STUDIES ON THE INHERITANCE OF RESISTANCE TO SHOOT FLY (*Atherigona soccata* Rondani) OF SORGHUM

By

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CERTIFICATE

Mr. Ahmed Saeed Awadh Bin Jeewad has satisfactorily prosecuted the course of research and that the thesis entitled **STUDIES ON THE INHERITANCE OF RESISTANCE TO SHOOT FLY (*Atherigona soccata* Rondani) OF SORGHUM** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any University.

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CERTIFICATE

This is to certify that the thesis entitled **"Studies on the inheritance of resistance to shoot fly (*Atherigona soccata* Rondani) of sorghum"** submitted in partial fulfilment of the requirements for the degree of **'Master of Science in Agriculture'** of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bonafide research work carried out by **Mr. Ahmed Saeed Awadh Bin Jeewad** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma. The published part has been fully acknowledged. All assistance and help received during the course of the investigations have been duly acknowledged by the author of the thesis.

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AHMED SAEED AWADH BIN JEEWAD

DECLARATION

I declare that this thesis entitled **STUDIES ON THE INHERITANCE OF RESISTANCE TO SHOOT FLY (*Atherigona soccata* Rondani) OF SORGHUM** is a bonafide record of work done by me during the period of research at ICRISAT, Patancheru. This thesis has not formed in whole or in part, the basis for the award of any degree or diploma.

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Abstract

A study of the inheritance of resistance to shoot fly (*Atherigona soccata* Rondani) was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Andhra Pradesh, India in the 1992 rainy and 1992-93 postrainy seasons. The experiment was laid out in a randomized block design with 48 hybrids (developed at ICRISAT in 1991-92) associated with their parents (12 restorer lines and 12 male-sterile lines) and four control cultivars. Interlard and fish meal techniques were used to increase shoot fly population.

Data were recorded on shootfly parameters (number of eggs per plant and deadheart percentage) and other related traits [vigour, glossiness, trichome density, seedling height, yield score and leaf surface wetness (LSW)] and were subjected to statistical analysis according to the line x tester model proposed by Kempthorne (1957), to estimate variances, variance components, general combining ability (gca), specific combining abilities (sca), heritabilities and correlation coefficients.

It was found that both additive and non-additive types of gene action appear important for shoot fly resistance. Non-additive gene action was more important for LSW, and low to moderate heritability was observed for this trait. Although it was closely associated with glossiness and shoot fly susceptibility (in the case of the parents), it did not contribute directly to deadheart percentage.

Glossiness among all characters exhibited highest heritability, genetic advance and strongly correlated with deadheart percentage, followed by trichome density on leaf abaxial surface.

Correlation coefficients, heritability and genetic gain were more apparent and higher for parents and during postrainy season where shoot fly infestation was optimum.

INTRODUCTION

CHAPTER I

INTRODUCTION

Sorghum, *Sorghum bicolor* (L.) Moench Graminae, is the world fifth largest grain crop and over 57.8 million tonnes of grain are harvested annually (FAO, 1991).

In Yemen, sorghum ranks the first in area and production among cereal crops. The total area under sorghum during 1990 was 0.5 million hectares and production was 0.4 million tonnes (Agri. Statistics Year Book, 1990).

Over 150 insects have been reported as pests of sorghum. Shootfly, *Atherigona soccata* is a widespread pest of sorghum in south and south-east Asia, the Middle East, the Mediterranean, Europe, and Africa but is absent from the Americas and Australia.

In Yemen shootfly is the most important pest of sorghum after birds and is a major factor limiting the adoption of higher yielding varieties of sorghum (Ba-Aangood, 1985).

Shootfly causes damage to sorghum seedlings particularly in delayed plantings (Doggett *et al.*, 1970). The female fly lays eggs on the abaxial surface of the seedlings leaves, usually on the third to sixth leaves (Jain and Bhatnagar, 1962). After hatching, the larvae migrate to the whorl and feed on the shoot apex leading to death of the expanding leaf (Maiti and Bidinger, 1979). Considerable losses of plant stand can occur. The problem is particularly acute in the postrainy season sorghum crop in India.

Host plant resistance is an effective and cheap method of reducing losses caused by shootfly and is the most appropriate method for the small subsistence farmers who grow sorghum. Therefore, high priority must be given to breeding for resistance. To breed resistant varieties efficiently it is necessary to know the mechanisms of resistance and their genetic control. Due to lack of such knowledge, there has been limited success in incorporating resistance into improved varieties and hybrids, although sources of resistance have been known for about 42 years.

Knowlege of the inheritance of resistance to shootfly would be useful to optimize selection methodologies and breeding procedures and for transfering resistance traits from resistant sources to high yielding varieties.

Resistance to *A. soccata* is inherited quantitatively, and is predominantly controlled by additive gene action (Rao *et al.*, 1974; Balakotaiah *et al.*, 1975; Sharma *et al.*, 1977; Rana *et al.*, 1975), whereas Halalle *et al.* (1982) and Agrawal and Abraham (1985) reported both additive and non-additive gene effects were predominant. Inheritance of traits associated to shoot fly resistance were also studied and it was found that trichome density was controlled by both additive and non-additive gene effects (Halalle *et al.*, 1982), whereas Gibson and Maiti (1983) found a single recessive gene governed it. Glossiness also was controlled by a single recessive gene (Turmato, 1980). Egg count/plant and deadheart percentage were found to be controlled by both additive and non-additive gene effects, (Halalle *et al.*, 1982). Most of these studies have shown that traits associated to shootfly resistance have a moderately high heritability.

In order to broaden the genetic base of shoot fly resistance and to combine diverse resistance genes in one base population for shoot fly resistance, many resistant germplasm were tested at ICRISAT and 12 resistant lines (representing the available genetic diversity) have been selected and used in this investigation as restorer lines which were crossed to 12 male-sterile lines (high yielding breeding lines available at ICRISAT).

By using pedigree methods and population improvement to develop insect resistance varieties, it is impossible to exploit that part of genetic variance which is caused by dominance effects due to expression of dominance effects in the early generations of segregating materials which disturb the selection of superior progenies. For pedigree selection in early generations it is therefore important to know how much of the observed genetic variance is due to dominance effects.

The objectives of my study are:

1) To estimate the importance of dominance variation in the inheritance of shootfly resistance and some of its associated traits (trichomes, glossiness, recovery resistance and leaf surface wetness).

2) To suggest appropriate selection strategies for shootfly resistance breeding.

3) To determine the heritability of leaf surface wetness character and its relation with other resistance associated traits.

CHAPTER II

REVIEW OF LITERATURE

Atherigona soccata Rondani was first reported and named by Rondani (1871) and first considered as a pest species on sorghum by Ballard and Ramachandra Rao (1924). *A. soccata* is the only shoot fly species that causes significant damage to sorghum (Seshu Reddy and Davies, 1978).

HOST PLANT RESISTANCE

Host plant resistance seems to be the most effective, economical and practical way of controlling sorghum insect pests and it is the cheapest method of reducing grain yield losses.

Recently at ICRISAT and other crop research stations and universities all over the world major emphasis has been invested in developing sorghum cultivars resistant to shoot fly and other insect pests.

The host plant resistance breeding work can be summarized under four headings:

1) Identification of resistant sources.
2) Studying mechanisms of resistance.
3) Studying inheritance of resistance.

4) Host plant resistance breeding.

2.1 IDENTIFICATION OF RESISTANT SOURCES

The existence of resistance in sorghum to shoot fly was first reported by Ponnaiya (1951a). He screened 214 sorghum types and selected 15 which possessed some resistance. Rao and Rao (1956) and Jain and Bhatanagar (1962) evaluated 42 and 192 cultivars respectively and selected a few promising resistant sources. Singh *et al.* (1968), Pradhan (1971) and Young (1972) at the All India Co-ordinated Sorghum Improvement Project (AICSIP), Jotwani (1978), Rao *et al.* (1978), Jotwani and Davis (1980) at ICRISAT, Mote *et al.* (1983), Kishore *et al.* (1985) and Nimbalkar *et al.* (1985) have continued searching for resistance to shoot fly through field evaluation of thousands of germplasm lines of the world sorghum collection. Bapat and Mote (1982) identified *Sorghum purpureosericeum, S. versicolor* and a wild species to be immune to shoot fly infestation and damage. de Wet *et al.* (1976) identified *Saccharum* genus as to be resistant. Among thirteen wild sorghum accessions (*Sorghum versicolor, S. purpureosericeum* and *S. dimidiatum*) evaluated at ICRISAT under no choice conditions, six showed < 5% damage compared to 95% in the susceptible hybrid CSH 1. In India, Rao (1972) identified *Maldandi* or *dagadi* types of Indian winter sorghum as sources of resistance. Salunkhe *et al.* (1982) identified three Indian check lines, Improved sooner, GM-2-3-1 and IS 3922, which had no deadhearts and were promising for resistance. Purple pigmented plant types with greater levels of resistance were

REVIEW OF LITERATURE

reported by Singh *et al.* (1981). The cultivars IS 1151, IS 4776, IS 5469, IS 5470 and IS 5410 and varieties CSV 5, CSV 6, SPV 8, SPV 13, SPV 14 and SPV 19 showed resistance to both shoot fly and stem borer.

Among 16 and 45 varieties and advanced breeding material tested in Maharashtra by Mote *et al.* (1983) and Nimbalkar *et al.* (1985) respectively, IS 5490, SPV 489, SPV 504, SPV 570 and SPV 713 were highly resistant to shootfly while E 303, E 501, E 502, E 503, E 601 and E 601 were moderately resistant to both shoot fly and stem borer.

The percentage of deadhearts was used as indicator for resistance in the study of Shinde *et al.* (1985). The percentages of deadhearts were 1.7 and 13 in the resistant varieties IS 2312 and SPV 101 respectively.

Mote *et al.* (1983) screened some male-sterile lines for shoot fly reaction and identified 365A3, 367A, and 368B7 as promising male-sterile lines against shoot fly.

Screening of large germplasm and breeding stocks has been made possible at ICRISAT by adopting the interlard and fish meal techniques under field conditions.

2.2 MECHANISMS OF RESISTANCE

Painter (1951) classified the nature of varietal resistance to insects into three categories.

1) Non-preference for oviposition
2) Recovery resistance
3) Antibiosis

2.2.1 Non-Preference for Oviposition

This refers to the situation in which the plant possesses factors that render it unattractive to insect pests for their oviposition, feeding and shelter. Non-preference by insects is often projected as a property of the plant. Ovipositional non-preference by the shoot fly in resistant cultivars was first detected by Jain and Bhatnagar (1962). They found significantly less oviposition (0.8 eggs/plant) on resistant vaieties compared to susceptible ones (2.0 eggs/plant). More recent workers, including Blum (1969), Klaipongpan (1973), Soto (1974) and Maiti and Bidinger (1979) have confirmed that non-preference for oviposition under low shoot fly population is a major factor in resistance to the shoot fly.

Singh and Jotwani (1980a) and Borikar *et al.* (1982) indicated that the efficiency of this mechanism is not stable and tends to break down under no choice conditions and heavy shoot fly population.

Dahms (1972) stated that one criterion to evaluate resistance is to determine the number of eggs deposited. Taneja and Leuschner (1985) reported that susceptible cultivars were preferred for egg laying in terms of higher number of eggs per plant and plants with eggs. Significantly higher egg laying was observed on susceptible cultivars CSV 1 and CSH 1 under low pressure of shoot fly while oviposition was equal on both resistant and susceptible cultivars under no choice conditions (in cages).

Ovipositional non-preference has been associated with leaf position. Ogwaro (1978) in Kenya reported that the third leaf was highly preferred for oviposition followed by second, fourth, fifth, sixth, first and seventh leaves under field condition. But in India, Davies and Seshu Reddy (1980) found that the fifth and fourth leaves were preferred in that order for oviposition in the field. On the contrary, oviposition on fourth followed by fifth leaf was more important in CSH 1 seedlings and egg laying on third, second and first leaf showed significant reduction in deadhearts (Sukhani and Jotwani, 1979). In the infested seedlings, the production of deadhearts was inversely proportional to the distance between the site of oviposition and the base of the leaf blade (Mowafi, 1967). Sharma *et al.* (1977) found significant and positive correlation between the number of eggs deposited and number of deadhearts.

Studies on behavioural resistance showed that the initial choice of a susceptible cultivar such as CSH 1 for oviposition was random although the time spent by female shoot flies on IS 2146, IS 3962 and IS 5613 (resistant cultivars) was brief (Raina *et al.*, 1984). In addition, adult females laid eggs on non-preferred cultivars only after laying several eggs on alternate susceptible CSH 1 seedlings. Non-preference appears to be a relative term since none of the known resistant cultivars were completely non-preferred for egg laying (Sharma and Rana, 1983).

Soto (1974) and Mote *et al.* (1986) studied the oviposition behaviour of shoot fly and reported that leaves of some of the sorghum cultivars resistant to shoot fly were pale green compared to the dark green colour of susceptible cultivars. Narrowness and erectness of leaves reduced both deadhearts and egg laying as shoot fly had less area for egg laying compared to broad leaved plants (Mote *et al.*, 1986). Bapat and Mote (1982) reported leaf colour and hairiness (with trichomes) as non-preference mechanisms.

MORPHOLOGICAL CHARACTERS POSSIBLY ASSOCIATED WITH SHOOT FLY RESISTANCE

Some morphological characters such as seedling vigour, glossiness of leaves, presence of trichomes on the leaves, seedling height and plant recovery may contribute to resistance of sorghum to shoot fly.

2.2.1.1 Seedling Vigour: Rapid growth of seedling might retard the first instar larva from reaching the growing point. Incidence of shoot fly was higher in sorghum lines that were less vigorous at seedling stage, and conditions such as low temperature, low fertility, drought etc. which reduce seedling vigour increased the susceptibility to shoot fly (Taneja and Leuschner, 1985; Sukhani and Jotwani, 1979). Mate *et al.* (1979) indicated that most resistant types grew taller and had higher growth rate than susceptible ones.

2.2.1.2 Glossiness: It has been found that varieties resistant to shoot fly usually have narrow, upright leaves with yellow-green glossy appearance at the seedling stage which is termed "glossy leaf" (Jotwani *et al.*, 1971; Maiti and Bidinger, 1979; Maiti *et al.*, 1980; Bapat and Mote, 1982; Omori *et al.*, 1988; and Taneja and Leuschner, 1985). Expression of glossiness in seedlings is an important trait for identifying shoot fly resistance in sorghum and it is easily identifiable (Agrawal and House, 1982). Maiti and Gibson (1983) suggested that glossy expression in sorghum seedlings can be utilized as a simple and reliable selection criterion for shoot fly resistance. Agrawal and Abraham (1985) reported that glossiness is highly correlated with shoot fly resistance.

Jadav *et al.* (1986) estimated the correlation between deadhearts and glossiness and found it negative and highly significant (correlation coefficient (r) = -0.77).

2.2.1.3 Trichomes: Prickle hairs on the leaf sheath were noted to be numerous on resistant varieties and absent on susceptible ones (Blum, 1968; Langham, 1968). Maiti and Bidinger (1979) identified 32 lines from 8000 germplasm lines with trichomes on the abaxial surface of the leaf blade. These had fewer plants with eggs, fewer plants with deadhearts and a lower ratio of plants with deadhearts to plants with eggs than 35 lines without trichomes. Maiti *et al.* (1980) observed that the presence of trichomes on the leaf surface resulted in a lesser frequency both of oviposition by shoot fly and of subsequent larval damage. The resistant cultivars IS 2146, IS 3962 and IS 5613 had high density of trichomes on the abaxial leaf surface while susceptible hybrid CSH 1 was found to lack trichomes.

Trichomes have high correlation with oviposition non-preference (genotypic correlation coefficient (r) = -0.75) (Agrawal and Abraham, 1985). When these correlations were partitioned into direct and indirect effects through path coefficient analysis, direct effect of trichomes was low and they contributed to shoot fly resistance mainly through other traits. Jadhav *et al.* (1986) found similar results.

The association of both glossy leaf and trichomes with shoot fly resistance in sorghum has been supported by several workers (Maiti and Bidinger, 1979; Agrawal and House, 1982; Omori *et al.*, 1983; Maiti and Gibson, 1983; Agrawal and Abraham, 1985; and Sharma *et al.*, 1992). They found that the level of resistance was greater when both the glossy and trichome traits occur together. The glossy leaf character contributed more than trichomes and the combination of the two traits was more effective than either of the traits alone.

2.2.1.4 Seedling Height: Height of sorghum seedlings as a trait contributing to shoot fly resistance was studied by Singh and Jotwani (1980a), Khurana and Verma (1985), Sandhu *et al.* (1986) and Mate *et al.* (1988). They reported that height was negatively correlated with susceptibility.

2.2.1.5 Silica Content: Ponnaiya (1951b), Blum (1968), Bothe and Pokharkar (1985) and Dalvi *et al.* (1990) reported that silica may be a factor in shoot fly resistance. Blum (1968) found much greater silica deposition at the base of the first, second and third leaf sheaths of resistant selections than in the susceptible check Tx 7078.

