GENETIC ANALYSIS OF STRIGA ASIATICA (L.) KUNTZE RESISTANCE IN LINE X TESTER CROSSES OF SORGHUM

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ABSTRACT

The current study was conducted to investigate the genetics of *Striga* resistance in 72 'sorghum (*Sorghum bicolor L. Moench)* hybrids and their 17 parents. The experiments were carried out in India during the 1995 rainy season at two locations, ICRISAT Asia Center (IAC), Patancheru, and Akola, Maharashtra State, in randomized complete block designs. The traits measured were *Striga* incidence, days to 50% flowering, plant height, and grain yield plant^{-1}. The traits showed significant differences at both locations. Both additive and non-additive gene action was found important for the different traits. The non-additive gene action was found important for *Striga* resistance though the levels of infestation in the two locations were low.

The male-sterile lines L2 (SPST 94011B) and L3 (SPST 94001B) as well as the restorers, T4 (SAR 35) and T6 (SAR 42) were found to be also resistant. These were bred earlier for resistance to *Striga*, and these results confirmed that. These lines and testers could be further used in hybrid development for *Striga* resistance. Among the hybrids, entries 42 (SPST 94008A x SAR 42) and entry 49 (SPST 94026A x SAR 35) were resistant in individual locations and in combined analysis.

Among the lines, L3 (SPST 94001B) and L6 (SPST 94026B) were best combiners for *Striga* resistance as well as for earliness. Among the restorers, T6 (SAR 42) and T2 (SAR 16) were good combiners for *Striga* low incidence as well as for most of the other traits across locations. As regard plant height, the male-sterile lines L8 (ICSB 93) and L7 (ICSB 89) were found to be the tallest lines across the locations and in combined analysis. Among the restorers, T1 (SAR 1) and T3 (SAR 34) were the tallest.

Examination of SCA effects for transformed *Striga* incidence (SI%) at IAC revealed that entry 72 (ICSA 93 x ICSR 93004) had maximum negative SCA effects and high per se performance, followed by entry 37 (SPST 94008A x SAR 1), while at Akola, entry 52 (SPST 94026A x ICSR 92001) exhibited the highest negative SCA effects followed by entry 63 (ICSA 89 x ICSR 93004).

The highest contribution to total variances was observed by lines and lines x testers interaction at Akola for *Striga* incidence, whereas at IAC L x T interaction and testers showed the highest contribution to this trait, suggesting that both lines and testers were highly diverse. For yield plant^{-1} high contributions were shown by L x T interaction and lines which confirmed the diversity of the lines used. At IAC, high negative heterosis for *Striga* incidence (transformed) (TSI%) were shown by nine entries, the highest three were entry 45 (SPST 94008A x ICSR 93004), followed by entry 37 (SPST 94008A x SAR 1), and entry 64 (ICSA 93 x SAR 1). At Akola, 28 entries expressed high negative heterosis. The highest negative heterosis percentage was shown by entry 67 (ICSA 93 x SAR 35) and entry 9 (SPST 94009A x ICSR 93004) for *Striga* incidence.

The entries showing highly positive heterosis and heterobeltiosis for grain yield were entry 18 (SPST 94011A x ICSR 92003) at IAC and entry 34 (SPST 94011A x ICSR 92001) at Akola. Across both locations entry 37 (SPST 94008A x SAR 1) showed the highest heterosis. The highest positive heterobeltiosis at IAC was expressed by entry 60 (ICSA 89 x SAR 42), followed by entry 54 (SPST 94026A x ICSR 93004), whereas at Akola, the highest heterobeltiosis was shown by entry 37, followed by entry 40 (SPST 94008A x SAR 35). Most of these entries had high grain yield plant^{-1}. Low heritability

values were observed for *Striga* incidence, 10% at IAC and 2% at Akola, which resulted from the low and non-uniform infestation of *Striga* at the two locations. Therefore, for further reflection of the actual potential of these genotypes, the continuation of this study with added genetic material, locations across countries (perhaps India and Sudan), and *Striga sp.* (*S. asiatica* and *S. hermonthica*) is suggested.

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DEDICATION

I dedicate this work with pleasure to my mother, Haleema Hassan, my brothers Ezadeen, Essam, Faisal, El Hadi and sisters Souad and Assia who endeavored to educate me and to the memory of my father and sister Mastura.

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Introduction

1.INTRODUCTION

Sorghum *(Sorghum bicolor)* is the fifth most important cereal crop world wide, following wheat, rice, corn, and barley in terms of area, grain yield, and production. It is grown in approximately 45 million ha on a global scale with a production of 60-70 million t. In many developing countries, particularly in Africa and Asia, yields range from 0.5 to 0.7 t ha^{-1} while in developed countries of Latin America yields range from 3 to 5 t ha^{-1}. The average world level was 2 t ha^{-1} (FAO 1992). The area under sorghum production has declined substantially in Africa, Latin America, and Asia during the last decade. Production, however, remained stable because farmers grow improved cultivars associated with proper farming systems.

In Sudan, sorghum is the main staple food. In many parts, the crop is wholly utilized. The grain is used for making kisra (unleavened bread from fermented dough), a significant portion is also used as thick porridge, "Aseeda", and as a popular beverage "Abreh". The stalks are used as building material and straw as animal feed or as fuel. Total area under sorghum in Sudan is estimated at 4.68 million ha, with yield of 509 kg ha^{-1}, and total production of 2.39 million t in 1993 (FAO 1993). In India the crop is known as jowar in the North, and jonna, cholan in the South. It ranks second with respect to area and third after wheat and rice with respect to production. Total area under this crop is estimated to be 13.3 million ha, with average yield of 940 kg ha^{-1}, and a total production of 12.5 million t in 1993 (FAO 1993).

Although sorghum is an important food and feed crop, especially for subsistence farmers in the semi-arid tropics, grain yields are generally low (600 - 800 kg ha^{-1}). Several factors are held responsible for this low productivity, one of which is noxious weeds.

Striga spp. (witchweeds) are widely recognized as being among the most noxious weeds of crops and they affect crop production significantly in dry, semi-arid, and harsh environments of tropical and subtropical Africa, the Arabian peninsula, India and a small part of USA. Cereal crops seem to suffer the most, although some legumes are also known to be devastated by *Striga* attack (Nelson 1958). *Striga asiatica* (L.) Kuntze and *S. hermonthica* (Del.) Benth. are the major species on cereals, while *S. gesnerioides* (Willd.) Vatke is important on legumes (Reid and Parker 1979). *Striga hermonthica*. causes loss of yield reaching up to 70% in sorghum (Doggett 1988), and other cereals such as pearl millet and maize, which are staple food in the diets of millions of people in Africa, while *S. asiatica* is recognized as a major problem on sorghum in parts of Africa and Asia (Barber 1904, Butt-Davy 1905). According to Mboob (1989) *Striga* is distributed in more than 40% of the arable land in South Sahara (in countries of West and East Africa as well as Asia), with a mean of 48% of the grain sorghum fields being infested with *Striga*. The yield loss sums up to an average of 24%, with a loss of total grain production amounting to 12%. *Striga* infested area of Africa was estimated to be 21 million ha and the loss in grain yield was about 4.1 million t (Sauerborn 1991). Recently, Lagoke et al. (1991) estimated an annual cereal grain loss associated with *Striga* damage as about 40% when averaged across Africa. In Sudan,

Striga caused sorghum yield reductions up to 70% in fertile, heavy soils (Basinski 1955). It has been estimated that *Striga* causes an annual yield loss of 53 000 tonnes in hybrid production in India, and at ICRISAT Center yield losses of up to 49% have been recorded (Vaidya et al. 1991).

Severity of *Striga* infestation increases as land becomes progressively exhausted by continuous sorghum cultivation (Thomas 1943). The degree of damage is influenced by the susceptibility of the cultivar itself, the *Striga* species, the level of infestation, and additional stresses imposed by the environment. Considering the economic proportions of losses to several important food crops in the semi-arid tropics, breeding resistant varieties offers an economically viable option to control this problem for two reasons:

1. A resistant variety is a non-cost input in any improved technology.
2. No other control method than genetic resistance is able to lessen the subterranean damage by *Striga* (Vasudeva Rao et al. 1982).

The information on the genetics of *Striga* resistance is limited. Available data suggest that *Striga* resistance is controlled by relatively few genes with additive effects. Only two types of inheritance studies have been carried out, the inheritance of low stimulant production, and the inheritance of field resistance as measured by the number of emerged *Striga* plants.

Studies at ICRISAT Center revealed that inheritance of low stimulant production is controlled by a single recessive gene (ICRISAT 1978, Vasudeva Rao et al. 1983). While Shinde and Kulkarni (1982) reported that field resistance was controlled by both additive and non-additive gene actions, with a preponderance of additive gene action.

The cytoplasmic-genic male sterility systems in sorghum allowed sorghum breeders to develop sorghum hybrids for commercial cultivation. The superiority of hybrids in productivity, greater stability, and better adaptation to stress over open pollinated varieties is widely appreciated (Ejeta 1988). However, hybrids developed and released for cultivation in India and Africa do not have much tolerance or resistance to *Striga*. CSH1 and Hageen Dura 1, the first commercial sorghum hybrids released in India and Sudan, respectively, are both highly susceptible to *Striga*. The viability of *Striga* seeds may be 20 years (Doggett 1988) and the continual growing of susceptible varieties and/or hybrids will increase the quantity of *Striga* seeds in the soil and over the years the fields will become unfit for sorghum cultivation. Ejeta et al. (1991) directed efforts towards developing parental lines with genes for resistance with the goal of developing *Striga* resistant grain sorghum hybrids. They initiated transfer of low stimulant production gene in SRN 39 into agronomically elite B-lines (potential female) parents, then they tested the combining ability and heterotic performance of SRN 39 in combination with established A-line (male-sterile female) parents. The results were found to be encouraging.

The present study is an attempt along the same lines with the following objectives.

1. To evaluate hybrids and their parents for *Striga* resistance, and estimate the differences in performance among the hybrids which reflect differences in the general combining ability of the male-sterile lines and restorers.

2. To understand the nature of gene action involved in the expression of *Striga* resistance.

3. To estimate heterosis for resistance to *Striga*, and to identify parents with elite combining ability for *Striga* resistance and yield and to develop breeding strategy for developing high yielding *Striga* resistant cultivars.

2. REVIEW OF LITERATURE

2.1. Botanical Classification, Host Range, and Distribution

The genus *Striga*, with more than 25 species, belongs to the family Scrophulariaceae, only a few of which are economically important, for instance *S. hermonthica, S. asiatica, S. gesnerioides, S. densiflora, S. euphrasioides, S. aspera and S. forbesii* (in order of importance). Species range from almost completely parasitic to almost totally autotrophic. They attack several food crops, mainly cereals, but also some broad-leaved crops such as cowpea. The following botanical classification is quoted from Ramaiah et al. 1983.

2.1.1. *Striga asiatica* (L.) Kuntze (= *S. Lutea* Lours.= *S. hirsuta* Benth.)

It is a self-pollinated species with established morphological differences among strains (morphotypes). It is the most widespread among the important species centered on the Indian subcontinent, where it has a white flower, and in China and South East Asia where it more commonly has a yellow flower. The species commonly parasitizes members of Poaceae including sorghum, pearl millet, maize, rice and sugar cane. The main distinguishing features include slender, usually branched habit, up to 30 cm high, and the large number of ribs on the calyx (at least 10).

2.1.2. *S. hermonthica* (Del.) Benth. (= *S. senegalensis* Benth.)

It is a cross-pollinated species. The cross pollination results in a continuous variation in this species, whereas in *S. asiatica*, the spontaneous mutations may be fixed by self-pollination. It is the main species of Africa extending across a northern belt from

Senegal to Sudan, extending eastward into South Western Arabia and south into Tanzania, Malawi, and Zimbabwe. It has pink flowers, branching habit and grows up to 50 cm height. The host range is almost the same as *S. asiatica.*

2.1.3. *Striga densiflora* Benth.

It is almost restricted to the Indian subcontinent attacking sorghum but it does also occur in South East Arabia. It has a white flower, but less branched and with more dense inflorescence than *S. asiatica*, calyx ribs are only five.

2.1.4. *Striga euphrasioides* Benth. (= *S. angustifolia* (Don) Saldhana)

Striga euphrasioides is less parasitic than the previously described species. It attacks sorghum, maize, sugarcane, upland rice, and grass weeds. It is small erect herb reaching a maximum height of 0.45 m; white flowers in long lax terminal spikes , calyx 15-17 ribbed.

2.1.5. *Striga aspera* (Willd.) Benth. (= *Euphrasia aspera* Willd.)

It distributed throughout West Africa and Sudan. It attacks upland rice, and wild grasses, but it is rarely an economic problem. It is similar to *Striga hermonthica* except that it is smaller, the only difference is that the corolla tube has gland hairs extending beyond the tip of the calyx before it bends.

2.1.6. *Striga gesnerioides* (Willd.) Vatke (= *S. orobanchoides* Benth.)

Striga gesnerioides is almost completely parasitic, and contain less chlorophyll than other species. It attacks cowpea, tobacco, Euphorbia, hairy indigo (*Indigofera hirsuta*). It extends from Cape Verde Islands through tropical and southern Africa and through the Arabian Peninsula and western and southern India. also found in Florida in

USA. It is distinctly different from other species. A large number of short branches arise from the ground level, the species shows variation in flower size and color: flowers usually bluish, pink, purple, or creamy white.

5.1.7. *Striga forbesii* Benth.

It rarely an economic problem. It extends throughout West and East Africa, South Africa and Madagascar. It attacks maize, sorghum, rice. It is an erect, simple or little branched herb growing to height of about 0.5 m, flowers pink, scarlet, or yellow, 10-20 mm diameter, corolla tube 20-25 mm long.

2.2. Biology of *Striga*

2.2.1 Germination

Due to successful adaptation to the parasitic habit, *Striga spp.* produce tiny, long-lived seeds that generally do not germinate unless aged (after-ripening), conditioned (imbibition) and stimulated by exogenous germination stimulant (Worsham and Egley 1990). Seeds are numerous, up to 0.5 million plant^{-1}, and can remain viable for as long as 20 years (Doggett 1988).

2.2.2. Germination requirements

2.2.2.1. After-ripening period

Striga seeds require a period of after-ripening or post-harvest ripening before they are able to germinate. Saunders (1933) found that the minimal period for *S. asiatica* to germinate is about 6 months. Vallance (1950) found similar behavior in *S. hermonthica.* Kust (1963) working with *S. asiatica* noticed the necessity for after-ripening and found that the higher the temperature of the seed storage the shorter the period of after-

ripening.

2.2.2.2. Dormancy and viability

Striga seeds are known to remain dormant but viable for many years provided they are stored under dry conditions. Saunders (1933) recorded high degree of germinability for *S. asiatica* stored for 7 years. Kust (1963) reported that storage at high relative humidity and high temperature rapidly reduced viability of *S. asiatica* seeds, but at low relative humidity and at low temperature, the seed remain viable longer. Bebawi et al. (1984) reported that *S. asiatica* seeds remain viable for 6 years under open shelf laboratory conditions, and after 14 years of burial in soil at a depth of 152 cm there was still 10% germination.

2.2.2.3 Preconditioning

Brown and Edwards (1944) reported that *Striga* seeds require to be soaked in water for a period of 10 to 21 days prior to exposure to germination stimulant for germination to occur.

2.2.2.4. Exposure of seeds to a chemical stimulant that triggers germination

Stimulants are exuded by the roots of host and non-host plants (Doggett 1988). Germination of *Striga* seed is stimulated by other compounds which may occur widely in nature (Visser 1989, Dale and Egley 1971). Cook et al. (1966 and 1972) reported the first natural molecule (strigol) to stimulate germination. This compound was isolated from the root exudate of cotton, which is not a host for *Striga*.

Sorgoleone is the first *Striga* seed-germination stimulant to be isolated and identified from a natural host plant (Chang et al. 1986, Netzly and Butler 1986, Netzly

et al. 1988).

2.3. Attachment to the Host Plant

Successful *Striga* infestation entails seed germination, radicle elongation, haustorium initiation, contact and penetration of a suitable host root (Visser and Dorr 1987, Riopel et al. 1990). Upon germination, *Striga* rootlets close to a host root develop an organ of attachment, the haustorium, which forms a morphological and physiological bridge between the host and parasite Lynn and Chang (1990) reported that germination and haustorium initiation are two separate developmental events which are coordinated in time and space. They involve an orderly series of successive changes which are controlled by signal molecules exuded from roots of host and non-host plants. The chemical signals for germination and haustorial initiation are different from each other (Lynn and Chang 1990). The chemical, 2,6-dimethoxybenzoquinone acts as a haustorial initiation factor in *S. asiatica*, but the natural signal produced by host roots has not been identified. Musselman (1980) reported that Striga spp. produced adventitious roots which penetrated the host root along with the primary haustorium.

2.4. Effect on the Host

Absorption of water, minerals, and photosynthetically fixed carbon from the host is only a minor component of the *Striga*-induced reduction in host crop productivity. The productivity of the host is affected mainly through decreased photosynthetic efficiency (Press et al. 1990). The damage to the host caused by *Striga* (stunting, bleaching, and

wilting) is usually obvious even before emergence of the parasite. Ejeta et al. (1992) found that crude extracts of *Striga* leaves and stems can induce loss of chlorophyll and wilting of susceptible host plants suggesting that *Striga* produces toxic compounds which are transported to host photosynthetic tissue and produce the observed inhibitory effects. They also reported that SRN 39 seems to have multiple mechanisms of resistance (low stimulant production and insensitivity to *Striga* toxins).

2.5. Factors Influencing Severity of Attack

The cultivation of *Striga* host crops in subsequent seasons without rotation will lead to building up of *Striga* seed in the soil (Vierich and Stoop 1990). It has also been suggested that unreliable rainfall and drought may favor the spread of *Striga* (Thomas 1943, Andrews 1945, Ayensu et al. 1984, Porteres, 1984, Ogborn 1984, Bebawi 1987).

2.5.1. Relationship between *Striga* infestation and soil structure and moisture

Saunders (1933) and Hattingh (1954) reported that in South Africa, *S. asiatica* occurs most commonly on light, sandy soils. ICRISAT (1982) and Stoop et al. (1983) showed that in Burkina Faso and in North Ghana, *S. hermonthica* is most abundant on shallow, drought-sensitive soils with a coarse structure and a low organic matter content. On the other hand, in East Africa, *S. hermonthica* appeared to be very troublesome on heavy soils (Basinski 1955, Doggett 1965, Bebawi 1984, Ogborn 1987), whereas *S. asiatica* seem to prefer light soils (Doggett 1965).

Ogborn (1972) stated that soil moisture is the main environmental factor causing

variations in the emergence of *Striga*. Andrews (1945) reported that at Gezira, Sudan, lightly irrigated soils were more severely infested with *S. hermonthica* than heavily irrigated soils. In pot experiments in India medium soil moisture levels turned out to be optimal for *S. asiatica* development (Solomon 1952). It appeared that in soaked soils oxygen depletion might inhibit germination. Another influence of excessive moisture could be that the effectiveness of the germination stimulant might decrease because of a dilution of the root exudate of the host plant (Saunders 1933). Nelson (1957) reported that in pot experiments excessive watering also negatively affected the development of *Striga* shoots, indicating that the moisture effect was not limited to seed germination and/or early attachment.

2.5.2. Fertilizer application

Raju et al. (1990) reported that *Striga* is active in low fertility soils. The effect of nitrogen on *Striga* seed germination via reduction of stimulant exudation was reported by Teferedegn (1973). Low fertility encourages *Striga*, particularly low nitrogen status. In contrast, high N helps to suppress the weed. The mechanism responsible for this effect is not clearly known, but the possibilities include: A reduction in stimulant exudation (Teferedegn 1973), a change of host physiology resulting in reduced susceptibility to attachment, reduced vigor of the *Striga* radicle, a reduced root/shoot ratio accompanied by reduced flow of photosynthates to the root, or increased leafiness of the crop resulting in greater shade and lower soil temperature.

2.5.3. Crop rotation

A succession of susceptible sorghum crops under soil and climatic conditions conducive to *Striga* results in a buildup of infestation. Any rotation with resistant crops will interrupt this buildup and crops exuding stimulant may act as trap crops to accelerate the natural depletion of seed in the soil.

2.5.4. Trap crops

The use of trap crops for stimulating *Striga* is a very effective method in reducing the problem. There are many crops known to stimulate the *Striga* seed to germinate without themselves being parasitized. Trap crops proved to be effective include: cotton, sunflower, millet, cowpeas, groundnut, castor bean, lablab bean, velvet bean, field peas, but different strains of *S. hermonthica* may differ in their response to some of these trap crops. In USA, Robinson and Dowler (1966) found millet the most effective trap crop for *S. asiatica.*

Sorghum genotypes vary in amount of stimulant production (Ramaiah and Parker 1982, Hess et al. 1992). The depletion of the *Striga* seed population in the soil by promoting suicidal germination was identified in some maize genotypes (Reda et al. 1993) but these have not yet been field-tested for *Striga* resistance.

2.6. *Striga* Control Measures

Striga control measures include hand pulling or hoeing, irrigation, nitrogen application, early planting date, crop rotation, biological control, chemical control (soil fumigation, herbicides, and germination stimulants), and crop seed treatment.

specific to a host cultivar exist (Bebawi 1981, Ramaiah and Parker 1982). *Striga* has an extraordinary elasticity and capacity to adapt to new host species.

2.8. Mechanisms of Resistance

Olivier et al. (1991) have demonstrated from their pot experiment that *Striga* seed avoidance by means of reduced root growth is unlikely to be an important factor involved in the resistance of IS 7777 to *S. hermonthica*. They said that the production of sorgoleone could explain at least partly the low susceptibility of IS 14825, IS 14975 and Framida, but resistance of IS 7777 appears to be largely the result of defence reactions involved at the very beginning of haustorium development.

2.8.1. Stimulant production

Host cultivars which do not produce or produce very low quantity of the stimulant substance in their root exudate can avoid *Striga* attack. Sorghum with resistance based on a low stimulant mechanism have been reported by several workers (Kumar 1940, Rao 1948, Williams 1959, ICRISAT 1978). Root growth of host plants is also reported as an avoidance mechanism (Dixon and Parker 1984, Cherif-Ari et al. 1990).

Saunders (1933) working in South Africa and Doggett (1965) in East Africa and ICRISAT (1978) described host plant resistance based on mechanical antihaustorial barriers, which impede invasion of cortical cells by haustoria they observed thickened cells, and hardened vascular cylinders of host roots. Lignified pericycle cells and endodermal cells thickened with silica deposits physically obstruct attachment of haustoria roots of sorghum genotypes known to have good field resistance (Maiti et al. 1984).

Another suggested resistance mechanism is antibiosis (Ramaiah 1987, Doggett 1988) where germination and haustorial initiation are normal, but subsequent development of the parasite is impeded.

2.9. Resistant Sorghum Cultivars and Yield

It was reported that *Striga* resistance is mainly associated with very poor agronomic performance (Ramaiah and Parker 1982). This association between resistance and low yield and poor grain quality makes it difficult to improve the cultivars for resistance and grain yield. N 13 is the best resistance source available followed by SPV 103 and SRN 4341.

2.10. Inheritance of Resistance

Among three crosses in sorghum, Saunders (1933) reported that field resistance to *S. asiatica* was recessive in two , and in the third it was partially dominant. But Chandrasekharan and Parthasarathy (1953) reported that resistance was dominant over susceptibility, while Narsimha Murty and Sivaramakrishnaiah (1963) concluded that susceptibility may be dominant in some crosses and resistance may be inherited as a partial dominant in some other crosses of sorghum.

Tarr (1962) demonstrated the complex nature of inheritance it may be partial dominance of susceptibility, and incomplete dominance of resistance. Studies at ICRISAT Center revealed that inheritance of low stimulant production is controlled by a single recessive gene (ICRISAT 1978).

Kulkarni and Shinde (1983) found from the comparison of all susceptible and resistant parents for *Striga* incidence that group means of susceptible parents for *Striga* populations were double those of the resistant parents. They also found the group means of *Striga* dry weight and *Striga* height were 4 to 6 times greater than resistant parents. So it was suggested that all these three parameters should be considered while grading genotypes for *Striga* resistance.

Rao et al. (1983) tested hybrids for resistance and reported that all were susceptible. They indicated the importance of getting *Striga*-resistant A-lines for the production of resistant hybrids since the *Striga* resistance of the male parents is being suppressed in the hybrids.

Shinde et al. (1983a) reported from an experiment consisting of a set of 42 F_2 populations along with their parents planted in a *Striga*-infested field the importance of selection in crosses which involve resistant parents. They suggested selection in crosses involving resistant parents for the development of resistant varieties.

Shinde and Kulkarni (1983) measured resistance to *Striga* in terms of percentage *Striga* incidence, dry weight and *Striga* height. Also, they found that both additive and non additive gene action were important in the inheritance of resistance parameters with predominance of additive gene action. Reciprocal differences were considered important in the inheritance of *Striga* weight.

Kulkarni and Shinde (1984) stated that GCA and SCA mean squares determine the importance of additive and non additive gene action in the inheritance of stimulant

production. Low stimulant lines must be used as female parents in crossing programs for developing low stimulant production lines with other desirable agronomic characters. N 13, a stimulant positive line, has shown considerable field resistance which was confirmed to be due to mechanical barriers, as reported by Maiti et al. (1977). They also reported that in other crosses the expression of low stimulant production is due to non-additive gene action limiting its use in conventional selection methods.

Dangi (1989) reported that resistance is controlled predominantly by additive gene action, indicating that straight selection is effective.

Shinde et al. (1982) undertook heterosis studies involving a tolerant line (CSV 5), a moderately tolerant line (CSV 8 R) and two susceptible lines (CK60B and 1202 B). The 4 parents and 6 hybrids were grown in a *Striga*-sick plot. They found that the hybrid obtained from tolerant line (CSV 5) with susceptible male sterile line (CK60A), i.e., CK60A x CSV 5 developed a lower *Striga* population (636) but had the highest heterosis (234.7%) for grain yield. Subbarayudu et al. (1983) indicated that the nature of resistance/tolerance and susceptibility can be best studied through using a ratooned crops instead of seed crops, due to their better developed root system with closer proximity to *Striga* seeds ensuring successful infestation.

Shinde et al. (1983b) found that in F_3 progenies the lines selected from the crosses between resistant x resistant parents also were susceptible. This is indicative of the fact that the genes responsible for *Striga* resistance in the original parents might be in a heterozygous condition or the genes contributing to resistance may be located at different loci in the parents.

Shinde and Kulkarni (1987) studied seven parents and their 42 hybrids from a diallel cross grown in *Striga*-infested soil at 2 fertilizer application rates. They found that genotype x environment interaction was significant for yield, cluster analysis of means indicated that screening for *Striga* resistance should be done under low fertility conditions. Additive and non-additive components of genetic variance were significant under normal fertility, but non-additive gene action appeared to be predominant.

Obilana (1984) defining resistance as "low total number of *Striga* sorghum plant^{-1}", reported gene action to non-additive with over dominance of susceptibility and estimated two to five genes control the resistance action.

Barche et al. (1988) observed significant differences among genotypes for all the attributes in reciprocal crosses including 4 *Striga* resistant (SAR 1, SAR 2, AKSR 2, and N 13), susceptible (Swarna) and agronomically desirable (SPV 472 and SPV 475) genotypes. The analysis revealed that mean squares for both general combining ability (GCA) and specific combining ability (SCA) were significant for days to 50% flowering, grain yield plant^{-1} and positional check value for *Striga*. They reported that additive and non additive components of heritable variance were responsible for the inheritance of these attributes. They also reported that Swarna and SAR 2 were good combiners for earliness whereas N 13 and SPV 475 were undesirable (having significant and positive GCA for days to 50% flowering). SPV 472 and SPV 475 were desirable combiners for yield, since they had significant and positive GCA effects, but AKSR 2 was a poor combiner. Estimates of GCA effects of SPV 472 and N 13 were significant and negative for positional check values of *Striga* infestation, but SAR 1 was an undesirable combiner.

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Therefore, SPV 472 was desirable combiner not only for positional check value of *Striga* (resistance to *Striga*) but also for grain yield. N13 was desirable only for resistance to *Striga*. SAR 2 x SPV 472 was the only specific combination showing a significant and positive SCA for grain yield and a negative significant SCA for positional check values of *Striga* infestation (*Striga* resistance).

Hess and Ejeta (1992) conducted a pot study in Niger using a known volume of *S. hermonthica* seed and established that the stable resistance observed in the sorghum cultivar SRN 39 is inherited as a recessive trait controlled by one or two genes.

Mulatu and Kebede (1991) in their crossing program to transfer the resistance trait to agronomically elite material, ICSV 1007, found it to be a maintainer line on the three female lines (IS 10468, 221 A, and MA 44).

Ramaiah et al. (1990) recently reported a single recessive gene for low stimulant production in three sorghum genotypes using as an index percent *S. asiatica* seed germination in the presence of sorghum root exudate collected with the double-pot technique (Parker et al. 1977).

Materials and Methods

3. MATERIALS AND METHODS

3.1. Plant Materials and Data Collected

Plant material used in this study was developed by ICRISAT Asia Center (IAC). A total of 17 parental lines (selected for good agronomic characters) comprising 6 resistant cytoplasmic-genetic male steriles (A-lines), 6 resistant restorers (R-lines), 2 susceptible cytoplasmic-genetic male steriles (A-lines), and 3 susceptible R-lines as restorers were crossed in a line x tester (LxT) design. The resulting 72 hybrids and with their 17 parents formed the basic material of this study. In addition, 296 B as susceptible control and CSH 1 as a systematic susceptible control, and SAR 1, SAR 16, and SAR 34 as resistant controls were included. The genotypes used along with their origin and pedigree are shown in Appendix Table 1. The experimental trial was conducted in India during the rainy season of 1995, at two locations.

3.1.2. Location 1 experiment

The basic materials along with checks (totalling 93 entries) were evaluated in randomized complete block designs with three replications in a *Striga*-sick field at ICRISAT Asia Center (IAC), Patancheru, which is located in Andera Pradesh state at latitude 17° 32'N, longitude 78° 16' E and at an altitude of 545 m above sea level. The soil type is heavy black Vertisol. The seasonal rainfall extends over five months between June and October with a mean annual rainfall of 760 mm. During the period of experimentation, the rainfall was 716.4 mm (May 15 - September 15). During the study (May 15 - September 15) the mean minimum temperature was 23.4°C and the mean maximum temperature was 32.7°C.

