX I



Male and female adults, and nymphs of *E. oldi*.

APPENDIX II



Headcage on sorghum head