Incidence of *A. soccata* and silica content of stems and leaf sheath were negatively correlated at the sixth leaf stage; IS 5490 had the highest silica contents (19.97%) and lowest shoot fly incidence (16.8%) while CK 60B had the lowest silica content (11.67%) and second highest incidence (87.49%) (Bothe and Pokharkar, 1985). Dalvi *et al.* (1990) screened 45 varieties of sorghum for resistance to shoot fly and found that five varieties (R 24, 370 x 3660A, E0303, M-35-1 and M-47-3) were the most tolerant due to a higher silica content in their seedlings.

2.2.1.6 Biochemical Characters: Several biochemical studies on selected genotypes have shown interesting differences between susceptible and resistant genotypes. Khurana and Verma (1982) found that the quantities of amino acids are greater in resistant lines. In another study, Singh and Jotwani (1980b) showed that lysine was present in the leaf sheath of the susceptible hybrid CSH 1 but it was absent in the resistant varieties IS 1054, IS 5469 and IS 5490. The percentages of nitrogen, reducing sugars, total sugars, moisture and cholorophyll of the leaves were higher in the susceptible cultivars than in resistant ones.

The susceptibility of sorghum to *A. soccata* was positively correlated with phosphorus and negatively correlated with the content of total phenol (Khurana and Verma, 1983).

2.2.1.7 Leaf Surface Wetness (LSW) in Relation to Resistance of Shoot Fly in Sorghum: The role of leaf wettability was first studied by Rivnay (1961) who observed the use of morning dew by freshly hatched shoot fly larvae to glide down until they reached the leaf sheath. It has been supported by Blum (1963) who reported in his laboratory study that when freshly hatched larvae were placed on sorghum leaves, they fell down unless the plants were moistened with a fine spray of water.

The time of hatching coincides with the presence of moisture on the leaf, a condition favourable to movement of the larvae to the base of the leaf (Raina, 1981). Nwanze *et al.* (1990) reported that leaf surface wetness (LSW) of the central shoot leaf was higher in 10 day old seedlings than in seedlings of other ages and LSW was much higher in susceptible lines (>4 leaves densely covered with water droplets) than in resistant ones (<2, thin film of moisture). They also concluded that LSW of the central shoot leaf is a more reliable parameter of shoot fly resistance than glossy leaf or trichome density. Sree *et al.* (1992) concluded that LSW originates from the plant and it is not due to condensation of atmospheric moisture

2.2.2 Recovery Resistance or Tolerance

Plants recover by producing tillers which produce grain after the main culm has been destroyed by shoot fly. This type of resistance was referred to as recovery resistance (Dogget *et al.*, 1970). In Uganda, Doggett and Majisu (1966) found the variety *Namatera* to be shoot fly resistant as a result of its high tillering habit and ability to recover from early seedling attack. Blum (1972) reported that the resistant cultivars of sorghum Serena and Nematare recovered well even when more than 90 per cent of the main culms had been killed.

Among 14 hybrids, Mote *et al.* (1985) observed that SPH 196 and SPH 325 were least susceptible to *A. soccata* at the initial stage and had high recovery resistance resulting in the highest grain yield.

2.2.3 Antibiosis

Antibiosis against larval feeding offers exciting possibilities of exerting biotic pressure against the shoot fly (Dahms, 1969) and causes low larval survival on resistant varieties (Soto, 1974). Retardation of growth and development, prolonged larval and pupal periods and poor emergence of adults on resistant varieties provided direct evidence of antibiosis (Sharma *et al.*, 1977; Singh and Jotwani, 1980b; Raina *et al.*, 1981). The fecundity of the female shoot fly was higher when raised on susceptible *Swarna* than on moderately resistant IS 2123 and IS 5604 (Singh and Narayana, 1978).

Singh and Jotwani (1980b) found that the larval and pupal periods were extended by 8 to 15 days on resistant varieties. In addition to growth and development being retarded, the survival and fecundity of shoot flies were also adversely affected when reared on resistant varieties. Raina *et al.* (1981) found that the pre-oviposition period was extended from 3.1 days in susceptible hybrid CSH 1 to 5.6 and 6 days on the resistant varieties IS 1082 and IS 2312 respectively. They also observed very high mortality among the first instar larvae on resistant varieties IS 2196, IS 2312 and IS 5613. Larval survival and rate of larval development were dependent on the age of the host plant. Survival was usually highest when seedlings were two weeks old, low in very young seedlings and lowest in plants more than 50 days old (Ogwaro and Kokwaro, 1981). Survival of the first instar larvae not only depended on the ability of the female to select a suitable oviposition site on the leaf, but also the resistance to penetration of the leaf sheaths and the distance between the egg laying site and the growing point (Delobel, 1982).

Mote *et al.* (1986) found that in most resistant varieties the growing point was partially cut off but later recovered. In susceptible varieties the growing point was completely cut and destroyed, thus showing that antibiosis contributed to resistance.

2.3 INHERITANCE OF SHOOT FLY RESISTANCE IN SORGHUM

Studies on the inheritance of shoot fly resistance have generally concentrated on either the resistance as a whole or on a particular trait. This part of the review mentions briefly some such studies.

Veda Moorthy (1967), Langham (1968), Klaipongpan (1973), and Borikar and Chopde (1980) studied the inheritance of resistance in matings of resistant parents with susceptible ones. The hybrids were susceptible under high infestation indicating dominance or nearly complete dominance of susceptibility. But this relationships was reversed under low shoot fly infestation. In this case, resistance exhibited partial dominance. Agrawal and House (1982) reported that resistance was found to be polygenic in nature and governed by genes with predominantly additive effects. Maiti and Gibson (1983) concluded from their study of the F_3 and F_4 generations segregating from a cross of trichomed and trichomeless lines that there were at least two additional loci that interact with each other involved in resistance.

Further studies of Balakotaiah *et al.* (1975) conducted on a large F_2 population revealed that the frequency distribution of different mortality classes closely fits the normal curve and that the inheritance of shoot fly resistance is predominantly additive.

2.3.1 Non-Preference Mechanism

The genetics of ovipositional non-preference and deadheart formation as components of shoot fly resistance in sorghum were investigated by Sharma *et al.* (1977) through examination of the pattern of segregation of resistance genes in F_2 generation of susceptible x resistant crosses. They concluded that one single recessive gene (np0) governed the non-preference to oviposition while two duplicate recessive genes dh1 dh1, dh2 dh2 governed the resistance to deadheart formation. Rana *et al.* (1981) observed ovipositional non-peference mechanism under the influence of partially dominant genes under low to moderate shoot fly pressure and the reverse under heavy infestation. Borikar and Chopde (1982) observed both additive and non-additive gene action to be important under low pressure and additive gene action under moderate to high pressure.

Both additive and non-additive gene effects were equally important under high shoot fly pressure (Agrawal and Abraham, 1985).

2.3.2 Trichomes

Omori *et al.* (1988) assessed the genetic diversity of 20 sorghum cultivars with resistance to *A. soccata* originating from different geographic regions. They concluded that trichome density contributed mainly towards genetic divergence in resistance followed by glossiness.

Gibson and Maiti (1983) reported that the presence of trichomes on the abaxial surface was under the control of a single recessive gene.

2.3.3 Glossiness

Glossiness plays a significant role in shoot fly resistance in sorghum and it is a simply inherited character (Agrawal and House, 1982). Tarumoto (1980) indicated that the presence of glossiness is controlled by a single recessive gene.

Glossiness is highly correlated with shoot fly resistance and path analysis suggests the linkage of glossiness with some unknown inherent antibiotic factors; its intensity is quantitatively governed and is controlled by both additive and non-additive genes (Agrawal and Abraham, 1985).

2.3.4 Recovery Resistance

Doggett *et al.* (1970) identified the varieties 'Serena' and 'Nematare' and derivatives as shoot fly tolerant genotypes which recovered well even when more than 90 per cent of the main culms had been killed. The broad sense heritabilities were high for recovery.

Starks *et al.* (1970) discovered that additive effects and general heterosis accounted for most of the variance in the percentage of recovered plants.

The specific combining ability (sca) component of variance in crosses of resistant sorghum parents and susceptible ones was larger than the general combining ability (gca) component for recovery traits in the F_1 but less than the gca component in the F_2 (Sharma *et al.*, 1977). Borikar and Chopde (1982) studied the gene action of plant recovery and related traits of F_1 and F_2 diallels involving shoot fly resistant and susceptible lines. Additive gene action was predominant for seedling height and plant recovery. No correlation between shoot fly resistance and recovery was found indicating independent genetic control. Some entries showed high susceptibility in the initial stages but possessed high recovery resistance which was reflected in grain yield.

Heritability

Based on backcrosses, F_3s, and advanced generation progenies, Rana *et al.* (1975) and Halalli *et al.* (1983) found the heritability of shoot fly resistance to be around 25% and 30% respectively. Sharma *et al.* (1977) reported 49.7% and 82.1% heritability of deadhearts precentage in F_1 and F_2 generations respectively.

Under selection, narrow sense heritability for deadheart counts were 14.07%, 52.07%, 76.31%, on 14, 21 and 28 days respectively (Borikar and Chopde, 1980).

The heritability studies also revealed that the genetics of deadhearts and eggs/plant is influenced by the level of shoot fly population pressure.

Sharma and Rana (1983) found that the character no deadheart formation in spite of oviposition was found to be heritable in F_1 and F_2 generations of high yielding x resistant varietal crosses.

2.4 BREEDING FOR SHOOT FLY RESISTANCE IN SORGHUM

Breeding for resistance or tolerance to shoot fly in sorghum is an effective, cheap and appropriate method for small subsistence farmers. For achieving such purpose the following two stages are involved:

1) Selection of resistant lines.
2) Transfer of resistance.

2.4.1 Selection of Resistant Lines

Screening of the world collection of sorghum at the Indian Agricultural Research Institue (IARI), Coimbatore in 1968 showed that a number of lines of Indian origin possess a high degree of resistance to shoot fly. The strain M35-1 was one of them and it has been used as a donor parent in some crosses. Some of its progeny show less susceptibility under low level of infestation (Vidyabhushanam, 1972).

M35-1 and BP-53 (with multiple resistance to stem borer and shoot fly) were used in crosses with dwarf exotic lines which were susceptible to stem borer and shoot fly. Their advanced generation derivatives possessed moderate to high levels of resistance to both insects and the derivatives of M35-1 showed more resistance to shoot fly than BP-53 (Kishore, 1986).

A number of reasonably strong and stable sources of resistance representing different geographic areas and taxonomic races were identified but none of them possessed absolute resistance. Heterosis for resistance was found to be associated with genetic divergence but not with geographic or taxonomic divergence (Omori *et al.* 1988).

Salunkhe *et al.* (1982) evaluated 43 lines of sorghum for resistance to shoot fly and 15 of them were classed as promising. Of these, Improved saoner, GM-2-3-1 and IS 3922 had no deadhearts. Sithole and Mtisi (1987) screened 25 sorghum germplasm lines for resistance to stem borer and shoot fly. Some lines showed resistance for both insects and IS 155 was classed as highly resistant to shoot fly.

Some lines and hybrids were observed to be significantly low in susceptibility to shoot fly and percentage of deadhearts decreased after three years indicating their response to selection (Kishore *et al.*, 1985).

The sorghum varieties, *Namatera* and *Serena* (which show good recovery resistance to shoot fly in Uganda) have been used successfully as parents to develop lines with a good level of recovery resistance by utilizing recurrent selection method (Dogget *et al.*, 1970).

At ICRISAT both pedigree and population methods of breeding are being used. Population breeding a long term approach for simultaneously breeding for resistance to more than one pest. Broad populations (developed by using genetic male sterility) are being improved by mass selection using a low to moderate insect presures for a few cycles (Agrawal and Abraham, 1985).

2.4.2 Transfer of Resistance

Efforts are under way to incorporate genes responsible for resistance by making crosses between available resistant sources and the elite susceptible lines, then evaluating their derivative generations using pedigree method and screening for shoot fly resistance, agronomic traits and grain quality (Agrawal and Abraham, 1985).

Many shoot fly resistant lines with moderate levels of resistance and reasonable yield potential have been developed at ICRISAT. The levels of their resistance are comparable with *Maldandi*, a local standard shoot fly resistant cultivar. Some of these lines – PS 21171, PS 21217 and PS 21318 - have been found promising even under no choice conditions. PS 14093, PS 14103, PS 14454 and PS 21318 have shown good promise against shoot fly both within and outside India.

The segregating populations of resistant x susceptible crosses can be exploited for isolating resistant lines with desirable agronomic attributes (Borikar *et al.*, 1982).

Mote and Bapat (1988) tested the F_3 generation derived from a cross between resistant sorghum varieties and other ones. The derivatives RSV 8R and

RSV 9R are consistently more resistant than their parents.

Blum (1972) crossed resistant lines with some adapted R and B lines. He found the seedling infestation in F_1 was equal to or higher than in the susceptible parents and the proportion of non-infested seedling in F_2 ranged between 4.9 and 9.8%. He realized that resistance would have to be built into all the three parents if a resistant hybrid was to be developed.

Bapat and Mote (1982) tested promising selections from Indian x Indian crosses for their reaction to shoot fly in F_4 and F_5 generations and identified the highly promising derivatives against shoot fly.

Lal *et al.* (1986) identified SPV 346 x 2219B and PS 14413 x E 602 as desirable cross combinations, and indicated that the parents PS 14413, PPS 14454 and E 602 tended to transmit genes for relatively less deadheart formation.

General and specific combining ability (gca and sca) effects were estimated by Patel *et al.* (1984) in 28 F_1s from an 8 x 8 diallel. sca effects in the desired direction were shown by 19 combinations with the best combinations being 296B x M51 and M35 x M51 in normal and late sowing respectively. Mote *et al.* (1983) tested advanced breeding materials for their reaction to shoot fly. PS 18527, PS 14533, SPV 491 and RHR 5 were highly resistant showing less than 20% deadhearts.

In F_2 generation of resistant x resistant and susceptible x resistant crosses the percentage of healthy plant with eggs was 16.8 and 6.3 respectively. Such plants can be selected in segregating generations. The character no deadheart formation in spite of oviposition may provide a criterion for transferring/strengthening antibiosis in resistance breeding programmes (Sharma and Rana, 1983). The progenies of the following three crosses NCL3 x CSV 5, CSV4 x IS 2123 and CSV 5 x IS 4533 showed significant variability for resistance to *A. soccata* and selection could be made among these progenies (Paul *et al.*, 1984).

Attempts to transfer shoot fly resistance genes from wild sorghum relatives and other genera were made. de Wet *et al.* (1976) indicated the possibility of transfering the resistance from *Saccharum* genus to sorghum. Another attempt was made at ICRISAT through introgression from *Sorghum dimidiatum* to the cultivated types and the evaluation of their progenies for shoot fly resistance is still being continued.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

3.1 EXPERIMENTAL MATERIAL

Forty eight F_1 hybrids were produced at ICRISAT during the 1991/92 postrainy season by crossing 12 shoot fly resistant restorer lines with 12 shoot fly susceptible cytoplasmic male-sterile lines. The restorer lines (shown in Table 1a with their races and origins) were shoot fly resistant germplasm lines known to show different levels and mechanisms of resistance. The male-sterile lines (listed in Table 1b with their pedigrees) were chosen to represent the range of elite, high yielding breeding lines available at ICRISAT. The male and female parents were crossed in the combinations shown in Tables 2 and 3. The resulting 48 hybrids comprised three (4 lines x 4 testers) sets. Those hybrids plus four control cultivars were sown together and represented one experiment. The 12 restorer lines, 12 male-sterile lines (represented by their corresponding maintainer lines), and six control cultivars comprised the other. The hybrids and parents were sown separately but adjacent to one another for shoot fly resistance evaluation.

3.2 FIELD METHODOLOGY

The shoot fly testing experiments were sown in the field during kharif (rainy season, July to December 1992) and rabi (postrainy season, November 1992 to

Table 1a. Shootfly resistant R-lines, their races and countries of origin.

	Lines	Race	Origin
Set 1	IS 2205	DB	India
	IS 5480	D	India
	IS 5622	D	India
	IS 18533	KC	Pakistan
Set 2	IS 1082	D	India
	IS 2123	D	USA
	IS 5801	DB	India
	IS 22114	D	India
Set 3	IS 923	D	Sudan
	IS 5566	DB	India
	IS 18366	D	India
	IS 22145	D	India

D = Durra; DB = Durra-bicolor; KC = Kafir-caudatum

Table 1b. The pedigrees of testers.

Sl.No.	Line	Pedigree
1	ICSA 11	[(BTx624xUCHV2) B lines bulk]-5-1-1-1
2	ICSA 18	[(BTx623x1807B) B lines bulk]-18-3-1
3	ICSA 49	(FLR 141xCSV4)-3-3-1-1
4	ICSA 88001	[(ICSB22xICSB53) x Dialles 7-2-862]-1-1
5	ICSA 32	[(MR307xBTx622) B lines bulk]-3-1-6-1
6	ICSA 38	[(BTx623xMR862) B lines bulk]-5-1-3-5
7	ICSA 70	Ind. Syn. 422-1
8	ICSA 84	(Ind. Syn. 89-1xUS/R-20-682)-5-1-3
9	ICSA 73	[(296BxSPV105) x (2077BxM35-1)]-19
10	ICSA 77	(E303 x 2077B)-4
11	ICSA 95	(296BxSPV105)-12
12	ICSA 101	(Ind. Syn. 89-1 x RS/R20-682)-5-1-3

Table 2. Mating scheme.