3.1.2.1. The *Striga*-sick field

It is an isolated infested field developed by ICRISAT for *Striga* screening purposes. The field was developed by providing for season after season conditions known to favour *Striga*, such as shallow tillage and low fertilizer inputs and light perfo irrigation, in order to improve the incidence and regular appearance of *Striga* in the field. In addition to the *Striga* seeds stored in the soil accumulated from naturally infested *Striga* plants, two-year- old *Striga* seeds collected from farmers' fields were thoroughly mixed with sand in 1:20 proportion and inoculated into the soil two weeks before planting to increase the infestation level. The rate of application of *Striga* seeds was 0.8 kg ha^{-1}.

The land was prepared by discing and ridgers were made with 60 cm space between rows. A light perfo-irrigation was given ten days prior to sowing of experimental material. The trial was planted mechanically on 17 May 1995, one month earlier than the beginning of the season to synchronize the stimulant production by the test entries with high temperatures which enhance the germination of the *Striga* seeds. One light perfo-irrigation was applied for germination. Thereafter the crop was completely rainfed. One hand weeding was done once two weeks after planting. Thinning of plants to leave plants at 10 cm interval within the rows was carried out 14 days after planting. Seventy five kilograms of ammonium phosphate (28:28:0) ha^{-1} was applied as basal fertilizer prior to the sowing. As side dressing, urea 50 kg ha^{-1} was applied mechanically. The trial consisted of 94 genotypes which include 72 hybrids, 17 parents, 4 checks and CSH 1 as systematic check (planted after every five test plots). The genotypes were replicated three times in a randomized complete block design (RCBD). The plot size was 3 rows

of 2 m length with 60 cm between rows and with 15 cm within row spacing.

3.1.3. Location 2 experiment

The basic materials along with checks (totalling 93 entries) were evaluated in randomized complete block designs with two replications in a *Striga*-sick field at Punjabrao Krishi-Vidyapeeth, Akola in a *Striga*-sick field. Akola is located in Maharashtra state at latitude 20°42'N and longitude 77°02'E at 415 m above mean sea level. It is clayey soil with clay 47.0%, sand 24.4% and silt 28.6%. The pH is 8.1, with total nitrogen of 0.022%, available P_2O_5 of 14.8 kg ha^{-1} and available K_2O 290 kg ha^{-1}. The rainy season extends over 4 month period between June and September. The mean annual rainfall during experimentation (23 June - 30 October) was 542 mm. During the season the mean minimum temperature was 21.8°C and mean maximum temperature was 34.6°C.

3.1.3.1. The *Striga*-sick field

Striga-sick plot at Akola has been maintained for the last 15 years by allowing natural infestation of *Striga* and providing proper conditions for *Striga* germination and growth plus artificial inoculation of *Striga* seeds collected from farmers' fields into the soil every year. In this season the rate of application of Striga seed was 20 kg ha^{-1} which was thoroughly mixed with fine sand and broadcast 15 days before sowing. Ploughing by bullocks was carried out at the end of May and a harrowing in June. The same set of 94 genotypes used in location 1 was repeated in this location with CSH 1 as systematic check planted after every five test plots. The plots were assigned in a randomized complete block designs (RCBD), with two replications. The plot size was

3 rows of 2 m length with 45 cm between rows and with 15 cm within row spacing. The trial was planted manually on 24 June 1995, and irrigated once on the same day by furrow irrigation to ensure germination. Thereafter, the crop was completely rainfed. The plants were thinned to one plant per hill two weeks after germination. One hand weeding and two-hoeings were carried out within 23-25 days after germination. Ninety six kilograms of ammonium phosphate (21:21:0) ha^{-1} was applied as basal fertilizer prior to sowing. As top dressing, 23 kg urea ha^{-1} was applied. The following observations were recorded at both locations:

3.1.4. Days to 50% flowering

Number of days required for 50% of the plants in the plot to have 50% of the florets open.

3.1.5. Plant height

Plant height was measured in cm as average of five plants at physiological maturity.

3.1.6. *Striga* count

At IAC the number of emerged *Striga* plants per plot in the central row was counted at four intervals 55, 70, 85, and 100 days after sowing. The maximum *Striga* count among the four intervals was used for the analysis. At Akola, the number of *Striga* plants emerged per plot in the central row was counted at two intervals, 55 and 85 days, and maximum count among two counts was used for the analysis. *Striga* incidence (SI%) which is the percentage of the maximum *Striga* plant count in the test plot over the average maximum number of *Striga* plants in CSH 1 plots (systematic susceptible

checks) was calculated as

$$\textit{Striga} \text{ incidence (IS\%)} = \frac{(S)}{\{(S_1+S_2,\ldots S_n)/n\}} \times 100$$

Where,

S = maximum number of *Striga* plant in test entry.

S_1, S_2,....S_n = maximum number of *Striga* plant in CSH 1 plots.

Heads from all the plants in the central row in the test entries were harvested on 15 September 1995. The heads were harvested in bags and oven dried for three days at 40°C.

3.1.7. Grain yield plant^{-1}

Threshing was done mechanically and the grain yield from the central row of each plot (1.2 m^2) was considered for the analysis.

3.2. Statistical Analysis

Analysis were carried out by using Genstat version 4 developed by Rothamstead Experimental Station. In these analyses the null hypothesis that there are no genotypic differences was being tested. The testing procedure involved the randomized complete block design. The variance due to entries was further partitioned into lines, testers, hybrids, lines x testers, and parents vs checks vs hybrids. The outline analysis of variance for individual locations is shown in Table 3.1.

3.2.1. Analysis of variance for combining ability in line x tester (L X T) experiment at individual location

Combining ability for 72 hybrids was based on the procedures developed by Kempthorne (1957) which is related to design II of Comstock and Robinson (1952). The sources of variation are shown in Table 3.2.

3.2.2 Genetic components

σ^2_{GCA} (line) = Cov. half sib (line) = $[M_l - M_{lxt}]/rxt$

σ^2_{GCA} (tester) = Cov. half sib (tester) = $[M_t - M_{lxt}]/(rxl)$

Covariance half sib (average) = $\{[(l-1)(M_l)+(t-1)(M_t)]/(l+t-2) - M_{lxt}\}/r(2lt-l-t)$

Covariance full sib = $[(M_l - M_e)+(M_t - M_e)+(M_{lxt} - M_e)]/3xr$ - [6r Cov. Hs - r(l+t) Cov Hs]/3xr

Where,

M_l = Lines mean squares

M_t = testers mean squares

M_{lxt} = L x T mean squares

M_e = Error mean squares

r = No. of replications

σ^2_{GCA} = Cov. half sib = $[(1+F)/4]^2 x\sigma^2_A$

$\sigma^2_{SCA} = (M_{lxt} - M_e)/r = [(1+F)/2]^2 x\sigma^2_D$

where,

F = Coefficient of inbreeding depression

A = Additive variance.

D = Dominance variance.

The ratio between σ^2_{GCA} (variance of general combing ability) and σ^2_{SCA} (variance of specific combining ability) was expressed as $\sigma^2_{GCA}/\sigma^2_{SCA}$. This ratio >1 indicates the additive gene action is more important and <1 indicates non-additive gene action is

important.

3.2.3. Estimates of general and specific combining ability effects

The model used to estimate the general and specific combining ability effects of the (ij) observation was based on the procedures developed by Kempthorne (1957).

$X_{ij} = \mu + g_i + g_j + s_{ij} + e_{ij}$

Where,

μ = Population mean,

g_i = GCA effects of the i^{th} line,

g_j = GCA effects of the J^{th} tester,

s_{ij} = SCA effects of the $(ij)^{th}$ combination,

e_{ij} = error associated with the observation.. xij,

i = lines 1,2,3...i, and

j = testers 1,2,3.. t.

The analysis is based on individual observation over replications.

$\mu_{l\,t}$ = X...

Where X... = grand total of all ij^{th} hybrids combinations

$g_i = X_i../tr - X.../ltr$

where,

X_i = total of i^{th} males over all females

l = No. of lines

t = No. of testers

r = No. of replication

g_j = $X_{.j.}$ /lr - X.../ltr,

Where,

$X_{j.}$ = total of j^{th} males over all females

s_{ij} = X_{ij} - $X_{i..}$ /tr - $X_{.j.}$ /lr + X.../ltr

where, X_{ij} = $(ij)^{th}$ combination

3.2.4 Calculation of S.E. mean for general and specific combining ability effects

1. S.E. (GCA for lines) = $(M_e/rt)^{1/2}$

2. S.E. (GCA for testers) = $(M_e/rl)^{1/2}$

3. S.E. (SCA effects) = $(M_e/r)^{1/2}$

4. S.E. (g_i-g_j)line = $(2M_e/rt)^{1/2}$

5. S.E. $(g_i- g_j)$tester = $(2M_e/lr)^{1/2}$

6. S.E. (sij-skl) = $(2M_e/r)^{1/2}$

Where,

M_e = Error mean squares

l = No. of lines

t = No. of testers

3.2.5 Proportional contribution of males, females, and their interaction to the sum of squares of the hybrids at individual location

The percentage contribution of females (lines), males (testers) and females (lines)

x males (testers) to the hybrids were calculated as:

1. Percentage contribution of lines = {SS(L) x 100}/ hybrids SS

2. Percentage contribution of Testers = {SS(T) x 100}/hybrids SS

3. Percentage contribution of Lines x Testers interaction = {SS(LxT) x 100}/hybrids SS Where,

SS (L) = Sum squares of the lines

SS (T) = Sum squares of the testers

Hybrids SS = Sum squares of the hybrids

3.2.6 Estimation of heterosis for individual location

The amount of heterosis over higher parent (HP) (heterobeltiosis) as well as mid-parent (MP) were computed for days to 50% flowering, plant height and yield plant^{-1} using the formula developed by Singh and Narayanan (1993), and for *Striga* resistance heterosis over mid parents (MP) was only calculated.

Heterobeltiosis (HP) = $\{(F_1 - HP) \times 100\}/HP$

Heterosis over mid parents (MP) = $\{(F_1 - MP) \times 100\}/MP$

where,

$MP = (P_1 + P_2)/2$

The standard errors for above estimates were calculated as follows

SE of heterobeltiosis = $(2 \times M_e \times 1/r)^{1/2}$

SE of heterosis = $(1.5 \times M_e \times 1/r)^{1/2}$

Where M_e is error mean square obtained from analysis of variance. If the

differences between the F_1 value and HP and F_1 value and MP were greater than the values obtained from the formulae above respectively, the heterosis estimates were considered significant.

3.2.7 Heritability

Heritability in broad sense (on plot basis) was calculated by using Genstat version 4, RBDMEAN.PRO (Appendix p.143).

3.4. Combined Analysis For Two Locations:

The combined analysis was done by considering two replications with the least standard error from IAC (replications one and three) and the two replications of Akola location. The ANOVA table is given in Table 3.3. The analysis was carried out by using Genstat 4 computer program. The combined analysis of variance for combining ability is shown in Table 3.4.

Table 3.1. Form of analysis of variance for individual locations.

Source of variation	DF
Replications (R)	(r-1)
Treatments (E)	(e-1)
Genotypes (G)	(g-1)
Hybrids (H)	(h-1)
Lines (L)	(l-1)
Testers (T)	(t-1)
L x T	(l-1)(t-1)
Parents (P)	(p-1)
Parents vs Hybrids	1
Controls (C)	(c-1)
Resistant controls (RC)	(rc-1)
Resistant vs susceptible	1
Genotypes vs controls	1
Error	(r-1)(e-1)
Total	r(e-1)

Table 3.2. Form of analysis of variance for combining ability for individual locations.

Source of variation	DF	MS	EMS
Lines (L)	l-1	M_l	$\sigma^2_e+\sigma^2_{lt}+t\sigma^2_l$
Testers (T)	t-1	M_t	$\sigma^2_e+\sigma^2_{lt}+l\sigma^2$
L x T	(l-1)(t-1)	M_{lt}	$\sigma^2_e+\sigma^2$
Error	lt(r-1)	M_e	σ^2

1. l and t are numbers of lines and testers respectively
2. Error is obtained from analysis of variance table directly as line x tester analysis is based on individual observation over replications. Mean squares due to lines, testers, and lines x testers are tested against error.

Table 3.3 Form of analysis of variance for combined locations

Source of variation	DF
Locations (Loc)	(r-1)
Location x replications	2
parents vs hybrids vs controls	2
Locations vs parents vs controls	2
Treatments (E)	(e-1)
Genotypes (G)	(g-1)
Hybrids (Hy.)	(Hy-1)
Lines (L)	(l-1)
Testers (T)	(t-1)
L x T	(l-1)(t-1)
Parents (P)	(p-1)
Parents vs Hybrids	1
Controls (C)	(c-1)
Resistant (RC)	(rc-1)
Resistant controls vs susceptible controls	1
Genotypes vs control	1
Loc x Controls	(Loc-1)(c-1)
Loc x parents	(Loc-1)(p-1)
Loc x L	(Loc-1)(l-1)
Loc x T	(Loc-1)(t-1)
Loc x L x T	(Loc-1)(l-1)(t-1)
Error	(Loc(r-1)(e-1)
Total	(Loc x r(e-1)

Table 3.4. Form of combined analysis of variance for combining ability

SV	DF	MS	EMS
Lines (L)	(l-1)	M_l	$\sigma^2_e + rL\sigma^2_{lt} + rLt\sigma^2_l$
Testers (T)	(t-1)	M_t	$\sigma^2_e + rL\sigma^2_{lt} + rLl\sigma^2_t$
L x T	(l-1)(t-1)	M_{lt}	$\sigma^2_e + rL\sigma^2_{lt}$
Loc x L	(Loc-1)(l-1)	$M_{Loc\,l}$	$\sigma^2_e + r\sigma^2_{Llt} + rt\sigma^2_{Ll}$
Loc x T	(Loc-1)(t-1)	$M_{Loc\,t}$	$\sigma^2_e + r\sigma^2_{Llt} + rl\sigma^2_{Lt}$
Loc x L x T	(Loc-1)(l-1)(t-1)	$M_{Loc\,lt}$	$\sigma^2_e + r\sigma^2_{Llt}$
Error	lt(r-1)	M_e	σ^2_e

4. RESULTS

4.1.1. Mean Performance

4.1.1.1. *Striga* incidence (SI%)

The mean *Striga* plants plot^{-1} (1.2 m^2) is given in Appendix 2a. In general, the infestation was low (1 plant plot^{-1}) as indicated by average *Striga* plants in the trial. The coefficient of variation (CV) was high (188%) which may indicate that infestation was not uniform across the trial in the field; and the differences for the susceptibility to the *Striga* among the test entries was not significant. Therefore, the *Striga* incidence in the test plots was weighed in relation to the average *Striga* plants in the nearest systematic susceptible control (CSH 1) plots, and a relative measure called *Striga* incidence (SI%) was calculated. Both SI% values and square root transformed values of SI% i.e., $\sqrt{}$(IS%+1) are given in Appendix 2a, and the coefficient of variation has been reduced to 76% in TSI% . Accordingly, entries were classified based on *Striga* incidence (SI%) as follows: those with less than 10% incidence as resistant, 11 to 20% as moderately resistant, and those with greater than 20 percent *Striga* incidence as susceptible.

Among the male-sterile lines, L1 (SPST 94009B), L2 (SPST 94011B), and L3 (SPST 94001B) confirmed to be resistant to *Striga* (having less than 10 percent incidence over the systematic susceptible control). Among the restorers, T1 (SAR 1), T3 (SAR 34), T4 (SAR 35), T6 (SAR 42), and T9 (ICSR 93004) showed less than 10 percent *Striga* incidence compared to the systematic susceptible control, therefore, were resistant. The susceptible male-sterile lines were L7 (ICSB 89) and L8 (ICSB 93), both with 60 IS%, and also the control 296B with 26.7% whereas susceptible restorer was T8

(ICSR 93002) with the maximum SI% (100). The other restorers (SAR 16, SAR 41, ICSR 92001) were moderately resistant.

The hybrids showed different responses to *Striga*. Among them, 23 showed less than 10 percent incidence over CSH 1. Of these, five hybrids had zero SI%. These were entry 16 (SPST 94011A x ICSR 92001), entry 41 (SPST 94008A x SAR 41), entry 42 (SPST 94008A x SAR 42), entry 47 (SPST 94026A x SAR 16), and entry 49 (SPST 94026A x SAR 35). However, the susceptible control entry 90 (296B) showed 26.7% i.e., susceptible, while resistant controls SAR 16 with zero SI% and SAR 34 was scored 13.3 SI%.

4.1.1.2. Days to 50% flowering (DFL)

At IAC average days to 50% flowering was 80 days (Appendix 2a). Among the male- sterile lines, the earliest to flower was L3 (SPST 94001B) which flowered in 72 days followed by L4 (SPST 94014B), and L6 (SPST 94026B), which both flowered at 75 days. Among the restorers, T5 (SAR 41) was the earliest (79 days), followed by T2 (SAR 16) and T3 (SAR 34), both of which flowered in 80 days, and T4 (SAR 35) which took 81 days to flower. Among the hybrids, the following were the earliest: entry 5 (SPST 94009A x SAR 41) and entry 29 (SPST 94014A x SAR 16) flowered in 73 days, entry 20 (SPST 94001A x SAR 16), entry 22 (SPST 94001A x SAR 35), and entry 47 (SPST 94026A x SAR 16) took 74 days to flower, while the following six hybrids attained 50% flowering in 76 days; entry 10 (SPST 94011A x SAR 1), entry 19 (SPST 94001A x SAR 1), entry 23 (SPST 94001A x SAR 41), entry 24 (SPST 94001A x SAR 42), entry 27 (SPST 94001A x ICSR 93004), entry 67 (ICSR 93 x SAR 35). The earliest

controls in this location were entry 92 (SAR 16) with 76 days, and entry 91 (SAR 1) (79 days).

4.1.1.3. Plant height (PHT)

The mean values for plant height at IAC are given in Appendix 2a. The average height was 1.85 m. Among the male-sterile lines, L8 (ICSB 93) was the tallest (1.93 m), while the shortest line was L4 (SPST 94014B) with 1.05 m plant height. Among the testers T1 (SAR 1) was the tallest (2.05 m), and T2 (SAR 16) was shortest (1.10 m). The following six hybrids were the tallest: entry 64 (ICSA 93 x SAR 1) (2.55 m), entry 66 (ICSA 93 x SAR 34) (2.50 m), entry 71 (ICSA 93 x ICSR 93002) (2.47 m), entry 70 (ICSA 93 x ICSR 92001), entry 37 (SPST 94008A x SAR 1), entry 55 (ICSA 89 x SAR 1) the last three hybrids had 2.40 m height. However, the lowest height was recorded in entry 38 (SPST 94008A x SAR 16) with plant height of 1.20 m, entry 31 (SPST 94014A x SAR 35) (1.30 m), entry 20 (SPST 94001A x SAR 16), and entry 29 (SPST 94014A x SAR 16) both with 1.35 m plant height. Among the controls, entry 91 (2.25 m) was the tallest, followed by entry 93 (SAR 34) with 1.75 m height.

4.1.1.4. Grain yield plant^{-1} (GYLD/PLT)

The mean grain yield plant^{-1} at IAC is given in Appendix 2a. In this location, the mean performance for grain yield was poor due to cultural practices (conditions for inducing *Striga* germination).

Among the male sterile-lines, L5 (SPST 94008B) and L8 (ICSB 93) had high grain yield (11.73 g plant^{-1}), and it was low in L6 (SPST 94026B) (3.33 g plant^{-1}). Among the restorers, the grain yield was high in T2 (SAR 16) (11.63 g plant^{-1}) followed by T5 (SAR

41) (11.37 g plant^{-1}), and the lowest in T7 (ICSR 92001) which was 6.37 g plant^{-1}. Among the hybrids, the following were the highest yielders: entry 35 (SPST 94011A x ICSR 93002), with 26.93 g plant^{-1}, entry 42 (SPST 94008A x SAR 42) with 23.10 g plant^{-1}, entry 15 (SPST 94011A x SAR 42) (21.00 g plant^{-1}), and entry 16 (SPST 94011A x ICSR 92001) which gave 20.83 g plant^{-1}. The grain yield was poor in the entry 38 (SPST 94008A x SAR 16) and entry 66 (ICSA 93 x SAR 34), which gave 1.83, and 2.43 g plant^{-1}, respectively. Among the controls entry 92 (SAR 16) scored the highest yield (10.10), followed by the susceptible control entry 296B with 9.20 g.

4.1.2. Analysis of variance

4.1.2.1. *Striga* incidence (SI%)

The analysis of variance for transformed *Striga* incidence is given in Table 4.1a. At IAC *Striga* infestation was low and not uniform which led to high heterogeneity among the data across the replications. Replications, treatments, genotypes, hybrids, lines and testers showed significant differences among the sources of variation.

4.1.2.2. Days to 50% flowering (DFL)

At this location (IAC) all sources of variation showed significant differences with the exception of replications, resistant controls, and genotypes vs controls (Table 4.1a).

4.1.2.3. Plant height (PHT)

The analysis of variance for plant height at IAC is given in Table 4.1a. All sources of variation for plant height were highly significant at IAC.

4.1.2.4. Grain yield plant^{-1} (GYLD/PLT)

As indicated in Table 4.1a, all sources of variation were highly significant for grain yield plant^{-1} at IAC location except resistant control vs susceptible control which was non significant.

4.1.3. The combining ability and gene action

4.1.3.1. *Striga* incidence (SI%)

The GCA and SCA variance at IAC is given in Table 4.2a. The variances due to general combining ability (GCA) of the lines and testers were significant at IAC location which indicates predominance of additive type of gene actions in determining the resistance (Table 4.2a). The ratio between GCA and SCA variance was less than one indicating that non-additive gene action was more important than additive gene action in governing the trait (Table 4.2a). For *Striga* resistance L5 (SPST 94008B) was the best combiner at IAC (highly negative significant GCA i.e., -0.90), followed by L2 (SPST 94011B) (-0.48) (Table 4.3a).

None of the testers had significant GCA effect in the desirable direction. However, high negative GCA effect was estimated in T6 (SAR 42), T2 (SAR 16), and T7 (ICSR 92001) and were the best combiners for *Striga* resistance (Table 4.4a).

The proportions contributed by lines, testers and their interaction to the total variance of SI% at IAC is given in Table 4.5a. The highest contribution to TSI% was shown by lines x testers. The lowest percentage was contributed by the male-sterile lines which was 14.5 which indicated the high diversity of the restores used in the crosses.

From the estimation of SCA effects at IAC (Table 4.6a), 37 hybrids showed negative (resistant) SCA for TSI%. The highest negative SCA effects were shown by the following ten' entries: entry 72 (ICSA 93 x ICSR 93004) with -2.60, entry 37 (SPST 94008A x SAR 1) with -2.49, entry 30 (SPST 94014A x SAR 34) with -2.36, entry 36 (SPST 94014A x ICSR 93004) with -2.27, entry 64 (ICSA 93 x SAR 1) had -2.16, entry 15 (SPST 94011A x SAR 42) with -2.04 SCA effect, entry 14 (SPST 94011A x SAR 41) with -1.76, entry 50 (SPST 94026A x SAR 14) with -1.76, entry 27 (SPST 94001A x ICSR 93004) with -1.66, entry 23 (SPST 94001A x SAR 41), entry 3 (SPST 94009A x SAR 34) with -1.62, and entry 4 (SPST 94009A x SAR 35) with -1.57 SCA effects.

4.1.3.2. Days to 50% flowering (DFL)

The Line x Tester analysis for DFL at IAC is given in Table 4.2a. Highly significant differences due to lines and testers were shown for DFL at IAC location, while LxT was significant. The ratio of GCA to SCA variance for DFL was less than one, indicating that days to 50% flowering is controlled mostly by non-additive gene action.

At IAC, L3 (SPST 94001B) was observed to be good combiner for earliness with significant (negative) GCA effects (-5.83), followed by L4 (SPST 94014A) (Table 4.3a). Among the testers, T2 (SAR 16) and T4 (SAR 35) were good combiners for earliness at IAC, with GCA effect values of -2.90, and -1.73, respectively (Table 4.4a).

Percent contribution to the total variance of lines, testers, and LxT interaction for DFL is presented in Table 4.5a. The highest contribution to the total variance of DFL at IAC was through LxT interaction (48.5), followed by lines (30.1).

The highest SCA effects was shown by the entry 42 (SPST 94008A x SAR 42) with -3.60, entry 18 (SPST 94011A x ICSR 93004) (-3.44), entry 32 (SPST 94014A x SAR 41) with -3.34, entry 33 (SPST 94014A x SAR 42) with -3.21 SCA effects, and entry 49 (SPST 94026A x SAR 35) with -3.04 SCA effects (Appendix 3).

4.1.3.3. Plant height (PHT)

The combining ability effect and gene action at IAC for plant height are given in Table 4.2a. Highly significant differences due to lines, testers, and lines x testers were observed at this location. The ratio between the GCA and SCA variances was less than one which indicated the importance of non-additive gene action. Among the male-sterile lines, L1 (SPST 94009B), L6 (SPST 94026B), L7 (ICSB 89), and L8 (ICSB 93) showed positive GCA effects (Table 4.3a), while, T1 (SAR 1) and T3 (SAR 34) were found to be good combiners with high positive GCA effects (Table 4.4a) among the restorers.

The proportion contributed by lines, testers, and their interaction to the total variance for plant height at IAC is shown in Table 4.5a. The highest percentage was contributed by lines (52.5%), while lowest contribution to the total variances was scored by LxT interaction (19.8%), which indicated that the restores used in the hybrids development were less diverse for plant height. The following hybrids had the highest positive significant SCA values (Appendix 4): entry 65 (ICSA 93 x SAR 16) with 0.40, entry 33 (SPST 94014A x SAR 42) with 0.31, entry 22 (SPST 94001A x SAR 35) with 0.20, and entry 41 (SPST 94008A x SAR 41) (0.18), and entry 59 (ICSR 89 x SAR 41) with 0.18.

4.1.3.4. Grain yield plant^{-1} (GYLD/PLT)

Analysis of variance for line x tester at IAC for grain yield plant^{-1} is given in Table 4.2a. Variances were significant with respect to grain yield plant^{-1} in lines, testers, and their interactions. The SCA variance was very large compared to that of GCA in this location (IAC), and the ratio, GCA variance to SCA variance was less than one which indicates the importance of non-additive gene action in governing this trait.

Line 2 (SPST 94011B) was found to be good combiner at IAC location, followed by L4 (SPST 94014B) and both had highly significant positive GCA effects i.e., 5.02 and 3.96, respectively (Table 4.3a). Among the testers, T6 (SAR 42), T8 (ICSR 93002) and T9 (ICSR 93004) showed positive significant GCA effect (Table 4.4a).

The proportional contributions of lines, testers, and LxT to the total variance of grain yield plant^{-1} at IAC is presented in Table 4.5a. The highest contribution was expressed by LxT, followed by lines. Significant positive SCA effect was found for 20 hybrids at IAC (Table 4.6b), and it was the highest in the following hybrids: entry 60 (ICSA 89 x SAR 42) with 10.23 , followed by entry 37 (SPST 94008A x SAR1) with 9.00 entry 67 (ICSR 93 X SAR 35) with 4.87, entry 17 (SPST 94011A X ICSR 93002) , entry 27 (SPST 94001A x ICSR 93004) 4.54, and entry 54 (SPST 94026A x ICSR 93004) with 3.37 SCA effects.

4.1.4. Heterosis

4.1.4.1. *Striga* incidence (SI%)

The average heterosis% (compared with the mean SI% of the two parents) wa calculated for individual locations separately. The heterosis analysis for *Striga* incidence at IAC is given in Table 4.6a. Heterosis for transformed *Striga* incidence (TSI%) ranged from 0.0 to 292.47% in opposite direction, and 0.00 to -69.97% in the desirable direction. At this location nine hybrids, i.e., entry 45 (SPST 94008A x ICSR 93004) (-69.97%), entry 37 (SPST 94008A x SAR 1) (-63.37%), entry 64 (ICSA 93 x SAR 1) (-61.56), entry 24 (SPST 94001A x SAR 42) (-58.95%), entry 30 (SPST 94014A x SAR 34) (-54.34), entry 14 (SPST 94011A x SAR 41) (-54.34), entry 72 (ICSA 93 x ICSR 93004) (-53.47), entry 8 (SPST 94009A x ICSR 93002) (-47.52), and entry 16 (SPST 94011A x ICSR 92001) (-36.46) showed highly negative heterosis, and most of these hybrids had negative SCA effects which is desirable (Table 4.6a).

4.1.4.2. Grain yield plant^{-1} (GYLD/PLT)

At IAC heterosis ranged from 0.00 to -80.26 in the opposed direction, and from 0.00 to 185.22% in the desirable direction, and heterobeltiosis ranged from -83.87 to 149.50%. There were 18 entries showing highly positive heterosis and heterobeltiosis at IAC (Table 4.6b). The following crosses showed the highest heterosis: entry 60 (ICSA 89 x SAR 42) with 185.22%, followed by entry 50 (SPST 94026A x SAR 41) (178.40%), entry 54 (SPST 94026A x ICSR 93004) (141.81%), entry 51 (SPST 94026A x SAR 42) (135.00%), and entry 37 (SPST 94008A x SAR 1) (134.01), while the highest heterobeltiosis showed by the following crosses: entry 60 (ICSA 89 x SAR 42) with

149.50%, entry 54 (SPST 94026A x ICSR 93004) (138.52%), entry 45 (SPST 94008A x ICSR 93004) (96.88%), entry 37 (SPST 94008A x SAR 1) with 81.52% and entry 50 (SPST 94026A x SAR 41) (79.09%).

4.4. Heritability

The broad sense heritability for the four traits (transformed SI%, days to 50% flowering, plant height, and grain yield plant^{-1}) at IAC is given in Table 4.7. The highest heritability was exhibited by grain yield plant^{-1} at IAC, 0.91, while the lowest heritability value was expressed by *Striga* incidence (0.10).

Akola (Location 2)

4.2.1. Mean performance

4.2.1.1. *Striga* incidence (SI%)

The mean of *Striga* plants plot^{-1} is given in Appendix 2b. The infestation was low (1 plant plot^{-1}) as showed by the average *Striga* plants in the experiment. The coefficient of variation (CV) was high (178%) indicating the non-uniformity of the infestation across the trial in the field, and the differences for the reaction with the *Striga* among the test entries was not significant. Therefore, the *Striga* incidence in the test plots was weighed in the same way as was done at IAC (location 1) by calculating the *Striga* incidence (SI%) in relation to the systematic control (CSH 1). The analysis of the SI% values transformed to square root transformation [$\sqrt{(SI\%+1)}$] is presented in Appendix 2b. The CV(%) has been reduced from 178 to 97. The entries were classified into three groups according to *Striga* incidence (SI%) as in the first location, those with SI% from 0.0 to 10 as resistant, from 11 to 20 percent as moderately resistant, and above 20 as susceptible.

Among the male-sterile lines, L2 (SPST 94011B), L3 (SPST 94001B), L4 (SPST 94014B), and L6 (SPST 94026B) were found to be resistant (having less than 10 SI%), while L5 (SPST 94008B) was moderately resistant (20 SI%). Among the restorers, the following entries were found to be resistant: T2 (SAR 16), T4 (SAR 35), T6 (SAR 42), and T9 (ICSR 93004). While, T3 (SAR 34) was moderately resistant to *Striga*. The susceptible male-sterile lines, L7 (ICSB 89) and L8 (ICSB 93) both depicted 110.0 SI%, whereas the susceptible restorers, T7 (ICSR 92001) and T8 (ICSR 93002) had 30.0 and

50.0 SI%, respectively. However, T9 (ICSR 93004) though was used as susceptible tester, but did not harbor any *Striga* plants in the plot.

Among the hybrids 37 found to be resistant with *Striga* incidence from 0.0 to 10 percent, among them 20 showed zero SI%: entry 2 (SPST 94009A x SAR 16), entry 7 (SPST 94009A x ICSR 92001), entry 12 (SPST 94011A x SAR 34), entry 13 (SPST 94011A x SAR 35), entry 19 (SPST 94001A x SAR 1), entry 20 (SPST 94001A x SAR 16), entry 22 (SPST 94001A x SAR 35), entry 23 (SPST 94001A x SAR 41), entry 24 (SPST 94001A x SAR 42), entry 27 (SPST 94001A x ICSR 93004), entry 33 (SPST 94014A x SAR 42), entry 34 (94014A x ICSR 92001), entry 37 (SPST 94008A x SAR 1), entry 38 (SPST 94008A x SAR 16), entry 42 (SPST 94008A x SAR 42), entry 43 (SPST 94008A x ICSR 92001), entry 47 (SPST 94026A x SAR 16), entry 49 (SPST 94026A x SAR 35), entry 51 (SPST 94026A x SAR 42), and entry 67 (ICSR 93 x SAR 35), while the susceptible control entry 90 (296B) showed 100 SI% and the resistant controls entry 91 (SAR 1), and entry 93 (SAR 34) were scored 0 and 10 SI% respectively.

4.2.1.2. Days to 50% flowering (DFL)

Days to flowering at Akola is given in Appendix 2b. Among the male-sterile lines, L3 (SPST 94001B) was the earliest line (flowered in 64 days), followed by L6 (SPST 94026B) which took 69 days to flower, and L2 (SPST 94011B) and L4 (SPST 94014B) both flowered in 77 days. Among the restorers, T5 (SAR 41) was the earliest, which flowered in 75 days, followed by T2 (SAR 16) (76 days), and T3 (SAR 34) which took 77 days to flower. Among the controls entry 93 (SAR 34) was the earliest (77 days), followed by entry 92 (SAR 16) which flowered in 78 days.

The following 10 entries were the earliest ones among the hybrids: entry 5 (SPST 94026A x ICSR 93004) and entry 56 (ICSA 89 x SAR 16) both flowered in 6 days, entry 53 (SPST 94026A x ICSR 93002) flowered in 67 days, entry 24 (SPST 94001A x SAR 42) took 68 days to flower, entry 48 (SPST 94026A x SAR 34), entry 49 (SPST 94026A x SAR 34) and flowered in 69 days; entry 19 (SPST 94001A x SAR 1) and entry 27 (SPST 94001A x ICSR 93004) both flowered in 70 days, entry 21 (SPST 94001A x SAR 34) and entry 50 (SPST 94026A x SAR 41) took 71 days to flower. The remaining six flowered in 72 days: entry 1 (SPST 94009A x SAR 1) , entry 29 (SPST 94014A x SAR 16), entry 32 (SPST 94014A x SAR 41), entry 47 (SPST 94026A x SAR 16), entry 51 (SPST 94026A x SAR 42), and entry 66 (ICSA 93 x SAR 34).

4.2.1.3. Plant height (PHT)

The means for plant height at Akola are given in Appendix 2b. The average height was 1.68 m. Among the male-sterile lines the tallest lines were L7 (ICSB 89) with 1.85 m plant height, followed by L8 (ICSB 93) with 1.70 m, while the shortest lines were L2 (SPST 94011B) and L4 (SPST 94014B), both with 0.95 m plant height. Among the testers, the tallest were T3 (SAR 34) with 1.80 m and T1 (SAR 1) (1.75 m), while the lowest plant heights were recorded in T2 (SAR 16) (1.15 m), T5 (SAR 41), and T9 (ICSR 93004) both with 1.40 m. Among the controls entry 91 (SAR 1) was the tallest (1.75 m), followed by susceptible control entry 90 (296B) with 1.70 m.

Among the hybrids, the following were the tallest: entry 61 (ICSA 89 x ICSR 92001) with 2.45 m height, entry 64 (ICSR 93 x SAR 1) with 2.40 m, entry 37 (SPST 94008A x SAR 1), entry 71 (ICSA 93 x ICSR 93002) the two with 2.30 m, entry 62 (ICSA

89 x ICSR 93002), and entry 70 (ICSA 93 x ICSR 92001) both with 2.25 m plant height. However, the shortest entries were the following: entry 28 (SPST 94014A x SAR 1) entry 38 (SPST 94008A x SAR 16) both with 0.95 m height, entry 29 (SPST 94014A SAR 16) with 1.10 m height, entry 32 (SPST 94014A x SAR 42) with 1.15 m heigh entry 20 (SPST 94001A x SAR 16), entry 18 (SPST 94011A x ICSR 93004) and 3 (SPST 94014A x SAR 35) each with 1.30 m height.

4.2.1.4. Grain yield plant^{-1} (GYLD/PLT)

The means for grain yield plant^{-1} are given in Appendix 2b. Among the male-sterile lines, entries L7 (ICSB 89), L6 (SPST 94026B), L5 (SPST 94008B), and L8 (ICSB 93) were the highest yielding lines with grain yield plant^{-1} of 29.4 g, 28.4 g, 22.9 g, and 21.3 g, respectively. Among the restorers, T2 (SAR 16) was highest yielder with 26.15 g plant^{-1}, followed by T8 (ICSR 93002) of 25.15 g plant^{-1} and T6 (SAR 42) with 23.55 g plant^{-1}.

Among the hybrids the following entries had the highest grain yield plant^{-1}: entry 65 (ICSA 93 x SAR 16) with 72.75 g, entry 64 (ICSA 93 x SAR 1) with 72.65 g, entry 72 (ICSA 93 x ICSR 93004) with 69.75 g, entry 23 (SPST 94001A x SAR 41) (69.00 g), entry 41 (SPST 94008A x SAR 41) with 63.00 g, entry 54 (SPST 94026A x ICSR 93004) with 59.1 g, and entry 67 (ICSA 93 x SAR 35) with 58.55 g. The poorest grain yields were recorded in entry 57 (ICSA 89 x SAR 34) with 11.75 g, entry 60 (ICSA 89 x SAR 42) with 16.55 g, and entry 25 (SPST 94001 x ICSR 92001) with 20.90 g. However, among the hybrids, the high yield was recorded in the susceptible control entry 90 (296B) with 19.40 g plant^{-1}.

4.2.2. Analysis of variance

4.2.2.1 *Striga* incidence (SI%)

At Akola, *Striga* infestation was low and not uniform, which resulted in high heterogeneity among the data across the replications of the same location. Square root transformation of SI% was used for the analysis. Only lines, controls, and resistant control vs susceptible control showed significant differences (Table 4.1a).

4.2.2.2. Days to 50% flowering (DFL)

Treatments, genotypes, lines, parents vs controls vs hybrids and parents vs controls exhibited significant differences in this location (Table 4.1a).

4.2.2.3. Plant height (PHT)

Most sources of variation for plant height were significant at Akola with the exception of replications, and resistant controls vs susceptible controls (Table 4.1a).

4.2.2.4. Grain yield plant^{-1} (GYLD/PLT)

Consistent highly significant differences for grain yield plant^{-1} at this location were due to treatments, genotypes, lines, testers, LxT, parents, parents vs controls vs hybrids, parents vs controls, and genotypes vs controls Table 4.1a.

4.2.3. The combining ability and gene action

4.2.3.1. *Striga* incidence (SI%)

The variances due to GCA of the lines was significant at Akola location which indicated both additive and non-additive type of gene actions are involved in determining the resistance (Table 4.2a). The ratio between GCA variance and SCA variance was

less than one indicating that non-additive gene action was more important than additive gene action in governing the trait (Table 4.2a). Testers variances due to GCA were not significant. Among the lines, L3 (SPST 94001B) was the best combiner for *Striga* resistance, followed by L6 (SPST 94026B) (Table 4.3a). Among the testers T6 (SAR 42) was the best combiner (showed the highest negative GCA effect), followed by T4 (SAR 35) (Table 4.4a).

The proportions contributed by lines, testers and their interaction to the total variances of TSI% is given in Table 4.5a. The highest contribution to TSI% was shown by lines x testers (66.70), and the lowest percentage was contributed by testers which was 14.8.

From the estimation of SCA effects at Akola, 41 entries expressed negative SCA effects (Table 4.6a), with the highest SCA effects expressed by the following entries: entry 52 (SPST 94026A x ICSR 92001) (-3.11), entry 32 (SPST 94014A x SAR 41) (-3.02), entry 63 (ICSA 89 x ICSR 93004) (-2.79), entry 18 (SPST 94011A x ICSR 93004) (-2.68), entry 44 (SPST 94008A x ICSR 93002) (-2.38), and entry 56 (ICSA 89 x SAR 16) (-2.24).

4.2.3.2. Days to 50% flowering (DFL)

Significant differences due to lines and testers were shown for DFL at Akola location. GCA variance for DFL was relatively large at Akola when compared with that of IAC, while SCA variance was relatively smaller at Akola than at IAC, and the ratio between GCA and SCA variance was less than one (Table 4.2a), an indication that days to 50% flowering is controlled by non-additive gene action as found at IAC.

Line 3 (SPST 94001B) with -5.83 GCA effect and L6 (SPST 94026A) (-4.20) were found to be good general combiners at Akola (Table 4.3a). Among the testers T5 (SAR 41) (-4.69) and T3 (SAR 34) (-1.76) were good combiners (Table 4.4a).

Percent contribution to the total variance, of lines, testers, and LxT interaction for DFL at Akola is presented in Table 4.5a. The highest contribution to the total variance of DFL was expressed by LxT interaction (52.30), followed by lines (31.90).

Estimates of SCA effects indicated that entry 70 (ICSA 93 x ICSR 92001) had the highest SCA effects (-5.78), followed by entry 1 (SPST 94009A x SAR 1) (-5.72), entry 24 (SPST 94001A x SAR 42) (-4.76), entry 32 (SPST 94014A x SAR 41) (-4.33), entry 12 (SPST 94011A x SAR 34) with -3.65 SCA effect (Appendix 3).

4.2.3.3. Plant height (PHT)

Highly significant differences due to lines, testers and lines x testers were observed at Akola location (Table 4.2a). GCA and SCA variances for plant height at Akola location were very small, and the ratio between the GCA variance and SCA variance was less than one which indicated the importance of non additive gene action. Among the lines, L8 (ICSB 93), and L7 (ICSB 89) were found to be good combiners for plant height with highly positive significant GCA effects (Table 4.3a). Among the resistant testers T3 (SAR 34) and T1 (SAR 1) were found to be good combiners with highly positive GCA effects at Akola location (Table 4.4a).

The proportions contributed by lines, testers, and their interaction to the total variance for plant height is shown in Table 4.5a. The highest percentage was contributed by lines, and the lowest contribution to the total variances was scored by LxT

interaction (Table 4.5a). Among the hybrids the following showed highest SCA effects: entry 2 (SPST 94009A x SAR 16) (0.37), entry 5 (SPST 94009A x SAR 41) with 0.31, entry 55 (ICSA 89 x SAR 1) (0.31), entry 9 (SPST 94009A x ICSR 93004) with 0.28, and entry 69 (ICSA 93 x SAR 42) with 0.25 SCA effects (Appendix 4).

4.2.3.4. Grain yield plant^{-1} (GYLD/PLT)

At Akola, significant differences for grain yield plant^{-1} were observed for the lines, testers, and their interactions (Table 4.2a). The SCA variance was very large compared to that of GCA in this location, and the ratio of GCA variance to SCA variance was less than one which indicated the importance of non-additive gene action in governing this trait. Line 8 (ICSB 93) was found to be good combiner (positively high significant GCA effects i.e., 10.03), followed by L5 (SPST 94008B) (9.69), and L3 (SPST 94001B) (4.49) (Table 4.3a). Among the testers, T9 (ICSR 93004) showed positive highly significant GCA (11.60), followed by T1 (SAR 1) with 4.17 GCA effects (Table 4.4a).

The proportional contribution of lines, testers, and LxT to the total variance of yield is presented in Table 4.5a. The highest contribution was expressed by LxT interaction (60.10) followed by lines (24.40).

On examination of the SCA effects for grain yield at Akola, revealed that 19 entries showed significant positive SCA effects. The highest significant SCA effects was observed in the following entries: entry 55 (ICSA 89 x SAR 1) with value of 26.39, entry 35 (SPST 94014A x ICSR 93002) with value of 26.07 SCA effects, entry 16 (SPST 94011A x ICSR 92001) with 22.11 SCA, entry 22 (SPST 94001A x SAR 35) with 20.34, entry 8 (SPST 94009A x ICSR 93002) with 19.43,and entry 37 (SPST 94008A x SAR 1)

with 18.87. High negative SCA effect was expressed by entry 56 (ICSA 89 x SAR 16) with value of -25.34, followed by entry 69 (ICSA 93 x SAR 42) with -20.72.

4.2.4. Heterosis

4.2.4.1. *Striga* incidence (SI%)

At this location (Akola) heterosis ranged from 0.00 to -83.87% in the desirable direction, and from 0.00 to 78.26% in the opposed direction (Table 4.6a). Highly negative heterosis was shown by 28 entries. Following entries showed highly negative heterosis: entry 67 (ICSA 93 x SAR 35) with -83.87%, entry 9 (SPST 94009A x ICSR 93004) with -81.31%, entry 45 (SPST 94008A x ICSR 93004) with (-75.16), entry 49 (SPST 94026A x SAR 35) with -73.86%, entry 43 (SPST 94008A x ICSR 92001) with -71.01% and entry 65 (ICSR 93 x SAR 16) with -66.67%.

4.2.4.2. Grain yield plant^{-1} (GYLD/PLT)

At Akola heterosis ranged from 0.00 to -41.03 in the opposed direction, and from 0.00 to 376.61% in the desirable direction, and heterobeltiosis ranged from 0.00 to -29.72% in the opposed direction, and from 0.00 to 317.94% in the desirable direction. Among the hybrids 34 entries showed highly positive heterosis and heterobeltiosis (Table 4.6b). The highest heterosis percent was expressed by entry 37 (SPST 94008A x SAR 1) with 375.61%, entry 16 (SPST 94011A x SPST 92001) with 366.35%, entry 32 (SPST 94014A x SAR 41) with 292.95%, entry 8 (SPST 94009A x ICSR 93002) with 286.95%, and entry 29 (SPST 94014A x SAR 16) with 238.98%. However, the highest heterobeltiosis was reflected by entry 37 (SPST 94008A x SAR 1) with 317.94%, entry

16 (SPST 94011A x ICSR 92001) with 286.97%, entry 32 (SPST 94014A x SAR 42) with 236.49%, entry 29 (SPST 94014A x SAR 16) 216.09%, and entry 40 (SPST 94008A x SAR 35) with 196.37%.

4.2.5. Heritability

The broad sense heritability for the four traits (SI%, days to 50% flowering, plant height and grain yield plant^{-1}) is given in Table 4.7. The highest heritability was showed by grain yield plant^{-1} which was 0.95, while the lowest heritability value was expressed by *Striga* incidence (0.02). However, for DFL the heritability was high at the two locations.

4.3. Combined Analysis

4.3.1. Mean Performance

4.3.1.1. *Striga* incidence (SI%)

The pooled mean *Striga* plants plot^{-1} (1.05 m^2) is given in Appendix 2c. The infestation was low (1 plant plot^{-1}) as indicated by average *Striga* plants in the experiment. The coefficient of variation CV (%) was high (157) for actual *Striga* plants and (164) for SI% indicating the infestation was not uniform, and the differences for the susceptibility to the *Striga* among the test entries was not significant. The same procedure used in the individual locations for calculating SI% was applied in the combined analysis. Square root transformation of SI% [$\sqrt{(SI\%+1)}$] was used for the analysis. The CV% reduced from 164 to 71. Classification for *Striga* resistance based on *Striga* incidence (SI%) was used in the combined analysis as follows: 0-10 percent incidence as resistant, 11-20 percent as moderately resistant, and those with greater than 20 percent *Striga* incidence as susceptible.

All resistant male-sterile lines, L1 (SPST 94009B) (7.0), L2 (SPST 94011B) (0.5), L3 (SPST 94001B) (0.5), L4 (SPST 94014B) (0.5), and L5 (SPST 94008B) (6.7) were resistant to *Striga* except L6 (SPST 94026B) which was moderately resistant (10.5). Among the restorers used as resistant sources, T1 (SAR 1), T3 (SAR 34), T4 (SAR 35), and T6 (SAR 42) had less than 10 percent *Striga* incidence over the systematic susceptible control, while in, T2 (SAR 16), and T5 (SAR 41) 10.5 and 17.3% *Striga* incidence was noticed, respectively. Similarly, susceptible male-sterile lines, L7 (ICSB 89) with 43.7 SI% and L8 (ICSB 93) with 49.5 SI%, whereas the early classified

susceptible restorers were T7 (ICSR 92001) with 7.5%, T8 (ICSR 93002) with 32.50 and T9 (ICSR 93004) with 0.5 SI%. All resistant controls (SAR 1, SAR 16, and SAR 34) were confirmed to be resistant, while the susceptible control 296B was showed 24.5 SI%.

Among the hybrids, 37 showed less than 10 percent incidence over CSH 1. Some of the hybrids with lowest SI% (less than 2.5%) were entry 7 (SPST 94009A x ICSR 92001), entry 11 (SPST 94011A x SAR 16), entry 16 (SPST 94011A x ICSR 93001), entry 28 (SPST 94014A x SAR 1), entry 32 (SPST 94014A x SAR 41), entry 41 (SPST 94008A x SAR 41), entry 42 (SPST 94008A x SAR 42), entry 47 (SPST 94026A x SAR 16), entry 49 (SPST 94026A x SAR 35), entry 51 (SPST 94026A x SAR 42).

4.1.1.2. Days to 50% flowering (DFL)

The means for DFL in combined analysis are given in Appendix 2c. In this analysis the average DFL was 78 days. Among the male-sterile lines, the earliest one to flower was L3 (SPST 94001B) which flowered in 69 days, followed by L6 (SPST 94026B) (72 days). Among the restorers, T2 (SAR 16) was the earliest to flower (77 days), followed by T3 (SAR 34) and T5 (SAR 41) both took 78 days to flower. While the earliest control was entry 92 (SAR 16) (78 days), followed by entry 93 (SAR 34) which flowered in 79 days.

The following hybrids were the earliest: entry 24 (SPST 94001A x SAR 42), entry 49 (SPST 94026A x SAR 35) both flowered in 72 days, entry 20 (SPST 94001A x SAR 16), entry 29 (SPST 94014A x SAR 16), entry 47 (SPST 94026A x SAR 16) and entry 48 (SPST 94026A x SAR 34) flowered in 73 days, entry 21 (SPST 94001A x SAR 34),

entry 27 (SPST 94001A x ICSR 93004), and entry 53 (SPST 94026A x ICSR 93002) which took 74 days to flower.

4.1.1.3. Plant height (PHT)

The mean of plant height in the combined analysis is given in Appendix 2c. The average height was 1.77 m. Among the male-sterile lines L7 (ICSB 89) was the tallest (1.84 m), while the shortest line was L4 (SPST 94014B) with 0.99 m height. Among the testers T1 (SAR 1) was the tallest with 1.93 m height, whereas T2 (SAR 16) was shortest restorer with 1.15 m plant height. The following six hybrids were the tallest in the experiment: entry 64 (ICSA 93 x SAR 1) (2.49 m), entry 61 (ICSA 89 x ICSR 92001) (2.39 m), entry 70 (ICSA 93 x ICSR 92001) (2.38 m), entry 66 (ICSA 93 x SAR 34) (2.35 m), entry 71 (ICSA 93 x ICSR 93002) (2.38 m), entry 48 (SPST 94026A x SAR 34) (2.31 m), and entry 62 (ICSA 93 x ICSR 93002) (2.31 m). However, the lowest height was recorded in entry 29 (SPST 94014A x SAR 16), entry 32 (SPST 94014A x SAR 41), entry 38 (SPST 94008A X SAR 16), the three with plant height of 1.26 m, followed by entry 31 (SPST 94014A x SAR 35) (1.28 m). While the tallest control was entry 91 (SAR 1) with 2.05 height.

4.1.1.4. Grain yield plant^{-1} (GYLD/PLT)

The mean for grain yield plant^{-1} in combined analysis is given in Appendix 2c. In the pooled mean grain yield plant^{-1} was 21.95 g. Among the male-sterile lines, L8 (ICSB 93), and L7 (ICSB 89) had high grain yield of 20.52 g and 18.50 g plant^{-1}, respectively, and the lowest by L4 (SPST 94014B) which was 9.03 g plant^{-1}. Among the restorers, the highest grain yield was recorded in T9 (ICSR 93004)(17.23 g plant^{-1}),

followed by T3 (SAR 34) (16.30 g plant^{-1}), and the lowest by T6 (SAR 42) which was 9.25 g plant^{-1}. Among the controls the highest yield was recorded in entry 90 (296B) with 15.40 g grain yield plant^{-1} , followed by entry 92 (SAR 16) (12.15 g). Among the hybrids, the following were the highest yielders: entry 41 (SPST 94008A x SAR 41), with 41.88 g plant^{-1}, entry 72 (ICSA 93 x ICSR 93004) with 41.48 g plant^{-1}, entry 64 (ICSA 93 x SAR 1) (39.15 g plant^{-1}), and entry 65 (ICSA 93 x SAR 16) which gave 39.08 grams plant^{-1}. The grain yield was poor in entry 57 (ICSA 89 x SAR 34) (10.90 g), and entry 47 (SPST 94026A x SAR 16) which gave 11.93 g plant^{-1}.

4.1.2. Analysis of variance

4.1.2.1. *Striga* incidence (SI%)

Low *Striga* infestation and non-uniformity led to high heterogeneity among the data across the locations and within the replications of the same location, hence for combined analysis two replications with least standard errors were considered. The coefficient of variation CV(%) was very high (164), the square root transformation of SI% reduced CV% to 71 (Appendix 2c). From the analysis, variances due to locations, replications within location, treatments, genotypes, resistant control vs susceptible control, testers and parents were significant (Table 4.1b). Locations x genotypes interaction effects were not significant indicating that the data can be pooled across the locations. However, since locations effects are significant, individual locations data are analyzed and presented in previous sections.

4.1.2. Days to 50% flowering (DFL)

In combined analysis, the locations, parents vs hybrids vs controls, treatments, genotypes, hybrids, lines, testers, parents, parents vs hybrids showed highly significant differences (P= 0.01).(Table 4.1b.). As in SI%, locations x genotypes effects were not significant.

4.1.3 Plant height (PHT)

Most sources of variation were significant for plant height, except replications within locations, locations vs parents vs hybrids vs control, resistant control vs susceptible control, location x parents, locations x lines, and locations x testers (Table 4.1b).

4.1.4. Grain yield plant^{-1}

From combined analysis all sources of variations were highly significant except replications within the location, controls, resistant controls, and resistant controls vs susceptible controls (Table 4.1b).

4.3.3. The combining ability and gene action

4.3.3.1. *Striga* incidence (SI%)

The pooled analysis indicated that the variances due to lines, testers, and LxT were not significant. The ratio between GCA and SCA variance was less than one indicating non-additive gene action was more important than additive gene action in governing the trait (Table 4.2b). Estimates of GCA effect for lines in combined analysis (Table 4.3b) indicated that L5 (SPST 94008B) was the best combiner for *Striga*

resistance (high negative GCA effect i.e., -4.70), followed by L2 (SPST 94011B) (-2.26) Among the testers, T6 (SAR 42) showed the highest negative GCA (-5.96) followed by T2 (SAR 16) (-3.94) (Table 4.4b).

The proportions contributed by lines, testers and their interaction to the total variance for SI% is given in Table 4.5b. The highest percentage to SI% was contributed by lines x testers (70.06), followed by testers (23.65) which indicated the diversity of the testers used in the trial.

From the estimation of SCA effects in combined analysis, six crosses showed highly negative SCA effects; they were entry 70 (ICSA 93 x ICSR 92001) with -1.68, entry 60 (ICSA 89 x SAR 42) with -1.60, entry 28 (SPST 94014A x SAR 1) with -1.50, entry 49 (SPST 94026A x SAR 35), with -1.33, and entry 54 (SPST 94026A x ICSR 93004) with -1.08 (Table 4.6c).

4.3.3.2. Days to 50% flowering (DFL)

In the combined analysis, the SCA variance (0.70) was more important than GCA variance (0.41) and the ratio between GCA and SCA variance was less than one (Table 4.2b), an indication that DFL is controlled by non-additive gene action. Among the lines, L3 (SPST 94001B) with -4.84, and L6 (SPST 94026B) with -1.89 were found to be good general combiners in the combined analysis (Table 4.3b). Among the testers T5 (SAR 41) with -2.27, and T2 (SAR 16) with -1.14 were the best combiners for DFL (Table 4.4b).

Percent contribution to the total variances of lines, testers, and LxT interaction for days to 50% flowering is presented in Table 4.5b. The highest contribution to the total

variances of DFL was expressed by LxT interaction (43.54), followed by lines (38.88).

In the combined analysis the highest negative SCA effects were shown by the following entries: entry 51 (SPST 94026A X SAR 42) with -12.04, followed by entry 1 (SPST 94009A x SAR 1) with -3.59, entry 36 (SPST 94014A x ICSR 93004) (-3.44), entry 49 (SPST 94026A x SAR 35) (-2.87), entry 70 (ICSA 93 X ICSR 92001) with -2.30 SCA effects (Table 4.6c).

4.3.3.3. Plant height (PHT)

Highly significant differences due to lines, testers and line x testers were observed in the combined analysis for plant height (Table 4.2b). The ratio between the GCA variance to SCA variance was equal to one indicating the importance of both additive and non-additive gene action in controlling the plant height. Among the male-sterile lines, L8 (ICSB 93) (0.93) and L7 (ICSB 89) (0.28) were found to be good combiners for height (Table 4.3b). Among the testers, T3 (SAR 34) with (0.23), T1 (SAR 1) with (0.22) were found to be good combiners with high positive GCA effects in the combined analysis (Table 4.4b).

The proportions contributed by lines, testers, and their interaction to the total variance for plant height is shown in Table 4.5b. The highest percentage was contributed by the lines (59.84), while the lowest contributor to the total variances was LxT interaction (16.59).

The highest positive SCA effects were shown by the following crosses: entry 10 (SPST 94011A x SAR 1) and entry 22 (SPST 94001A x SAR 35) both with significant values of 0.26, other crosses, namely, entry 18 (SPST 94011A x ICSR 93004), entry 24

(SPST 94001A x SAR 42), entry 32 (SPST 94014A x SAR 41), and entry 33 (SPST 94014A x SAR 42), and entry 37 (SPST 94008A x SAR 1) also had high SCA effects (Table 4.6c).

4.3.3.4. Grain yield plant^{-1} (GYLD/PLT)

In the combined analysis, significant variances for grain yield plant^{-1} was observed due to lines, testers, and the their interactions (Table 4.2b). The SCA variance was very large compared to that of GCA, and the ratio of GCA variance to SCA variance was less than one which indicates the importance of non-additive gene action in governing the grain yield plant^{-1}

Among the lines, L5 (SPST 94008A) (5.50) was found to be good combiner, followed by L8 (ICSB 89) with 3.50 GCA effect (Table 4.3b). Among the testers, T9 (ICSR 93004) was the best combiner for the yield (6.65), followed by T1 (SAR 1) with 0.71 GCA effects (Table 4.4b).

The proportions contributed by lines, testers, and LxT to the total variance of grain yield is presented in Table (4.5b). The highest contribution was through LxT interaction (74.97), followed by testers (19.46).

On examination of the SCA effects for grain yield in combined analysis (Table 4.6c) reflected that, entry 24 (SPST 94001A x SAR 42) showed the highest SCA effects (13.03), followed by entry 72 (ICSA 93 x ICSR 93004) (11.83), entry 69 (ICSA 93 x SAR 42) (11.67), and entry 51 (SPST 94026A x SAR 42) (10.66). On the other hand the highest negative SCA effect was noticed in the entry 19 (SPST 94001A x SAR 1) (-12.12), followed by entry 14 (SPST 94011A x SAR 41) (-9.71).

Table 4.1a. Analysis of variance for transformed *Striga* incidence (TSI%), days to 50% flowering (DFL), plant height (PHT), and grain yield plant^{-1} (GYLD/PLT) at ICRISAT Asia Center (IAC) and Akola.