	IS 2205	IS 5480	IS 5622	IS 18533	IS 1082	IS 2123	IS 5801	IS 21114	IS 923	IS 5566	IS 18366	IS 22145
ICSA 11	*	*	*	*								
ICSA 18	*	*	*	*								
ICSA 49	*	*	*	*								
ICSA 88001	*	*	*	*								
ICSA 32					*	*	*	*				
ICSH 38					*	*	*	*				
ICSA 70					*	*	*	*				
ICSA 84					*	*	*	*				
ICSA 73									*	*	*	*
ICSA 77									*	*	*	*
ICSA 95									*	*	*	*
ICSA 101									*	*	*	*

Table 3. Cross combinations.

Entry No.	Pedigree	Entry No.	Pedigree
1	ICSA 11 x IS 2205	25	ICSA 70 x IS 1082
2	ICSA 11 x IS 5480	26	ICSA 70 x IS 2123
3	ICSA 11 x IS 5622	27	ICSA 70 x IS 5801
4	ICSA 11 x IS 18533	28	ICSA 70 x IS 22114
5	ICSA 18 x IS 2205	29	ICSA 84 x IS 1082
6	ICSA 18 x IS 5480	30	ICSA 84 x IS 2123
7	ICSA 18 x IS 5622	31	ICSA 84 x IS 5801
8	ICSA 18 x IS 18533	32	ICSA 84 x IS 22114
9	ICSA 49 x IS 2205	33	ICSA 73 x IS 923
10	ICSA 49 x IS 5480	34	ICSA 73 x IS 5566
11	ICSA 49 x IS 5622	35	ICSA 73 x IS 18366
12	ICSA 49 x IS 18533	36	ICSA 73 x IS 22145
13	ICSA 88001 x IS 2205	37	ICSA 77 x IS 923
14	ICSA 88001 x IS 5480	38	ICSA 77 x IS 5566
15	ICSA 88001 x IS 5622	39	ICSA 77 x IS 18366
16	ICSA 88001 x IS 18533	40	ICSA 77 x IS 22145
17	ICSA 32 x IS 1082	41	ICSA 95 x IS 923
18	ICSA 32 x IS 2123	42	ICSA 95 x IS 5566
19	ICSA 32 x IS 5801	43	ICSA 95 x IS 18366
20	ICSA 32 x IS 22114	44	ICSA 95 x IS 22145
21	ICSA 38 x IS 1082	45	ICSA 101 x IS 923
22	ICSA 38 x IS 2123	46	ICSA 101 x IS 5566
23	ICSA 38 x IS 5801	47	ICSA 101 x IS 18366
24	ICSA 38 x IS 22114	48	ICSA 101 x IS 22145

March 1993) at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Patancheru, Andhra Pradesh.

3.3 EXPERIMENTAL DESIGN

Both experiments were arranged in randomised complete block designs with three replications. Each genotype was planted in plots of a single row 4 m long. Rows were spaced 75 cm apart and ends of rows were separated by 1 m alleys.

To ensure a heavy build up of shoot fly, two techniques were adopted by:

1) sowing a susceptible hybrid (CSH 1) 20 days prior to the planting of test materials, (two rows of CSH 1 after every 24 rows of test material), and
2) placing moist fish meal between the rows one week after sowing the test materials.

All recommended agronomic practices for sorghum were adopted for raising the crop except that experiments were not protected against shoot fly or other insects.

Sowing was done by planter machine. Ten days after emergence plots were thinned to give plant-to-plant spacing within rows of approximately 10 cm.

Leaf Surface Wetness Study

An additional pot experiment was conducted (February to March 1993) in a glasshouse at ICRISAT Center to study the inheritance of the leaf surface wetness (LSW) character and its relation to shoot fly resistance (Plate 1). In this experiment, all parents, hybrids and control cultivars were grown, each genotype replicated three times in three pots (16 cm diameter) with 5 seedlings/pot. Because it was impossible to take observations on all test materials in one day, they were subdivided into groups of genotypes which were planted and examined simultaneously on the same date. Nine groups were sown at 2-3 days intervals. Recommended agronomic practices were carried out and plants protected from shoot fly by removing their eggs immediately.

3.4 OBSERVATIONS

Observations on seedling vigour, glossiness, plant height, trichome density, yield, eggs/plot and deadhearts/plot were recorded both in the rainy (kharif) and postrainy (rabi) seasons. Leaf surface wetness (LSW) data were only collected for rabi season.

3.4.1 Seedling Vigour

Seedling vigour was scored 14 days after emergence (DAE) on 1-9 scale where 1=highly vigorous and 9=slow growing and weak seedling.

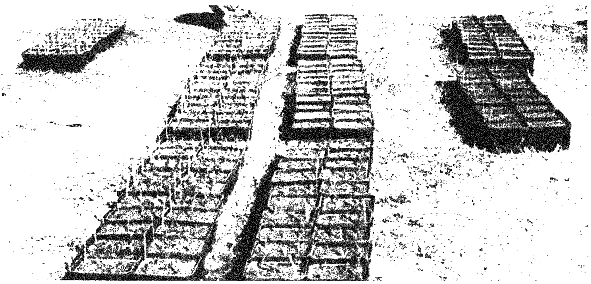


Plate No. 1. Pot experiment conducted at ICRISAT for studying leaf surface wetness.

3.4.2 Glossiness

Seedlings were scored 14 DAE on 1-9 scale where 1=completely glossy, 9=non-glossy.

3.4.3 Trichomes

To study the leaf trichome density the procedure suggested by Maiti and Bidinger (1979) was adopted. The central portion of the 5th leaf (from the base) was taken from 5 randomly selected seedlings. Those leaf segments (approximately 1 cm^2) were preserved in 20 cc 1:2 acetic acid and alcohol solution in small glass vials (2 cm diameter) to remove the chlorophyll from the leaf. Two days prior to examination this solution was replaced by 20 cc acetic acid (90%).

For microscopic examination, the segments were mounted on a slide after immersing in distilled water and observed under a compound microscope (40X magnification). The trichomes on the adaxial (upper) and abaxial (lower) surfaces were counted through randomly selected microscopic fields and expressed as trichome density/mm^2.

3.4.4 Plant Stand

Numbers of plants per plot were counted 21 DAE. This figure was used as a base for some other measures such as egg laying, and deadheart percentage.

3.4.5 Plant Height

Plant height was measured in cm from the soil surface to the tip of the whorl of the unopened leaf of undamaged plants at 21 DAE.

3.4.6 Egg Counts

Numbers of shoot fly eggs on all plants in the row were recorded at 28 DAE and number of eggs per plant was calculated.

$$\text{Eggs per plant} = \frac{\text{Total no. of eggs on all plants in the row}}{\text{Plant stand per row}}$$

3.4.7 Deadheart percentage

It is the ratio of plants with deadhearts caused by shoot fly (recorded at 28 DAE) to the total plant stand per row and expressed in percent.

$$\text{Deadheart percentage} = \frac{\text{No. of plants with deadhearts x 100}}{\text{Plant stand per row}}$$

3.4.8 Yield Score

At maturity time, yield was scored visually on a 1-9 scale where 1=high yield, 9=very poor.

3.4.9 Leaf Surface Wetness (LSW)

To study the leaf surface wetness (LSW) character, the pot experiment was conducted during the 1993 rabi season. The seedlings at 5th leaf stage (about 12-14 DAE) were taken from the pots, and the 5th leaf (the whorl) was mounted and examined under a binocular microscope between 0200 and 0500 h. LSW was assessed using a visual score scale of 1-9 where 1=no apparent moisture to a very thin film of moisture on the leaf lamina and 9=leaf densely covered with water droplets.

3.5 STATISTICAL ANALYSIS

3.5.1 Combining Ability Analysis

The analysis of combining ability for lines, testers and crosses for each character in each set of 4 x 4 crosses (see Table 2) were done as described in observations on the basis of:

1) Mean values of randomly selected plants (number of trichomes and LSW).
2) Mean values of total plot values (eggs/plant, and percentage of deadhearts).
3) Score scale (vigour, glossy, and yield scores).

Data analysis for such characters was calculated according to the method suggested by Kempthorne (1957).

Anova table for combining ability analysis.

Source	df	SS	MS	Expected mean square
Replication	r-1			
Parents	[(l+t)-1]			
Parents Vs crosses	1			
Lines	l-1	SSl	M_l	$\sigma^2_e + \sigma^2_{lt} + rt\sigma^2_l$
Testers	t-1	SSt	M_t	$\sigma^2_e + \sigma^2_{lt} + rl\sigma^2_t$
Lines x testers	(l-1)(t-1)	SS(lxt)	$M_l x M_t$	$\sigma^2_e + \sigma^2_{lt}$
Error	*G x r		M_e	

*G = Total df for all sources except for replication.

Test of significance: Mean squares due to lines (M_l) and testers (M_t) were tested against the mean square due to lines x testers (M_l x M_t) if the latter was significant. The lines x testers mean square was in turn tested against mean square due to error. If this was not significant, the mean squares due to lines (M_l) and testers (M_t) were tested against the mean square due to error.

3.5.2 Pooled Combining Ability Analysis

The pooled analysis of combining ability for both season was follows.

ANOVA

Source	df	MS
Seasons	(Se-1)	
Error (a)	Se(r-1)	
Sets	(St-1)	
Sets x season	(St-1) (Se-1)	
Error (b)	Se(r-1)(st-1)	
Males/sets	St(M-1)	
Females/sets	St(F-1)	
Male x female/sets	St(M-1)(F-1)	
Males x season/sets	St(M-1)(Se-1)	
Females x seasons/sets	St(F-1)(Se-1)	
Male x female x seas./sets	St(M-1)(F-1)(Se-1)	
Error (c)	(G-1)(Se-1)	

3.5.3 Combining Ability Effects

The combining ability effects were estimated according to Singh and Chaudhary's procedure (1977).

a) **Lines**

gca(line) $g_i = (X_i \div tr) - (X... \div ltr)$

Where:
- X = total of all hybrids
- X_i = total of *ith* line over all testers and replications
- l = number of lines
- t = number of testers
- r = number of replication

b) **Testers**

gca(tester) $g_t = (X_j \div lr) - (X... \div ltr)$

Where:
- X_j = total of *jth* tester over all lines and replications

c) **Hybrids**

Sca(hybrid) $S_{ij} = (X_{ij} \div r)-(X_i \div tr)-(X_j \div lr)-(X... \div ltr)$

Where X_{ij} = *ijth* combination total over all replications.

Standard Error for Combining Ability Effects

SE for lines SE $(g_i) = \sqrt{M_e/tr}$

" for tester SE $(g_j) = \sqrt{M_e/lr}$

" for hybrids SE $(g_{ij}) = \sqrt{M_e/r}$

Least Significant Differences Between Estimates

For lines SE $(g_i\text{-}g_k)$ = $SE(g_i) \times \sqrt{2}$

For testors SE $(g_j\text{-}g_k)$ = $SE(g_j) \times \sqrt{2}$

For hybrids SE $(g_{ij}\text{-}g_k)$ = $SE(g_{ij}) \times \sqrt{2}$

For comparing lines, testers or hybrids, the critical differences (CD) were used which where calculated by multiplying the standard errors (SE) with 't' values for error degrees of freedom at 5 and 1% level of probability.

3.5.4 Proportional Contribution of Lines, Testers and their Interactions to Total Variance

Contribution of lines = SS(l) x 100 ÷ SS crosses

Contribution of testers = SS(t) x 100 ÷ SS crosses

Contribution of (l x t) = SS(lxt) x 100 ÷ SS crosses

Where SS(l) = sum of squares due to lines from combining ability

estimate table

SS crosses = total sum squares of lines, testers, and (lxt) from the same table

SS(t) = sum of squares due to testers

SS(lxt) = sum of squares due to interactions

3.5.5 Genetic Components

σ^2_{gca} (line) = Cov (HS)l = $(M_l - M_{l*t})/rt$

σ^2_{gca} (tester) = Cov (HS)t = $(M_t - M_{l*t})/rl$

$\sigma^2_{sca} = M_{lxt} - M_e \div r$

Where: r = no. of replication

l = no. of lines

t = no. of testers

M_l = mean square of lines

M_t = mean square of testers

M_{lxt} = Interaction mean squares

M_e = Error mean square

3.5.6 Phenotypic and Genotypic Variance

From the analysis of variance for each character in each season for parents and testcrosses separately phenotypic and genotypic variances were computed according to the procedure given by Choudhari and Prasad (1968) as follows:

Source	df	Ms	Expected MSS
Replication	r-1	M_1	
Treatments (genotypes)	t-1	M_2	$\sigma^2_e + r\sigma^2_t$
Error	(r-1)(t-1)	M_3	σ^2_e

Genotypic variance $\sigma^2_g = (M_2 - M_3) \div r$

Phenotypic variance $\sigma^2_p = \sigma^2_g + \sigma^2_e$

Where M_2 = treatment (genotype) MSS, M_3 = Error MSS

Genotypic coefficient of variation (GCV) = $(\sqrt{\sigma^2_g} \times 100) \div \bar{X}$

Phenotypic coefficient of variation (PCV) = $(\sqrt{\sigma^2_p} \times 100) \div \bar{X}$

Where $\sqrt{\sigma^2_g}$ = genotypic standard deviation
$\sqrt{\sigma^2_p}$ = phenotypic standard deviation
$\bar{X}$ = general mean of character

3.5.7 Heritability

Heritability (h^2) in broad sense is the ratio of genetic variance to phenotypic variance and was computed according to Lush (1940).

$$h^2 = \sigma^2_g \div \sigma^2_p \times 100$$

3.5.8 Genetic Advance

Genetic advance was computed according to Johanson *et al.* (1955) procedure as follows:

Genetic advance = $h^2 \times K \times \sigma_p$

Where h^2 = heritability

σ_p = phenotypic standard deviation

K = selection intensity, the value is 2.06 when top 5% individuals are selected.

3.5.9 Correlations and Path Analysis

Analysis of covariance was carried out for characters in pairs following Panse and Sukhatme method (1961). The correlation coefficients among different characters were computed at genotypic level as follows.

$$r(X_1X_2) = \text{Cov } X_1X_2 \div \sqrt{Var(X_1) * Var(X_2)}$$

Where -

$r(X_1X_2)$ = Correlation coefficient between X_1 and X_2.

Cov $(X_1X_2$ = Covariance between X_1 and X_2.

The test of significance of correlations was carried out using 'r' table values of Fisher and Yates (1963) at (n-2) df at one per cent and five per cent levels where n denotes the number of genotypes tested.

Path coefficient analysis at genotypic level for each season and for parents and test crosses separately was done by solving the following simultaneous equations as suggested by Dewey and Lu (1959).

$$r_1Y = P_1 + P_2\, Yr_{12} + P_3\, Yr_{13} + ... + P_k\, Yr_{1k}$$

Where

r_1Y = Simple correlation coefficient between X_1 and X_2.

P_1Y = Direct effect of X_1 and Y.

$P_2\ Yr_{12}$ = Indirect effect of X_1 and Y through X_2.

$P_3\ Yr_{13}$ = Indirect effect of X_1 and Y through X_3.

$P_k\ Yr_{1k}$ = Indirect effect of X_1 and Y through X_k.

In the same way equations for r_2Y upto r_9Y were computed and path coefficients viz., direct and indirect effect were calculated.

RESULTS

CHAPTER IV

RESULTS

The result of the two experiments conducted in the present investigations are presented under the following headings:

4.1 Analysis of variance

4.2 Mean performance

4.3 General and specific combining ability effects

4.4 Estimates of components of variance

4.5 Analysis of genetic variability

4.6 Correlations and path analysis

4.7 Stability analysis

4.1 ANALYSIS OF VARIANCE

Line x tester analysis of variance of the hybrid data (Table 4) showed that parent lines were significantly different from each other for all characters except eggs per plant in kharif, yield score in set 1 in kharif and plant height in set 2 in rabi.

Similarly, parents vs crosses exhibited significant differences for all characters except vigour score and plant height (for all sets in kharif) and eggs per

Table 4. Mean squares for diffeent characters associated with sorghum shoot fly resistance in kharif(K) 1992 and rabi(R) 1992-93.