		Mean squares							
		TSI%[a]		DFL		PHT		GYLD/PLT	
SV	DF	IAC	Akola	IAC	Akola	IAC	Akola	IAC	Akola
Replication	2(1[b])	31.50**	3.07	16.96	0.65	0.07*	0.08	0.68	3.07
Treatment	92	11.13*	9.77	43.75**	61.67*	0.42**	0.26**	67.19**	471.73**
Genotypes(G)	88	11.35*	9.35	43.35**	62.69*	0.40**	0.26**	68.84**	464.21**
Hybrids (Hy)	71	11.39*	8.48	28.80**	59.43	0.34**	0.26**	79.15**	405.90
Lines (L)	7	16.76*	22.36*	87.93**	192.47**	1.79**	1.38**	267.06**	1019.56**
Testers (T)	8	19.05*	10.99	54.76**	83.24	0.82**	1.47**	171.30**	545.86**
L x T	56	9.63	6.39	17.70*	39.39	0.08**	0.09*	42.49**	309.20**
Parents (P)	16	10.83	13.76	100.42**	65.88	0.26**	0.18**	19.95**	66.83**
P vs C vs Hy	2	10.05	2.46	85.34**	178.50*	4.01**	1.40**	85.62**	6715.32**
P vs C	1	16.47	0.40	163.24**	243.39**	7.37**	2.41*	119.13**	10962.19**
Controls (C)	3	7.10	23.84*	67.78**	14.17	0.90**	0.17*	24.01**	26.91
Resis. Cont.	2	7.51	3.10	21.44	17.17	1.02**	0.25**	29.48**	18.50
Resis.Cont.vs Sus. Cont	1	6.28	65.34**	160.44**	8.17	0.63**	0.02	13.08*	43.74
G vs C	1	3.62	11.5	7.45	114.21	0.65**	0.38**	52.10**	2468.45**
Error	184(92[b])	8.31	9.46	11.95	42.27	0.03	0.04	2.10	12.01

*,**, Significant at 0.05 and 0.01 levels of probability, respectively.
Lines and testers mean squares were tested against lines x testers mean squares, and lines x testers mean squares are tested against error mean squares.
a = Square root transformation $\sqrt{(SI\% + 1)}$. b = DF for Akola.

Table 4.1b. Combined Analysis of variance for transformed *Striga* incidence (TSI%), days to 50% flowering (DFL), plant height (PHT), and grain yield plant^{-1} (g) (GYLD/PLT)

		Mean squares			
SV	DF	TSI%[a]	DFL	PHT	GYLD/PLT
Locations	1	331.43**	2191.96**	3.38*	57985.09**
Replication within location	2	29.50**	23.13	0.08	1.89
P vs HY. vs Cont.	2	4.76	221.26**	4.08**	3989.25**
Loc. vs P vs HY. vs Cont.	2	4.29	24.47	0.14	2780.91**
Treatments	92	5.58*	66.22**	0.50**	267.93**
Genotypes	88	5.59*	67.49**	0.49**	262.30**
Genotypes vs controls	1	0.15	76.84	0.80**	1514.52**
Controls	3	6.99	25.42	0.65**	17.67
Resistant cont.	2	2.96	7.75	0.91**	3.01
Resis. cont. vs sus.cont.	1	15.06*	60.75	0.13	47.01
Hybrids	71	5.19	49.51**	0.43**	224.65**
Lines (L)	7	3.99	195.27**	2.62**	481.68*
Testers (T)	8	10.29*	77.25**	0.90**	309.10*
L x T	56	4.61	27.33	0.09**	180.34**
Parents (P)	16	7.15*	125.65**	0.32**	41.73**
Parents vs Hybrids	1	9.37	365.67**	7.36**	6463.93**
Loc x parents	16	3.99	13.71	0.01	36.59**
Loc x cont.	3	3.55	14.08	0.15**	26.25**
Loc x lines	7	1.79	44.57	0.04	721.10**
Loc x testers	8	6.96	47.88	0.04	343.20**
Loc x (LxT)	56	4.59	22.57	0.07**	159.04**
Error	184	4.20	25.39	0.04	7.18

*,**, Significant levels at 0.05, and 0.01 levels of significant respectively.
Mean squares of lines and testers were tested against mean squares of lines x testers.
Mean squares of lines x testers were tested against mean squares of error.
a = Square root transformation $\sqrt{(SI\%+1)}$.

Table 4.2a. Line x tester analysis of variance for transformed *Striga* incidence (TSI%), days to 50% flowering (DFL), plant height (PHT), and grain yield plant^{-1} (g) (GYLD/PLT).

		Mean squares							
		TSI%[a]		DFL		PHT		GYLD/PLT	
SV	DF	IAC	Akola	IAC	Akola	IAC	Akola	IAC	Akola
Lines	7	16.76*	22.36*	87.3**	192.47**	1.78**	1.38**	267.06**	1019.56*
Testers	8	19.05*	10.99	54.76**	83.24	0.82**	1.47**	171.30**	545.86**
Lines x testers	56	9.63	6.39	17.70*	39.39	0.08**	0.09**	42.49**	309.20**
Error	184(92[b])	8.31	9.46	11.95	42.27	0.020	0.040	2.10	12.01
σ^2_{GCA}		0.020	0.040	0.14	0.370	0.003	0.003	0.46	1.80
σ^2_{SCA}		0.440	-1.540	1.920	-1.400	0.020	0.026	13.470	148.600
$\sigma^2_{GCA}/\sigma^2_{SCA}$		0.046	-0.026	0.073	-0.257	0.150	0.125	0.030	0.010

*,** Significant at 0.05, 0.01 levels of probability, respectively
Mean squares due to lines and testers were tested against mean squares due Lines x testers, and Lines x testers, were tested against error mean squares.
a = Square root transformation $\sqrt{}$(SI%+1).
b = DF for Akola.

Table 4.2b. Combined analysis of variance for *Striga* incidence (TSI%), days to 50% flowering (DFL), Plant height (PHT), and grain yield plant^{-1} (g) (GYLD/PLT) in Line x tester experiment.

		Mean squares			
SV	DF	TSI%[a]	DFL	PHT	GYLD/PLT
Lines	7	3.99	195.27**	2.60**	481.68**
Testers	8	10.29	77.25*	0.90**	309.96**
L x T	56	4.61	27.33	0.09**	180.34**
Loc x L	7	1.79	44.57	0.90**	721.10**
Loc x T	8	6.97	47.88	0.15**	343.20**
Loc x L x T	56	4.59	22.57	0.07**	159.04**
Error	184	4.20	25.39	0.03	7.17
σ^2_{GCA}		0.01	0.41	0.01	0.83
σ^2_{SCA}		0.10	0.71	0.01	37.97
$\sigma^2_{GCA}/\sigma^2_{SCA}$		0.10	0.58	1.00	0.02

*,** Significant at 0.05 and 0.01 levels of probability, respectively.
a = Square root transformation $\sqrt{}$ (SI%+1).

Table 4.3a. Estimates of GCA effects for transformed *Striga* incidence (TSI%), days to 50% flowering (DFL), plant height (PHT), and grain yield plant^{-1} (GYLD/PLT) on lines (male sterile lines) in line x tester experiment at ICRISAT Asia Center (IAC) and Akola.

		TSI%[a]		DFL		PHT		GYLD/PLT	
Lines	Pedigree	IAC	Akola	IAC	Akola	IAC	Akola	IAC	Akola
L1	SPST 94009B	-0.39	-0.41	-0.33	0.90	0.13**	0.05	-2.22**	-0.01
L2	SPST 94011B	-0.48	-0.07	1.52*	2.18	-0.29**	-0.25	5.02**	-1.01
L3	SPST 94001B	0.12	-1.68*	-3.63*	-5.83**	-0.19**	-0.18	-2.34**	4.49**
L4	SPST 94014B	0.07	0.92	-1.37	0.46	-0.33**	-0.44**	3.96**	-8.20**
L5	SPST 94008B	-0.90	-0.52	1.00	2.74	-0.05	0.06	1.60*	9.69**
L6	SPST 94026B	-0.37	-0.92	-0.11	-4.20**	0.12**	0.06	-2.39**	-6.64**
L7	ICSB 89	1.70*	1.02	1.33*	0.74	0.25**	0.31**	-0.59*	-8.35**
L8	ICSB 93	0.25	0.65	1.59*	3.01	0.38**	0.39**	3.04**	10.03**
SE		0.56	0.73	0.67	1.53	0.03	0.05	0.28	0.82

*,** Significant at 0.05, and 0.01 levels of probability, respectively.
a = Square root transformation $\sqrt{(SI\%+1)}$.

Table 4.3b. Estimates of GCA effects for transformed *Striga* incidence (TSI%), days to 50% flowering (DFL), plant height (PHT), and grain yield plant^{-1} (GYLD/PLT) on lines (male sterile lines) in line x tester experiment in combined analysis.

ENT#	Pedigree	TSI%[a]	DFL	PHT	GYLD/PLT
L1	SPST 94009B	-0.21	0.52	0.08	-1.04
L2	SPST 94011B	-2.26	1.77	-0.27**	2.07**
L3	SPST 94001B	-1.39	-4.84**	-0.19**	1.01
L4	SPST 94014B	1.02	-0.60	-0.40**	-2.02**
L5	SPST 94008B	-4.70	1.83	0.01	5.50**
L6	SPST 94026B	-0.65	-1.89	0.09*	-4.52**
L7	ICSB 89	4.96	0.75	0.28**	-4.50**
L8	ICSB 93	1.39	1.91	0.93**	3.50**
SE		5.09	1.17	0.04	0.63

*, ** Significant at, 0.05, and 0.01 levels of probability, respectively.
a = Square root transformation $\sqrt{}$ (SI%+1).

Table 4.4a. Estimates of GCA effects for transformed *Striga* incidence (TSI%), days to 50% flowering (DFL), plant height (PHT), and grain yield plant^{-1} (GYLD/PLT) on testers (restorers) in line x tester experiment at ICRISAT Asia Center (IAC) and Akola.

		TSI%[a]		DFL		PHT		GYLD/PLT	
Testers	Pedigree	IAC	Akola	IAC	Akola	IAC	Akola	IAC	Akola
T1	SAR 1	-0.20	-0.45	0.06	1.49	0.32**	0.18**	-2.71**	4.17**
T2	SAR 16	-0.76	-0.80	-2.90**	0.39	-0.27**	-0.32**	-2.96**	1.59
T3	SAR 34	-0.59	0.54	-0.23	-1.76	0.24**	0.22**	1.55**	-9.57**
T4	SAR 35	-0.16	-0.84	-1.73*	0.49	-0.13**	-0.15**	-3.24**	1.56
T5	SAR 41	0.50	0.68	0.73	-4.69**	-0.09**	0.01	0.20	0.32
T6	SAR 42	-0.82	-1.19	0.94	-0.38	-0.02	-0.01	3.44**	-2.14**
T7	ICSR 92001	-0.65	-0.02	2.23**	3.62*	-0.08**	0.09	-1.77**	-5.06**
T8	ICSR 93002	0.82	1.15	0.35	0.84	-0.05	0.09	2.89**	-2.03*
T9	ICSR 93004	1.84**	0.82	0.56	0.06	-0.08**	-0.11*	2.23*	11.60**
SE		0.59	0.77	0.71	1.60	0.03	0.05	0.30	0.87

*,** Significant at 0.05, and 0.01 levels of probability, respectively.
a = Square root transformation of $\sqrt{(SI\%+1)}$.

Table 4.5a. Percent contribution of lines, testers, and lines x testers to total variances for transformed *Striga* (TSI%), days to 50% flowering (DFL), plant height (PHT), and grain yield plant^{-1} (GYLD/PLT) in line x tester experiment at ICRISAT Asia Center (IAC) and Akola.

	Lines		Testers		Lines x Testers	
Traits	IAC	Akola	IAC	Akola	IAC	Akola
TSI%[a]	14.5	26.0	18.8	14.8	66.7	59.4
DFL	30.1	31.9	21.3	15.8	48.5	52.3
PHT	52.5	52.8	27.7	20.4	19.8	26.9
GYLD/PLT	33.1	24.8	24.4	15.2	42.3	60.1

*,** Significant at 0.05, and 0.01 levels of probability, respectively.
a = Square root transformation of √ (SI%+1).

Table 4.5b. Percent contribution of lines, testers, and lines x testers to total variances for transformed *Striga* incidence (TSI%), days to 50 % flowering (DFL), plant height (PHT), and grain yield plant^{-1} in line x tester experiment in combined analysis.

Traits	Lines	Testers	Lines x Testers
TSI%[a]	5.56	23.65	70.06
DFL	38.88	17.58	43.54
PHT	59.84	23.67	16.59
GYLD/PLT	5.57	19.46	74.97

*,** Significant at, 0.05, and 0.01 levels of probability, respectively.
a = Square root transformation √(SI%+1).

Table 4.6a. SCA effects and heterosis for *Striga* incidence (TSI%[a])in line x tester experiment at IAC and Akola.

Ent #	Pedigree	SCA effects		Average heterosis(%)	
		IAC	Akola	IAC	Akola
1	SPST 94009A x SAR 1	0.70	0.25	150.16	-32.03
2	SPST 94009A x SAR 16	0.18	-0.09	35.87	16.00
3	SPST 94009A x SAR 34	-1.62	-0.08	00.00	-55.06
4	SPST 94009A x SAR 35	-1.57	-0.02	00.00	24.50
5	SPST 94009A x SAR 41	0.60	-1.24	24.18	-64.29
6	SPST 94009A x SAR 42	0.07	0.76	54.79	16.00
7	SPST 94009A x ICSR 92001	2.80	0.42	193.55	38.34
8	SPST 94009A x ICSR 93002	-1.14	0.12	-47.52	50.82
9	SPST 94009A x ICSR 93004	1.84	-1.00	187.15	-81.31
10	SPST 94011A x SAR 1	-0.47	1.86	-12.22	66.34
11	SPST 94011A x SAR 16	2.27	0.26	152.51	-73.33
12	SPST 94011A x SAR 34	0.18	-0.73	54.79	02.97
13	SPST 94011A x SAR 35	-0.04	-0.90	-19.34	-76.88
14	SPST 94011A x SAR 41	-1.76	-0.49	-54.34	-60.40
15	SPST 94011A x SAR 42	-2.04	1.61	-00.36	10.99
16	SPST 94011A x ICSR 92001	0.00	-1.61	-36.46	-24.59
17	SPST 94011A x ICSR 93002	2.30	-1.74	226.65	-32.00
18	SPST 94011A x ICSR 93004	-0.63	-2.68	-12.22	00.00
19	SPST 94001A x SAR 1	0.57	0.53	82.19	16.85
20	SPST 94001A x SAR 16	1.09	0.98	103.65	46.50
21	SPST 94001A x SAR 34	-0.21	4.06	-19.78	16.07
22	SPST 94001A x SAR 35	-0.13	-0.23	27.85	16.00
23	SPST 94001A x SAR 41	-1.63	-2.17	21.25	-14.05
24	SPST 94001A x SAR 42	-1.36	0.25	-58.95	85.25
25	SPST 94001A x ICSR 92001	-1.15	1.49	37.30	-09.80
26	SPST 94001A x ICSR 93002	1.82	-1.30	103.21	00.00

Ent #	Pedigree	SCA effects		Average heterosis(%)	
		IAC	Akola	IAC	Akola
27	SPST 94001A x ICSR 93004	-1.66	0.31	0.00	-56.06
28	SPST 94014A x SAR 1	0.18	0.16	82.19	24.50
29	SPST 94014A x SAR 16	1.17	1.60	46.15	23.21
30	SPST 94014A x SAR 34	-2.36	-0.45	-54.34	00.00
31	SPST 94014A x SAR 35	0.21	1.21	102.87	52.07
32	SPST 94014A x SAR 41	1.81	-3.02	08.53	-67.21
33	SPST 94014A x SAR 42	-1.20	-0.03	75.55	-09.80
34	SPST 94014A x ICSR 92001	-1.17	-0.37	-12.22	24.50
35	SPST 94014A x ICSR 93002	0.68	-1.21	136.99	-55.06
36	SPST 94014A x ICSR 93004	-2.27	-0.61	00.00	32.00
37	SPST 94008A x SAR 1	-2.49	0.08	-63.37	23.21
38	SPST 94008A x SAR 16	-0.35	-0.37	67.58	16.00
39	SPST 94008A x SAR 34	4.85**	-1.46	292.47	14.05
40	SPST 94008A x SAR 35	2.49	3.97	33.65	21.15
41	SPST 94008A x SAR 41	0.10	0.89	27.56	-48.51
42	SPST 94008A x SAR 42	0.78	1.40	09.53	55.06
43	SPST 94008A x ICSR 92001	1.97	0.56	86.02	-71.01
44	SPST 94008A x ICSR 93002	-0.97	-2.38	-21.51	-55.06
45	SPST 94008A x ICSR 93004	-1.19	-0.60	-69.97	-75.16
46	SPST 94026A x SAR 1	-0.53	-0.20	-21.51	-55.06
47	SPST 94026A x SAR 16	0.20	0.31	35.69	-18.82
48	SPST 94026A x SAR 34	0.04	-0.32	-42.88	-09.30
49	SPST 94026A x SAR 35	-0.66	-1.78	-00.23	-73.86
50	SPST 94026A x SAR 41	-1.76	0.93	-67.69	30.50
51	SPST 94026A x SAR 42	-0.62	1.08	21.51	16.85
52	SPST 94026A x ICSR 92001	0.07	-3.11	21.51	00.00
53	SPST 94026A x ICSR 93002	1.65	-1.68	18.82	64.29

Ent #	Pedigree	SCA effects		Average heterosis(%)	
		IAC	Akola	IAC	Akola
54	SPST 94026A x ICSR 93004	-0.68	2.33	-21.51	36.00
55	ICSA 89 x SAR 1	-1.57	4.48*	00.00	18.76
56	ICSA 89 x SAR 16	2.93	-2.24	-08.17	-14.75
57	ICSA 89 x SAR 34	-0.93	1.95	-04.37	-15.41
58	ICSA 89 x SAR 35	-0.24	0.76	-16.24	21.69
59	ICSA 89 x SAR 41	-0.84	-0.09	-03.62	-05.63
60	ICSA 89 x SAR 42	2.83	2.32	48.06	83.13
61	ICSA 89 x ICSR 92001	0.18	-0.40	-14.24	-42.02
62	ICSA 89 x ICSR 93002	2.40	-0.84	62.56	-37.35
63	ICSA 89 x ICSR 93004	-1.24	-2.79	09.49	-57.89
64	ICSA 93 x SAR 1	-2.16	-0.91	-61.56	-17.74
65	ICSA 93 x SAR 16	-1.00	-1.02	22.14	-66.67
66	ICSA 93 x SAR 34	2.02	-0.51	63.55	-13.65
67	ICSA 93 x SAR 35	-1.39	-1.36	07.73	-83.87
68	ICSA 93 x SAR 41	0.46	3.25	51.21	64.82
69	ICSA 93 x SAR 42	0.35	-0.92	10.90	-61.62
70	ICSA 93 x ICSR 92001	3.34*	-0.51	109.90	-47.74
71	ICSA 93 x ICSR 93002	-1.18	-1.61	32.47	-50.71
72	ICSA 93 x ICSR 93004	-2.60	2.67	-53.47	18.86
SE		1.66	2.18	02.01	2.66

a = square root transformation √(SI%+1)

Table 4.6b. SCA effects and heterosis (%) for yield plant^{-1} at IAC and Akola.

Ent #	Pedigree	SCA effects		Heterosis (%)			
				IAC		Akola	
		IAC	Akola	MP	HP	MP	HP
1	SPST 94009A x SAR 1	1.55	-13.03**	-18.14	-13.71	49.26	19.88
2	SPST 94009A x SAR 16	-0.26	1.73	13.52	2.30	109.30	74.55
3	SPST 94009A x SAR 34	-1.82**	-22.52**	-62.76	-68.21	-1.95	-3.82
4	SPST 94009A x SAR 35	2.34**	0.51	40.91	38.02	76.18	45.15
5	SPST 94009A x SAR 41	-3.30**	3.48	-47.51	-52.20	180.35	124.06
6	SPST 94009A x SAR 42	2.23**	8.10**	-14.86	-25.35	141.68	77.53
7	SPST 94009A x ICSR 92001	-2.44**	2.41	-47.77	-56.07	52.57	47.71
8	SPST 94009A x ICSR 93002	1.71*	19.43**	-27.35	-37.85	286.95	188.87
9	SPST 94009A x ICSR 93004	0.53	-0.20	-23.90	-27.78	137.30	114.87
10	SPST 94011A x SAR 1	-0.68	-9.04**	19.29	-3.44	71.63	62.50
11	SPST 94011A x SAR 16	-0.28	7.31**	-38.16	-40.74	133.15	100.38
12	SPST 94011A x SAR 34	3.31**	3.74	67.33	45.56	112.96	92.89
13	SPST 94011A x SAR 35	-6.66**	1.76	-80.26	-83.87	207.35	167.86
14	SPST 94011A x SAR 41	2.64**	-17.32**	0.23	-0.93	8.82	2.94
15	SPST 94011A x SAR 42	-0.37	-8.36**	-12.54	-17.60	12.87	1.49
16	SPST 94011A x ICSR 92001	1.52	22.11**	-22.40	-25.47	366.35	286.97
17	SPST 94011A x ICSR 93002	4.62**	11.91**	35.73	15.05	161.49	153.07
18	SPST 94011A x ICSR 93004	-2.72**	-2.11	-0.64	-10.60	84.59	81.85
19	SPST 94001A x SAR 1	-2.72**	-5.19*	-59.33	-65.24	35.54	9.94
20	SPST 94001A x SAR 16	-2.79**	3.25	-0.52	-2.73	55.80	50.31
21	SPST 94001A x SAR 34	1.47	-16.89**	10.00	0.00	41.95	36.50
22	SPST 94001A x SAR 35	2.87**	20.34**	7.35	-5.73	207.12	164.72
23	SPST 94001A x SAR 41	2.30**	-9.34**	27.66	7.53	-41.03	-50.11
24	SPST 94001A x SAR 42	-2.82**	-6.08*	-69.46	-73.84	132.75	104.91
25	SPST 94001A x ICSR 92001	0.08	-5.17	-19.51	-30.93	116.85	103.45

Ent #	Pedigree	SCA effects		Heterosis (%)			
				IAC		Akola	
		IAC	Akola	MP	HP	MP	HP
26	SPST 94001A x ICSR 93002	-1.23	1.23	27.87	-10.60	138.60	134.48
27	SPST 94001A x ICSR 93004	4.54**	11.58**	56.68	33.33	160.16	116.63
28	SPST 94014A x SAR 1	-3.43**	-5.98*	-0.70	-26.71	62.21	51.72
29	SPST 94014A x SAR 16	-2.64**	4.73	-30.41	-51.02	238.98	216.09
30	SPST 94014A x SAR 34	1.12	-10.65**	-8.57	-24.17	59.59	33.91
31	SPST 94014A x SAR 35	1.79*	-3.68	41.82	22.51	39.44	21.23
32	SPST 94014A x SAR 41	-0.33	7.94**	-40.83	-49.75	292.95	236.49
33	SPST 94014A x SAR 42	1.74	3.06	50.26	47.94	218.20	178.03
34	SPST 94014A x ICSR 92001	-0.03	-8.43**	64.99	26.94	112.06	77.98
35	SPST 94014A x ICSR 93002	-4.33**	26.07**	-47.66	-48.98	272.30	167.30
36	SPST 94014A x ICSR 93004	-2.57**	-8.43**	52.91	17.47	73.26	51.82
37	SPST 94008A x SAR 1	9.00**	18.87**	134.01	81.52	375.61	317.94
38	SPST 94008A x SAR 16	-1.58	-11.06**	-8.77	-13.74	86.64	83.47
39	SPST 94008A x SAR 34	-1.48	-2.75	26.12	25.13	61.66	19.96
40	SPST 94008A x SAR 35	-0.47	-12.62**	1.29	-1.51	208.82	196.37
41	SPST 94008A x SAR 41	1.23	4.13	35.16	4.83	146.25	127.15
42	SPST 94008A x SAR 42	3.00**	13.53**	79.75	78.98	183.50	173.68
43	SPST 94008A x ICSR 92001	-4.17**	-8.87**	-26.18	-42.33	47.06	24.28
44	SPST 94008A x ICSR 93002	-4.81**	0.72	15.84	5.97	77.11	62.88
45	SPST 94008A x ICSR 93004	8.22**	1.43	100.00	96.88	196.03	165.93
46	SPST 94026A x SAR 1	-5.81**	8.41**	-46.71	-57.39	158.96	114.13
47	SPST 94026A x SAR 16	3.81**	-11.98**	82.32	40.63	-20.43	-29.72
48	SPST 94026A x SAR 34	-1.07	-7.36**	-0.17	-21.87	159.77	119.11
49	SPST 94026A x SAR 35	-4.84**	0.55	-8.16	-30.42	80.87	50.66
50	SPST 94026A x SAR 41	4.26**	6.61**	178.40	79.09	92.24	72.71
51	SPST 94026A x SAR 42	2.49**	-17.54**	135.00	58.00	-14.78	-20.08

Ent #	Pedigree	SCA effects		Heterosis (%)			
				IAC		Akola	
		IAC	Akola	MP	HP	MP	HP
52	SPST 94026A x ICSR 92001	-1.85*	3.24	109.20	40.42	52.43	26.74
53	SPST 94026A x ICSR 93002	-3.69**	12.76**	28.80	-16.72	197.23	146.28
54	SPST 94026A x ICSR 93004	3.37**	-6.67**	141.81	138.52	19.02	-9.83
55	ICSA 89 x SAR 1	0.00	26.39**	126.12	72.25	123.90	120.81
56	ICSA 89 x SAR 16	0.26	-25.34**	75.94	32.17	5.67	-18.56
57	ICSA 89 x SAR 34	-1.25	3.02	20.09	2.56	83.28	40.85
58	ICSA 89 x SAR 35	1.81*	-3.32	88.45	68.20	44.47	14.96
59	ICSA 89 x SAR 41	1.44	8.93**	56.42	29.56	84.78	77.46
60	ICSA 89 x SAR 42	10.23**	9.26**	185.22*	149.50	74.74	53.98
61	ICSR 89 x ICSR 92001	-1.21	-18.42**	28.13	15.54	30.03	-0.53
62	ICSA 89 x ICSR 93002	-4.54**	-6.70**	-28.24	-36.49	17.66	-16.73
63	ICSA 89 x ICSR 93004	-4.18**	14.86**	2.80	-12.77	67.47	53.17
64	ICSA 93 x SAR 1	-2.40**	-7.17**	-7.40	-20.07	93.14	38.73
65	ICSA 93 x SAR 16	-3.76**	-4.17	-32.97	-48.01	106.05	56.46
66	ICSA 93 x SAR 34	-3.37**	-4.42	-17.55	17.05	93.72	52.21
67	ICSA 93 x SAR 35	4.87**	0.83	59.28	24.44	97.66	86.73
68	ICSA 93 x SAR 41	-0.44	-16.58**	45.35	32.96	58.92	20.41
69	ICSA 93 x SAR 42	-1.18	-20.72**	8.23	6.54	157.14	94.39
70	ICSA 93 x ICSR 92001	-0.21	15.56**	0.90	-19.31	186.89	101.02
71	ICSA 93 x ICSR 93002	0.58	-7.43**	33.34	2.85	29.93	17.01
72	ICSA 93 x ICSR 93004	3.50**	9.54**	36.48	6.82	233.73	137.24
SE		0.84	2.45	1.02	1.18	3.00	3.47

Table 4.6c. SCA effects for transformed *Striga* incidence (TSI%), days to 50 % flowering, plant height (PHT), and grain yield plant^{-1} in combined analysis.

Ent#	Pedigree	TSI%[a]	DFL	PHT	GYL
1	SPST 94009A x SAR 1	-0.41	-3.59	-0.31**	-5.6
2	SPST 94009A x SAR 16	0.00	0.00	0.00	0.0
3	SPST 94009A x SAR 34	0.00	0.00	0.00	0.0
4	SPST 94009A x SAR 35	-0.30	0.68	-0.07	2.2
5	SPST 94009A x SAR 41	2.05	-1.25	0.11	9.7
6	SPST 94009A x SAR 42	1.23	-0.92	0.13	4.8
7	SPST 94009A x ICSR 92001	-1.01	0.24	0.17	1.1
8	SPST 94009A x ICSR 93002	-0.41	1.38	-0.11	-2.2
9	SPST 94009A x ICSR 93004	0.67	0.98	0.23	0.0
10	SPST 94011A x SAR 1	-0.33	1.91	0.26*	0.6
11	SPST 94011A x SAR 16	0.00	0.00	0.00	0.0
12	SPST 94011A x SAR 34	0.00	0.00	0.00	0.0
13	SPST 94011A x SAR 35	0.62	-0.10	-0.10	-3.3
14	SPST 94011A x SAR 41	-0.39	-1.39	-0.17	-9.7
15	SPST 94011A x SAR 42	-0.01	3.05	-0.05	-1.7
16	SPST 94011A x ICSR 92001	-0.16	-0.15	0.01	-3.6
17	SPST 94011A x ICSR 93002	0.92	0.04	-0.26*	9.2
18	SPST 94011A x ICSR 93004	-0.62	-0.52	0.19	-4.7
19	SPST 94001A x SAR 1	-0.56	-0.48	-0.03	-12.
20	SPST 94001A x SAR 16	0.00	0.00	0.00	0.0
21	SPST 94001A x SAR 34	0.00	0.00	0.00	0.0
22	SPST 94001A x SAR 35	-0.18	-1.74	0.26*	-2.1
23	SPST 94001A x SAR 41	0.95	-1.92	-0.19	-5.3
24	SPST 94001A x SAR 42	-0.35	0.66	0.17	13.0
25	SPST 94001A x ICSR 92001	-0.52	2.79	0.13	-2.7
26	SPST 94001A x ICSR 93002	-0.59	-1.46	-0.03	-0.4
27	SPST 94001A x ICSR 93004	1.45	1.84	-0.08	3.6

Ent#	Pedigree	TSI%[a]	DFL	PHT	GYLD/P
55	ICSA 89 x SAR 1	2.65	-0.31	-0.13	0.07
56	ICSA 89 x SAR 16	0.00	0.00	0.00	0.00
57	ICSA 89 x SAR 34	0.49	2.16	-0.06	1.06
58	ICSA 89 x SAR 35	-0.90	0.13	-0.10	5.44**
59	ICSA 89 x SAR 41	0.82	-1.32	0.05	-6.47**
60	ICSA 89 x SAR 42	-1.60	0.68	-0.17	-5.27**
61	ICSA 89 x ICSR 92001	1.15	1.27	-0.17	0.90
62	ICSA 89 x ICSR 93002	0.05	-1.30	0.02	-4.31*
63	ICSA 89 x ICSR 93004	-0.01	0.00	0.02	-4.31*
64	ICSA 93 x SAR 1	-0.06	1.52	0.02	10.50**
65	ICSA 93 x SAR 16	-0.25	1.57	-0.00	-4.01*
66	ICSA 93 x SAR 34	-0.41	0.66	-0.11	-1.40
67	ICSA 93 x SAR 35	-0.15	1.99	-0.16	-7.43**
68	ICSA 93 x SAR 41	-0.43	1.90	0.00	-2.27
69	ICSA 93 x SAR 42	-1.12	4.30	0.09	11.67**
70	ICSA 93 x ICSR 92001	-1.68	-2.30	-0.07	-4.56*
71	ICSA 93 x ICSR 93002	-1.21	1.32	-0.17	-3.71*
72	ICSA 93 x ICSR 93004	-0.22	0.84	-0.11	11.83**
SE		1.48	3.56	0.12	1.89

a = Square root transformation of √(SI%+1).