Source of variation	df	Vigour score		Glossy score		Upper surface trichomes		Lower surface trichomes	
		K	R	K	R	K	R	K	R
					Set-1				
Parents	7	6.67*	6.09**	33.14**	36.86**	14371.5**	19587.2**	1928.1**	2499.3**
Parents vs crosses	1	3.30	25.00**	3.68	35.01**	33726.1**	19367.4**	6629.0**	5650.0**
Lines (L)	3	3.69	6.25**	7.36*	1.19	842.9	644.7	43.54	10.92
Testers(T)	3	9.97*	9.47**	13.85**	7.57**	2019.7*	4566.3*	24.49	12.97
L x T	9	1.45	1.27	2.19	0.63*	236.9	859.2**	28.50	13.88
Error	46	2.40	0.70	1.49	0.23	518.3	156.7	83.26	55.27
					Set-2				
Parents	7	7.40*	3.81**	31.77**	35.14**	13697.1**	17803.5**	1643.7**	1665.02*
Parents vs crosses	1	0.18	23.36**	14.64**	41.17**	18791.8**	19136.1**	5341.2**	3640.11*
Lines (L)	3	2.61	0.47	3.24	3.91*	415.2	168.2	0.47	37.83
Testers(T)	3	5.72	2.81	15.63**	3.74*	2111.1*	5230.1**	0.47	46.83
L x T	9	2.26	1.34*	1.08	0.72	465.4	268.3	0.65	42.67
Error	46	2.64	0.63	1.45	0.27	341.4	322.0	24.47	23.05
					Set-3				
Parents	7	6.98*	5.43**	28.68**	29.18**	16664.0**	15966.4**	2877.1**	1363.3**
Parents vs crosses	1	3.30	30.25**	49.31**	18.06**	43499.5**	36322.0**	13890.7**	4021.7**
Lines (L)	3	2.91	2.31	1.41	0.19	416.1	393.9	14.90	17.30
Testers(T)	3	0.80	0.92	2.69	14.69**	5139.7**	2035.6	28.42	26.19
L x T	9	2.41	1.73**	2.54	1.22	451.4	660.4**	17.23	34.41
Error	46	2.33	0.43	1.71	0.63	216.7	207.9	50.50	27.30

Table 4. (contd.)

Source of variation	df	Plant height		Yield score		Eggs/plant		Deadheart %		Leaf surface wetness
		K	R	K	R	K	R	K	R	R
Set-1										
Parents	7	137.85**	63.90**	2.19	2.99**	0.03	0.26**	544.0**	1856.9**	13.35**
Parents vs crosses	1	79.51	751.67**	19.51**	9.51**	0.54**	2.35**	1007.5**	8343.3**	143.60**
Lines (L)	3	45.80	85.08*	10.52*	3.41	0.015	0.04	111.4	65.2	1.63
Testers(T)	3	148.91**	101.08**	4.13	15.58**	0.028	0.05	60.6	758.2*	0.42
L X T	9	48.37	17.39	0.39	1.30*	0.056	0.04	40.9	138.9	1.77
Error	46	29.41	12.95	1.51	0.55	0.070	0.05	139.5	217.7	1.24
Set-2										
Parents	7	111.33**	28.19	6.10**	3.40**	0.08	0.26**	373.7*	1670.5*	12.34*
Parents vs crosses	1	32.11	697.84**	5.44**	4.00*	0.05	1.71**	1396.3**	5606.3**	128.26*
Lines (L)	3	2.53	49.24	1.83*	2.39*	0.37*	0.05	432.5	46.3	2.60
Testers(T)	3	22.47	93.97	4.89**	18.39**	0.21	0.16**	116.3	654.1*	0.81
L x T	9	60.99	34.28*	1.15	0.30	0.10	0.02	76.7	92.7	1.80
Error	46	31.26	15.50	0.57	0.57	0.09	0.04	168.2	178.8	1.42
Set-3										
Parents	7	172.42**	81.33**	3.33**	7.31**	0.11	0.18**	243.4*	1176.9**	12.57**
Parents vs crosses	1	128.44	935.34**	16.00**	17.36**	0.10	1.96**	459.8*	6745.9**	137.28**
Lines (L)	3	44.81	20.41	0.58	3.42	0.17	0.08*	71.4	210.6	5.90
Testers(T)	3	37.36	15.74	7.81**	1.81	0.04	0.02	29.86	113.6	4.23
L x T	9	18.45	25.61	0.82	1.29*	0.07	0.04	77.67	124.5	2.85*
Error	46	34.15	12.47	1.07	0.55	0.09	0.03	85.41	162.4	1.37

Significant at probability 0.05 and 0.01 respectively.

plant (sets 2 and 3 in kharif).

Differences between lines were significant for vigour score (set 1 in kharif), glossy score (set 1 in kharif and set 2 in rabi), plant height (set 1 in rabi), yield score (set 2 in both seasons and in set 1 during kharif), and eggs per plant (kharif set 2 and rabi set 3).

Differences between testers were significant for vigour score (set 1 in both seasons), glossy score (except kharif set 3) upper surface trichomes (except rabi set 3), plant height (set 1 in both seasons), yield score (except kharif set 1 and rabi set 3), eggs per plant (only in rabi set 2) and dead heart percentage (rabi set 1 and 2).

Line x tester interactions were significant only during rabi season for at least one set for vigour score, glossy score, upper surface trichomes, plant height, yield score and leaf surface wetness. An examination of variances pooled over sets (Table 5) indicated that males (resistant lines) exhibited higher mean squares than females (male-sterile lines) for all characters under study except eggs per plant and deadheart percentage during kharif indicating greater diversity in lines for most characters. Lines also showed higher mean squares for leaf surface wetness when analyses of variances were done separately for each set (Table 4) indicating greater diversity among lines within sets than among females within sets.

Table 5. Analysis of variance (mean squares) pooled over sets in respect of 9 in sorghum parents and hybrids during kharif(K) 1992 and rabi(R) 1992-93.

Source of variation	df	Vigour score		Glossy score		Upper surface trichomes		Lower surface trichomes	
		K	R	K	R	K	R	K	R
Sets	2	0.51	1.33	2.11	22.75	100.5	249.8	9.68	0.13
Error (a)	4	6.44	0.67	5.74	0.65	71.2	98.1	10.81	7.22
Males/sets	9	5.56*	4.40*	10.73**	8.67**	3107.1**	3944.0**	20.11	28.66
Females/sets	9	3.01	3.01*	4.00	1.76	557.7	402.3	18.89	22.02
Male x female/sets	27	2.03	1.45**	1.93	0.86*	379.4*	596.0**	14.63	30.32**
Error(b)	90	2.78	0.47	2.11	0.52	232.9	231.2	17.43	13.24

Table 5. (Contd..)

Source of variation	df	Plant height		Yield score		Eggs/plant		Deadheart %	
		K	R	K	R	K	R	K	R
Sets	2	74.84	14.08	14.38	0.55	0.04	0.09	33.8	234.5
Error (a)	4	53.30	11.86	1.81	0.38	0.03	0.07	106.5	169.9
Males/sets	9	69.58	70.26**	5.44**	11.92**	0.09	0.08	68.9	508.6**
Females/sets	9	31.04	51.58	4.31**	3.07**	0.18	0.05	205.1	107.4
Male x female/sets	27	42.61*	25.76*	0.79	0.96*	0.08	0.03	65.1	118.7
Error(b)	90	26.14	15.14	1.06	0.58	0.09	0.04	106.4	181.2

Significant at probability 0.05 and 0.01 respectively.

4.2 MEAN PERFORMANCE

The means for eight characters associated with shoot fly resistance measured during kharif (1992) and nine characters measured in rabi (1992-93) were calculated for the 48 hybrids, 24 parents and two check cultivars and are shown in Tables 6a and 6b.

4.2.1 Mean Performance of Parents

4.2.1.1 Seedling Vigour: Seedling vigour was rated on a 1-9 scale, where 1 is highly vigorous and 9 least vigorous. Significant differences were found between seasons as well as parents for this trait. Most of the parents were more vigorous in kharif than in rabi. With regard to parental lines, resistant ones (males) were found to be more vigorous; all males (except IS 18533, IS 5801 in both seasons and IS 2205 in kharif) had lower scores than experimental mean values (4.31 in kharif and 4.74 in rabi). IS 22114 (1.87) and IS 5566 (1.67) in kharif and IS 5622 (2.33), IS 1082 (2.67) and IS 5566 (3.0) in rabi had significantly lower scores than the experimental mean values, while susceptible male-sterile lines, except ICSA 84 and ICSA 101 in kharif and ICSA 32, 77 and 84 in rabi, recorded higher scores than the mean values.

4.2.1.2 Glossiness: The glossy score was rated on a 1-9 scale, where 1 is completely glossy and 9 is non-glossy. Parents were statistically different from each other. Resistant lines (males), except IS 18533 and IS 5801, were glossy; whereas

Table 6a. Mean performance of parents for different characters associated with shoot fly resistance during kharif (K) 1992 and rabi (R) 1992-93.

S. No.	Parents	Vigour score		Glossy score		Upper surface trichomes		Lower surface trichomes	
		K	R	K	R	K	R	K	R
1	IS 2205	4.67	4.33	2.00	2.33	171.33	205.67	44.67	37.33
2	IS 5480	3.00	4.00	2.00	2.00	122.00	114.67	57.67	60.67
3	IS 5622	2.33	2.33	2.00	2.00	108.67	123.67	49.67	63.33
4	IS 18533	5.67	5.00	8.67	9.00	83.00	0.00	18.00	0.00
5	IS 1082	4.00	2.67	2.00	2.33	130.33	148.33	54.67	17.00
6	IS 2123	2.67	4.00	2.00	2.00	113.67	103.67	42.33	49.00
7	IS 5801	4.67	5.00	8.33	9.00	0.00	18.00	0.00	8.00
8	IS 22114	1.87	3.33	1.96	2.33	152.00	188.00	41.00	57.33
9	IS 923	2.67	3.33	2.00	3.00	125.67	109.33	55.33	24.67
10	IS 5566	1.67	3.00	1.33	2.00	183.00	195.00	71.67	57.00
11	IS 18366	2.67	4.33	2.33	3.00	139.33	111.33	56.67	19.33
12	IS 22145	3.67	4.67	2.00	3.00	94.33	100.33	51.00	36.00
13	ICSA 1	5.67	5.00	8.67	9.00	0.00	3.67	0.00	0.00
14	ICSA 18	4.67	5.00	8.00	9.00	0.00	0.00	0.00	0.00
15	ICSA 49	6.33	7.00	8.67	9.00	0.00	0.00	0.00	0.00
16	ICSA 88001	6.33	6.33	8.00	8.33	0.00	0.00	0.00	0.00
17	ICSA 32	6.67	4.67	9.00	9.00	0.00	0.00	0.00	0.00
18	ICSA 38	5.00	6.00	8.67	9.00	0.00	0.00	0.00	0.00
19	ICSA 70	5.67	5.67	8.00	9.00	2.33	0.00	0.00	0.00
20	ICSA 84	3.67	4.67	5.67	8.00	14.00	6.00	9.33	0.00
21	ICSA 73	4.67	7.00	8.00	9.00	16.00	0.00	8.00	0.00
22	ICSA 77	6.00	4.67	8.33	8.33	0.00	2.33	0.00	0.00
23	ICSA 95	5.67	6.00	8.00	9.00	0.00	0.00	0.00	0.00
24	ICSA 101	3.57	5.67	3.92	7.67	0.00	13.67	0.00	0.00
Mean of Parents		4.31	4.74	5.40	6.10	60.65	60.15	23.33	17.90
SE ±		0.73	0.51	0.30	0.17	14.86	8.67	6.22	5.18
CD 5%		2.09	1.47	0.85	0.48	42.29	24.69	17.70	14.75

(Contd.)

Table 6a (contd..).

S. No.	Parents	Plant height		Yield score		Eggs per plant		Deadhert percentage		Leaf surface wetness
		K	R	K	R	K	R	K	R	R
1	IS 2205	23.67	26.33	6.33	6.00	0.77	0.17	51.51	14.23	1.73
2	IS 5480	32.00	28.67	6.00	6.33	0.77	0.10	73.01	8.03	1.07
3	IS 5622	28.67	33.67	6.33	5.00	1.00	0.43	79.20	16.03	2.70
4	IS 18533	17.67	27.33	8.00	7.00	0.97	0.87	92.90	65.00	5.83
5	IS 1082	21.33	32.33	5.00	4.33	1.03	0.27	69.94	17.83	2.07
6	IS 2123	31.67	28.00	4.33	5.33	1.27	0.27	67.78	13.77	1.13
7	IS 5801	21.33	24.00	7.00	6.00	1.27	0.90	90.81	66.87	5.20
8	IS 22114	26.67	29.00	6.00	5.67	0.90	0.30	63.89	25.53	1.33
9	IS 923	30.00	32.33	5.67	4.33	1.10	0.37	75.53	26.40	2.47
10	IS 5566	38.00	28.67	5.67	6.00	0.83	0.23	66.49	17.13	1.53
11	IS 18366	27.00	30.00	7.00	4.67	0.97	0.37	81.44	35.70	2.40
12	IS 22145	22.67	27.67	4.67	6.00	0.97	0.23	79.07	16.57	2.20
13	ICSA 1	14.67	24.33	8.00	6.00	1.00	0.83	93.85	63.63	5.80
14	ICSA 18	18.33	24.00	7.00	6.00	0.83	0.73	86.92	61.97	6.33
15	ICSA 49	13.33	20.33	7.67	8.33	0.93	0.50	82.02	41.03	5.27
16	ICSA 88001	16.67	19.33	8.00	5.67	0.83	0.70	79.28	60.47	5.67
17	ICSA 32	12.67	26.00	8.00	6.33	0.83	0.70	83.87	62.67	4.67
18	ICSA 38	16.33	26.33	8.33	6.00	0.90	0.87	92.53	63.53	4.53
19	ICSA 70	16.33	25.00	7.33	7.67	1.13	0.90	87.14	61.23	5.23
20	ICSA 84	20.00	22.67	7.33	7.33	1.03	0.80	74.23	66.13	6.50
21	ICSA 73	16.00	16.67	7.00	9.00	1.30	0.73	94.12	65.67	6.60
22	ICSA 77	17.00	26.00	7.67	6.67	1.07	0.83	85.95	61.83	3.53
23	ICSA 95	21.33	23.67	5.00	6.67	1.33	0.70	90.94	56.80	6.40
24	ICSA 101	17.67	20.33	6.33	8.00	0.83	0.67	75.73	47.80	5.60
Mean of Parents		21.71	25.94	6.65	6.26	0.99	0.56	79.92	43.16	3.99
SE ±		3.35	1.96	0.61	0.40	0.15	0.10	7.76	7.70	0.72
CD 5%		9.54	5.60	1.75	1.14	0.43	0.28	22.09	21.92	2.05

susceptible male-sterile lines (females) were non-glossy in both seasons (Plate 2).

4.2.1.3 Upper Surface Trichomes: Resistant lines, except IS 5801 in kharif and IS 5801 and IS 18533 in rabi, were observed to have significantly more trichomes on their upper surface than the experimental mean values (60.65 trichomes mm^{-2} in kharif and 60.15 in rabi). Susceptible male-sterile lines had no trichomes or very few trichomes (Plate 3).

4.2.1.4 Lower Surface Trichomes: Similarly, for lower surface trichomes, resistant lines (with the exceptions of IS 18533 and IS 5801) had significantly higher than the mean values (23.30 in kharif and 17.90 mm^{-2} in rabi). In contrast, all susceptible male-sterile lines (except ICSA 73 and ICSA 84 in kharif) had no trichomes.

4.2.1.5 Seedling Height: Differences between seasons as well as between parental lines were significant for this character. In rabi, most of the parents were taller than in kharif. Lines IS 5480, IS 2123 and IS 5566 in kharif and IS 5622, IS 1082 and IS 923 in rabi, significantly exceeded the mean values (21.71 cm in kharif and 25.94 cm in rabi).

4.2.1.6 Yield Score: Significant differences were observed between parents in both seasons. Lines IS 2123 and IS 22145 in kharif and IS 5622, IS 1082 and IS 923 in rabi were found to have significantly lower score than the mean values (6.65 in kharif and 6.26 in rabi).

Plate No. 2a. Glossy shoot fly resistant line (background) and non-glossy susceptible line (foreground).

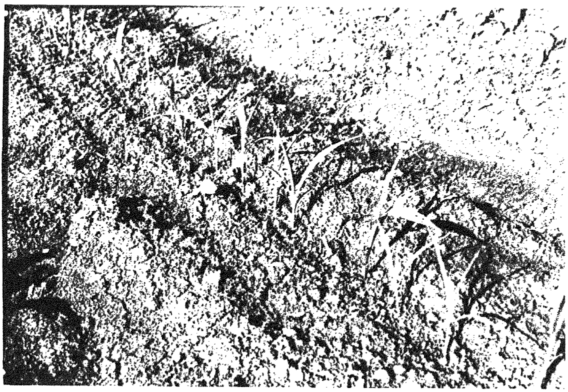


Plate No. 2b. Glossy shoot fly resistant line.

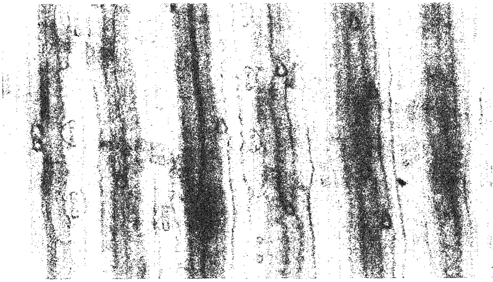


Plate No. 3a. High density of trichomes on the adaxial surface of resistant check (ICSV 88088).