Table 4.7. Estimate of broad sense heritability for *Striga* incidence (TSI), days to 50 % flowering (DFL), plant height (PHT), and grain yield plant^{-1} at IAC and Akola.

Trait	IAC	Akola
TSI %[a]	0.10	0.02
DFL	0.47	0.76
PHT	0.84	0.67
GYLD/PLT	0.91	0.95

a = Square root transformation of √(SI%+1).

Discussion

5. DISCUSSION

The discovery of cytoplasmic-genic male sterility systems in sorghum enhanced the development of sorghum hybrids for commercial cultivation. The superiority of hybrids overall performance in productivity, greater stability, and better adaptation to stress over open pollinated varieties is widely acknowledged (Ejeta 1988). Unfortunately, to date sorghum hybrids developed and released for cultivation in India and Africa do not have tolerance or resistance to *Striga*. Both CSH 1 and Hageen Dura-1, the first commercial sorghum hybrids released in India, and Sudan, respectively, are highly susceptible to *Striga*.

The most commonly adopted method in breeding for *Striga* resistance is the pedigree method in which crossing between one or more source(s) of resistance and desirable parents is carried out with the purpose of generating new gene combinations that will allow the placement of the factors of resistance in an agronomically superior genetic background. But the use of this method is limited by the absence of an appropriate screening method that allows identification of genotypes having high levels of resistance in segregating populations.

There is no previous effort directed to developing parental lines with genes for resistance, with the goal of developing *Striga* resistant grain sorghum hybrids. ICRISAT developed *Striga* resistant male-sterile lines using pedigree breeding coupled with back crossing and screening for resistance (ICRISAT 1993). In this study a set of resistant male-sterile lines were crossed with a set of resistant and susceptible restorers with an aim to exploit the general combining ability and hybrid vigor, and to produce hybrids that

are resistant to *Striga* with good agronomic traits. This will be very useful to farmers, especially in Africa and India where *Striga* is a main constraint for sorghum production.

5.1. Mean Performance

Differences observed in means for most of the characters studied were high across two locations. However, within these groups, specific relationships were observed in mean performance of some lines and hybrids.

5.1.1. *Striga* incidence (SI%)

The selected lines, testers, and hybrids are given in Table 5.1. Among the male-sterile lines, L2 (SPST 94011B), L3 (SPST 94001B), and L4 (SPST 94014A) were confirmed to be resistant to *Striga* in individual locations and in combined analysis. Among the restorers, T4 (SAR 35) and T6 (SAR 42) were confirmed to be resistant over locations and in combined analysis. Therefore the combination of the above lines with these restorers will give promising resistant hybrids. It is clear that the majority of the restorers and male-sterile lines bred earlier specifically for resistance are resistant in this study. However, though T9 (ICSR 93004) was considered as susceptible it was found to be resistant in the present study.

The hybrids showed different responses to *Striga* across locations and in combined analysis. Some of them were confirmed to be resistant in one location but not in another. Among them, entry 42 (SPST 94008A x SAR 42) and entry 49 (SPST 94026A x SAR 35) were confirmed to be resistant across locations and in combined analysis. These hybrids were produced by the resistant restorers SAR 42, and SAR 35,

respectively. However, most of the other hybrids which were resistant across locations and in combined analysis are the ones that were produced from one of the male sterile lines (female), or the restorers (male) resistant parent.

5.1.2. Days to 50% flowering (DFL)

Breeding of *Striga* resistance with earliness is of vital importance in hybrids with good agronomic characters to suit the semi-arid Tropics like Sudan. The genotypes used in the study were variable and behaved differently for days to 50% flowering, both the locations and in combined analysis. Consistent and early flowering was recorded in L3 (SPST 94001B), followed by L6 (SPST 94026B) at Akola and in combined analysis, both were earlier than the widely adapted control 296B. Among the restorers, at IAC the earliest were: T6 (SAR 42), followed by T2 (SAR 16), and T3 (SAR 34), both earlier than control 296B, at Akola T5 (SAR 41), T2 (SAR 16), and T3 (SAR 34) were earlier among the testers and in compared to the control 296B, and in combined analysis T2 (SAR 16) and T3 (SAR 34).

Early flowering in hybrids was noticed across locations and in combined analysis, when either female, male or both the parents were early except in entry 5 (SPST 94009A x SAR 41). This indicated the manifestation of heterosis.

Among the hybrids, the moderately resistant hybrid entry 29 (SPST 94014A x SAR 16), resistant hybrid entry 47 (SPST 94026A x SAR 16), and susceptible hybrid entry 27 (SPST 94001Ax ICSR 93004) were the earliest across locations and in combined analysis. Among them entry 47 was found to be resistant. entry 29 moderately resistant, and entry 27 was susceptible. The tallest hybrid among these

three was entry 47, followed by entry 27. However, the highest yielding hybrid among these was entry 27, followed by entry 29, both yielded higher than control 296B as well as other controls.

5.1.3. Plant height (PHT)

Sorghum grain and stover are both economic products in vast areas of the semi-arid tropics, particularly Sudan, where sorghum is grown in moisture limited environment. Under such conditions the combination of *Striga* resistance with earliness associated with tall plant stature are important. Among the male-sterile lines, L8 (ICSB 93) and L7 (ICSB 89) were found to be the tallest lines across the locations and in combined analysis. Among the restorers, T1 (SAR 1) and T4 (SAR 34) were the tallest. Therefore combination of the male sterile lines with these restorers is expected to produce tall hybrids. Among the hybrids the following three showed consistent height across the locations, and in combined analysis: entry 64 (ICSA 93 x SAR 1), entry 70 (ICSA 93 x ICSR 92001), entry 61 (ICSA 89 x ICSR 92001). Regarding the other three traits (*Striga* incidence, days to 50%, and grain yield plant^{-1} GYLD PLT) at IAC, entry 61 and entry 64 appeared to be moderately resistant, and earlier than entry 70 and the control 296B, while entry 70 was susceptible. However, entry 61 was yielding the highest among the three hybrids, and compared to the four controls. At Akola entry 70 was found to be resistant, while entry 61 and entry 64 were susceptible. With respect to the earliness, entry 61 and entry 70 were earlier than the widely adapted controls 296B and SAR 1, but were later than the other two controls SAR 16 and SAR 34 at Akola, regarding the yield, entry 65 was the highest, followed by entry 64, and both were higher in yield than

the controls. In the combined analysis entry 61 was resistant, entry 64 moderately resistant, and entry 70 was susceptible. For days to flowering, in combined analysis entry 61 and entry 64 were the earliest (reaching flowering at same time) and higher yielding than the two controls 296B and SAR 1. It is clear that height in three hybrids resulted, when either female, male, or both the parents were tall, which is reflected in the superiority of the hybrids over the mid- and high parents.

5.1.4. Grain yield plant^{-1} (GYLD/PLT)

Grain sorghum hybrids that combine yield potential, adaptation, and grain quality with resistance to *Striga*, earliness and high biomass will make a significant contribution in increasing the crop yields in *Striga*-endemic environments like Sudan. The genotypes behaved differently across locations, but in general the performance of the genotypes at Akola was better than at IAC. Among the male-sterile lines at IAC, the moderately resistant line L5 (SPST 94008B), and susceptible line, L8 (ICSB 93), gave the highest grain yield plant^{-1} compared to all the controls, and both were earlier than the control 296B, but later than the other controls (SAR 1, SAR 16, SAR 34). Regarding the height, L8 was taller than all the controls except SAR 1. At Akola the best line with respect to grain yield was the susceptible line, L7 (ICSB 89), followed by the resistant line, L6 (SPST 94026B), both earlier than the controls 296B and SAR 1. However in pooled analysis the highest yielding lines L8 (ICSB 93) and L7 (ICSB 89) both found to be susceptible, but earlier than the controls 296B and SAR 1, and both taller than the control 296B. Among the restorers at IAC, the highest yield plant^{-1} was shown by T2 (SAR 16), followed by T5 (SAR 41). Both were found to be moderately resistant to

Striga. Among the two testers, T5 was earlier than all the controls, and it was taller than the two controls 296B and SAR 16. At Akola, the high yielding testers were T2 (SAR 16), followed by T8 (ICSR 93002), T2 was found to be resistant with zero SI% and earlier than all the controls, and T8 was susceptible and taller than all controls except SAR 1. In combined analysis the highest grain yield was recorded in T9 (ICSR 93004), followed by T3 (SAR 34), both confirmed to be resistant and earlier than the adapted control 296B. Regarding the height T3 was taller than all the controls except SAR 1. Among the hybrids at IAC, the highest yielding entries were: entry 35 (SPST 94011 x ICSR 93002) which found to be susceptible, entry 42 (SPST 94008A x SAR 42) which was resistant, and entry 15 (SPST 94011A x SAR 42) which was moderately resistant, among the three entry 35 was the earliest, and earlier than all the controls except SAR 16, regarding the plant height, entry 42 was the tallest, and it is taller than all the controls except SAR 1. At Akola, the best combinations for grain yield were entry 65 (ICSA 93 x SAR 16) which was confirmed to be moderately resistant, followed by entry 64 (ICSR 93 x SAR 1), and entry 72 (ICSA 93 x ICSR 93004) which were found to be susceptible, the earliest hybrids among the three were entry 65 and entry 72 both flowered at the same time with the well adapted control 296B, and the tallest hybrids among these three was entry 64 in compared all controls. In combined analysis entry 41 (SPST 94008A x SAR 41) which was found to be resistant, was the best yielder, followed by entry 72 (ICSA 93 x ICSR 93004) which found to be moderately resistant, the two hybrids were flowered at the same time but entry 72 was taller than all the controls. It is clear that the yield at Akola was higher than at IAC, this may be due to the difference

in the two environments.

5.2. Analysis of Variance

Analysis of variance indicated significant variation among parents and hybrids for three traits: grain yield plant^{-1}, days to 50% flowering, and plant height indicating the diversity in the material tested. For *Striga* incidence (SI%), the entries showed different behavior at IAC, Akola, and in combined analysis which reveal low infestation pressure which did not allow the genotypes to fully express their reaction to *Striga* infestation. *Striga* incidence was low and this led to high CV, and the CV may not be entirely due to non-uniformity in the germination of the striga. The combined analysis showed no significant variation in locations x parents, locations x controls, locations x lines, locations x testers, and locations x L x T for *Striga* incidence (TSI%) which indicated that IAC *Striga* strain is not different from that of Akola.

5.3. Combining Ability Effects and Gene Action

Variation among the genotypes is an important tool for the breeder to be able to fully exploit the diversity in the population to select parents for hybrids. In such programs knowledge of combining ability of parents becomes necessary. The majority of studies on the nature of combining ability in sorghum populations pointed to preponderance of additive gene action for most characters including yield (Beil and Atkins 1967 and Rao 1970). The present study showed the importance of non-additive gene action for resistance to *Striga* as shown by the low ratio of GCA variance to SCA variance at IAC, and Akola, as well as in combined analysis. This finding is in line with

that found by Obilana (1984), Kulkarni and Shinde (1985) and Shinde and Kulkarni (1987). but contradicts that of Shinde and Kulkarni (1983) and Vasudeva Rao et al. (1983) and,Dangi (1989) who reported predominance of additive genes in controlling the *Striga* resistance.

For days to 50% flowering, the analysis revealed that ratio of GCA to SCA variance was less than one which indicated the importance of non-additive components of variance for the inheritance of earliness. This in line with Manicham and Vijendra Das (1994), but opposed to that of Kambal and Webster (1965), and Patel et al. (1983) who reported the preponderance of additive gene action. However, Barche et al. (1988) reported the importance of both additive and non-additive gene action in controlling days to 50% flowering.

Specific combining ability variance of grain yield plant^{-1} was higher than the mean squares for general combining ability variance indicating the importance of non-additive gene action in controlling this character. This finding was in agreement with that of Shinde and Jagadeshwar (1986), Goyal and Joshi (1983), and Madupuri et al. (1983) who reported the predominate role of non-additive gene action for grain yield. Barche et al. (1988) found that both additive and non-additive components of variances are important for the inheritance of grain yield plant^{-1}. Beil and Atkins (1967), Rao (1970), Patel et al.

(1983), and Kambal and Webster (1965) reported the importance of additive gene action for inheritance of grain yield plant^{-1}. However, Barche et al. (1988) found both the variances were important for the inheritance of the grain yield plant^{-1}.

The GCA variances for plant height in individual analyses were less than SCA, while in combined analysis the ratio GCA to SCA variance was equal to one, indicating the importance of both additive and non-additive gene action for the inheritance of this character, these results are in line with what found by Kambal and Webster (1965), Patel et al. (1983), and Dass et al. (1985). Whereas, Manicham and Vijendra Das (1994) reported the non-additive gene action for controlling plant height.

In this study, contribution of line x tester interaction to the total variance high in most of the characters, followed by that of the lines. Therefore, the lines used in this study were more diverse for most of the characters than the testers (Mushonga 1991). While, the testers were diverse for *Striga* incidence.

5.3.1. General combining ability (GCA) effects on male sterile lines

The lines under study differed from one another with respect to their GCA effects for *Striga* and other traits at two locations as well as in combined analysis. The resistant lines L3 (SPST 94001B) and L6 (SPST 94026B) were the best general combiners for *Striga* resistance (highly negative GCA effects) at Akola, while at IAC, they were L5 (SPST 9008), and L2 (SPST 94011B). However, in the combined analysis L5 (SPST 94008B) and L3 (SPST 94001B) were the good combiners for the *Striga* resistance.

The combination of *Striga* resistance with earliness and other agronomic traits is of vital importance to produce resistant hybrids for arid and semi-arid conditions. In case of DFL the resistant lines, L3 (SPST 94001B) and L4 (SPST 94014B) were found to be good combiners for earliness (having highly negative significant GCA effects) at IAC, Akola as well as in combined analysis, and L6 (SPST 94026B) was good combiner at

Akola and in combined analysis. The early lines, L3 (SPST 94001B) and L6 (SPST 94026B) had negative GCA effects for *Striga* incidence (SI%) at Akola and in combined analysis, so these two lines can be exploited to produce early resistant hybrids.

The analysis of the GCA effects for plant height revealed that the highest positive significant GCA effect was shown by L8 (ICSB 93) at IAC, and Akola as well as in the combined analysis. The highest negative significant difference was observed for L4 (SPST 94014B) at both locations and in combined analysis.

The best combiner for grain yield across locations and in combined analysis was L5 (SPST 94008B) (which had positively significant GCA effects), followed by L8 (ICSB 93). It was interesting to note that L5 (SPST 94008B) was good combiner for *Striga* resistance as well as for grain yield^{-1} over the locations as well as in combined analysis. This may imply that such line can be used to produce high yielding *Striga* resistance hybrids.

5.3.2. General combining ability (GCA) effects for testers (restorers)

Among the testers, T6 (SAR 42) was found to be the best combiner for *Striga* resistance (having high negative GCA effects) followed by T2 (SAR 16). Tester, T3 (SAR 34) was good combiner for earliness since it had negative GCA effects for DFL at IAC, Akola and in combined analysis. However, it had highly significant positive GCA effects for plant height at the two locations and in combined analysis. Tester, T9 (ICSR 93004) appeared to be a good combiner for yield over locations and in combined analysis, followed by T1 (SAR 1) at Akola and in combined analysis. This indicates that SAR 42 and SAR 16 were good combiners for *Striga* resistance as well as for most of

the other traits at the two locations and in the combined analysis.

5.3.3. Specific combining ability effects (SCA)

Examination of the negative SCA effects for *Striga* incidence (TSI%) at IAC, revealed that entry 72 (ICSA 93 x ICSR 93004) had the highest per se performance, it had highest negative SCA effect, followed by entry 37 (SPST 94008A x SAR 1), entry 30 (SPST 94014A x SAR 34), entry 64 (ICSA 93 x SAR 1), entry 15 (SPST 94011A x SAR 42), and entry 14 (SPST 94011A x SAR 41). At Akola entry 52 (SPST 94026A x ICSR 93004), entry 32 (SPST 94014A x SAR 41), showed the highest negative SCA effects. However, in combined analysis entry 70 (ICSA 93 x ICSR 92001) was showed the highest negative SCA effects, followed by entry 60 (ICSA 89 x SAR 42), and entry 28 (SPST 94014A x SAR 1). It is noticed that most of the high specific combining genotypes were from resistant x resistant crosses, while others from resistant x susceptible, or susceptible x resistant crosses, whereas some resistant hybrids resulted from susceptible x susceptible parents. this indicates the complex nature of resistance inheritance, and incomplete dominance of resistance. Tarr (1962) reported that resistance may be recessive in some crosses, dominant in some and partially dominant in other crosses (Saunders 1933 and Ramaiah 1987). Obilana (1984) reported the overdominance of susceptibility, and two to five genes control the resistance reaction, while Ramaiah et al. (1990) reported single recessive gene for low stimulant production in three sorghum genotypes. Hess and Ejeta (1991) reported that the stable resistance in sorghum cultivar SRN 39, is inherited as a recessive trait controlled by one or two genes.

With regard to grain yield plant^{-1} at IAC, entry 60 (ICSA 89 x SAR 42) had the highest positive SCA effect followed by entry 37 (SPST (94008A x SAR 1), and entry 45 (SPST 94008A x ICSR 93004), while at Akola, entry 55 (ICSA 89 x SAR 1) had the highest positive SCA effect followed by entry 35 (SPST 94014A x ICSR 93002), entry 16 (SPST 94011A x ICSR 92002), and entry 22 (SPST 94001A x SAR 35. However, in the combined analysis entry 24 (SPST 94001A x SAR 42) was found to be the best specific combination, followed by entry 72 (ICSA 93 x ICSR 93004) and entry 69 (ICSA 93 x SAR 42).

5.4. Proportional Contribution of Lines, Testers and L x T to Total Variances

From the analysis, the LxT contribution seems to be the highest in most cases and characters, followed by that of the lines. The lines used in this study were very diverse for days to 50% flowering, plant height, and yield plant^{-1}, while both lines and testers were diverse for *Striga* incidence. Mushonga (1991) found in line x tester experiment in sorghum, the proportions contributed by lines and line x tester interaction to the total variance for diastatic unit, 1000 seed weight, grain hardness, and protein content, then he concluded that the lines were more diverse than the testers.

5.5. Heterosis

5.5.1. *Striga* incidence (SI%)

Several studies on the manifestation of hybrid vigor in grain sorghum have been reported (Kanaka 1982; Nayeem and Bapat 1984; and Kambal and Webster 1966).

Grain yield and its components have been reported to be more heterotic than other characters.

Kulkarni and Shinde (1985) reported that heterosis breeding is useful when the trait is controlled by non-additive gene action. In this study, although there was a great variation in the estimates of heterosis from cross to cross, certain traits exhibited higher heterosis than others. For *Striga* incidence at IAC the highest negative heterosis% over mid parents showed by entry 45 (SPST 94008A x ICSR 93004) (-69.97%), which resulted from resistant x susceptible cross, followed by entry 37 (SPST 94008A x SAR 1) resistant x resistant, and entry 64 (ICSA 93 x SAR 1) susceptible x resistant. At Akola, entry 67 (ICSA 93 x SAR 35) (susceptible x resistant) expressed the highest heterotic value over mid parents (-83.87%), followed by entry 9 (SPST 94009A x ICSR 93004) (R x S). Some hybrids showed highly negative heterosis across locations suggesting dominance gene effects for resistance. It appeared from the study the crosses with highest heterotic values were not necessarily the best in performance for resistance to *Striga* and other characters.

For grain yield plant^{-1} some crosses showed high positive heterosis percentage. The highest heterotic percentage over mid parent at IAC were shown by: entry 37 (SPST 94008A x SAR 1), entry 50 (SPST 94026A x SAR 41), and entry 60 (ICSA 89 x SAR 42) all the three with highly positive SCA. At Akola, entry 16 (SPST 94011A x ICSR 92001), entry 32 (SPST 94014A x SAR 41), and entry 37 (SPST 94008A x SAR 1) had highly heterosis in addition to highly significant SCA effects. Most of the hybrids mentioned above showed high negative heterosis percentage over mid parent for *Striga* resistance.

In addition to heterosis, per se performance of these hybrids for the traits was also quite high as compared to controls. This is an important finding for the breeder, since his interest is not only in highest heterosis, but also high performance of the genotypes in the desirable directions some heterosis with good yield. The highly positive heterobeltiosis values of the hybrids; entry 37 (SPST 94008A x SAR 1) which confirmed to be resistant to *Striga* at Akola and in combined analysis and entry 50 (SPST 94026A x SAR 41) which is moderately resistant at Akola, indicated the effect of overdominance for grain yield plant^{-1}. According to Sokol and Baker (1977) dominant gene action always contributes to heterosis, and when gene frequencies are not equal to 0.5 then additive x dominance gene action also contributes to heterosis. Correlated gene contribution and repulsion phase linkage may convert dominance to overdominance, and non-allelic interactions also cause heterosis (Jinks and Mather, 1955).

5.6. Heritability

The magnitude of the estimates of broad sense heritabilities, varied greatly between characters studied at both locations. The estimates of heritability for *Striga* incidence was 10, and 2 percent, at IAC and Akola, respectively. In addition to low and non-uniform *Striga* infestation, the high sensitivity of *Striga* plant to the environmental condition led to low heritability values at both locations. Frey (1954) inferred that characters which are highly influenced by environment tend to have low heritabilities.

Days to 50% flowering appeared to be moderately sensitive to the environmental condition since its heritable values varied from one location to another, i.e., 47, 76

percent at IAC and Akola, respectively. The plant height showed high heritability at both locations, hence it appears to be less sensitive to the environment. This may be because the plant height is governed by few genes (Mushonga 1991).

Grain yield plant^{-1} showed high heritability at both locations (91, and 95 percent at IAC and Akola, respectively). This is in line with the finding of Kukadia et al. (1983) who found that heritability of grain yield plant^{-1} was 95.53 percent. This is a broad sense heritability which might be due to both dominance and additive (and their interactions) types of gene action.

The conclusion which can be deduced from this study based on GCA to SCA variances ratios is that non additive genes are involved in the inheritance of resistance to *Striga*, days to 50% flowering and grain yield. However, plant height is found to be controlled by both additive and non-additive genes.

The male sterile lines, L2 (SPST 94011B) and L3 (SPST 94001B) were confirmed to be resistant, and good combiners for striga resistance, and L3 also good combiners for earliness, and among the restorers, T4 (SAR 35) and T6 (SAR 42) were confirmed to be resistant. Therefore these lines and testers could be further used in hybrid development for *Striga* resistance. Among the hybrids entries 42 (SPST 94008A x SAR 42) and entry 49 (SPST 94026A x SAR 35) were confirmed to be resistant over locations and in combined analysis. Among the lines, L3 (SPST 94001B) and L6 (SPST 94026B) were best combiners for *Striga* resistant as well as for earliness, while among the restorers, SAR 42 and SAR 16 were good combiners for *Striga* resistance as well as for most of the other traits.

It was observed that *Striga* germination in the field was low. *Striga* growth is very sensitive to the heavy rains that followed the germination. To avoid these events, the *Striga* experiment could be conducted in the post-rainy season instead of the main season to avoid low temperatures and heavy rain which prevent the germination and subsequent growth of *Striga*. Yet in this study, the incidence was low which might be due other reasons, such as natural fertility of the soils, compaction of the field

For further reflection of the actual potentiality of these genotypes, the continuation of this study with added genetic material, locations across countries (perhaps India and Sudan), and *Striga sp.* (*S. asiatica* and *S. hermonthica*) is suggested.

Table 5.1. Selected lines, testers, and hybrids for *Striga* resistance.

No.	Pedigree	IAC	Akola	combined
Lines				
L1	SPST 94009B	6.7	30.0	7.0
L2	SPST 94011B	6.7	0.0	0.5
L3	SPST 94001B	6.7	0.0	0.5
L4	SPST 94014B	13.3	0.0	5.5
L5	SPST 94008B	13.3	20.0	6.7
Testers				
T1	SAR 1	0.0	90.0	3.3
T2	SAR 16	13.3	0.0	10.5
T3	SAR 34	6.7	20.0	1.7
T4	SAR 35	6.7	0.0	5.5
T6	SAR 42	6.7	0.0	0.5
T9	ICSR 93004	6.7	0.0	0.5
Hybrids				
entry 2	SPST 94009A x SAR 16	20.0	0.0	11.7
entry 7	SPST 94009A x ICSR 92001	6.7	0.0	0.5
entry 11	SPST 94011A x SAR 16	6.7	20.0	2.1
entry 12	SPST 94011A x SAR 34	6.7	0.0	5.5
entry 13	SPST 94011A x SAR 35	33.3	0.0	2.5
entry 16	SPST 94011A x ICSR 92001	0.0	30.0	2.0
entry 17	SPST 94011A x ICSR 93002	20.0	30.0	7.5
entry 19	SPST 94001A x SAR 1	6.7	0.0	5.5
entry 20	SPST 94001A x SAR 16	46.7	0.0	30.5
entry 22	SPST 94001A x SAR 35	6.7	0.0	5.5
entry 23	SPST 94001A x 41	26.7	0.0	15.5
entry 24	SPST 94001A x SAR 42	26.7	0.0	10.5
entry 27	SPST 94001A x ICSR 93004	26.7	0.0	20.5

No.	Pedigree	IAC	Akola	combined
entry 28	SPST 94014A x SAR 1	6.7	20.0	1.7
entry 32	SPST 94014A x SAR 41	6.7	20.0	2.1
entry 33	SPST 94014A x SAR 42	6.7	0.0	5.5
entry 34	SPST 94011A x ICSR 92001	13.3	0.0	10.5
entry 37	SPST 94008A x SAR 1	13.3	0.0	5.5
entry 38	SPST 94008A x SAR 16	6.7	0.0	5.5
entry 41	SPST 94008A x SAR 41	0.0	0.0	1.7
entry 42	SPST 94008A x SAR 42	0.0	0.0	0.5
entry 43	SPST 94008A x ICSR 92001	20.0	0.0	15.5
entry 47	SPST 94026A x SAR 16	0.0	0.0	0.5
entry 49	SPST 94026A x SAR 35	0.0	0.0	0.5
entry 51	SPST 94026A x SAR 42	6.7	0.0	0.5
entry 67	ICSA 93 x SAR 35	33.3	0.0	15.5
Susc. control				
entry 90	296B	26.7	100.0	24.5
Resis. control				
entry 91	SAR 1	20.0	0.0	10.5
entry 92	SAR 16	0.0	20.0	1.7
entry 94	SAR 34	13.3	10.0	11.3

Table 5.2. Selected lines, Testers, and hybrids for earliness.

No.	Pedigree	IAC	Akola	Combined
Lines				
L3	SPST 94001B	72	64	69
L6	SPST 94026B	75	69	72
Testers				
T2	SAR 16	80	76	77
T3	SAR 34	80	77	78
T5	SAR 41	79	75	78
Hybrids				
entry 5	SPST 94009A x SAR 41	73	74	75
entry 20	SPST 94001A x SAR 16	74	72	73
entry 21	SPST 94001A x SAR 34	78	71	74
entry 22	SPST 94001A x SAR 35	74	78	77
entry 24	SPST 94001A x SAR 42	76	68	72
entry 27	SPST 94001A x ICSR 93004	76	70	74
entry 29	SPST 94014A x SAR 16	73	72	73
entry 47	SPST 94026A x SAR 16	74	72	73
entry 48	SPST 94026A x SAR 34	77	69	73
entry 49	SPST 94026A x SAR 35	75	69	72
entry 53	SPST 94026A x ICSR 93002	79	67	74
entry 54	SPST 94026A x ICSR 93004	83	65	75
entry 56	ICSR 89 x SAR 16	78	65	77
Controls				
entry 92	SAR 16	76	78	78
entry 93	SAR 34	82	77	79

Table 5.3. Selected lines, testers, and hybrids for plant height.

No.	Pedigree	IAC	Akola	Combined
Lines				
L8	ICSB 93	1.93	1.70	1.78
L7	ICSB 89	1.75	1.85	1.84
Testers				
T1	SAR 1	2.05	1.75	1.93
T3	SAR 34	1.80	1.80	1.83
Hybrids				
entry 37	SPST 94008A x SAR 1	2.40	2.30	2.30
entry 48	SPST 94026A x SAR 34	2.30	2.10	2.31
entry 55	ICSA 89 x SAR 1	2.40	2.15	2.23
entry 61	ICSA 89 x ICSR 92001	2.35	2.45	2.39
entry 62	ICSR 89 x ICSR 93002	2.25	2.25	2.31
entry 64	ICSA 93 x SAR 1	2.55	2.40	2.49
entry 66	ICSA 93 x SAR 34	2.50	2.20	2.35
entry 70	ICSA 93 x ICSR 92001	2.40	2.25	2.38
entry 71	ICSA 93 x ICSR 93002	2.47	2.30	2.38
Controls				
entry 91	SAR 1	2.25	1.75	2.05
entry 93	SAR 34	1.75	1.50	1.66

Table 5.4. Selected lines, testers, and hybrids for grain yield plant^{-1}.

No.	Pedigree	IAC	Akola	Combined
Lines				
L5	SPST 94008B	11.73	22.90	15.05
L6	SPST 94026B	3.33	28.40	13.18
L7	ICSB 89	9.13	29.40	18.50
L8	ICSB 93	11.73	21.30	20.52
Testers				
T2	SAR 16	11.63	26.15	14.23
T3	SAR 34	6.60	15.15	16.30
T5	SAR 41	11.37	11.80	13.13
T6	SAR 42	7.03	23.55	9.25
T8	ICSR 93002	6.63	25.15	9.80
T9	ICSR 93004	9.33	18.80	17.23
Hybrids				
entry 15	SPST 94011A x SAR 42	21.00	49.40	35.63
entry 16	SPST 94011A x ICSR 92001	20.83	39.55	30.35
entry 23	SPST 94001A x SAR 41	3.37	69.00	36.38
entry 35	SPST 94011A x ICSR 93002	26.93	38.05	32.45
entry 41	SPST 94008A x SAR 41	20.63	63.00	41.88
entry 42	SPST 94008A x SAR 42	23.10	48.00	35.00
entry 54	SPST 94026A x ICSR 93004	9.47	59.10	34.20
entry 64	ICSA 93 x SAR 1	5.80	72.65	39.15
entry 65	ICSA 93 x SAR 16	5.37	72.75	39.08
entry 67	ICSA 93 x SAR 35	3.33	58.55	31.23
entry 72	ICSR 93 x ICSR 93004	12.53	69.75	41.48
Controls				
entry 90	296B	9.20	19.40	15.40
entry 92	SAR 16	10.10	14.40	12.15

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Appendices

Appendix 1. Sorghum genotypes used in the study.

Entry #	Origin	Pedigree
A. Hybrids		
1.	44069A x 44092	SPST 94009A x SAR 1
2.	44069A x 44093	SPST 94009A x SAR 16
3.	44069A x 44094	SPST 94009A x SAR 34
4.	44069A x 44095	SPST 94009A x SAR 35
5.	44069A x 44096	SPST 94009A x SAR 41
6.	44069A x 44097	SPST 94009A x SAR 42
7.	44069A x 44098	SPST 94009A x ICSR 92001
8.	44069A x 44100	SPST 94009A x ICSR 93002
9.	44069A x 44102	SPST 94009A x ICSR 93004
10.	44071A x 44092	SPST 94011A x SAR 1
11.	44071A x 44093	SPST 94011A x SAR 16
12.	44071A x 44094	SPST 94011A x SAR 34
13.	44071A x 44095	SPST 94011A x SAR 35
14.	44071A x 44096	SPST 94011A x SAR 41
15.	44071A x 44097	SPST 94011A x SAR 42
16.	44071A x 44098	SPST 94011A x ICSR 92001
17.	44071A x 44100	SPST 94011A x ICSR 93002
18.	44071A x 44102	SPST 94011A x ICSR 93004
19.	44073A x 44092	SPST 94001A x SAR 1
20.	44073A x 44093	SPST 94001A x SAR 16
21.	44073A x 44094	SPST 94001A x SAR 34
22.	44073A x 44095	SPST 94001A x SAR 35
23.	44073A x 44096	SPST 94001A x SAR 41
24.	44073A x 44097	SPST 94001A x SAR 42
25.	44073A x 44098	SPST 94001A x ICSR 92001
26.	44073A x 44100	SPST 94001A x ICSR 93002
27.	44073A x 44102	SPST 94001A x ICSR 93004
28.	44075A x 44092	SPST 94014A x SAR 1
29.	44075A x 44093	SPST 94014A x SAR 16
30.	44075A x 44094	SPST 94014A x SAR 34
31.	44075A x 44095	SPST 94014A x SAR 35
32.	44075A x 44096	SPST 94014A x SAR 41
33.	44075A x 44097	SPST 94014A x SAR 42
34.	44075A x 44098	SPST 94014A x ICSR 92001
35.	44075A x 44100	SPST 94014A x ICSR 93002
36.	44075A x 44102	SPST 94014A x ICSR 93004
37.	44077A x 44092	SPST 94008A x SAR 1
38.	44077A x 44093	SPST 94008A x SAR 16
39.	44077A x 44094	SPST 94008A x SAR 34
40.	44077A x 44095	SPST 94008A x SAR 35
41.	44077A x 44096	SPST 94008A x SAR 41
42.	44077A x 44097	SPST 94008A x SAR 42
43.	44077A x 44098	SPST 94008A x ICSR 92001
44.	44077A x 440100	SPST 94008A x ICSR 93002
45.	44077A x 440102	SPST 94008A x ICSR 93004

Appendix 1 (continued)

Entry #	Origin	Pedigree
46.	44079A x 44092	SPST 94026A x SAR 1
47.	44079A x 44093	SPST 94026A x SAR 16
48.	44079A x 44094	SPST 94026A x SAR 34
49.	44079A x 44095	SPST 94026A x SAR 45
50.	44079A x 44096	SPST 94026A x SAR 41
51.	44079A x 44097	SPST 94026A x SAR 42
52.	44079A x 44098	SPST 94026A x ICSR 92001
53.	44079A x 44100	SPST 94026A x ICSR 93002
54.	44079A x 44102	SPST 94026A x ICSR 93004
55.	44089A x 44092	ICSA 89 x SAR 1
56.	44089A x 44093	ICSA 89 x SAR 16
57.	44089A x 44094	ICSA 89 x SAR 34
58.	44089A x 44095	ICSA 89 x SAR 35
59.	44089A x 44096	ICSA 89 x SAR 41
60.	44089A x 44097	ICSA 89 x SAR 42
61.	44089A x 44098	ICSA 89 x ICSR 92001
62.	44089A x 440100	ICSA 89 x ICSR 93002
63.	44089A x 440102	ICSA 89 x ICSR 93004
64.	44091A x 44092	ICSA 93 x SAR 1
65.	44091A x 44093	ICSA 93 x SAR 16
66.	44091A x 44094	ICSA 93 x SAR 34
67.	44091A x 44095	ICSA 93 x SAR 35
68.	44091A x 44096	ICSA 93 x SAR 41
69.	44091A x 44097	ICSA 93 x SAR 42
70.	44091A x 44098	ICSA 93 x ICSR 92001
71.	44091A x 44122	ICSA 93 x ICSR 93002
72.	44091A x 44102	ICSA 93 x ICSR 93004

b. Resistant restorers.

73 SAR 1
74. SAR 16
75 SAR 34
76. SAR 35
77 SAR 41
78. SAR 42

c. **Susceptible restorers**

79. ICSR 92001
80. ICSR 93002
81. ICSR 93004

d. Resistant male sterile lines

82. SPST 94009B
83. SPST 94011B
84. SPST 94001B
85. SPST 94014B
86. SPST 94008B
87. SPST 94026B

e. Susceptible male sterile lines

88. ICSB 89
89. ICSB 93

Appendix 2a. Mean *Striga* plants, *Striga* incidence (SI%), transformed *Striga* incidence (TSI%), days to 50 % flowering, plant height (PHT), and grain yield plant^{-1} at IAC.

Ent#	Pedigree	MSM	SI%	TSI%[a]	DFL	PHT	GYLD/ PLT
1	SPST 94009A x SAR 1	1	20.0	4.0	79	1.90	5.50
2	SPST 94009A x SAR 16	1	20.0	4.6	78	1.88	5.50
3	SPST 94009A x SAR 34	2	40.0	5.2	78	2.00	11.00
4	SPST 94009A x SAR 35	0	6.7	2.2	85	1.95	4.50
5	SPST 94009A x SAR 41	1	13.3	2.8	73	2.30	9.50
6	SPST 94009A x SAR 42	1	13.3	2.8	79	1.80	12.50
7	SPST 94009A x ICSR 92001	0	6.7	2.2	79	2.00	4.50
8	SPST 94009A x ICSR 93002	1	13.3	3.4	81	1.90	9.50
9	SPST 94009A x ICSR 93004	2	6.7	4.3	79	2.40	6.10
10	SPST 94011A x SAR 1	1	6.7	3.4	76	2.05	11.90
11	SPST 94011A x SAR 16	0	6.7	2.2	80	1.40	11.23
12	SPST 94011A x SAR 34	0	6.7	2.2	78	1.95	10.40
13	SPST 94011A x SAR 35	2	33.3	5.1	81	1.55	10.40
14	SPST 94011A x SAR 41	0	6.7	2.2	81	1.45	14.75
15	SPST 94011A x SAR 42	1	13.3	3.4	79	1.65	21.00
16	SPST 94011A x ICSR 92001	0	0.0	1.0	83	1.75	20.83
17	SPST 94011A x ICSR 92002	1	20.0	4.0	81	1.55	19.73
18	SPST 94011A x ICSR 92003	3	53.3	7.3	84	1.50	13.73
19	SPST 94001A x SAR 1	0	6.7	2.2	76	1.80	3.00
20	SPST 94001A x SAR 16	2	46.7	5.5	74	1.35	4.27
21	SPST 94001A x SAR 34	1	20.0	4.0	78	2.05	3.23
22	SPST 94001A x SAR 35	0	6.7	2.2	74	1.60	8.80
23	SPST 94001A x SAR 41	1	26.7	5.2	76	1.65	3.37
24	SPST 94001A x SAR 42	1	26.7	5.2	76	1.75	6.77
25	SPST 94001A x ICSR 92001	1	13.3	3.4	78	1.75	11.70
26	SPST 94001A x ICSR 93002	1	20.0	4.0	77	1.85	11.83
27	SPST 94001A x ICSR 93004	1	26.7	4.5	76	1.50	14.60

Ent#	Pedigree	MSM	SI%	TSI%*	DFL	PHT	GYLD/ PLT
28	SPST 94014A x SAR 1	0	6.7	2.2	77	2.20	13.40
29	SPST 94014A x SAR 16	1	13.3	3.4	73	1.35	14.17
30	SPST 94014A x SAR 34	1	26.7	4.5	83	1.95	9.47
31	SPST 94014A x SAR 35	1	20.0	4	79	1.30	7.13
32	SPST 94014A x SAR 41	0	6.7	2.2	78	1.40	11.43
33	SPST 94011A x SAR 42	0	6.7	2.2	80	1.50	12.43
34	SPST 94011A x ICSR 92001	1	13.3	3.4	80	1.60	13.67
35	SPST 94011A x ICSR 93002	3	60.0	7.6	78	1.65	26.93
36	SPST 94011A x ICSR 93004	2	40.0	6.3	78	1.45	15.60
37	SPST 94008A x SAR 1	1	13.3	3.4	79	2.40	5.43
38	SPST 94008A x SAR 16	0	6.7	2.2	73	1.20	1.83
39	SPST 94008A x SAR 34	0	6.7	2.2	82	2.10	11.37
40	SPST 94008A x SAR 35	1	20.0	4.0	76	1.70	5.57
41	SPST 94008A x SAR 41	0	0.0	1.0	84	1.80	20.63
42	SPST 94008A x SAR 42	0	0.0	1.0	82	1.85	23.10
43	SPST 94008A x ICSR 92001	1	20.0	4.0	84	2.00	9.47
44	SPST 94008A x ICSR 93002	1	20.0	4.0	81	1.95	13.13
45	SPST 94008A x ICSR 93004	1	26.7	5.2	79	2.25	12.50
46	SPST 94026A x SAR 1	1	13.3	3.4	82	2.20	6.97
47	SPST 94026A x SAR 16	0	0.0	1.0	74	1.75	7.13
48	SPST 94026A x SAR 34	1	13.3	2.8	77	2.30	8.77
49	SPST 94026A x SAR 35	0	0.0	1.0	75	2.00	5.33
50	SPST 94026A x SAR 41	1	26.7	3.7	84	1.90	6.07
51	SPST 94026A x SAR 42	0	6.7	2.2	81	2.10	5.00
52	SPST 94026A x ICSR 92001	0	6.7	2.2	82	2.25	12.53
53	SPST 94026A x ICSR 93002	2	46.7	6.7	79	1.90	5.80
54	SPST 94026A x ICSR 93004	4	80.8	8.7	83	1.65	9.47

Ent#	Pedigree	MSM	SI%	TSI%*	DFL	PHT	GYLD/ PLT
55	ICSA 89 x SAR 1	4	73.3	8.2	81	2.40	4.10
56	ICSA 89 x SAR 16	1	13.3	2.8	78	1.90	5.93
57	ICSA 89 x SAR 34	1	13.3	3.4	81	2.35	10.30
58	ICSA 89 x SAR 35	2	33.3	5.7	77	2.15	7.30
59	ICSA 89 x SAR 41	10	200.0	11	82	2.05	7.97
60	ICSA 89 x SAR 42	1	26.7	4.6	85	2.05	16.50
61	ICSA 89 x ICSR 92001	1	13.3	3.4	83	2.35	10.97
62	ICSA 89 x ICSR 93002	2	26.7	5.2	84	2.25	7.97
63	ICSA 89 x ICSR 93004	1	40.0	6.3	80	2.10	12.06
64	ICSA 93 x SAR 1	1	13.3	2.8	80	2.55	5.80
65	ICSA 93 x SAR 16	1	13.3	3.4	78	1.95	5.37
66	ICSA 93 x SAR 34	0	6.7	2.2	80	2.50	2.43
67	ICSA 93 x SAR 35	2	33.3	5.8	76	2.20	3.33
68	ICSA 93 x SAR 41	3	53.3	7.1	82	2.30	6.53
69	ICSA 93 x SAR 42	1	13.3	3.4	86	2.10	9.17
70	ICSA 93 x ICSR 92001	3	60.0	7.0	89	2.40	8.77
71	ICSA 93 x ICSR 93002	1	13.3	2.8	80	2.47	7.30
72	ICSA 93 x ICSR 93004	1	13.3	3.4	83	2.30	12.53
73	SAR 1 (T1)	0	0.0	1.0	83	2.05	6.47
74	SAR 16 (T2)	1	13.3	2.8	80	1.10	11.63
75	SAR 34 (T3)	0	6.7	2.2	80	1.80	6.60
76	SAR 35 (T4)	0	6.7	2.2	81	1.40	9.73
77	SAR 41 (T5)	1	20.0	3.3	79	1.45	11.37
78	SAR 42 (T6)	0	6.7	2.2	84	1.58	7.03
79	ICSR 92001 (T7)	1	13.3	3.4	94	1.80	6.37
80	ICSR 93002 (T8)	5	100.0	8.5	82	1.60	6.63
81	ICSR 93004 (T9)	0	6.7	2.2	84	1.35	9.33
82	SPST 94009B (L1)	0	6.7	2.2	81	1.55	7.20

Ent#	Pedigree	MSM	SI%	TSI%[a]	DFL	PHT	GYLD/ PLT
83	SPST 94011B (L2)	0	6.7	2.2	77	1.10	9.30
84	SPST 94001B (L3)	0	6.7	2.2	72	1.35	4.63
85	SPST 94014B (L4)	0	13.3	2.2	75	1.05	6.27
86	SPST 94008B (L5)	1	13.3	3.4	84	1.25	11.73
87	SPST 94026B (L6)	1	13.3	3.4	75	1.65	3.33
88	ICSB 89 (L7)	3	60.0	7.6	84	1.75	9.13
89	ICSB 93 (L8)	3	60.0	7.6	86	1.93	11.73
90	296B	1	26.7	4.5	87	1.20	9.20
91	SAR 1	1	20.0	4.0	79	2.25	3.87
92	SAR 16	0	0.0	1.0	76	1.15	10.10
93	SAR 34	1	13.3	3.4	82	1.75	5.40
Mean		1	22.4	3.73	80	1.85	9.43
SE		2.10	42.11	2.89	3.46	0.16	1.45
CV(%)		187.7	187.7	75.8	4.30	8.40	15.40

a= Square root transformation $\sqrt{(SI\%+1)}$.

Appendix 2b Mean performance for *Striga* plant, *Striga* incidence (SI%), transformed *Striga* incidence (TSI%), days to 50 % flowering, plant height (PHT), and grain yield plant^{-1} at Akola.

Ent# Pedigree	MSM	SI%	TSI%	DFL	PHT	GYLD /PLT
1. SPST 94009A x SAR 1	1	10.0	2.8	72	1.75	30.15
2. SPST 94009A x SAR 16	0	0.0	1.0	76	1.75	40.40
3. SPST 94009A x SAR 34	1	10.0	2.8	75	1.85	41.25
4. SPST 94009A x SAR 35	1	20.0	3.7	79	1.75	34.40
5. SPST 94009A x SAR 41	1	20.0	3.7	74	1.95	42.40
6. SPST 94009A x SAR 42	1	10.0	2.8	75	1.60	41.00
7. SPST 94009A x ICSR 92001	0	0.0	1.0	77	2.00	34.50
8. SPST 94009A x ICSR 93002	2	40.0	6.4	78	2.05	40.00
9. SPST 94009A x ICSR 93004	1	10.0	2.8	78	1.40	46.00
10. SPST 94011A x SAR 1	1	10.0	2.8	78	2.05	43.90
11. SPST 94011A x SAR 16	1	20.0	4.6	76	1.40	30.55
12. SPST 94011A x SAR 34	0	0.0	1.0	75	1.65	30.55
13. SPST 94011A x SAR 35	0	0.0	1.0	76	1.40	40.80
14. SPST 94011A x SAR 41	1	20.0	3.7	74	1.35	29.90
15. SPST 94011A x SAR 42	1	20.0	3.7	78	1.50	49.40
16. SPST 94011A x ICSR 92001	2	30.0	4.4	79	1.40	39.55
17. SPST 94011A x ICSR 93002	2	30.0	5.5	79	1.40	32.65
18. SPST 94011A x ICSR 93004	1	20.0	3.7	80	1.30	44.75
19. SPST 94001A x SAR 1	0	0.0	1.0	70	1.60	25.15
20. SPST 94001A x SAR 16	0	0.0	1.0	72	1.75	52.50
21. SPST 94001A x SAR 34	1	10.0	2.8	71	2.05	28.75
22. SPST 94001A x SAR 35	0	0.0	1.0	78	1.40	56.65
23. SPST 94001A x SAR 41	0	0.0	1.0	81	1.55	69.00
24. SPST 94001A x SAR 42	0	0.0	1.0	68	1.60	30.50
25. SPST 94001A x ICSR 92001	1	10.0	2.8	77	1.45	20.90
26. SPST 94001A x ICSR 93002	1	10.0	2.8	75	1.70	50.40
27. SPST 94001A x ICSR 93004	0	0.0	1.0	70	1.50	54.90

Ent# Pedigree	MSM	SI%	TSI%	DFL	PHT	GYLD /PLT
28. SPST 94014A x SAR 1	1	20.0	3.7	80	0.95	35.50
29. SPST 94014A x SAR 16	1	10.0	2.8	72	1.10	36.15
30. SPST 94014A x SAR 34	2	40.0	6.2	74	1.70	24.50
31. SPST 94014A x SAR 35	1	20.0	3.7	75	1.30	26.40
32. SPST 94014A x SAR 41	1	20.0	4.6	72	1.15	23.00
33. SPST 94014A x SAR 42	0	0.0	1.0	77	1.40	29.40
34. SPST 94014A x ICSR 92001	0	0.0	1.0	78	1.40	29.00
35. SPST 94014A x ICSR 93002	6	120.0	8.25	77	1.45	38.05
36. SPST 94014A x ICSR 93004	4	80.0	9.0	75	1.30	35.40
37. SPST 94008A x SAR 1	0	0.0	1.0	79	2.30	56.35
38. SPST 94008A x SAR 16	0	0.0	1.0	80	0.95	52.05
39. SPST 94008A x SAR 34	6	110.0	8.0	76	2.10	22.25
40. SPST 94008A x SAR 35	1	20.0	3.7	78	1.35	55.00
41. SPST 94008A x SAR 41	1	20.0	3.7	79	2.00	63.00
42. SPST 94008A x SAR 42	0	0.0	1.0	76	1.60	48.00
43. SPST 94008A x ICSR 92001	0	0.0	1.0	78	2.05	56.40
44. SPST 94008A x ICSR 93002	1	20.0	3.7	77	1.95	28.25
45. SPST 94008A x ICSR 93004	1	10.0	2.8	78	1.95	57.15
46. SPST 94026A x SAR 1	1	10.0	2.8	74	2.20	44.64
47. SPST 94026A x SAR 16	0	0.0	1.0	72	1.45	16.65
48. SPST 94026A x SAR 34	1	10.0	2.8	69	2.10	43.15
49. SPST 94026A x SAR 35	0	0.0	1.0	69	1.45	23.30
50. SPST 94026A x SAR 41	1	10.0	2.8	71	1.95	21.56
51. SPST 94026A x SAR 42	0	0.0	1.0	72	2.00	38.65
52. SPST 94026A x ICSR 92001	2	40.0	5.0	80	1.65	20.65
53. SPST 94026A x ICSR 93002	1	10.0	2.8	67	1.60	23.65
54. SPST 94026A x ICSR 93004	1	10.0	2.8	65	1.85	59.10

Ent#	Pedigree	MSM	SI%	TSI%	DFL	PHT	GYLD /PLT
55.	ICSA 89 x SAR 1	1	20.0	4.6	76	2.15	37.15
56.	ICSA 89 x SAR 16	2	30.0	5.5	65	1.80	23.90
57.	ICSA 89 x SAR 34	1	10.0	2.8	76	2.05	11.75
58.	ICSA 89 x SAR 35	2	40.0	5.0	75	2.00	28.55
59.	ICSA 89 x SAR 41	1	20.0	3.7	74	1.85	28.25
60.	ICSA 89 x SAR 42	1	20.0	3.7	74	2.05	16.55
61.	ICSA 89 x ICSR 92001	5	90.0	9.0	80	2.45	52.00
62.	ICSA 89 x ICSR 93002	1	10.0	2.8	77	2.25	43.50
63.	ICSA 89 x ICSR 93004	1	20.0	4.7	74	1.85	34.40
64.	ICSA 93 x SAR 1	2	40.0	5.7	84	2.40	72.65
65.	ICSA 93 x SAR 16	1	20.0	5.0	81	1.70	72.75
66.	ICSA 93 x SAR 34	2	40.0	3.7	72	2.20	33.40
67.	ICSA 93 x SAR 35	0	0.0	1	74	2.10	58.55
68.	ICSA 93 x SAR 41	6	110.0	10	78	2.15	36.75
69.	ICSA 93 x SAR 42	1	20.0	3.7	77	2.10	39.55
70.	ICSA 93 x ICSR 92001	1	10.0	2.8	80	2.25	18.65
71.	ICSA 93 x ICSR 93002	3	50.0	5.5	76	2.30	39.40
72.	ICSA 93 X ICSR 93004	5	90.0	9.2	81	1.95	69.75
73.	SAR 1 (T1)	5	90.0	7.3	79	1.75	15.25
74.	SAR 16 (T2)	0	0.0	1.0	76	1.15	26.15
75.	SAR 34 (T3)	1	20.0	3.7	77	1.80	15.15
76.	SAR 35 (T4)	0	0.0	1.0	80	1.45	15.05
77.	SAR 41 (T5)	2	40.0	5.0	75	1.40	11.80
78.	SAR 42 (T6)	0	0.0	1.0	79	1.55	23.55
79.	ICSR 92001 (T7)	2	30.0	5.5	92	1.70	12.40
80.	ICSR 93002 (T8)	3	50.0	7.0	82	1.65	25.15
81.	ICSR 93004 (T9)	0	0.0	1	81	1.40	18.80
82.	SPST 94009B (L1)	2	30.0	4.4	79	1.40	16.30

Ent# Pedigree	MSM	SI%	TSI%	DFL	PHT	GYLD /PLT
83. SPST 94011B (L2)	0	0.0	1.0	77	0.95	17.40
84. SPST 94001B (L3)	0	0.0	1.0	64	1.15	11.40
85. SPST 94014B (L4)	0	0.0	1.0	77	0.95	18.05
86. SPST 94008B (L5)	1	20.0	3.7	80	1.35	22.90
87. SPST 94026B (L6)	0	0.0	1.0	69	1.40	28.40
88. ICSB 89 (L7)	6	110.0	8.0	79	1.85	29.40
89. ICSB 93 (L8)	5	110.0	9.9	80	1.70	21.30
90. 296B	5	100.0	9.9	81	1.55	19.40
91. SAR 1	0	0.0	1.0	82	1.75	13.90
92. SAR 16	1	20.0	3.7	78	1.05	14.40
93. SAR 34	1	10.0	2.8	77	1.50	14.40
Mean	1	23.0	3.5	76	1.68	34.43
SE	2.04	40.86	5.8	4.60	0.13	3.47
CV(%)	177.61	177.60	96.80	8.61	11.30	10.10

a = Square root transformation √(SI%+1)

Appendix 2c. Mean *Striga* plants, *Striga* incidence (SI%), transformed *Striga* incidence (TSI%), days to 50% flowering (DFL), plant height (PHT), and grain yield plant^{-1} in combined analysis.

Ent#	Pedigree	MSM	SI%	TSI%^{1}	DFL	PHT	GYLD/ PLT
1	SPST 94009A x SAR 1	1	6.7	2.3	76	1.85	18.45
2	SPST 94009A x SAR 16	1	11.7	3.0	78	1.86	22.77
3	SPST 94009A x SAR 34	2	26.3	3.7	77	1.90	27.35
4	SPST 94009A x SAR 35	1	6.7	2.4	80	1.94	19.80
5	SPST 94009A x SAR 41	1	11.7	2.9	75	2.15	25.88
6	SPST 94009A x SAR 42	1	11.3	2.8	78	1.90	26.53
7	SPST 94009A x ICSR 92001	0	0.5	1.2	78	2.08	19.15
8	SPST 94009A x ICSR 93002	2	12.9	3.6	81	1.89	24.70
9	SPST 94009A x ICSR 93004	2	31.3	3.9	80	1.85	26.05
10	SPST 94011A x SAR 1	1	6.3	2.3	83	2.08	27.88
11	SPST 94011A x SAR 16	1	2.1	1.6	78	1.48	21.08
12	SPST 94011A x SAR 34	0	5.5	2.1	77	1.79	20.73
13	SPST 94011A x SAR 35	1	2.5	4.3	77	1.48	25.45
14	SPST 94011A x SAR 41	1	6.7	2.4	77	1.41	22.75
15	SPST 94011A x SAR 42	1	11.7	3.3	78	1.58	35.63
16	SPST 94011A x ICSR 92001	1	2.0	1.6	82	1.57	30.35
17	SPST 94011A x ICSR 93002	1	7.5	2.6	80	1.49	25.35
18	SPST 94011A x ICSR 93004	2	31.7	4.9	81	1.41	29.43
19	SPST 94001A x SAR 1	0	5.5	2.1	74	1.86	14.05
20	SPST 94001A x SAR 16	2	30.5	3.7	73	1.29	28.43
21	SPST 94001A x SAR 34	1	6.3	2.3	74	2.10	16.05
22	SPST 94001A x SAR 35	0	5.5	2.1	77	1.49	32.70
23	SPST 94001A x SAR 41	1	15.5	3.5	85	1.61	36.38
24	SPST 94001A x SAR 42	1	10.5	3.0	72	1.70	19.60
25	SPST 94001A x ICSR 92001	1	6.3	2.3	78	1.60	16.43
26	SPST 94001A x ICSR 93002	1	6.3	2.3	75	1.83	31.20
27	SPST 94001A x ICSR 93004	1	20.5	3.8	74	1.53	34.33

Ent#	Pedigree	MSM	SI%	TSI%*	DFL	PHT	GYLD/ PLT
28	SPST 94014A x SAR 1	1	1.7	1.5	79	1.59	24.70
29	SPST 94014A x SAR 16	1	6.3	2.3	73	1.26	24.93
30	SPST 94014A x SAR 34	2	22.8	4.4	78	1.85	16.98
31	SPST 94014A x SAR 35	1	11.7	2.9	79	1.28	16.90
32	SPST 94014A x SAR 41	1	2.1	1.6	76	1.26	17.43
33	SPST 94014A x SAR 42	0	5.5	2.1	80	1.44	20.77
34	SPST 94014A x ICSR 92001	1	10.5	3.0	79	1.48	21.98
35	SPST 94014A x ICSR 93002	5	38.8	5.4	77	1.58	32.45
36	SPST 94014A x ICSR 93004	3	29.1	5.1	78	1.36	25.75
37	SPST 94008A x SAR 1	0	5.5	2.1	80	2.30	30.63
38	SPST 94008A x SAR 16	0	5.5	2.1	80	1.26	26.80
39	SPST 94008A x SAR 34	3	8.7	2.7	79	2.15	17.05
40	SPST 94008A x SAR 35	1	16.7	3.7	77	1.56	30.03
41	SPST 94008A x SAR 41	1	1.7	1.5	81	1.93	41.88
42	SPST 94008A x SAR 42	0	0.5	1.2	79	1.73	35.00
43	SPST 94008A x ICSR 92001	1	15.5	3.5	81	2.07	33.15
44	SPST 94008A x ICSR 93002	1	6.7	2.4	78	1.70	20.48
45	SPST 94008A x ICSR 93004	1	16.3	3.7	78	2.04	34.50
46	SPST 94026A x SAR 1	1	11.3	3.2	79	2.23	25.68
47	SPST 94026A x SAR 16	0	0.5	1.2	73	1.58	11.93
48	SPST 94026A x SAR 34	1	11.3	2.8	73	2.31	25.93
49	SPST 94026A x SAR 35	0	0.5	1.2	72	1.74	14.55
50	SPST 94026A x SAR 41	1	21.3	3.4	76	2.03	14.05
51	SPST 94026A x SAR 42	0	0.5	1.2	76	2.09	21.67
52	SPST 94026A x ICSR 92001	1	7.3	2.5	82	1.98	16.55
53	SPST 94026A x ICSR 93002	1	21.3	4.0	74	1.76	14.78
54	SPST 94026A x ICSR 93004	3	51.3	5.8	75	1.75	34.20

Ent#	Pedigree	MSM	SI%	TSI%[1]	DFL	PHT	GYLD/ PLT
55	ICSA 89 x SAR 1	3	52.1	6.1	79	2.23	20.73
56	ICSA 89 x SAR 16	1	12.5	3.1	77	1.85	14.93
57	ICSA 89 x SAR 34	1	6.3	2.3	79	2.19	10.90
58	ICSA 89 x SAR 35	2	22.3	4.2	75	2.08	18.38
59	ICSA 89 x SAR 41	1	11.7	3.3	77	2.00	17.98
60	ICSA 89 x SAR 42	1	11.7	2.9	78	2.13	16.88
61	ICSA 89 x ICSR 92001	3	9.3	3.0	82	2.39	31.40
62	ICSA 89 x ICSR 93002	1	16.3	3.7	79	2.31	25.25
63	ICSA 89 x ICSR 93004	2	21.7	4.1	77	2.01	23.08
64	ICSA 93 x SAR 1	2	12.3	3.0	82	2.49	39.15
65	ICSA 93 x SAR 16	1	6.7	2.4	79	1.84	39.08
66	ICSA 93 x SAR 34	1	7.8	2.7	76	2.35	17.90
67	ICSA 93 x SAR 35	1	15.5	3.5	75	2.23	31.23
68	ICSA 93 x SAR 41	5	39.8	5.8	81	2.23	21.33
69	ICSA 93 x SAR 42	1	6.7	2.4	81	2.13	24.38
70	ICSA 93 x ICSR 92001	2	36.3	4.1	82	2.38	13.75
71	ICSA 93 x ICSR 93002	1	2.6	1.7	79	2.38	23.27
72	ICSA 93 x ICSR 93004	3	9.2	2.9	81	2.20	41.48
73	SAR 1 (T1)	2	3.3	1.8	80	1.93	11.00
74	SAR 16 (T2)	1	10.5	2.6	77	1.15	14.23
75	SAR 34 (T3)	1	1.7	1.5	78	1.83	16.30
76	SAR 35 (T4)	0	5.5	2.1	80	1.45	11.68
77	SAR 41 (T5)	2	17.3	3.3	78	1.44	13.13
78	SAR 42 (T6)	0	0.5	1.2	81	1.60	9.25
79	ICSR 92001 (T7)	1	7.5	2.6	94	1.75	15.02
80	ICSR 93002 (T8)	3	32.5	4.1	88	1.61	9.80
81	ICSR 93004 (T9)	0	0.5	1.2	83	1.37	17.23
82	SPST 94009B (L1)	1	7.0	2.5	80	1.48	13.05

Ent#	Pedigree	MSM	SI%	TSI%[a]	DFL	PHT	GYLD/ PLT
83	SPST 94011B (L2)	0	0.5	1.2	77	1.05	12.70
84	SPST 94001B (L3)	0	0.5	1.2	69	1.23	11.68
85	SPST 94014B (L4)	0	5.5	2.1	77	0.99	9.03
86	SPST 94008B (L5)	1	6.7	2.4	83	1.29	15.05
87	SPST 94026B (L6)	1	10.5	3.0	72	1.50	13.18
88	ICSB 89 (L7)	5	43.7	4.7	82	1.84	18.50
89	ICSB 93 (L8)	5	49.5	5.9	82	1.78	20.52
90	296B	4	24.5	4.7	84	1.40	15.40
91	SAR 1	1	10.5	2.6	81	2.05	11.70
92	SAR 16	1	1.7	1.5	78	1.10	12.15
93	SAR 34	1	11.3	3.2	79	1.66	10.48
Mean		1	13.0	2.9	78	1.77	21.95
SE		1.79	21.31	2.05	5.0	0.17	2.68
CV(%)		156.8	164.2	70.8	6.5	9.7	12.2

a= Square root transformation of √(SI%+1)

Appendix 3. SCA effects and heterosis for days to 50% flowering (DFL) in line x tester experiment at IAC and Akola.