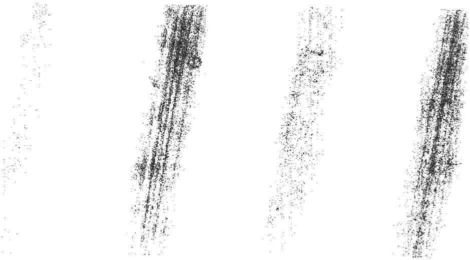


Plate No. 3b. Few trichomes on the adaxial surface of a hybrid (ICSA 95 x IS 18366).

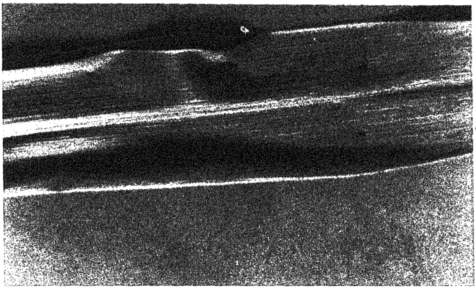
Plate No. 3c. No trichomes on the adaxial surface of the susceptible check (CSH 11).

4.2.1.7 Eggs Per Plant: Differences among parents were significant only in rabi season, in which all resistant lines (except IS 18533 and IS 5801) had significantly lower number of eggs per plant than the mean (0.56). In contrast all susceptible male-sterile lines (except ICSA 49) had more eggs per plant than the mean.

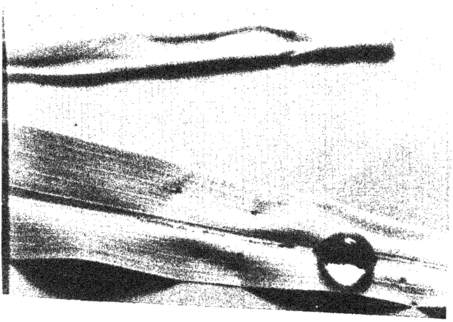
4.2.1.8 Deadheart Percentage: Highly significant differences were observed between seasons for this important trait. Deadheart percentages were significantly less in rabi (43.16%) than in kharif (79.92%). Parental lines also varied significantly. All resistant lines (except IS 18533, IS 5801 and IS 18366 in kharif and IS 18533 and IS 5801 in rabi) had lower shoot fly deadheart percentage than experimental mean values (79.92% in kharif and 43.16% in rabi). In rabi three resistant lines IS 2205 (14.22%), IS 5480 (8.03%) and IS 2123 (15.60%) had lower deadheart percentages than even the resistant check (15.60%).

4.2.1.9 Leaf Surface Wetness: LSW score was rated on a 1-9 scale, where 1 is = no moisture on the leaf lamina (desirable trait for resistance) and 9 = leaf densely covered with water droplets. Differences among parents were highly significant. Leaves of resistant lines were completely dry, their scores significantly lower than the mean (3.99) and (except IS 5622, IS 18533 and IS 5801) lower than the resistant check (2.47) too. In contrast, susceptible male-sterile lines had water droplets on their leaves and all except ICSA 77 exceeded the mean value score (3.99) (Plate 4).

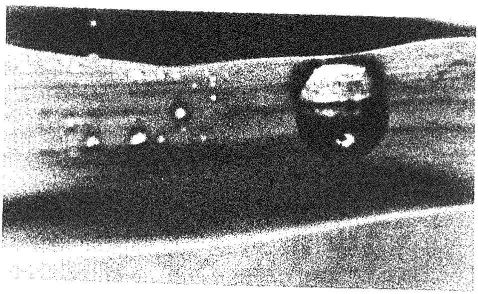
Plate No. 4. Leaf surface wetness of central shoot leaves of 13 days-old seedling.



a) ICSV 88088 resistant check (completely dry).



b) ICSA 95 x IS 18366 (hybrid).



c) CSH 1, susceptible check.

4.2.2 Mean Performance of Hybrids

4.2.2.1 Seedling Vigour: Differences among hybrids for vigour score were significant in rabi for sets 2 and 3 (Table 4). Seven out of 48 hybrids were observed to have significantly lower score (more vigorous) than the resistant check (4.0) and the mean value (3.46). In kharif season, ICSA 32 x IS 1082 (2.33) and ICSA 38 x IS 1082 (2.33) among hybrids were more vigorous than the resistant check, ICSV 88088 (4.0) (Table 6b).

Generally hybrids were more vigorous than their parents, when considered individually or as a group of hybrids derived from the same parents.

4.2.2.2 Glossiness: Significant differences among hybrids were found in rabi for set 1 (Table 4). Four hybrids were completely non-glossy in this set with score (9.0), produced when non-glossy resistant line IS 18533 was used as the pollinator. In general all hybrids were non-glossy like their female parents.

Differences were marked between seasons for this character; hybrids recorded higher score in rabi (7.48) than in kharif (6.46).

4.2.2.3 Upper Surface Trichomes: Generally hybrids resembled their female parents (susceptible lines) and had only few to very few trichomes on the upper surface of the leaf compared with the resistant check or male parents (resistant lines).

Table 6b. Mean performance of 48 hybrids of sorghum for different characters associated with shoot fly resistance during kharif(K) 1992 and rabi(R) 1992-93.

S.No.	Hybrids	Vigour score		Glossy score		Upper surface trichomes		Lower surface trichomes	
		K	R	K	R	K	R	K	R
1	ICSA 11 x IS 2205	4.33	2.67	7.33	6.33	11.00	34.33	0.00	4.67
2	ICSA 11 x IS 5480	3.00	3.00	6.00	7.33	9.33	22.33	0.00	1.67
3	ICSA 11 x IS 5622	3.00	2.00	5.67	7.33	5.67	15.33	0.00	0.00
4	ICSA 11 x IS 18533	5.00	5.00	8.33	9.00	0.67	0.00	0.00	0.00
5	ICSA 18 x IS 2205	4.33	2.67	7.33	7.33	35.67	40.67	0.00	1.33
6	ICSA 18 x IS 5480	3.33	2.67	6.33	7.33	5.82	1.33	0.51	0.00
7	ICSA 18 x IS 5622	3.67	2.33	6.33	7.33	0.00	5.67	0.00	0.00
8	ICSA 18 x IS 18533	6.67	4.00	8.33	9.00	2.00	0.00	0.00	0.00
9	ICSA 49 x IS 2205	5.33	5.33	4.67	8.00	36.67	83.33	0.00	4.00
10	ICSA 49 x IS 5480	5.33	3.67	6.67	8.00	11.00	5.67	0.00	0.00
11	ICSA 49 x IS 5622	4.83	4.00	7.17	8.00	11.33	4.00	0.00	0.00
12	ICSA 49 x IS 18533	5.00	5.00	8.33	9.00	4.67	6.00	0.00	0.00
13	ICSA 88001 x IS 2205	4.33	5.00	4.00	8.00	46.33	38.00	2.33	0.00
14	ICSA 88001 x IS 5480	3.33	2.67	5.33	6.67	37.00	25.00	12.67	5.00
15	ICSA 88001 x IS 5622	3.00	3.00	4.67	7.33	19.33	47.00	0.00	5.33
16	ICSA 88001 x IS 18533	5.67	5.00	7.33	9.00	1.00	5.33	0.00	0.00
17	ICSA 32 x IS 1082	2.33	2.67	5.67	7.33	5.00	2.00	0.00	0.00
18	ICSA 32 x IS 2123	3.33	3.33	5.67	8.00	22.67	41.33	0.67	15.00
19	ICSA 32 x IS 5801	4.33	3.00	8.33	9.00	5.33	5.00	0.00	0.00
20	ICSA 32 x IS 22114	5.00	3.00	7.33	8.33	26.00	60.33	0.00	0.00
21	ICSA 38 x IS 1082	2.33	2.67	5.00	8.00	9.00	4.67	0.00	0.00
22	ICSA 38 x IS 2123	3.67	3.00	6.67	7.67	7.00	11.67	0.00	2.00
23	ICSA 38 x IS 5801	3.67	5.00	8.00	9.00	22.33	7.67	1.67	1.00
24	ICSA 38 x IS 22114	5.67	2.67	5.67	8.33	18.00	55.33	0.00	3.33
25	ICSA 70 x IS 1082	5.00	3.00	7.00	8.00	1.67	12.33	0.00	0.00
26	ICSA 70 x IS 2123	3.67	3.33	6.00	8.00	14.33	18.33	0.00	0.00
27	ICSA 70 x IS 5801	5.33	4.33	8.67	8.67	0.00	3.00	0.00	0.00
28	ICSA 70 x IS 22114	5.00	3.00	7.67	8.33	40.67	48.67	0.00	0.00
29	ICSA 84 x IS 1082	3.67	4.33	5.33	7.67	23.33	21.00	0.00	0.00
30	ICSA 84 x IS 2123	5.00	2.67	5.33	5.67	15.33	16.00	0.00	0.00
31	ICSA 84 x IS 5801	4.67	3.67	8.00	8.00	3.67	18.00	0.00	0.00
32	ICSA 84 x IS 22114	4.00	3.00	6.00	7.00	62.00	49.33	0.00	0.00
33	ICSA 73 x IS 923	5.00	4.67	6.33	7.67	9.67	12.67	0.00	0.00
34	ICSA 73 x IS 5566	3.33	3.33	5.00	4.67	61.67	53.33	0.00	0.00
35	ICSA 73 x IS 18366	4.33	3.67	7.67	7.00	1.67	7.00	0.00	0.00
36	ICSA 73 x IS 22145	4.67	3.00	6.33	7.00	5.67	28.67	0.00	6.67
37	ICSA 77 x IS 923	3.67	2.67	5.33	6.33	6.82	2.67	0.51	0.00
38	ICSA 77 x IS 5566	6.33	3.00	7.67	6.00	28.67	48.00	0.33	0.00
39	ICSA 77 x IS 18366	5.00	3.00	6.67	7.67	12.67	0.00	0.00	0.00
40	ICSA 77 x IS 22145	4.67	2.67	7.00	6.33	6.67	20.67	0.00	0.00
41	ICSA 95 x IS 923	4.00	3.33	6.00	7.33	3.00	9.67	0.00	0.00
42	ICSA 95 x IS 5566	3.67	3.00	5.67	5.33	29.67	0.00	2.33	0.00
43	ICSA 95 x IS 18366	3.67	3.67	5.33	7.67	7.33	15.00	0.00	0.00
44	ICSA 95 x IS 22145	5.00	4.00	7.00	6.67	6.33	22.00	0.00	2.67
45	ICSA 101 x IS 923	3.00	2.33	4.67	7.33	16.67	23.67	0.00	0.00
46	ICSA 101 x IS 5566	4.67	3.67	6.33	4.67	74.33	45.00	10.00	11.00
47	ICSA 101 x IS 18366	4.00	5.00	6.67	8.67	1.33	4.67	0.00	0.00
48	ICSA 101 x IS 22145	3.33	4.33	6.00	6.67	7.33	8.67	0.00	0.00
49	CSH 1 (Susc. check)	5.33	5.33	8.25	8.67	0.00	7.33	0.00	0.00
50	ICSV 88088 (Res.check)	4.33	4.00	1.67	2.00	158.33	156.67	12.33	26.67
Mean of hybrids		4.27	3.46	6.46	7.48	16.53	21.15	0.65	1.33
SE ±		0.99	0.40	0.87	0.42	8.66	8.56	2.38	2.08
CD 5%		2.78	1.12	2.44	1.17	24.37	24.35	6.71	5.84

Contd..

Table 6b (contd.)

S.No.	Hybrids	Plant height		Yield score		Eggs/plant		Deadheart %		Leaf surface wetness
		K	R	K	R	K	R	K	R	R
1	ICSA 11 x IS 2205	16.67	35.33	5.67	5.33	1.17	0.77	92.73	50.23	8.20
2	ICSA 11 x IS 5480	27.33	34.33	6.33	4.00	0.93	1.00	91.63	71.83	8.33
3	ICSA 11 x IS 5622	23.67	39.00	6.67	4.67	1.17	0.90	88.83	57.10	6.60
4	ICSA 11 x IS 18533	12.00	29.00	6.67	5.67	1.03	1.13	88.87	67.23	7.73
5	ICSA 18 x IS 2205	16.67	34.00	5.33	4.33	1.03	1.00	85.23	58.50	8.20
6	ICSA 18 x IS 5480	24.33	37.33	5.33	4.33	1.33	0.90	94.57	55.03	7.13
7	ICSA 18 x IS 5622	15.33	38.00	6.00	5.33	0.90	1.00	87.33	71.37	7.97
8	ICSA 18 x IS 18533	10.67	28.67	7.33	7.00	0.97	0.87	88.60	78.60	6.67
9	ICSA 49 x IS 2205	19.33	30.00	6.33	4.67	0.90	0.83	85.80	53.90	6.00
10	ICSA 49 x IS 5480	14.33	30.33	7.33	5.67	1.13	1.07	84.13	71.57	7.50
11	ICSA 49 x IS 5622	16.00	29.33	7.00	5.67	1.10	0.97	75.40	65.77	7.40
12	ICSA 49 x IS 18533	17.00	26.00	7.67	8.33	1.00	1.00	88.43	74.13	6.93
13	ICSA 88001 x IS 2205	21.67	28.33	4.33	5.67	1.17	0.73	83.83	54.90	6.20
14	ICSA 88001 x IS 5480	22.00	36.33	4.67	4.33	1.10	0.73	89.77	55.20	7.30
15	ICSA 88001 x IS 5622	22.67	31.67	4.67	5.67	1.17	0.93	88.63	65.60	7.13
16	ICSA 88001 x IS 18533	14.67	30.00	5.67	7.67	1.03	0.97	90.70	75.20	7.43
17	ICSA 32 x IS 1082	22.67	36.67	4.67	4.33	1.07	0.77	93.53	60.23	6.77
18	ICSA 32 x IS 2123	17.67	33.00	7.00	5.33	1.23	0.87	89.77	57.40	6.07
19	ICSA 32 x IS 5801	17.67	36.67	6.33	7.00	1.03	0.97	98.77	72.30	5.00
20	ICSA 32 x IS 22114	17.67	31.67	7.33	4.67	1.17	0.87	86.47	62.10	7.07
21	ICSA 38 x IS 1082	19.33	35.33	5.67	4.33	1.30	0.93	97.77	61.87	5.87
22	ICSA 38 x IS 2123	16.67	34.33	5.67	4.33	1.33	0.77	86.00	55.67	5.90
23	ICSA 38 x IS 5801	22.67	26.33	6.33	7.33	0.97	1.07	97.23	72.23	7.20
24	ICSA 38 x IS 22114	17.67	32.33	7.33	4.33	1.17	1.07	92.80	76.37	6.33
25	ICSA 70 x IS 1082	18.33	36.67	5.67	5.33	0.83	0.83	82.37	56.73	8.27
26	ICSA 70 x IS 2123	28.67	36.33	6.67	5.67	1.17	0.93	91.40	66.67	7.47
27	ICSA 70 x IS 5801	13.67	27.67	6.67	7.33	0.83	1.23	85.67	80.17	6.13
28	ICSA 70 x IS 22114	19.00	41.00	6.00	5.33	0.57	0.87	86.77	65.67	6.90
29	ICSA 84 x IS 1082	22.67	33.00	5.00	5.33	1.63	0.93	74.03	66.37	6.80
30	ICSA 84 x IS 2123	16.33	32.33	5.00	5.67	1.17	0.93	76.93	59.67	7.13
31	ICSA 84 x IS 5801	16.00	26.00	6.00	8.00	1.17	1.20	89.30	80.00	6.93
32	ICSA 84 x IS 22114	23.33	33.00	6.00	5.00	1.00	1.00	80.93	61.20	6.80
33	ICSA 73 x IS 923	19.33	31.00	5.33	6.33	1.03	1.03	89.33	69.83	6.27
34	ICSA 73 x IS 5566	22.00	35.00	4.67	6.00	1.27	0.93	91.37	61.27	8.07
35	ICSA 73 x IS 18366	21.33	34.67	6.00	5.67	1.03	1.07	81.67	67.33	7.80
36	ICSA 73 x IS 22145	23.33	36.33	5.00	5.67	1.00	0.87	84.03	60.87	6.33
37	ICSA 77 x IS 923	18.33	35.33	4.67	4.33	1.03	0.87	86.90	60.33	5.47
38	ICSA 77 x IS 5566	17.00	35.67	5.00	5.33	1.00	1.03	90.17	67.07	6.53
39	ICSA 77 x IS 18366	24.33	32.00	6.00	5.33	0.97	0.73	83.83	61.80	6.27
40	ICSA 77 x IS 22145	17.33	35.33	5.67	4.67	0.93	0.90	85.17	72.63	8.07
41	ICSA 95 x IS 923	18.33	33.00	5.00	4.33	1.10	0.80	93.33	58.67	5.40
42	ICSA 95 x IS 5566	18.67	32.67	3.67	5.33	1.17	0.80	90.97	60.23	5.80
43	ICSA 95 x IS 18366	19.67	32.67	6.00	5.00	1.60	0.80	91.03	63.60	4.53
44	ICSA 95 x IS 22145	21.00	31.67	4.67	5.00	1.13	0.80	82.53	49.13	7.80
45	ICSA 101 x IS 923	24.67	38.67	5.00	4.33	1.33	0.80	76.40	60.20	6.93
46	ICSA 101 x IS 5566	17.67	31.00	4.00	5.33	1.23	0.70	80.93	52.20	7.27
47	ICSA 101 x IS 18366	26.33	27.67	7.00	7.00	1.07	1.03	90.33	68.93	8.20
48	ICSA 101 x IS 22145	24.67	30.33	4.33	6.33	1.13	0.70	86.30	50.23	7.60
49	CSH 1 (Susc.check)	13.67	30.33	6.63	5.00	0.73	1.03	87.10	62.63	7.90
50	ICSV 88088 (Res.check)	22.33	24.67	4.33	6.33	0.57	0.13	47.00	15.60	2.00
Mean of hybrids		19.55	32.98	5.76	5.49	1.10	0.91	87.47	63.86	6.91
SE ±		3.01	2.23	0.60	0.43	0.17	0.12	5.94	7.74	0.66
CD 5%		8.47	6.28	1.69	1.22	0.49	0.33	16.72	21.79	1.85

Differences among hybrids for this trait were significant in rabi (sets 1 and 2). ICSA 49 x IS 2205 (83.33 trichomes mm^{-2}), ICSA 88001 x IS 2205 (47.0), ICSA 73 x IS 5566 (53.33) and ICSA 77 x IS 5566 (48) among hybrids had significantly more trichomes than the mean value (21.15), but were significantly lower than the resistant check ICSV 88088 (156.67) (Plate 3c).