		SCA effects		Heterosis(%)			
				Akola		IAC	
Ent#	Pedigree	IAC	Akola	MP	HP	MP	HP
1	SPST 94009A x SAR 1	-0.54	-5.72	-5.37	-5.56	-10.06	-11.18
2	SPST 94009A x SAR 16	4.61**	-0.49	5.28	2.77	0.32	-3.11
3	SPST 94009A x SAR 34	-0.58	-0.38	-7.32	-9.52	-11.11	-13.04
4	SPST 94009A x SAR 35	-1.17	2.73	-5.85	-7.54	0.63	-1.24
5	SPST 94009A x SAR 41	-2.21*	-0.05	-3.46	-5.95	1.66	-1.86
6	SPST 94009A x SAR 42	2.24*	1.28	-2.18	-2.37	-7.55	-8.70
7	SPST 94009A x ICSA 92001	-0.54	-1.55	-9.33	14.44	-12.46	-17.93
8	SPST 94009A x ICSA 93002	-1.80	4.17	-9.44	-13.67	3.09	2.45
9	SPST 94009A x ICSA 93004	3.42**	-0.60	-2.63	-3.99	-4.13	-4.43
10	SPST 94011A x SAR 1	1.23	-1.37	-0.82	-1.64	-1.94	-3.80
11	SPST 94011A x SAR 16	1.05	2.24	-7.43	-8.19	-8.33	-9.43
12	SPST 94011A x SAR 34	-2.21*	-3.65	-9.23	-9.42	-9.15	-9.49
13	SPST 94011A x SAR 35	-0.25	1.57	-3.11	-4.09	3.25	0.63
14	SPST 94011A x SAR 41	-2.47*	0.41	-9.85	-11.46	9.21	-9.49
15	SPST 94011A x SAR 42	-0.58	-0.92	-11.36	-17.61	-12.28	18.48
16	SPST 94011A x ICSR 92001	-0.18	2.30	-9.57	-15.11	0.31	-1.23
17	SPST 94011A x ICSR 93002	-1.25	2.54	-2.70	-6.38	-4.18	-5.10
18	SPST 94011A x ICSR 93004	-3.44**	-0.74	-0.85	-2.50	-2.61	-3.25
19	SPST 94001A x SAR 1	2.38*	3.38	0.01	1.66	-8.44	-8.44
20	SPST 94001A x SAR 16	4.45**	-0.02	4.64	2.47	-6.07	-7.55
21	SPST 94001A x SAR 34	1.75	-0.30	5.31	3.77	-0.66	-1.95
22	SPST 94001A x SAR 35	-2.81*	0.04	-4.74	-8.69	-12.25	-12.10
23	SPST 94001A x SAR 41	0.42	1.70	-5.05	-13.73	-10.65	-17.93
24	SPST 94001A x SAR 42	-1.51	-4.76	-5.88	-13.67	-9.78	-12.27
[illegible]	[illegible]	6.53**	2.78	8.78	1.20	10.88	0.64

Ent#	Pedigree	SCA effects		Heterosis(%)			
				Akola		IAC	
		IAC	Akola	MP	HP	MP	HP
26	SPST 94001A x ICSR 93002	1.07	-0.99	6.58	1.25	7.86	-0.66
27	SPST 94001A x ICSR 93004	-0.45	8.62	-2.20	-7.09	10.64	1.30
28	SPST 940014A x SAR 1	2.29*	-0.77	3.70	-2.06	4.53	-5.66
29	SPST 940014A x SAR 16	-1.08	-0.55	3.29	-1.68	11.51	3.33
30	SPST 940014A x SAR 34	-2.64**	-2.72	-3.19	-10.27	1.72	-9.20
31	SPST 940014A x SAR 35	-2.42*	-1.05	-7.21	-18.32	-3.85	-18.48
32	SPST 940014A x SAR 41	-3.34**	-4.33	-6.88	-17.27	1.72	-9.20
33	SPST 940014A x SAR 42	-3.21**	2.47	-2.94	-7.58	-5.47	-6.37
34	SPST 940014A x ICSR 92001	-0.73	1.69	4.93	2.09	-3.27	-3.90
35	SPST 940014A x ICSR 93002	-0.58	23.70**	-1.50	-4.16	-47.40	-47.40
36	SPST 940014A x ICSR 93004	-1.17	1.42	-0.01	-3.30	-7.99	-9.43
37	SPST 94008A x SAR 1	2.13*	6.14	8.15	5.43	3.95	2.60
38	SPST 94008A x SAR 16	3.57**	4.47	5.41	0.00	-9.32	-10.19
39	SPST 94008A x SAR 34	0.46	3.14	-2.94	-12.68	-12.43	-19.57
40	SPST 94008A x SAR 35	-0.47	4.36	-2.58	-11.51	-2.21	-4.91
41	SPST 94008A x SAR 41	-2.08	-2.34	-6.16	-6.35	-5.06	-5.66
42	SPST 94008A x SAR 42	-3.60**	0.88	-3.66	-5.95	-0.32	-2.52
43	SPST 94008A x ICSR 92001	-1.45	-0.51	-7.32	-9.52	-13.10	-14.47
44	SPST 94008A x ICSR 93002	0.29	1.60	-3.03	-4.76	-3.77	-3.77
45	SPST 94008A x ICSR 93004	0.58	-1.63	1.02	-1.58	-2.27	-5.03
46	SPST 94026A x SAR 1	0.03	1.76	-3.76	-3.95	-8.86	-9.43
47	SPST 94026A x SAR 16	2.92**	-1.17	-4.48	-9.87	-13.70	-19.57
48	SPST 94026A x SAR 34	3.32**	-0.45	-2.64	-7.20	-4.35	-5.52
49	SPST 94026A x SAR 35	-3.04**	-2.34	-0.63	-5.58	4.76	-1.91
50	SPST 94026A x SAR 41	-0.89	-1.62	6.87	3.75	9.34	3.95
51	SPST 94026A x SAR 42	-0.75	4.50	0.43	-2.50	5.84	0.00

Ent#	Pedigree	SCA effects		Heterosis(%)			
				Akola		IAC	
		IAC	Akola	MP	HP	MP	HP
52	SPST 94026A x ICSR 92001	-0.67	-0.40	2.77	-0.83	4.73	-2.52
53	SPST 94026A x ICSR 93002	0.63	-3.17	8.39	5.43	8.71	4.00
54	SPST 94026A x ICSR 93004	0.07	5.16	3.13	-2.37	8.16	1.27
55	ICSA 89 x SAR 1	-0.37	0.83	-1.96	-11.98	-0.31	-13.04
56	ICSA 89 x SAR 16	5.00**	-1.95	5.95	-3.96	-6.00	-12.45
57	ICSA 89 x SAR 34	-0.83	0.98	-3.57	-3.95	-1.59	-7.90
58	ICSA 89 x SAR 35	-0.35	1.91	-0.60	-3.15	1.94	-3.34
59	ICSA 89 x SAR 41	0.80	5.31	-5.47	-7.90	-3.85	-5.06
60	ICSA 89 x SAR 42	-0.80	0.92	-5.24	-7.11	-2.84	-3.04
61	ICSA 89 x ICSR 92001	0.17	-1.86	-0.40	-3.15	-0.65	-3.16
62	ICSA 89 x ICSR 93002	-1.06	-4.53	-5.93	-5.93	-14.92	-15.90
63	ICSA 93 x ICSR 93004	2.17*	0.64	-6.15	-11.25	-9.94	-16.30
64	ICSA 93 x SAR 1	-1.76	-2.64	-9.23	-13.32	-5.30	-9.75
65	ICSA 93 x SAR 16	-0.71	2.22	-6.27	-7.71	-1.58	-2.50
66	ICSA 93 x SAR 34	2.11	2.44	1.40	-2.32	1.92	-0.63
67	ICSA 93 x SAR 35	-0.41	0.56	-7.81	-11.19	-11.46	-13.13
68	ICSA 93 x SAR 41	-1.01	-0.83	-6.38	-9.27	-6.56	-6.88
69	ICSA 93 x SAR 42	-1.71	0.11	-3.61	-7.33	0.00	-3.13
70	ICSA 93 x ICSR 92001	3.07**	-5.78	-1.95	-3.08	-17.98	-18.75
71	ICSA 93 x ICSR 93002	-2.04	-1.61	-11.60	15.50	-13.95	-19.57
72	ICSR 93 x ICSR 93004	0.70	3.11	-7.26	-10.43	0.31	-0.61
SE		1.10	4.60	2.44	2.82	5.63	6.50

Appendix 4. SCA effects and heterosis for plant height (PHT) in line x tester experiment at IAC, and Akola.

Ent #	Pedigree	SCA effects		Heterosis(%)			
				IAC		Akola	
		IAC	Akola	MP	HP	MP	HP
1	SPST 94009A x SAR 1	-0.46*	-0.22	12.21	-6.76	11.11	0.00
2	SPST 94009A x SAR 16	0.10	0.37**	67.05**	51.82**	60.78**	46.43*
3	SPST 94009A x SAR 34	-0.11	-0.15	36.86**	19.78	0.00	-11.11
4	SPST 94009A x SAR 35	-1.17**	-0.54**	62.14**	58.74**	-33.33*	-34.48
5	SPST 94009A x SAR 41	-0.33**	0.31*	68.42**	62.16**	64.29**	64.29**
6	SPST 94009A x SAR 42	0.19*	0.21	53.90**	43.67**	49.15**	41.94*
7	SPST 94009A x ICSR 92001	-0.12	-0.08	53.31**	35.00**	38.71*	26.47
8	SPST 94009A x ICSR 93002	-0.08	0.08	73.06**	60.62**	57.38**	45.45*
9	SPST 94009A x ICSR 93004	0.08	0.28*	3.87	-9.18	11.11	0.00
10	SPST 94011A x SAR 1	0.04	0.22	7.12	-7.74	9.80	0.00
11	SPST 94011A x SAR 16	-0.13	0.00	19.88	-25.82	-21.88	-30.56
12	SPST 94011A x SAR 34	0.04	0.11	-7.38	10.93	-22.81	-24.14
13	SPST 94011A x SAR 35	0.08	-0.54**	12.21	9.68	-32.14*	-32.14
14	SPST 94011A x SAR 41	-0.02	-0.04	13.10	12.03	-1.69	-6.45
15	SPST 94011A x SAR 42	-0.02	0.07	13.43	5.56	16.13	5.88
16	SPST 94011A x ICSR 92001	-0.08	-0.11	25.71*	23.75	11.48	3.30
17	SPST 94011A x ICSR 93002	-0.33**	-0.16	24.14*	-4.35	37.04*	5.71
18	SPST 94011A x ICSR 93004	-0.05	-0.06	74.11**	74.11**	57.14**	43.48*
19	SPST 94001A x SAR 1	0.07	0.24	40.82**	17.74	49.09**	13.89
20	SPST 94001A x SAR 16	0.13	0.18	55.29**	38.46**	41.67*	17.24
21	SPST 94001A x SAR 34	-0.01	0.08	52.29**	38.64**	78.72**	50.00*
22	SPST 94001A x SAR 35	0.20*	0.08	85.19**	58.23**	68.00**	35.48
23	SPST 94001A x SAR 41	-0.07	-0.22	62.33**	31.67**	54.72**	20.59
24	SPST 94001A x SAR 42	-0.05	-0.15	85.29**	57.50**	69.23**	33.33
25	SPST 94001A x ICSR 92001	0.01	0.11	14.04	-5.80	20.69	0.00

Ent #	Pedigree	SCA effects		Heterosis(%)			
				IAC		Akola	
		IAC	Akola	MP	HP	MP	HP
26	SPST 94001A x ICSR 93002	0.02	0.06	25.51**	14.81	21.74	21.74
27	SPST 94001A x ICSR 93003	-0.01	-0.02	2.21	-10.99	-5.08	-22.22
28	SPST 94014A x SAR 1	-0.20*	0.14	-7.91	-10.49	-0.00	-0.22
29	SPST 94014A x SAR 16	-0.04	-0.31*	21.55	16.22	5.88	-3.53
30	SPST 94014A x SAR 34	0.04	-0.21	39.93**	29.75*	7.41	6.45
31	SPST 94014A x SAR 35	0.09	0.10	36.51**	19.44	40.35*	17.65
32	SPST 94014A x SAR 41	0.01	0.12	49.15**	37.50**	50.00**	27.27
33	SPST 94014A x SAR 42	0.31**	0.16	47.44**	11.11	44.44**	11.43
34	SPST 94014A x ICSR 92001	-0.13	-0.15	33.64**	29.46*	28.57	17.39
35	SPST 94014A x ICSR 93002	-0.02	-0.02	14.98	-9.34	12.7	-13.89
36	SPST 94014A x ICSR 93004	-0.13	-0.16	12.90	-2.10	-4.17	-20.69
37	SPST 94008A x SAR 1	0.03	0.19	44.66**	23.56	70.21**	42.86*
38	SPST 94008A x SAR 16	-0.08	0.14	44.49**	20.25	56.00**	25.81
39	SPST 94008A x SAR 34	-0.06	-0.20	43.86**	13.89	39.62*	8.82
40	SPST 94008A x SAR 35	0.08	0.02	75.09**	45.00**	65.38**	30.30
41	SPST 94008A x SAR 41	0.18*	-0.17	33.53**	7.73	3.23	-8.57
42	SPST 94008A x SAR 42	0.04	0.02	40.59**	32.28**	20.00	11.11
43	SPST 94008A x ICSR 92001	0.03	0.05	14.56	-2.75	1.59	-11.11
44	SPST 94008A x ICSR 93002	-0.08	0.11	12.59	6.29	-0.00	-3.45
45	SPST 94008A x ICSR 93003	-0.03	-0.19	34.85**	25.00*	16.36	14.29
46	SPST 94026A x SAR 1	-0.12	0.21	52.98**	37.97**	37.93*	29.03
47	SPST 94026A x SAR 16	-0.12	0.01	34.85**	15.00	34.43*	20.59
48	SPST 94026A x SAR 34	-0.17	0.02	48.43**	33.13**	40.00*	27.27
49	SPST 94026A x SAR 35	-0.09	0.12	11.29	0.00	26.98	14.29
50	SPST 94026A x SAR 41	-0.01	-0.18	26.35*	6.06	9.80	0.00
51	SPST 94026A x SAR 42	-0.07	-0.21	2.02	-2.75	-9.37	-19.44

Ent #	Pedigree	SCA effects		Heterosis(%)			
				IAC		Akola	
		IAC	Akola	MP	HP	MP	HP
52	SPST 94026A x ICSR 92001	-0.10	0.01	3.90	-3.03	-1.75	-3.45
53	SPST 94026A x ICSR 93001	0.04	0.16	29.07**	22.42	46.43**	46.43
54	SPST 94026A x ICSR 93004	0.12	-0.24	40.56**	37.58**	11.86	6.45
55	ICSA 89 x SAR 1	0.11	0.31*	37.97**	32.22*	58.06**	44.12*
56	ICSA 89 x SAR 16	-0.01	0.03	47.69**	45.45**	47.54**	36.36
57	ICSA 89 x SAR 34	-0.10	0.17	0.52	-7.25	13.89	10.81
58	ICSA 89 x SAR 35	-0.06	-0.19	8.01	-11.43	-6.67	-24.32
59	ICSA 89 x SAR 41	0.18*	0.04	5.32	3.30	-6.85	-8.11
60	ICSA 89 x SAR 42	0.09	0.05	2.77	-5.71	-12.12	-21.62
61	ICSA 89 x ICSR 92001	-0.39**	0.05	-10.22	-17.14	20.00	5.41
62	ICSA 89 x ICSR 93002	-0.04	-0.30*	18.32	12.57	[illegible]88	-13.51
63	ICSA 89 x ICSR 93004	0.13	0.12	27.89*	26.11*	20.67	21.62
64	ICSA 93 x SAR 1	0.20*	0.08	47.46**	41.14	31.43	24.32
65	ICSA 93 x SAR 16	0.40**	-0.28*	20.00	15.94	-18.84	-20.00
66	ICSA 93 x SAR 34	-0.07	-0.09	-0.33	-21.24	-8.77	[illegible]3.53
67	ICSA 93 x SAR 35	-0.15	0.04	-18.40	-20.73	-14.29	-16.67
68	ICSA 93 x SAR 41	-0.09	0.10	-13.69	-24.87	-17.46	-23.53
69	ICSA 93 x SAR 42	0.13	0.25	14.37	1.04	25.81	14.71
70	ICSA 93 x ICSR 92001	-0.32**	0.15	-4.48	-13.47	13.85	8.82
71	ICSA 93 x ICSR 93002	0.01	-0.09	14.21	10.36	8.82	8.82
72	ICSA 93 x ICSR 93004	0.09	-0.07	32.01**	20.73	16.42	14.71
		0.09	0.13	0.11	0.13	0.16	0.19

Genstat Programs Used in the Analyses

LINE X TESTER PROGRAM

```
'REFE/NUNN=1000,NID=1000' LINE_X_TESTER_ANALYSIS
''
        '           INPUT
        NR: NUMBER OF REPLICATIONS
        NE: TOTAL NUMBER OF ENTRIES
        NL: NUMBER OF LINES
        NT: NUMBER OF TESTERS
''
'SCAL' NL=8 : NT=9 : NR=2  : NE=93 : NN,NOBS,IJ
'SCAL' NV=6
'INTE' NUM_VAR=1...NV
'CALC' NN=NL*NT
'CALC' NOBS=NR*NE
'R'
'MATR' M $ NL,NT : MM $ NT,NL
'VARI' LINES=1...NL : TESTER=1...NT : LXT=1...72
'VARI' GCALS $ NL : GCATS $ NT : SCALT $ NN
'SCAL' MSE,MSL,MST,MSLT,SEGCAL,SEGCAT,SESCA,SEDL,SEDT,SED,SSC,CCL,CCT,CCLT
  :  COVHSL,COVHST,COVHSA,COVFS1,COVFS2,COVFS,SSQA0,SSQA1,SSQD0,SSQD1,SCASQ
  :  COVHSA1
'UNITS' $ NOBS
'FACT' REP $ NR=(1,2)93
'FACT' TREAT $ NE=NR!(1...93)
'INPU/RECL=132' 2
'READ/P' DUM1,DUM2,DUM3,V(NUM_VAR)
'INPUT' 1
'R'
```

Enter your parents,lines and testers accordingly.

```
'INTE' I0=1,2...70,71,-72,73,74...87,88,-89,90,91,92,-93
'INTE' I2=1,2...70,71,-72,-73,-74...-87,-88,-89,90,91,92,-93
'INTE' IC1=1,2...70,71,-72,73,74...87,88,-89,-90,-91,-92,-93

'INTE' I0I2= 1, 2, 3, 4, 5, 6, 7, 8, -9, 10,11,12,13,14,15,16,17,-18,
          19,20,21,22,23,24,25,26,-27, 28,29,30,31,32,33,34,35,-36,
          37,38,39,40,41,42,43,44,-45, 46,47,48,49,50,51,52,53,-54,
          55,56,57,58,59,60,61,62,-63, 64,65,66,67,68,69,70,71,-72,
          73,74...87,88,-89,90,91,92,-93
'INTE' I0I1=1,10,19,28,37,46,55,-64, 2,11,20,29,38,47,56,-65,
          3,12,21,30,39,48,57,-66, 4,13,22,31,40,49,58,-67
          5,14,23,32,41,50,59,-68, 6,15,24,33,42,51,60,-69,
          7,16,25,34,43,52,61,-70, 8,17,26,35,44,53,62,-71,
          9,18,27,36,45,54,63,-72,
          73,74...87,88,-89,90,91,92,-93

'HEAD' H1='' GCA EFFECTS FOR LINES                    ''
'HEAD' H2='' GCA EFFECTS FOR TESTERS                  ''
```

```
'HEAD' H3=" SCA EFFECTS
'HEAD' H4=" STANDARD ERROR (GCA FOR LINE)
'HEAD' H5=" STANDARD ERROR (GCA FOR TESTER)
'HEAD' H6=" STANDARD ERROR (SCA EFFECTS)
'HEAD' H7=" STANDARD ERROR (G(I)-G(J)) LINE
'HEAD' H8=" STANDARD ERROR (G(I)-G(J)) TESTER
'HEAD',H9=" STANDARD ERROR
'HEAD' H10=" COV H.S. (LINE)
'HEAD' H11=" COV H.S. (TESTER)
'HEAD' H12=" COV H.S. (AVERAGE)
'HEAD' H13=" COV F.S.
'HEAD' H14=" SIGMA SQUARE A WHEN F=0
'HEAD' H15=" SIGMA SQUARE A WHEN F=1
'HEAD' H16=" SIGMA SQUARE D WHEN F=0
'HEAD' H17=" SIGMA SQUARE D WHEN F=1
'HEAD' H18=" CONTRIBUTION OF LINES
'HEAD' H19=" CONTRIBUTION OF TESTERS
'HEAD' H20=" CONTRIBUTION OF LINE X TESTER
'HEAD' H21=" VARIANCE RATIO OF GCA TO LINE X TERSTER
'HEAD' H22=" VARIANCE RATIO OF SCA TO LINE X TERSTER
'GROUP' IPXC=GROUP(TREAT ; I0)
'GROUP' IP=GROUP(TREAT ; I2)
'GROUP' CHK=GROUP(TREAT ; IC1)
'GROUP' IT=GROUP(TREAT ; I0I1)
'GROUP' IL=GROUP(TREAT ; I0I2)
'BLOC' REP/TREAT
'TREAT' (IPXC/(IP+CHK))+IPXC.IL+IPXC.IT+IPXC.IL.IT
'FOR' YSET=V(1,2,3,4,5,6,8)
'ANOV/SE=M,PR=00010,PROB=Y' YSET ; OUT=AOV1
'EXTR' AOV1 ; REP.TREAT $ SS=SSE ; DF=DFE
'EXTR' AOV1 ; IPXC.IL $ EFF=GCAL ; SS=SSL ; DF=DFL
'EXTR' AOV1 ; IPXC.IT $ EFF=GCAT ; SS=SST ; DF=DFT
'EXTR' AOV1 ; IPXC.IL.IT $ EFF=SCA ; SS=SSLT ,DF=DFLT
'SCAL' VRGCA,VRSCA 'CALC' VRGCA=(SSL/DFL)/(SSLT/DFLT)
'CALC' VRSCA=(SST/DFT)/(SSLT/DFLT)
'PRINT/C' H21,VRGCA $ 0,10.3
'PRINT/C' H22,VRSCA $ 0,10.3
'PRINT' GCAL $ 10.2
'PRINT' GCAT $ 10.2
'PRINT' SCA $ 10.2
'EQUA' GCALS=GCAL ; GCATS=GCAT ; M=SCA $ (NT,2X)NL
'CALC' MM=TRANS(M)
'EQUA' SCALT=MM
'CALC' MSE=SSE/DFE ; MSL=SSL/DFL ; MST=SST/DFT  MSLT=SSLT/DFLT
'CALC' SEGCAL=SQRT(MSE/(NR*NT))
'CALC' SEGCAT=SQRT(MSE/(NR*NL))
'CALC' SESCA=SQRT(MSE/NR)
'CALC' SEDL=SQRT(2)*SEGCAL
'CALC' SEDT=SQRT(2)*SEGCAT
'CALC' SED=SQRT(2)*SESCA
'SCAL' F0=0 ; F1=1
'CALC' COVHSL=(MSL-MSLT)/(NR*NT) ; COVHST=(MST-MSLT)/(NR*NL)
'CALC' COVHSA1=((NL-1)*MSL+(NT-1)*MST)/(NL+NT-2)
'CALC' COVHSA=(COVHSA1-MSLT)/(NR*(2*NL*NT-NL-NT))
'CALC' COVFS1=((MSL-MSE)+(MST-MSE)+(MSLT-MSE))/(3*NR)
'CALC' COVFS2=(6*NR*COVHSA-NR*(NL+NT)*COVHSA)/(3*NR)
'CALC' COVFS=COVFS1+COVFS2
```

```
'CALC' SSQA0=COVHSA*(4/(1+F0))
'CALC' SSQA1=COVHSA*(4/(1+F1))
'CALC' SCASQ=(MSLT-MSE)/NR
'CALC' SSQD0=SCASQ*((2/(1+F0))*(2/(1+F0)))
'CALC' SSQD1=SCASQ*((2/(1+F1))*(2/(1+F1)))
'CALC' SSC=SSL+SST+SSLT
'CALC' CCL=(SSL/SSC)*100
'CALC' CCT=(SST/SSC)*100
'CALC' CCLT=(SSLT/SSC)*100
'PRINT' H1
'PRINT/P,LABC=1' LINES,GCALS $ 10.0,10.4
'PRINT' H2
'PRINT/P,LABC=1' TESTER,GCATS $ 10.0,10.4
'PRINT' H3
'PRINT/P,LABC=1' LXT,SCALT $ 10.0,10.4
'PRINT/C,LABC=1,LABR=1' H4,SEGCAL $ 15.4
'PRINT/C,LABC=1,LABR=1' H5,SEGCAT $ 13.4
'PRINT/C,LABC=1,LABR=1' H6,SESCA  $ 16.4
'PRINT/C,LABC=1,LABR=1' H7,SEDL $ 13.4
'PRINT/C,LABC=1,LABR=1' H8,SEDT $ 11.4
'PRINT/C,LABC=1,LABR=1' H9,SED $ 30.4
'PRINT/C,LABC=1,LABR=1' H10,COVHSL $ 29.4
'PRINT/C,LABC=1,LABR=1' H11,COVHST $ 27.4
'PRINT/C,LABC=1,LABR=1' H12,COVHSA $ 26.4
'PRINT/C,LABC=1,LABR=1' H13,COVFS $ 36.4
'PRINT/C,LABC=1,LABR=1' H14,SSQA0 $ 21.4
'PRINT/C,LABC=1,LABR=1' H15,SSQA1 $ 21.4
'PRINT/C,LABC=1,LABR=1' H16,SSQD0 $ 21.4
'PRINT/C,LABC=1,LABR=1' H17,SSQD1 $ 21.4
'PRINT/C,LABC=1,LABR=1' H18,CCL $ 23.4
'PRINT/C,LABC=1,LABR=1' H19,CCT $ 21.4
'PRINT/C,LABC=1,LABR=1' H20,CCLT $ 15.4
'REPE'
'R'
'CLOS'
'STOP'
```

COMBINED LINE X TESTER

```
'REFE/NUNN=1000,NID=1000' LINE_X_TESTER_ANALYSIS_ACR_LOC
''
                    INPUT
        NR:  NUMBER OF REPLICATIONS
        NE:  TOTAL NUMBER OF ENTRIES
        NL:  NUMBER OF LINES
        NT:  NUMBER OF TESTERS
        NL2: NUMBER OF LOCATIONS
''
'SCAL' NL2=2 : NL=8 : NT=9 : NR=2  : NE=93 : NN,NOBS,IJ,NOBS2
'SCAL' NV=5
'INTE' NUM_VAR=1...NV
'CALC' NN=NL*NT
'CALC' NOBS=NL2*NR*NE
'CALC' NOBS2=NR*NE
'R'
'MATR' M $ NL,NT : MM $ NT,NL
'VARI' LINES=1...NL : TESTER=1...NT : LXT=1...72
'VARI' GCALS $ NL : GCATS $ NT : SCALT $ NN
'SCAL' MSE,MSL,MST,MSLT,SEGCAL,SEGCAT,SESCA,SEDL,SEDT,SED,SSC,CCL,CCT,CCLT
   : COVHSL,COVHST,COVHSA,COVFS1,COVFS2,COVFS,SSQA0,SSQA1,SSQD0,SSQD1,SCASQ
   : COVHSA1
'UNITS' $ NOBS
'FACT' LOC $ NL2=NOBS2!(1...NL2)
'FACT' REP $ NR=(1...NR)186
'FACT' TREAT $ NE=NR!(1...NE)2
'INPUT' 2
'READ/P' DUM1,DUM2,V(NUM_VAR)
'INPUT' 1
'CALC' V(4)=SQRT(V(4)+1) : V(5)=SQRT(V(5)+1)
'R'
```