4.2.2.4 Lower Surface Trichomes: Similarly, hybrids were like their female parents (susceptible male-sterile lines) and had no trichomes on the lower surface of their leaves. Generally trichome density on the lower surface of the leaf was much lower than that on the upper surface, even in the resistant check.

4.2.2.5 Seedling Height: Differences among hybrids for seedling height were significant in rabi (set 3). Only one hybrid, ICSA 70 x IS 22114 (41.0 cm), was found significantly superior to the general mean (32.98 cm). In kharif season, seedling height of the hybrids ranged from 13.67 cm to 28.67 cm and ICSA 70 x IS 2123 was the tallest one.

The mean seedling height of the hybrids in rabi season (32.98 cm) was significantly greater than in kharif (19.55 cm) (Table 7), and also they were taller than their parents either individually or when the two mean values were compared (mean value of parents in rabi was 25.94 cm).

4.2.2.6 Yield Score: Among the 48 F_1s, 19 hybrids in rabi season had significantly lower yield score (desirable) than the resistant check ICSV 88088

Table 7. Lines x tester analysis of variance pooled over seasons and sets of 8 characters in sorghum parents and hybrids.

Source of variation	df	Mean of squares							
		VS	GS	UST	LST	Pl.Ht	YS	E/P	DH%
Seasons	1	47.42*	76.12	1528.7	32.18	12987*	5.01	2.48	40143**
Error (a)	4	5.27	11.30	1161.0	101.65	880.4	3.31	0.70	1691
Sets	2	1.74	19.00*	162.9	4.96	71.2	10.17**	0.03	221
sets x season	2	0.10	5.86	187.4	4.86	17.8	4.76	0.10	47
Error (b)	8	3.56	3.19	84.6	9.01	32.6	1.10	0.05	138
Males/sets	9	8.42**	15.65**	6573.8**	32.52*	117.4**	12.37**	0.04	406**
Females/sets	9	3.40*	3.46**	810.5**	30.88*	42.5*	3.43**	0.09	114
Male x female/sets	27	2.00	1.39**	617.9**	32.19**	37.5*	1.11	0.05	104
Males x season/sets	9	1.54	3.75	477.2*	16.26	22.4	5.00**	0.13*	172
Females x season/sets	9	2.62	2.30	149.5	10.02	40.1*	3.96**	0.15*	199
Male x female x seas./sets	27	1.48	1.40	357.4	12.76	30.9	0.64	0.06	80
Error (c)	180	1.62	1.31	232.1	15.31	20.6	0.82	0.07	144

*,** = Significant at probability 0.05 and 0.01 respectively.
VS = Vigor score; GS = Glossy score; UST = Upper surface trichomes.
LST = Lower surface trichomes; Pl.Ht = Plant height.
YS = Yield score; DH% = % of deadheart.

(6.33). Out of these ICSA 11 x IS 5480 gave a score of 4.0 which was significantly lower than the hybrid general mean (5.49).

4.2.2.7 Eggs Laying: Hybrids in rabi season recorded lower egg laying (0.91 eggs per plant) than in kharif (1.13 eggs per plant), but the difference was not significant (Table 7). In kharif eggs per plant ranged from 0.57 (ICSA 70 x IS 22114) which was on a par with resistant check (ICSV 88001) to 1.6 (ICSA 95 x IS 18366).

In rabi season egg laying ranged between 0.70 (ICSA 101 x IS 5566) and 1.93 eggs per plant (ICSA 70 x IS 5801). The resistant check ICSV 88088 had significantly lower eggs per plant (0.57 in kharif and 0.13 in rabi) than the mean values of hybrids (1.10 and 0.91).

4.2.2.8 Deadhead Percentage: A highly significant difference was found between seasons for hybrids as well as parents (Table 7). Shoot fly deadheart percentage in kharif (87.47) was significantly higher than in rabi (63.86%). Among hybrids, deadheart percentage ranged from 74.0 (ICSA 84 x IS 1082) to 98.77 (ICSA 32 x IS 5801) in kharif season, and it ranged from 79.12 (ICSA 95 x IS 22145) to 80.17 (ICSA 70 x IS 5801) in rabi season. The mean deadheart percentages of the hybrids in both seasons (87.47 in kharif and 63.86 in rabi) were much higher than corresponding means of the resistant check ICSV 88088 (47.0 in kharif and in rabi).

4.2.2.9 Leaf Surface Wetness (LSW): LSW was estimated only in rabi. Among hybrids in set 3, differences were significant. Only one hybrid, ICSA 95 x IS 18366, had significantly lower score (4.53) than the hybrid mean (6.91), but was significantly higher than the resistant check ICSV 88088 (2.0).

Generally all hybrids were like their female parents (susceptible male-sterile lines) and had high scores (with water droplets on their leaves) (Plate 4c).

4.3 GENERAL AND SPECIFIC COMBINING ABILITY EFFECTS

The estimates of gca and sca effects for the 8 and 9 characters in kharif and rabi seasons respectively are given in Tables 8 and 9.

4.3.1 Vigour Score

In rabi season highly significant gca effects were noticed among lines and testers. The estimated effects ranged from -0.71 to 1.13. Line IS 5480 (-0.71) recorded high negative gca effect (desirable) while IS 5622 (0.88) exhibited high positive gca.

Among testers, ICSA 49 (-0.79) recorded high negative gca followed by ICSA 18 (-0.63) in rabi season.

None of the crosses exhibited significant sca effects. ICSA 88001 x IS 5622 and ICSA 73 x IS 22145 in kharif and rabi respectively were the best combiners.

Table 8. General combining ability (gca) effects of lines and testers for 9 characters in sorghum for shoot fly resistance in kharif(K) 1992 and rabi(R) 1992-93.

Lines/Testers	Vigour score		Glossy score		Upper surface trichomes		Lower surface trichomes	
	K	R	K	R	K	R	K	R
Lines								
IS 2205	-0.55	-0.46	0.35	-0.31	- 8.05	-2.00	-0.90	0.21
IS 5480	0.12	-0.71**	0.60	-0.06	- 4.36	-9.25	-1.06	-1.04
IS 5622	0.72	0.88**	0.19	0.44	1.20	3.58	-0.90	-0.38
IS 18533	-0.30	0.29	-1.15**	-0.06	11.20	7.67	2.85	1.21
Testers								
ICSA 11	0.20	0.29	-0.65	-0.40*	17.70*	27.92**	-0.31	1.13
ICSA 18	-0.63	-0.63*	-0.40	-0.48**	0.56	-7.58*	2.10	0.29
ICSA 49	-0.78	-0.79**	-0.56	-0.31	- 5.36	-3.17	-0.90	-0.04
ICSA 88001	1.20*	1.13**	1.60**	1.19**	-12.63	-17.17**	-0.90	-1.38
SE ± (gi)	0.45	0.24	0.35	0.14	6.57	3.61	2.63	2.15
SE ± (gi-gj)	0.63	0.34	0.50	0.20	9.29	5.11	3.73	3.04
Lines								
IS 1082	-0.42	-0.29	0.10	0.23	-2.52	3.75	0.02	2.42
IS 2123	-0.33	0.04	-0.31	0.31	-3.19	-3.58	0.27	0.25
IS 5801	0.58	0.13	0.69	0.31	-3.10	-2.83	-0.15	-1.33
IS 22114	0.17	0.13	-0.48	-0.85**	8.81	2.67	-0.15	-1.33
Testers								
ICSA 32	-0.83	-0.13	-0.90*	-0.19	-7.52	-13.42*	-0.15	-1.33
ICSA 38	-0.25	-0.21	-0.73	-0.60**	-2.44	-1.58	0.02	2.92
ICSA 70	0.33	0.71	1.60**	0.73**	-9.44	15.00*	0.27	-1.08
ICSA 84	0.75	-0.38	0.02	0.06	19.40**	30.00**	-0.15	-0.50
SE ± (gi)	0.47	0.23	0.35	0.15	5.33	5.18	1.43	1.39
SE ± (gi-gj)	0.66	0.32	0.49	0.21	7.54	7.33	2.02	1.96
Lines				Set-3				
IS 923	0.06	0.21	0.10	-0.10	2.02	6.56	-0.87	0.40
IS 5566	0.65	-0.63	0.44	-0.10	- 3.22	-1.02	-0.48	-1.27
IS 18366	-0.19	0.04	-0.23	0.06	- 6.07	-7.19	-0.29	-0.60
IS 22145	-0.52	0.38	-0.31	0.15	7.27	1.65	1.63	1.48
Testers								
ICSA 73	-0.35	-0.21	-0.65	0.48*	- 7.88	-6.69	-0.56	-1.27
ICSA 77	0.23	-0.21	-0.06	-1.52**	30.93**	17.73	2.30	1.48
ICSA 95	-0.02	0.38	0.35	1.06**	-11.90*	-12.19	-0.87	-1.27
ICSA 101	0.15	0.04	0.35	-0.02	-11.15*	1.15	-0.87	1.06
SE ± (gi)	0.44	0.19	0.38	0.23	4.25	4.16	2.05	1.51
SE ± (gi-gj)	0.62	0.27	0.53	0.32	6.01	5.89	2.90	2.13

contd

Table 8 (contd.)

	Plant height		Yield score		Eggs/plant		Deadheart %		Leaf surface wetness
	K	R	K	R	K	R	K	R	R
					Set-1				
Lines									
IS 2205	1.52	2.06	0.27	-0.60	0.00	0.03	2.74	-2.54	0.42
IS 5480	-1.65	2.15	-0.06	-0.27	-0.01	0.02	1.15	1.74	0.20
IS 5622	-1.73	-3.44**	1.02*	0.56	-0.04	0.04	-4.34	2.21	-0.34
IS 18533	1.85	-0.77	-1.23*	0.31	0.05	-0.08	0.45	-1.41	-0.28
Testers									
ICSA 11	0.19	-0.44	-0.65	-0.52*	0.00	-0.09	-0.88	-9.75*	-0.15
ICSA 18	3.60*	2.23*	-0.15	-0.94**	0.05	0.00	2.24	-0.73	0.27
ICSA 49	1.02	2.15*	0.02	-0.19	0.01	0.03	-2.73	0.82	-0.02
ICSA 88001	-4.81**	-3.94**	0.77	1.65**	-0.06	0.07	1.37	9.66*	-0.10
SE ± (gi)	1.57	1.04	0.35	0.21	0.08	0.07	3.41	4.26	0.32
SE ± (gi-gj)	2.21	1.47	0.50	0.30	0.11	0.09	4.82	6.02	0.45
IS 1082	-0.46	1.23	0.25	-0.25	0.02	-0.09	4.03	-2.91	-0.44
IS 2123	-0.29	-1.19	0.17	-0.50*	0.09	0.01	5.34	0.62	-0.34
IS 5801	0.54	2.15	0.17	0.33	-0.25*	0.01	-1.56	1.39	0.53
IS 22114	0.21	-2.19	-0.58*	0.42	0.14	0.06	-7.81	0.89	0.25
Testers									
ICSA 32	1.38	2.15	-0.83**	-0.75**	0.11	-0.09	-1.18	-4.61	0.26
ICSA 38	0.46	0.73	0.00	-0.33	0.12	-0.08	-2.08	-6.06	-0.02
ICSA 70	-1.88	-4.10	0.25	1.83**	-0.10	0.16*	4.63	10.26*	-0.35
ICSA 84	0.04	1.23	0.58*	-0.75**	-0.13	0.00	-1.37	0.42	0.11
SE ± (gi)	1.61	1.14	0.22	0.22	0.09	0.06	3.74	3.86	0.34
SE ± (gi-gj)	2.28	1.61	0.31	0.31	0.12	0.08	5.30	5.46	0.49
IS 923	0.63	0.94	0.13	0.54	-0.04	0.11*	0.08	3.30	0.35
IS 5566	-1.63	1.27	0.21	-0.46	-0.14	0.02	0.00	3.94	-0.19
IS 18366	-1.46	-0.81	-0.29	-0.46	0.12	-0.07	2.95	-3.61	-0.89
IS 22145	2.46	-1.40	-0.04	0.38	0.06	-0.06	-3.03	-3.63	0.73
Testers									
ICSA 73	-0.71	1.19	-0.13	-0.54	0.00	0.01	-0.03	0.74	-0.75
ICSA 77	-2.04	0.27	-0.79*	0.13	0.04	0.00	1.84	-1.33	0.15
ICSA 95	2.04	-1.56	1.13**	0.38	0.04	0.04	0.20	3.90	-0.07
ICSA 101	0.71	0.10	-0.21	0.04	-0.08	-0.05	-2.01	-3.30	0.68
SE ± (gi)	1.69	1.02	0.30	0.21	0.08	0.05	2.67	3.68	0.34
SE ± (gi-gj)	2.39	1.44	0.42	0.30	0.12	0.07	3.77	5.20	0.48

*,** Significant at probabaility 0.05 and 0.01 respectively.

Table 9. Specific combining ability (sca) effects for 9 characters in sorghum for shoot fly resistance in kharif(K) 1992, and rabi(R) 1992-93.

S.No.	Hybrids	Vigour score K	Vigour score R	Glossy score K	Glossy score R	Upper surface trichomes K	Upper surface trichomes R	Lower surface trichomes K	Lower surface trichomes R
				Set-1					
1	ICSA 11 x IS 2205	0.30	-0.79	1.15	-0.77*	-13.37	-12.75	0.31	1.96
2	ICSA 11 x IS 5480	-0.37	-0.54	0.90	-0.02	7.61	0.83	0.48	-0.13
3	ICSA 11 x IS 5622	0.03	0.54	-1.36	0.15	3.05	30.67**	0.31	1.88
4	ICSA 11 x IS 18533	0.05	0.79	-0.69	0.65	2.71	-18.75	-1.10	-3.71
5	ICSA 18 x IS 2205	-0.20	0.46	-0.44	0.31	2.11	10.75	-2.10	-0.21
6	ICSA 18 x IS 5480	-0.54	0.38	-0.35	0.06	-7.16	-3.00	-2.61	-0.63
7	ICSA 18 x IS 5622	0.86	-0.21	0.39	0.23	-5.47	-11.50	-2.10	-1.29
8	ICSA 18 x IS 18533	-0.12	-0.63	0.40	-0.60	10.53	3.75	6.81	2.13
9	ICSA 49 x IS 2205	-0.06	-0.38	-0.61	0.15	4.63	-0.67	0.90	-1.54
10	ICSA 49 x IS 5480	-0.06	0.21	-0.19	-0.10	-4.72	-3.08	1.06	-0.29
11	ICSA 49 x IS 5622	0.42	0.29	0.90	0.06	1.05	-17.58	0.90	-0.96
12	ICSA 49 x IS 18533	-0.31	-0.13	-0.11	-0.10	-0.95	21.33*	-2.85	2.79
13	ICSA 88001 x IS 2205	-0.04	0.71	-0.10	0.31	6.63	2.67	0.90	-0.21
14	ICSA 88001 x IS 5480	0.96	-0.04	-0.35	0.06	4.28	5.25	1.06	1.04
15	ICSA 88001 x IS 5622	-1.31	-0.63	0.06	-0.44	1.38	-1.58	0.90	0.38
16	ICSA 88001 x IS 18533	0.38	-0.04	0.40	0.06	-12.29	-6.33	-2.85	-1.21
SE ± (gi)		1.26	0.68	1.00	0.39	18.59	10.22	7.45	6.07
SE ± (gi-gj)		0.89	0.48	0.71	0.28	13.14	7.23	5.27	4.29

Table 9. (contd..)