Enter your parents,lines and testers accordingly.

```
'INTE' I0=1,2...70,71,-72,73,74...87,88,-89,90,91,92,-93
'INTE' I2=1,2...70,71,-72,-73,-74...-87,-88,-89,90,91,92,-93
'INTE' IC1=1,2...70,71,-72,73,74...87,88,-89,-90,-91,-92,-93

'INTE' I0I2= 1, 2, 3, 4, 5, 6, 7, 8, -9, 10,11,12,13,14,15,16,17,-18,
          19,20,21,22,23,24,25,26,-27, 28,29,30,31,32,33,34,35,-36,
          37,38,39,40,41,42,43,44,-45, 46,47,48,49,50,51,52,53,-54,
          55,56,57,58,59,60,61,62,-63, 64,65,66,67,68,69,70,71,-72,
          73,74...87,88,-89,90,91,92,-93
'INTE' I0I1=1,10,19,28,37,46,55,-64, 2,11,20,29,38,47,56,-65,
          3,12,21,30,39,48,57,-66, 4,13,22,31,40,49,58,-67,
          5,14,23,32,41,50,59,-68, 6,15,24,33,42,51,60,-69,
          7,16,25,34,43,52,61,-70, 8,17,26,35,44,53,62,-71,
          9,18,27,36,45,54,63,-72,
          73,74...87,88,-89,90,91,92,-93
```

```
'HEAD' H1=" GCA EFFECTS FOR LINES "
'HEAD' H2=" GCA EFFECTS FOR TESTERS "
'HEAD' H3=" SCA EFFECTS "
'HEAD' H4=" STANDARD ERROR (GCA FOR LINE) "
'HEAD' H5=" STANDARD ERROR (GCA FOR TESTER) "
'HEAD' H6=" STANDARD ERROR (SCA EFFECTS) "
'HEAD' H7=" STANDARD ERROR (G(I)-G(J)) LINE "
'HEAD' H8=" STANDARD ERROR (G(I)-G(J)) TESTER "
'HEAD' H9=" STANDARD ERROR "
'HEAD' H10=" COV H.S. (LINE) "
'HEAD' H11=" COV H.S. (TESTER) "
'HEAD' H12=" COV H.S. (AVERAGE) "
'HEAD' H13=" COV F.S. "
'HEAD' H14=" SIGMA SQUARE A WHEN F=0 "
'HEAD' H15=" SIGMA SQUARE A WHEN F=1 "
'HEAD' H16=" SIGMA SQUARE D WHEN F=0 "
'HEAD' H17=" SIGMA SQUARE D WHEN F=1 "
'HEAD' H18=" CONTRIBUTION OF LINES "
'HEAD' H19=" CONTRIBUTION OF TESTERS "
'HEAD' H20=" CONTRIBUTION OF LINE X TESTER "
'HEAD' H21=" VARIANCE RATIO OF GCA TO LINE X TERSTER "
'HEAD' H22=" VARIANCE RATIO OF SCA TO LINE X TERSTER "
'GROUP' IPXC=GROUP(TREAT ; I0)
'GROUP' IP=GROUP(TREAT ; I2)
'GROUP' CHK=GROUP(TREAT ; IC1)
'GROUP' IT=GROUP(TREAT ; I0I1)
'GROUP' IL=GROUP(TREAT ; I0I2)
'BLOC' LOC/REP/TREAT
'TREAT' LOC*((IPXC/(IP+CHK))+IPXC.IL+IPXC.IT+IPXC.IL.IT)
'FOR' YSET=V(1...NV)
'ANOV/SE=M,PR=00010,PROB=Y,LIMA=9' YSET ; OUT=AOV1
'EXTR' AOV1 ; LOC.REP.TREAT $ SS=SSE ; DF=DFE
'EXTR' AOV1 ; IPXC.IL $ EFF=GCAL ; SS=SSL ; DF=DFL
'EXTR' AOV1 ; IPXC.IT $ EFF=GCAT ; SS=SST ; DF=DFT
'EXTR' AOV1 ; IPXC.IL.IT $ EFF=SCA ; SS=SSLT ;DF=DFLT
'SCAL' VRGCA,VRSCA 'CALC' VRGCA=(SSL/DFL)/(SSLT/DFLT)
'CALC' VRSCA=(SST/DFT)/(SSLT/DFLT)
'PRINT/C' H21,VRGCA $ 0,10.3
'PRINT/C' H22,VRSCA $ 0,10.3
'PRINT' GCAL $ 10.2
'PRINT' GCAT $ 10.2
'PRINT' SCA $ 10.2
'EQUA' GCALS=GCAL ; GCATS=GCAT ; M=SCA $ (NT,X)NL
'CALC' MM=TRANS(M)
'EQUA' SCALT=MM
'CALC' MSE=SSE/DFE ; MSL=SSL/DFL ; MST=SST/DFT ; MSLT=SSLT/DFLT
'CALC' SEGCAL=SQRT(MSE/(NR*NT))
'CALC' SEGCAT=SQRT(MSE/(NR*NL))
'CALC' SESCA=SQRT(MSE/NR)
'CALC' SEDL=SQRT(2)*SEGCAL
'CALC' SEDT=SQRT(2)*SEGCAT
'CALC' SED=SQRT(2)*SESCA
'SCAL' F0=0 ; F1=1
'CALC' COVHSL=(MSL-MSLT)/(NR*NT) ; COVHST=(MST-MSLT)/(NR*NL)
'CALC' COVHSA1=((NL-1)*MSL+(NT-1)*MST)/(NL+NT-2)
'CALC' COVHSA=(COVHSA1-MSLT)/(NR*(2*NL*NT-NL-NT))
'CALC' COVFS1=((MSL-MSE)+(MST-MSE)+(MSLT-MSE))/(3*NR)
```

```
'CALC' COVFS2=(6*NR*COVHSA-NR*(NL+NT)*COVHSA)/(3*NR)
'CALC' COVFS=COVFS1+COVFS2
'CALC' SSQA0=COVHSA*(4/(1+F0))
'CALC' SSQA1=COVHSA*(4/(1+F1))
'CALC' SCASQ=(MSLT-MSE)/NR
'CALC' SSQD0=SCASQ*((2/(1+F0))*(2/(1+F0)))
'CALC' SSQD1=SCASQ*((2/(1+F1))*(2/(1+F1)))
'CALC' SSC=SSL+SST+SSLT
'CALC' CCL=(SSL/SSC)*100
'CALC' CCT=(SST/SSC)*100
'CALC' CCLT=(SSLT/SSC)*100
'PRINT' H1
'PRINT/P,LABC=1' LINES,GCALS $ 10.0,10.4
'PRINT' H2
'PRINT/P,LABC=1' TESTER,GCATS $ 10.0,10.4
'PRINT' H3
'PRINT/P,LABC=1' LXT,SCALT $ 10.0,10.4
'PRINT/C,LABC=1,LABR=1' H4,SEGCAL $ 15.4
'PRINT/C,LABC=1,LABR=1' H5,SEGCAT $ 13.4
'PRINT/C,LABC=1,LABR=1' H6,SESCA  $ 16.4
'PRINT/C,LABC=1,LABR=1' H7,SEDL $ 13.4
'PRINT/C,LABC=1,LABR=1' H8,SEDT $ 11.4
'PRINT/C,LABC=1,LABR=1' H9,SED $ 30.4
'PRINT/C,LABC=1,LABR=1' H10,COVHSL $ 29.4
'PRINT/C,LABC=1,LABR=1' H11,COVHST $ 27.4
'PRINT/C,LABC=1,LABR=1' H12,COVHSA $ 26.4
'PRINT/C,LABC=1,LABR=1' H13,COVFS $ 36.4
'PRINT/C,LABC=1,LABR=1' H14,SSQA0 $ 21.4
'PRINT/C,LABC=1,LABR=1' H15,SSQA1 $ 21.4
'PRINT/C,LABC=1,LABR=1' H16,SSQD0 $ 21.4
'PRINT/C,LABC=1,LABR=1' H17,SSQD1 $ 21.4
'PRINT/C,LABC=1,LABR=1' H18,CCL $ 23.4
'PRINT/C,LABC=1,LABR=1' H19,CCT $ 21.4
'PRINT/C,LABC=1,LABR=1' H20,CCLT $ 15.4
'REPE'
'R'
'CLOS'
'STOP'
```

HETEROSIS PROGRAM

```
'REFE/NUNN=400,NID=400' Heterosis_for_Line_X_Tester

'SCAL' NR=2     " Number of Replications "
'SCAL' NL=8     " Number of Lines "
'SCAL' NT=9     " Number of Testers "
'SCAL' NV=6     " Number of Variables "

'SCAL' VA(1)=11.95 : VA(2)=0.02453 : VA(3)=10.76 : VA(4)=425.4
'SCAL' VA(5)=8.309 : VA(6)=0.2121

"
 The data file should be as follows
      Data for Lines
      Data for Testers
      Data for Hybrids
      Line 1 X Tester 1
      Line 1 X Tester 2
      Line 1 X Tester 3
"

'INTE' NUM_VAR=1...NV
'SCAL' NP,NC,NO
'CALC' NP=NL+NT
'CALC' NC=NL*NT
'CALC' NO=NC+NP
'R'

'VARI' LINES(NUM_VAR) $ NL
'VARI' TESTS(NUM_VAR) $ NT
'VARI' HYBDS(NUM_VAR) $ NC

'INPU/RECL=132' 2
'READ/P' LINES(NUM_VAR)
'READ/P' TESTS(NUM_VAR)
'READ/P' HYBDS(NUM_VAR)
'INPU' 1

'NAME'  H1=Cross_No : H2=X : H3=Mid-Parent : H4=High-Parent : H5=Low-Parent
  : H6=Best-Parent : H7=Lowest-Par
'SCAL' IJ,PMIN(NUM_VAR),PMAX(NUM_VAR),PMID(NUM_VAR),PBES(NUM_VAR),PBE2(NUM_VAR)
'SCAL' HET%MP(NUM_VAR),HET%HP(NUM_VAR),HET%LP(NUM_VAR),HET%BP(NUM_VAR),
      HET%2P(NUM_VAR),HET2P(NUM_VAR),
      HETMP(NUM_VAR),HETHP(NUM_VAR),HETLP(NUM_VAR) HETBP(NUM_VAR),
      THTMP(NUM_VAR),THTHP(NUM_VAR),SEMP(NUM_VAR),SEHP(NUM_VAR),
      THTLP(NUM_VAR),THTBP(NUM_VAR),THT2P(NUM_VAR)

'VARI' PAR(NUM_VAR) $ 2
'VARI' HYB(NUM_VAR) $ 1
'VARI' PARS(NUM_VAR) $ NP
'EQUA' PARS(NUM_VAR)=LINES(NUM_VAR),TESTS(NUM_VAR)
'CALC' PBES(NUM_VAR)=MAX(PARS(NUM_VAR))
'CALC' PBE2(NUM_VAR)=MIN(PARS(NUM_VAR))

'FOR' I=1...NL
'FOR' J=1...NT
'CALC' IJ=J+NT*(I-1)
```

```
'COPY' PAR(NUM_VAR) $ 1=LINES(NUM_VAR) $ I
'COPY' PAR(NUM_VAR) $ 2=TESTS(NUM_VAR) $ J
'COPY' HYB(NUM_VAR)=HYBDS(NUM_VAR) $ IJ
'CALC' PMAX(NUM_VAR)=MAX(PAR(NUM_VAR))
'CALC' PMIN(NUM_VAR)=MIN(PAR(NUM_VAR))
'CALC' PMID(NUM_VAR)=MEAN(PAR(NUM_VAR))
'

'CALC' HET%MP(NUM_VAR)=(HYB(NUM_VAR)-PMID(NUM_VAR))/PMID(NUM_VAR)
:   HET%HP(NUM_VAR)=(HYB(NUM_VAR)-PMAX(NUM_VAR))/PMAX(NUM_VAR)
:   HET%LP(NUM_VAR)=(HYB(NUM_VAR)-PMIN(NUM_VAR))/PMIN(NUM_VAR)
:   HET%BP(NUM_VAR)=(HYB(NUM_VAR)-PBES(NUM_VAR))/PBES(NUM_VAR)
:   HET%2P(NUM_VAR)=(HYB(NUM_VAR)-PBE2(NUM_VAR))/PBE2(NUM_VAR)

'CALC' SEMP(NUM_VAR)=SQRT(1.5*VA(NUM_VAR)/NR)
'CALC' SEHP(NUM_VAR)=SQRT(2*VA(NUM_VAR)/NR)
'PRIN/P' SEMP(NUM_VAR) $ 12.4
'PRIN/P' SEHP(NUM_VAR) $ 12.4
'CALC' THTMP(NUM_VAR)=HET%MP(NUM_VAR)/SEMP(NUM_VAR)
'CALC' THTHP(NUM_VAR)=HET%HP(NUM_VAR)/SEHP(NUM_VAR)
'CALC' THTLP(NUM_VAR)=HET%LP(NUM_VAR)/SEHP(NUM_VAR)
'CALC' THTBP(NUM_VAR)=HET%BP(NUM_VAR)/SEHP(NUM_VAR)
'CALC' THT2P(NUM_VAR)=HET%2P(NUM_VAR)/SEHP(NUM_VAR)
'NAME' HDM=Tsthet
'PRINT/P,LABC=1' H1,I,H2,J,H3,HET%MP(NUM_VAR) $ 8,2,1,2,10,NV!(7.4)
'PRINT/P,LABC=1' HDM,I,H2,J,H3,THTMP(NUM_VAR) $ 8,2,1,2,10,NV!(7.4)
'PRINT/P,LABC=1' H1,I,H2,J,H4,HET%HP(NUM_VAR) $ 8,2,1,2,10,NV!(7.4)
'PRINT/P,LABC=1' HDM,I,H2,J,H4,THTHP(NUM_VAR) $ 8,2,1,2,10,NV!(7.4)
'PRINT/P,LABC=1' H1,I,H2,J,H5,HET%LP(NUM_VAR) $ 8,2,1,2,10,NV!(7.4)
'PRINT/P,LABC=1' HDM,I,H2,J,H5,THTHP(NUM_VAR) $ 8,2,1,2,10,NV!(7.4)
'PRINT/P,LABC=1' H1,I,H2,J,H6,HET%BP(NUM_VAR) $ 8,2,1,2,10,NV!(7.4)
'PRINT/P,LABC=1' HDM,I,H2,J,H6,THTBP(NUM_VAR) $ 8,2,1,2,10,NV!(7.4)
'PRINT/P,LABC=1' H1,I,H2,J,H7,HET%2P(NUM_VAR) $ 8,2,1,2,10,NV!(7.4)
'PRINT/P,LABC=1' HDM,I,H2,J,H7,THT2P(NUM_VAR) $ 8,2,1,2,10,NV!(7.4)
'REPE'
'REPE'
'R'
'CLOS'
'STOP'
```

RBD.PRO

```
'REFE/NID=6000,NUNN=6000,PRIN=Z' RANDOMIZEDBLOCK
'UNITS' $ 186
'SCAL' NT=93 : NREP= 2 : NSITES=1 : NVAR= 7
'INTE',NLOC=1...NSITES
'INTE' NUM_VAR=1...NVAR
'FACT' REPS $ NREP:TREAT$NT:PLOT $ NT: PLOT $ NT=(1...NT)NREP
'VARI' A(NUM_VAR),MYLD(NUM_VAR)$ NT
'VARI' B(NUM_VAR),M2(NUM_VAR) $ 3
'SCAL' SS2,DF2,MS,GR_MEAN,SE,CV
'VARI' V1=1...NT
''
'NAME' V1=

IB-11,IB-14,IB-15,IB-20,IB-30,IB-38,IB-44,IB-73,IB-75,
IB-79,IB-83,IB-84,IB-89,IB-93,IB-101,IB-88001,
IB-88010,IB-91003,I296B1,I296B2,
MR750B2,MR840B2,I88001B2,IS18551,CSH1,CSH9
''
'FACT' ENTRY$V1, NT=1...NT
'VARI' V2=1...NT
'FACT' E_NO $ V2, NT=1...NT
'NAME' NM=Mean,SE+/-,CV(%)
'FACT' ENAME$ NM,3=1...3
'HEAD' HX=''
    Table .  Characteristics of entries in ISVAT at
             Patancheru - 1982
    ------------------------------------------------
    Ent  ICSV-No.    Days to   Plant   Grain yield
    no               50%flo-   height  ----------
                     wering    (cm)  kg/ha  Rank


'HEAD' HY=''


'INPUT/recl=132' 2
'FOR' SF=SF(NLOC)
'READ/P,NUN=Q' REPS,TREAT,YLD(NUM_VAR)
'FOR' Z=YLD(NUM_VAR),M=MYLD(NUM_VAR);M1=M2(NUM_VAR)
'BLOCK' REPS/PLOT
'TREAT' TREAT
'OUTPUT'2
'ANOVA' Z ; OUT=AOV1
'EXTR' AOV1; REPS/PLOT $ SS=*,SS2; DF=*,DF2
'EXTR' AOV1; TREAT $ MEAN=MN
'CALC' MS=SS2/DF2
'CALC' GR_MEAN=MEAN(MN)
'CALC' CV=100*SQRT(MS)/GR_MEAN
'CALC' SE=SQRT(MS/NREP)
'EQUA' M=MN:M1=GR_MEAN,SE,CV
'REPE'
'PUT/FILE=1' SF $ MYLD(NUM_VAR),M2(NUM_VAR)
'REPE'
'JUMP' LB1*(NSITES.GT.1)
```

```
'FOR' SF=SF(NLOC)
'GET/FILE=1' SF $ A(NUM_VAR)=MYLD(NUM_VAR)
'GET/FILE=1' SF $ B(NUM_VAR)=M2(NUM_VAR)
'REPE'
'VARI' MEANS,RNK1,RNKS $ NT
'SCAL' MAXM
'EQUA' MEANS=A(NVAR)
'GROUP' RNK=RANK(MEANS)
'CALC' RNK1=FLOAT(RNK)
'CALC' MAXM=MAX(RNK1)
'CALC' RNKS=(MAXM-RNK1)+1
'PRIN/P,LABC=1' ENTRY,A(NUM_VAR),RNK $ 6, 6, 6(9.2),5
'' RNKS FOR DESCND   RNK ASCND   e_no for entry no. ENTRY FOR ORIGIN
'PRIN/P,LABC=1' ENAME,B(NUM_VAR) $ 6, 6,6(9.2)

'PRIN' HY
'JUMP' L5
'LABEL' LB1
'FOR' M=MYLD(NUM_VAR); M1=M2(NUM_VAR)
'FOR' SF=SF(NLOC);A=A(NLOC);B=B(NLOC)
'GET/FILE=1' SF $ A=M
'GET/FILE=1' SF $ B=M1
'REPE'
'PAGE'
'VARI' MEANS,RNK1,RNKS $ NT
'CALC' MEANS=VMEAN(A(NLOC))
'GROUP' RNK=RANK(MEANS)
'CALC' RNK1=FLOAT(RNK)
'CALC' RNKS=(NT-RNK1)+1
'CAPT' '' ***** 2 WAY TABLE OF GENOTYPE X ENVIRONMENT ***** ''
'LINE' 2
'PRIN/P' ENT_NO,GENOTYPE,A(NLOC),MEANS,RNKS $ 4.0,15.1,8.1,7.1,4(6.2)
'PRIN/P,LABC=1' STAT,B(NLOC) $ 14.0,8,7,8(7.1)
'REPE'
'PAGE'
'LABEL' L5
'INPUT'1
'RUN'
'CLOSE'
'STOP'
```

RBDMEAN.PROGRAM

```
'REFE/NUNN=2000,NID=2000' RBD_MEAN
''
            PERCENTAGE OVER GRAND MEAN

            NR      : No. of replications
            NT      : No. of treatments
            NV      : No. of variables
            NCHECK  : No. of check entries
            CENTRY  : Check entry nos.
            NTEST   : No.of test entries
            TEST    : Test entry nos.
            NN1     : Test entry names
            NN2     : Check entry names
''
'UNIT' $ 279
'SCAL' NR= 3: NT=93 : NV= 6:  NCHECK=4 :NTEST=89
'INTE' NORDER=2 '' 1 - RANK ON ENTRY; 2 - RANK ON RANKS ''
'VARI' CENTRY=90,91,92,93
'VARI' TEST=1...89
'vari' NN1=1...89
'vari' NN2=90,91,92,93
'NAME' N1=SE+/-. N2=MEAN : N3=CV(%) : N4=CHECKS : N5=h21
'NAME' N6=FRATIO : N7=h22
'FACT' S$N1,1=1: M$N2,1=1: CVS$N3,1=1: CT$N4,1=1 : H2 $ N5,1=1
'FACT' F$N6,1=1: H21 $ N7,1=1
'FACT' ENTRIES $ NN1,NTEST=1...NTEST
'FACT' CHECK $ NN2,NCHECK=1...NCHECK
'FACT' REP $ NR: TRT $ NT
'INPU/RECL=132' 2
'READ/P,NUN=Q' REP,TRT,oldeno,X(1...NV)
'inpu' 1
r'
'VARI' R2,%C,ENTRY,RNK $ NT
'BLOCK' REP/TRT
'TREAT' TRT
'FOR' ZZ=X(1...NV); M1=V(1...NV); SE=SE(1...NV); CV=CV(1...NV);
      HERIT1=H21(1...NV); HERIT2=H22(1...NV); FVAL=FV(1...NV)
'ANOVA/SE=M,PROB=Y' ZZ ; OUT=AOV
'EXTR' AOV; TRT $ MEAN=MM
'EXTR' AOV; REP.TRT $ SS=SS1; DF=DF1
'EXTR' AOV; TRT $ SS=SST; DF=DFT
'VARI' M1 $ NT
'EQUA' M1=MM
'SCAL' EMS,SE,CV,MST,FVAL
'CALC' EMS=SS1/DF1
'CALC' MST=SST/DFT
'CALC' FVAL=MST/EMS
'CALC' SE=SQRT(EMS/NR)
'CALC' CV=SQRT(EMS)*100/MEAN(M1)
'SCAL' SIG1,HERIT1,SIG2,HERIT2
'CALC' SIG1=(MST-EMS)/NR
'CALC' HERIT1=SIG1/(EMS+SIG1)
'CALC' HERIT2=SIG1/((EMS/NR)+SIG1)

'REPE'
'SCAL' M(1...NV)
```

```
'CALC' M(1...NV)=MEAN(V(1...NV))
'calc' M(1)=10*INTPT((M(1)/10)+0.5)
'VARI' ENTRY=1...NT
'CALC'  V(1)=10*INTPT((V(1)/10)+0.5)
'GROUP' R1=RANK(V(1);FLEV)
'CALC' RNK=VARFAC(R1)
'SCAL' MX
'CALC' MX=MAX(RNK)
'CALC' RNK=(MX-RNK)+1
'calc' RNK=INTPT(RNK)
'SCAL' NC(1...NCHECK)
'EQUA' NC(1...NCHECK)=CENTRY
'VARI' CE,CC(1...NV),%CC,CR2 $ NCHECK
'CALC' %C=(V(1)/M(1))*100
'FOR' I=1...NCHECK; J=NC(1...NCHECK)
'CALC' ELEM(CE,CC(1...NV),%CC,CR2;I)=ELEM(ENTRY,V(1...NV),%C,RNK;J)
'REPE'
'VARI' E,VV(1...NV),R22,PC $ NTEST
'SCAL' T(1...NTEST)
'EQUA' T(1...NTEST)=TEST
'FOR' Z=1...NTEST; J=T(1...NTEST)
'CALC' ELEM(E,VV(1...NV),R22,PC;Z)=ELEM(ENTRY,V(1...NV),RNK,%C;J)
'REPE'
'JUMP' LLB1*(NORDER.EQ.1)
'CALC' CHECK,CE,CC(1...NV),%CC,CR2=ORDER(CHECK,CE,CC(1...NV),%CC,CR2;CR2)
'CALC' ENTRIES,E,VV(1...NV),PC,R22=ORDER(ENTRIES,E,VV(1...NV),PC,R22;R22)
'JUMP' LLB2
'LABE' LLB1
'CALC' CHECK,CC(1...NV),%CC,CR2,CE=ORDER(CHECK,CC(1...NV),%CC,CR2,CE,CE)
'CALC' ENTRIES,VV(1...NV),PC,R22,E=ORDER(ENTRIES,VV(1...NV),PC,R22,E;E)
'LABE' LLB2
'HEAD' HX=
''
Table      : Summary of performance for PMEPAT  Kharif 1995   Location:
-------------------------------------------------------------------------------------------------------
                      Grain Yield                Time                 Plant  Panicle
                 --------------------- Panicle  to 75%  Plant  Panicle number number
Entry        Entry                 % of  yield    flowe- height length -------------- Ag.   DM   Rust  Smut
          number  kg ha  Rank   mean   kg ha    ring(d) (cm)  (cm)    (10  ha )   score (%)
-------------------------------------------------------------------------------------------------------
''
'HEAD' EOL=
''

-------------------------------------------------------------------------------------------------------
h21 on plot basis ; h22 on mean basis
''
'PRIN' HX
''
'PRIN/P,LABR=1,LABC=1' ENTRIES,E,VV(1),R22,PC,VV(2...NV)
''
'PRIN/P,LABR=1,LABC=1' ENTRIES,VV(1),VV(2...NV)
        $ 10,8,10(8.2)
'PRIN/LABR=1,LABC=1' CT
'PRIN/P,LABR=1,LABC=1' CHECK,CC(1),CC(2...NV)
        $ 10,8,10(8.2)
'PRIN/P,LABR=1,LABC=1' S,SE(1...NV) $ 8,19.2,22.2,10(8.2)
'PRIN/P,LABR=1,LABC=1' M,M(1...NV)  $ 8,16,22,10(8.2)
```

```
'PRI                    N/P,LABR=1,LABC=1' CVS,CV(1...NV) $ 8,18.1,22.1,10(8.1)
'PRIN/P,LABR=1,LABC=1' F,FV(1...NV) $ 8,19.2,22.2,10(8.2)
'PRIN/P,LABR=1,LABC=1' H2,H21(1...NV) $ 8,19.2,22.2,10(8.2)
'PRIN/  P,LABR=1,LABC=1' H21,H22(1...NV) $ 8,19.2,22.2,10(8.2)
'PRIN' EOL
'RUN'
'CLOSE'
'STOP'22
```

بسم الله الرحمن الرحيم

التحليل الوراثي لمقاومة هجن من الذرة الرفيعة للبودا الأسيوية

خلاصة الأطروحة

أجريت هذه الدراسة لبحث الوراثة لمقاومة البودا في ٧٢ هجين من الذرة الرفيعة وآبائهم السبعة عشر . نفذت التجارب خلال خريف ١٩٩٥ في موقعين، الأول في المعهد الدولي لبحوث المحاصيل في المناطق شبه الجافة باسيا (ICRISAT Asia Center) بتانشيرو ، والآخر في أكولا بولاية مهار استرا باستخدام تصميم القطاعات العشوائية الكاملة في كل من التجربتين الصفات التي تم قياسها هي : معدل الإصابة بالبودا ، عدد الأيام لإزهار ٥٠٪ من النباتات ، ارتفاع النبات، و إنتاجية الحبوب في النبات الواحد.

أظهرت النتائج وجود فروق معنوية في الموقعين، وأن تأثير الفعل الاضافي وغير الاضافي للجين ذا أهمية للصفات المختلفة في الدراسة. ولكن التأثير الغير إضافي للجين كان أكثر أهمية لمقاومة البودا. السلالات العقيمة (L2(SPST 94011B و (SPST 94001 B) L3 والآباء (SAR 35) T4 و (SAR 42) T6 والتي عرفت سابقاً بمقاومتها للبودا (ICRISAT). برهنت نتائج هذه الدراسة ذلك، ولذا يمكن استخدام هذه السلالات والآباء في إنتاج هجن مقاومة للبودا. الهجين رقم ٤٢ و ٤٩ أظهرا مقاومة للبودا في كل من التحاليل الإحصائية الفردية وكذلك في التحليل المشترك للموقعين معاً. السلالات (SPST84001 B) L3 و L6 (SPST94006 B) كانتا الأفضل في قدرتها العامة على الاتحاد (GCA) لإنتاج هجن مقاومة للبودا وللأزهار المبكر.

الآباء (SAR 42) T6و (SAR 16) T2 كانا جيدين في مقدرتهم على الاتحاد بمعدل الإصابة للبودا وكذلك لمعظم الصفات الأخرى عبر المواقع المختلفة. فيما يتعلق بارتفاع النبات، أثبتت التحاليل الإحصائية الفردية والمشتركة أن السلالات العقيمة (ICSP 93) L8 و (ICSP 89) L7 و الآباء (SAR 1) T1 و (SAR 34) T3 كانوا الأكثر طولاً.

أوضح اختبار تأثير القدرة الخاصة على الاتحاد (SCA) باستعمال معدل الإصابة المحولة للبودا وإنتاجية الحبوب في النبات الواحد في الموقع الأول أن الهجين رقم ٧٢ له أعلى تأثير سلبي على الاتحاد يليه الهجين رقم ٣٧. أما في أكولا فإن الهجين رقم ٥٢ أظهر أعلى تأثير سلبي على الاتحاد يليه الهجين رقم ٦٣.

لوحظ أن أعلى مساهمة في التباين الكلي لمعدل الإصابة بالبودا كان من السلالات وتفاعل السلالات X الآباء في أكولا، وتفاعل السلالات X الآباء والآباء في IAC مما يدل على تباين واختلاف كل من السلالات والآباء. أما بالنسبة لإنتاجية الحبوب في النبات الواحد، فإن أعلى مساهمة كانت من السلالات وتفاعل السلالات مع الملقحات. مما أكد تباين السلالات المستعملة.

عند دراسة قوة الهجين (Heterosis) وجد أن أعلى قوة هجين سالبة لمعدل الإصابة للبودا في موقع IAC كانت في تسعة هجين. وكانت أفضل ثلاثة هي هجين رقم ٤٥، ٣٧ و ٦٤. أما في أكولا فإن أعلى قوة هجين سالبة لوحظت في ٢٨ هجين، حيث أن الهجين رقم ٦٧ والهجين رقم ٩ أظهرا أعلى قوة سالبة لمعدل الإصابة بالبودا.

أما الهجين الذين أظهروا أعلى قوة موجبة مقارنة بمتوسط الأبوين وبأفضل أب لإنتاجية الحبوب في النبات الواحد هم الهجين رقم ١٨ في موقع IAC ورقم ٣٤ في موقع أكولا. الهجين رقم ٣٧ أظهر أعلى قوة موجبة عبر الموقعين.

لوحظ أن النسبة المئوية لدرجة التوريث (Heretability) لمعدل الإصابة بالبودا كانت ١٠٪ في IAC و ٢٪ في أكولا وذلك نتيجة لإنخفاض وعدم انتظام الإصابة بالبودا في الموقعين.

بناءا على ما تقدم نقترح مواصلة هذا البحث مع إضافة موارد وراثية جديدة على أن يتم اختبارها عبر البيئات المختلفة (السودان والهند) لمعرفة مدى تأثير الأنواع المختلفة للبودا (*Striga asiatica and S. hermonthica*) على نفس أصناف الذرة الرفيعة المستعملة.

Pulse Pathology (Chickpea) Report of Work

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