S.No.	Hybrids	Vigour score		Glossy score		Upper surface trichomes		Lower surface trichomes	
		K	R	K	R	K	R	K	R
					Set-2				
17	ICSA 32 x IS 1082	-0.58	-0.21	-0.19	-0.65	-2.23	-11.75	-0.02	-2.42
18	ICSA 32 x IS 2123	-0.67	-0.54	-0.44	-0.06	2.44	-1.75	-0.27	-0.25
19	ICSA 32 x IS 5801	1.08	-0.29	0.56	-0.06	-4.98	5.17	0.15	1.33
20	ICSA 32 x IS 22114	0.17	1.04	0.06	0.77	4.77	8.33	0.15	1.33
21	ICSA 38 x IS 1082	-0.17	0.54	-0.35	0.44	10.35	15.75	0.48	8.33*
22	ICSA 38 x IS 2123	0.08	-0.13	1.06	0.02	-4.65	-6.58	-0.44	-2.50
23	ICSA 38 x IS 5801	-0.83	0.13	-0.60	0.35	2.60	-0.67	-0.02	-2.92
24	ICSA 38 x IS 22114	0.92	-0.54	-0.10	-0.81*	-8.31	-8.50	-0.02	-2.92
25	ICSA 70 x IS 1082	0.25	-0.71	-0.02	0.10	0.02	-7.17	-0.44	-2.67
26	ICSA 70 x IS 2123	-0.50	0.96	0.06	0.02	17.69	2.83	0.98	0.50
27	ICSA 70 x IS 5801	0.25	0.21	-0.27	-0.31	-4.73	-2.58	-0.27	1.08
28	ICSA 70 x IS 22114	0.00	-0.46	0.23	0.19	-12.98	6.92	-0.27	1.08
29	ICSA 84 x IS 1082	0.50	0.38	0.56	0.10	-8.15	3.17	-0.02	-3.25
30	ICSA 84 x IS 2123	1.08	-0.29	-0.69	0.02	-15.48	5.50	-0.27	2.25
31	ICSA 84 x IS 5801	-0.50	-0.04	0.31	0.02	7.10	-1.92	0.15	0.50
32	ICSA 84 x IS 22114	-1.08	-0.04	-0.19	-0.15	16.52	-6.75	0.15	0.50
SE ± (gi)		0.94	0.65	0.98	0.43	15.09	14.65	4.04	3.92
SE ± (gi-gj)		1.33	0.46	0.70	0.30	10.67	10.36	2.86	2.77

Contd.

Table 9. (contd..)

Hybrids	Vigour score		Glossy score		Upper surface trichomes		Lower surface trichomes	
	K	R	K	R	K	R	K	R
				Set-3				
33 ICSA 73 X IS 923	1.02	1.21*	0.65	0.60	-2.12	-6.06	0.56	-0.40
34 ICSA 73 x IS 5566	-0.90	0.04	-0.69	-0.73	3.19	-8.48	1.40	1.27
35 ICSA 73 x IS 18366	0.27	0.04	0.65	0.10	-0.70	4.69	-0.02	0.60
36 ICSA 73 x IS 22145	-0.40	-1.29*	-0.60	0.02	-0.37	9.85	-1.94	-1.48
37 ICSA 77 x IS 923	-1.23	-0.13	-1.27	-0.40	11.07	10.19	-2.30	-3.15
38 ICSA 77 x IS 5566	1.19	0.38	1.06	0.94	-16.70	12.44	-2.36	-1.48
39 ICSA 77 x IS 18366	-0.65	-0.29	-0.27	0.10	-12.85	-29.40*	-0.55	-2.15
40 ICSA 77 x IS 22145	0.69	0.04	0.48	-0.65	18.49	6.77	5.20	6.77
41 ICSA 95 x IS 923	0.02	-0.38	0.98	-0.65	-6.10	-6.23	0.87	-0.40
42 ICSA 95 x IS 5566	0.10	-0.21	-0.35	0.02	10.13	-5.65	0.48	1.27
43 ICSA 95 x IS 18366	-0.40	-0.21	-1.02	-0.15	7.65	15.52	0.29	0.60
44 ICSA 95 x IS 22145	0.27	0.79	0.40	0.77	-11.68	-3.65	-1.63	-1.48
45 ICSA 101 x IS 923	0.19	-0.71	-0.35	0.44	-2.85	2.10	0.87	3.94
46 ICSA 101 x IS 5566	-0.40	-0.21	-0.02	-0.23	3.38	1.69	0.48	-1.06
47 ICSA 101 x IS 18366	0.77	0.46	0.65	-0.06	5.90	9.19	0.29	0.94
48 ICSA 101 x IS 22145	-0.56	0.46	-0.27	-0.15	-6.43	-12.98	-1.63	-3.81
SE ± (gi)	1.25	0.54	1.07	0.65	12.02	11.77	5.80	4.27
SE ± (gi-gj)	0.88	0.38	0.75	0.46	8.50	8.32	4.10	3.02

Contd.

Table 9. (contd..)

S.No.	Hybrids	Plant height		Yield score		Eggs/plants		Deadheart %		Leaf surface wetness
		K	R	K	R	K	R	K	R	R
					Set-1					
1	ICSA 11 x IS 2205	-3.44	1.35	-0.02	0.94	0.10	-0.09	3.10	-1.61	0.63
2	ICSA 11 x IS 5480	-0.27	-0.06	-0.02	-0.40	-0.02	0.15	-2.82	2.37	0.85
3	ICSA 11 x IS 5622	2.48	1.52	0.10	-0.90	-0.13	-0.04	3.24	-2.69	-0.81
4	ICSA 11 x IS 18533	1.23	-2.81	0.15	0.35	0.05	-0.02	-3.52	1.93	-0.67
5	ICSA 18 x IS 2205	3.81	-2.31	0.15	0.02	-0.20	0.05	-1.13	10.96	0.35
6	ICSA 18 x IS 5480	3.98	0.60	-0.52	0.02	0.22	-0.04	3.39	-10.11	-0.63
7	ICSA 18 x IS 5622	-5.94	-0.81	0.40	0.52	0.05	0.10	-1.55	5.95	0.27
8	ICSA 18 x IS 18533	-1.85	2.52	-0.02	-0.56	-0.07	-0.11	-0.71	-6.80	0.01
9	ICSA 49 x IS 2205	2.73	2.44	0.31	-0.06	0.08	-0.08	1.05	-5.32	-1.10
10	ICSA 49 x IS 5480	-2.44	1.35	-0.02	0.27	-0.17	0.03	1.13	4.67	0.50
11	ICSA 49 x IS 5622	-1.69	-1.73	-0.10	-0.23	0.05	-0.03	-5.31	-1.40	0.46
12	ICSA 49 x IS 18533	1.40	-2.06	-0.19	0.02	0.04	0.07	3.13	2.05	0.14
13	ICSA 88001 x IS 2205	-3.10	-1.48	-0.44	-0.90	0.02	0.12	-3.02	-4.02	0.12
14	ICSA 88001 x IS 5480	-1.27	-1.90	0.56	0.10	-0.03	-0.14	-1.70	3.07	-0.72
15	ICSA 88001 x IS 5622	5.15	1.02	-0.19	0.60	0.03	-0.03	3.62	-1.86	0.08
16	ICSA 88001 x IS 18533	-0.77	2.35	0.06	0.19	-0.02	-0.06	1.10	2.82	0.52
SE ± (gi)		4.43	2.94	1.00	0.60	0.22	0.19	9.64	12.05	0.91
SE ± (gi-gj)		3.13	2.08	0.71	0.43	0.16	0.13	6.82	8.52	0.64

Contd..

Table 9. (contd..)

S.No.	Hybrids	Plant height		Yield score		Eggs/plants		Deadheart %		Leaf surface wetness
		K	R	K	R	K	R	K	R	R
					Set-2					
17	ICSA 32 x IS 1082	2.38	0.02	-0.83	-0.25	-0.16	-0.01	2.58	1.84	0.28
18	ICSA 32 x IS 2123	-1.13	1.10	0.25	0.00	0.00	0.06	5.50	-0.05	-0.72
19	ICSA 32 x IS 5801	-2.96	-0.90	0.25	0.17	-0.12	-0.05	-3.00	-5.96	0.81
20	ICSA 32 x IS 22114	1.71	-0.23	0.33	0.08	0.29	0.00	-5.08	4.17	-0.38
21	ICSA 38 x IS 1082	-1.71	-2.23	0.67	0.33	-0.01	0.08	-0.28	0.46	-0.14
22	ICSA 38 x IS 2123	-2.88	1.52	-0.58	-0.42	0.02	-0.11	-5.37	-4.80	-0.40
23	ICSA 38 x IS 5801	8.29	0.19	0.42	0.08	0.19	0.04	6.93	5.42	0.30
24	ICSA 38 x IS 22114	-3.71	0.52	-0.50	0.00	-0.20	-0.01	-1.28	-1.08	0.24
25	ICSA 70 x IS 1082	0.63	6.27*	-0.25	-0.17	0.01	-0.06	2.00	-0.97	-0.88
26	ICSA 70 x IS 2123	5.46	-1.65	-0.17	0.42	-0.12	-0.06	-0.85	-4.56	1.22
27	ICSA 70 x IS 5801	-4.38	-3.65	0.17	-0.42	0.09	0.10	-5.52	2.60	-0.71
28	ICSA 70 x IS 22114	-1.71	-0.98	0.25	0.17	0.03	0.02	4.37	2.93	0.36
29	ICSA 84 x IS 1082	-1.29	-4.06	0.42	0.08	0.17	0.00	-4.30	-1.33	0.73
30	ICSA 84 x IS 2123	-1.46	-0.98	0.50	0.00	0.10	0.11	0.72	9.41	-0.10
31	ICSA 84 x IS 5801	-0.96	4.35	-0.83	0.17	-0.16	-0.10	1.58	-2.06	-0.40
32	ICSA 84 x IS 22114	3.71	0.69	-0.08	-0.25	-0.11	-0.01	2.00	-6.03	-0.23
SE ± (gi)		4.57	3.21	0.62	0.61	0.25	0.16	10.59	10.92	0.97
SE ± (gi-gj)		3.23	2.27	0.44	0.43	0.17	0.11	7.49	7.72	0.69

Table 9. (contd.)

S.No.	Hybrids	Plant height K	Plant height R	Yield score K	Yield score R	Eggs/plants K	Eggs/plants R	Deadheart % K	Deadheart % R	Leaf surface wetness R
					Set-3					
33	ICSA 73 x IS 923	-1.46	-4.44	0.21	0.96	-0.05	0.05	2.76	4.27	-0.10
34	ICSA 73 x IS 5566	-0.21	-0.44	-0.54	-0.04	0.05	-0.03	0.41	-5.86	-0.36
35	ICSA 73 x IS 18366	-0.38	-0.69	0.29	-0.04	-0.15	-0.01	3.89	0.02	0.27
36	ICSA 73 x IS 22145	2.04	5.56*	0.04	-0.88	0.14	-0.02	-7.06	1.57	0.19
37	ICSA 77 x IS 923	2.54	0.48	0.21	-0.04	0.14	-0.04	2.93	-2.23	0.80
38	ICSA 77 x IS 5566	-0.21	0.81	0.46	0.29	-0.02	0.15	1.81	2.94	-0.20
39	ICSA 77 x IS 18366	1.29	-0.10	-0.38	0.29	-0.12	0.00	-0.34	3.65	-0.23
40	ICSA 77 x IS 22145	-3.63	-1.19	-0.29	-0.54	0.00	-0.11	-4.40	-4.36	-0.38
41	ICSA 95 x IS 923	-2.21	1.98	-0.38	-0.63	-0.09	0.05	-5.13	-1.39	0.75
42	ICSA 95 x IS 5566	3.04	-1.02	-0.46	0.04	-0.06	-0.19	-2.88	-7.55	-0.25
43	ICSA 95 x IS 18366	-1.79	1.73	0.04	-0.29	0.31	-0.04	1.37	1.80	-1.28
44	ICSA 95 x IS 22145	0.96	-2.69	0.79	0.88	-0.16	0.18	6.64	7.15	0.77
45	ICSA 101 x IS 923	1.13	1.98	-0.04	-0.29	-0.01	-0.06	-0.56	-0.65	-1.46
46	ICSA 101 x IS 5566	-2.63	0.65	0.54	-0.29	0.03	0.07	0.66	10.48	0.80
47	ICSA 101 x IS 18366	0.88	-0.94	0.04	0.04	-0.04	0.05	-4.92	-5.47	1.24
48	ICSA 101 x IS 22145	0.63	-1.69	-0.54	0.54	0.02	-0.06	4.82	-4.35	-0.58
SE ± (gi)		4.77	2.88	0.85	0.61	0.24	0.13	7.55	10.40	0.96
SE ± (gi-gj)		3.37	2.04	0.60	0.43	0.17	0.09	5.34	7.36	0.68

*,** = Significant at probability 0.05 and 0.01 respectively.

4.3.2 Glossiness

The estimates of gca effects for lines and testers ranged from -1.15 to 1.60 in kharif and from -1.52 to 1.19 in rabi season. Among lines IS 18533 (-1.15) and IS 21114 (-0.85) in kharif and rabi season respectively showed highly significant negative gca effects (desirable).

Testers ICSA 11, 18, 38 and 77 exhibited high negative gca effects (desirable) in rabi season and only tester ICSA 32 in kharif.

Significant negative sca effects (desirable) were shown by two cross combinations. These were ICSA 38 x IS 22114 (-0.81) and ICSA 11 x IS 2205 (-0.77) in rabi season.

4.3.3 Upper Surface Trichomes

Only testers showed significant gca effects in both seasons. Testers ICSA 11 (17.70 in kharif and 27.92 in rabi season), ICSA 84 (19.40 and 30.0), ICSA 77 (30.93 and 17.73) and ICSA 70 (15.0 in rabi season) showed highly positive (desirable) gca effects.

Significant positive sca effects were noticed for two cross combinations in rabi season. These were ICSA 11 x IS 5622 (30.67) and ICSA 49 x IS 18533 (21.33).

4.3.4 Lower Surface Trichomes

No significant gca effect for this trait was noticed in either season in either lines or testers. Only one cross combination ICSA 38 x IS 1082 showed significant positive sca effect (8.33) in rabi season.

4.3.5 Plant Height

The estimates of gca effects for lines and testers showed highly significant negative gca effect (undesirable) for IS 5622 (-3.44) in rabi season. For testers, significant positive (desirable) gca effects were noticed for ICSA 18 (3.60 in kharif and 2.23 in rabi) and ICSA 79 (2.15 in rabi). On the contrary, ICSA 88001 showed negative gca effects in both seasons.

Two cross combinations, ICSA 70 x IS 1080 and ICSA 73 x IS 22145 (6.27 and 5.56 respectively) showed significant positive sca in rabi season.

4.3.6 Yield Score

Lines IS 18533 (-1.23) and IS 22114 (-0.58) in kharif season and IS 2123 (-0.50) in rabi season showed significant negative gca effects (desirable). Testers ICSA 32 (-0.83 in kharif and -0.75 in rabi), ICSA 18 (-0.97 in rabi), ICSA 84 (-0.75 in rabi) and ICSA 11 (-0.52 in rabi) showed significant negative gca effects.

None of the crosses exhibited significant sca effect.

4.3.7 Eggs Per Plant

Only one line IS 5801 (-0.25 in kharif) showed negative (desirable) significant gca effect. Significant positive (undesirable) gca effect was noticed for tester ICSA 70 (0.16 in rabi). None of the crosses showed significant sca effect.

4.3.8 Deadheart Percentage

The estimates of gca effects showed significant negative gca effect (desirable) for tester ICSA 11 (-9.75) in rabi season, while significant positive gca effect (undesirable) for tester ICSA 70 (10.26 in rabi).

Neither lines nor crosses showed significant combining ability.

4.3.9 Leaf Surface Wetness

No significant gca or sca was noticed for this trait.

4.4 ESTIMATES COMPONENTS OF VARIANCE

Components of variance due to general combining ability (gca) and specific combining ability (sca) were estimated (Table 10) for the eight and nine characters in kharif and rabi seasons respectively and when the differences among lines, testers or lines x testers were significant (Table 4).

The ratio of $\sigma^2_{sca}/\sigma^2_{gca}$ gave an approximate idea about the nature of gene effect and $\sqrt{\sigma^2_{sca}/\sigma^2_{gca}}$ estimated the degree of dominance. The percentage

Table 10. Estimates of components of variance.

	Season	Vigour score Set-1	Vigour score Set-2	Vigour score Set-3	Glossy score 1	Glossy score 2	Glossy score 3	Upper surface trichomes 1	Upper surface trichomes 2	Upper surface trichomes 3
σ²sca	K	NS	NS	NS	NS	NS	NS	NS	NS	NS
	R	NS	0.24	0.43	0.13	NS	NS	234.19	NS	150.83
σ²gca (Line)	K	NS	NS	NS	0.43	NS	NS	NS	NS	NS
	R	0.42	NS	NS	0.05	0.27	NS	-17.88	NS	NS
σ²gca (Tester)	K	0.71	NS	NS	0.97	1.21	NS	148.57	137.14	390.70
	R	0.68	0.12	NS	0.58	0.25	1.12	308.92	413.48	NS
σ²sca/σ²gca (Aver.)	K	@	-	-	@	@	-	@	@	@
	R	@	2.00	@	0.42	@	@	1.60	@	@
Degree of dominance			1.41		0.65			1.26		
Percent contriubution to total variance										
Lines	K	20.46	17.28	26.60	26.48	14.67	12.03	23.59	10.59	6.02
	R	32.01	6.46	27.39	11.14	39.78	1.01	8.29	2.71	8.93
Testers	K	55.33	37.87	7.30	49.84	70.72	22.94	56.52	53.82	74.38
	R	48.51	38.40	10.89	71.07	38.09	79.18	58.63	84.31	46.15
L x T	K	24.21	44.85	66.10	23.67	14.61	65.03	19.89	35.59	19.60
	R	19.49	55.13	61.72	17.79	22.12	19.81	33.10	12.97	44.92

Contd..

Table 10. (Contd..)

	Season	Lower surface trichomes 1	Lower surface trichomes 2	Lower surface trichomes 3	Plant height 1	Plant height 2	Plant height 3	Yield score 1	Yield score 2	Yield score 3
σ²sca	K	NS	NS	NS	NS	NS	NS	NS	NS	NS
	R	NS	NS	NS	NS	6.24	NS	0.25	NS	0.25
σ²gca (Line)	K	NS	NS	NS	NS	NS	NS	0.84	NS	NS
	R	NS	NS	NS	5.64	NS	NS	0.18	0.17	NS
σ²gca (Tester)	K	NS	NS	NS	8.38	NS	NS	NS	0.27	0.58
	R	NS	NS	NS	6.97	4.97	NS	1.19	1.51	NS
σ²sca/σ²gca (Aver.)	K	-	-	-	@	-	-	-	-	-
	R	-	-	-	@	1.26	-	1.18	@	@
								@	0.1	0.44
Degree of dominance								1.09	-	-
						1.12		-	0.32	0.66
Percent contriubution to total variance										
Lines	K	28.36	16.14	15.68	13.48	1.22	32.58	66.48	18.97	5.37
	R	16.66	17.79	11.79	35.70	20.01	18.06	14.90	11.03	37.61
Testers	K	15.95	16.14	29.91	43.82	10.81	27.17	26.11	45.40	71.87
	R	19.80	22.02	17.85	42.41	38.19	13.93	68.07	84.87	19.88
L x T	K	55.69	67.71	54.40	42.70	87.98	40.25	7.42	35.63	22.70
	R	63.54	60.19	70.36	21.89	41.80	68.00	17.03	4.10	42.51

Table 10. (Contd..)

	Season	Eggs/plant 1	Eggs/plant 2	Eggs/plant 3	% Dead heart 1	% Dead heart 2	% Dead heart 3	Leaf surface wetness 1	Leaf surface wetness 2	Leaf surface wetness 3
σ^2sca	K	NS	NS	NS	NS	NS	NS			
	R	NS	NS	NS	NS	NS	NS	NS	NS	0.50
σ^2gca	K	NS	0.02	NS	NS	NS	NS			
(Line)2	R	NS	NS	0.003	NS	NS	NS	NS	NS	0.25
σ^2gca	K	NS	NS	NS	NS	NS	NS			
(Tester)	R	NS	0.012	NS	51.61	46.78	NS	NS	NS	0.11
σ^2sca/σ^2gca	K	-	@	-	-	-	-			
(Aver.)	R	-	@	@	@	@	-	-	-	2.78
Degree of dominance										1.67
Percent contribution to total variance										
Lines	K	7.06	41.68	39.40	37.79	55.53	21.37			
	R	19.06	17.02	35.40	5.26	4.73	30.18	22.11	29.56	31.42
Testers	K	13.45	24.11	8.55	20.55	14.93	8.93			
	R	26.80	58.56	7.67	61.14	66.84	16.29	5.75	9.17	22.52
L x T	K	79.49	34.21	52.05	41.66	29.54	69.70			
	R	54.14	24.43	56.93	33.60	28.43	53.53	72.14	61.27	46.06

σ^2sca = Variance of general combining ability.

σ^2sca = Variance of specific combining ability.

σ^2sca/σ^2gca = Ratio of sca to gca = degree of dominance.
NS = Not significant

@ = Either sca or gca is not significant.

\- = Both sca and gca are not significant.

contribution of lines, testers and line x tester were computed and the results are presented in Table 10.

The $\sigma^2_{sca}/\sigma^2_{gca}$ estimates revealed the relative importance of two kinds of gene action in the genetic control of the various characters. The ratio $\sigma^2_{sca}/\sigma^2_{gca}$ being above one for the characters seedling vigour, plant height and LSW emphasized major role of non-additive gene action in their inheritance. In this group of characters, the percentage contribution of L x T was high in most cases.

For other characters – glossiness, upper surface trichomes, yield score, eggs per plant and deadheart percentage — where the ratio $\sigma^2_{sca}/\sigma^2_{gca}$ was less than one, additive component of genetic variation had major influence. Percentage contributions of either lines or testers were high in such characters.

4.5 ANALYSIS OF GENETIC VARIABILITY

The total variability was partitioned into genotypic and phenotypic variation and their respective coefficients of variation were computed for the 48 hybrids and 24 parents separately for 8 and 9 characters in kharif and rabi seasons respectively. Heritability (broad sense) and genetic advance (percentage over mean) were also estimated. The results obtained are presented in Tables 11 and 12.

Table 11. Mean, components of variance, heritability and genetic advance of different characters associated with sorghum shoot fly resistance for parents in kharif(K) 1992, rabi(R) 1992-93 and pooled(P) across seasons.

	Vigour score			Glossy score			Upper surface trichomes			Lower surface trichomes		
	K	R	P	K	R	P	K	R	P	K	R	P
Mean	4.31	4.74	4.52	5.40	6.10	5.75	60.65	60.15	60.40	22.23	17.90	20.62
Genotypic variance	1.76	1.32	1.44	9.80	10.35	9.93	4375	5360	4809	642.5	536.7	556.2
Phenotypic variance	3.37	2.11	2.63	10.07	10.44	10.11	5037	5586	5253	758.4	617.2	654.4
Error variance	1.61	0.79	1.19	0.27	0.09	0.18	662.0	226.0	444.0	115.9	80.5	98.2
GCV %	31.8	24.2	26.5	58.0	52.7	54.8	109.1	121.7	114.8	108.6	129.4	114.3
PCV %	42.6	30.6	35.9	58.8	53.0	55.3	117.0	124.2	120.0	118.0	138.8	124.1
Heritability (%)	52.2	62.6	54.8	97.3	99.1	98.2	86.9	95.9	91.5	84.7	87.0	85.0
Genetic advance (% over mean)	45.8	39.5	40.5	117.8	108.2	111.9	209.4	245.6	226.3	206.0	248.7	217.2

Table 11 (contd.)

	Plant height			Yield score			Eggs/ plant			Deadheart percentage			Leaf surface wetness
	K	R	P	K	R	P	K	R	P	K	R	P	R
Mean	21.71	25.94	23.83	6.65	6.26	6.46	0.99	0.56	0.78	79.92	43.16	61.54	3.99
Genotypic variance	33.63	14.01	20.91	0.99	1.25	0.81	0.01	0.06	0.02	58.60	426.5	213.6	3.41
Phenotypic Variance	67.33	25.60	43.56	2.12	1.73	1.62	0.07	0.09	0.07	239.2	604.4	392.9	4.97
Error variance	33.70	11.59	22.65	1.13	0.48	0.81	0.07	0.03	0.05	180.6	177.9	179.3	1.56
GCV %	26.70	14.40	19.20	15.0	17.9	13.9	7.10	43.7	18.1	9.60	47.80	23.70	46.3
PCV %	37.80	19.50	27.70	27.9	21.0	19.7	26.7	53.6	33.9	19.4	57.00	32.20	55.9
Heritability (%)	49.90	54.70	48.00	46.7	72.3	50.0	14.30	66.7	28.6	24.5	70.60	54.40	69.6
Genetic advance (% over mean)	38.90	22.00	27.40	21.1	31.3	20.3	3.90	92.9	20.0	9.80	82.80	36.10	80.1

GCV = Genotypic coefficient of variation.

PCV = Penotypic coefficient of variation.

Table 12. Mean, components of variance, heritability and genetic advance of different characters on sorghum shoot fly resistance for hybrids in kharif(K) 1992, rabi(R) 1992-93 and pooled (P) across seasons.

	Vigour score			Glossy score			Upper surface trichomes			Lowoer surface trichomes		
	K	R	P	K	R	P	K	R	P	K	R	P
Mean	4.27	3.46	3.87	6.46	7.48	6.97	16.53	21.15	18.84	0.65	1.33	0.99
Genotypic variance	-0.03	0.61	0.30	0.59	0.98	0.65	232.90	319.90	258.50	-0.28	4.72	2.64
Phenotypic variance	2.90	1.09	2.00	2.85	1.50	2.04	458.80	545.40	484.20	16.85	17.70	17.67
Error variance	2.93	0.48	1.70	2.26	0.52	1.39	225.90	225.50	225.70	17.13	12.98	15.03
GCV %	-	22.6	14.2	11.9	13.2	11.6	92.3	84.6	85.3	-	161.6	140.1
PCV %	39.2	30.2	36.5	26.1	16.4	20.5	129.6	110.4	116.7	631.5	316.3	424.6
Heritability (%)	-	56.0	15.0	20.7	65.3	31.9	50.8	58.7	53.4	0.0	26.7	14.9
Genetic advance (% over mean)	-	36.3	11.3	11.1	22.0	13.5	135.5	133.4	128.5	0.0	173.8	130.7

Table 12. (contd.)

	Plant hight			Yield score			Eggs/plant			Deadheart percentage			Leaf surfa wetness
	K	R	P	K	R	P	K	R	P	K	R	P	R
Mean	19.55	32.98	26.26	5.76	5.49	5.63	1.10	0.91	1.01	87.47	63.86	75.66	6.91
Genotypic variance	6.54	7.91	5.67	0.61	0.96	0.54	0.002	0.003	0.00	0.00	5.13	4.18	0.39
Phenotypic variance	33.84	22.91	26.82	1.70	1.53	1.37	0.09	0.04	0.07	101.40	185.90	147.80	1.69
Error variance	27.30	15.00	21.15	1.09	0.57	0.83	0.09	0.04	0.07	106.40	180.70	143.60	1.30
GCV %	13.1	8.6	9.1	13.6	17.8	13.1	4.2	5.6	-	-	3.5	2.7	9.0
PCV %	29.8	14.5	19.7	22.6	22.5	20.8	27.3	22.8	26.2	11.5	21.4	16.1	18.8
Heritability (%)	19.3	34.5	21.1	35.9	62.6	39.4	2.2	7.0	0.0	_	2.8	2.8	23.1
Genetic advance (% over mean)	11.8	10.3	8.6	21.8	29.1	16.9	1.2	3.3	0.0	-	1.2	0.9	8.9

GCV = Genotypic coefficient of variation.

PCV = Penotypic coefficient of variation.

4.5.1 Genotypic and Phenotypic Variance

A large amount of variation was observed among almost all the characters in both seasons. Phenotypic variance of both hybrids and parents was more than genotypic variance for all the characters in both seasons. The highest genotypic and phenotypic variance was observed for upper surface trichomes, whereas lowest values were observed for eggs per plant.

Among seasons genotypic and phenotypic variance of hybrids for characters viz., vigour score, glossiness, plant height, yield score and eggs per plant were highest in kharif.

4.5.2 Genotypic and Phenotypic Coefficient of Variance

For parents, vigour score, lower surface trichomes, plant height and yield score were highest in kharif. Maximum genotypic and phenotypic coefficients of variance (GCV) and (PCV) were observed for lower surface trichomes while minimum GCV and PCV were observed in kharif season for eggs per plant and deadheart percentage respectively.

4.5.3 Heritability

Characters were classified into four groups according to their heritability estimates:

1. Highly Heritable Characters (>80%)

The characters that fell under this group were; glossiness and trichomes on both surfaces of the leaf only for parents.

2. Intermediately Heritable Characters (50-80%)

These included seedling vigour and yield score (in rabi) for both parents and hybrids; plant height, eggs per plant, deadheart percentage and leaf surface wetness for parents in rabi and only glossiness for hybrids in rabi.

3. Low Heritable Characters (20-50%)

The traits in this group were yield score (for both parents and hybrids in kharif), deadheart percentage for parents in kharif, lower surface trichomes, plant height, LSW (for hybids in rabi) and glossiness for hybrids in kharif.

4. Very Low Heritable Characters (<20%)

Only eggs per plant (for hybrids as well as parents) and deadheart percentage (for hybrids) in kharif fell under this group.

Generally the heritabilities of the characters under study were higher for parents than for the corresponding hybrids. Some characters exhibited distinct changes in their heritability across seasons; yield score, eggs per plant and deadheart percentage showed lower heritability in kharif than in rabi.

4.5.4 Genetic Advance

Genetic advance (% over mean) was estimated to provide a clear picture about the expected gains when the best five per cent of genotypes were selected.

4.5.4.1 **For Parents**: Genetic advance (% over mean) was high for trichomes (upper and lower surface) followed by glossiness in both seasons whereas it was low for eggs per plant and deadheart percentage during kharif season.

4.5.4.2 **For Hybrids**: The genetic advance (% over mean) in both season was also high for trichomes and low for eggs per plant and deadheart percentage.

4.6 CORRELATION AND PATH ANALYSIS

Correlation coefficients were computed for eight different characters associated with shoot fly resistance in both seasons, and pooled over the two seasons for the 48 crosses also estimated. The correlation coefficient were also worked out for nine characters (leaf surface wetness was additional to the 8 characters) among hybrids and parents during rabi season. The results are presented in Tables 13 and 14.

4.6.1 Correlation Among 8 Characters

4.6.1.1 **Deadheart Percentage**: Deadheart percentage is an apparent indicator for shoot fly susceptibility and it was correlated with other traits. Strong positive correlations were observed with glossy score, yield score and eggs per plant in rabi

Table 13. Correlation coefficients among 8 characters of hybrids during kharif(K) 1992, and rabi(R) 1992-93, and pooled(P) over seasons.

		Glossy score	Upper surface trichomes	Lower surface trichomes	Plant height	Yield score	Eggs/ plant	Dead-heart %
Vigour score	K	0.56**	-0.04	-0.10	-0.60**	0.34*	-0.41**	-0.23
	R	0.43**	-0.06	-0.06	-0.79**	0.62**	0.23	0.22
	P	0.53**	0.01	-0.10	-0.71**	0.59**	-0.08	0.19
Glossy score	K		-0.34*	-0.17	-0.49**	0.47**	-0.47**	0.13
	R		-0.23	-0.21	-0.34*	0.39**	0.39**	0.52**
	P		-0.43**	-0.31	-0.48**	0.79**	-0.04	0.57**
Upper surface trichomes	K			0.49**	0.15	-0.34*	0.07	-0.19
	R			0.43**	0.10	-0.29*	-0.12	-0.27
	P			0.44**	0.13	-0.29*	-0.11	-0.34*
Lower surface	K				0.05	-0.36*	0.06	-0.02
	R				0.01	-0.14	-0.27	-0.33*
	P				0.02	-0.25	-0.13	-0.29*
Plant height	K					-0.25	0.19	0.04
	R					-0.63**	-0.33*	-0.34*
	P					-0.55**	-0.14	-0.29*
Yield score	K						-0.22	0.13
	R						0.45**	0.56**
	P						0.14	0.60**
Eggs/ plant	K							-0.07
	R							0.76**
	P							0.19

*,** Significant at probability 0.05 and 0.01 respectively.

season, significant negative correlations with lower surface trichomes and plant height in rabi season, and with upper surface trichomes (over both seasons). In kharif season, correlation coefficients were not significant and in some cases they were in the opposite direction to rabi correlations, such as for vigour score. Thus there was no consistent relationship across the seasons.

4.6.1.2 **Seedling Vigour**: Vigour score was positively correlated with glossy score and yield score, and negatively correlated with plant height for both seasons and eggs per plant in kharif season. This result was not on line with the predicted, which means there were more eggs per plant on more vigourous seedling. In rabi, the relationship was vice versa (but not significantly).

4.6.1.3 **Glossiness**: Glossy score was negatively correlated with plant height and positively correlated with yield score (in both seasons). Significant negative correlation was observed with upper surface trichomes (only in kharif). The relationship between glossiness and eggs per plant was also contradictory, while the correlation in kharif was significantly negative, it was significantly positive in rabi.

Glossiness was strongly significant and positively correlated with deadheart percentage (in rabi). This is in conformity with the hypothesis that more glossiness leads to less damage. In rabi, lines had lower glossy scores (more glossiness), and the shoot fly deadheart percentages were also low.

4.6.1.4 **Upper Surface Trichomes:** This trait was strongly and positively correlated with lower surface trichomes whereas it was negatively correlated with yield score for both seasons. The effect was significant for deadheart percentage over seasons.

4.6.1.5 **Lower Surface Trichomes:** Significant negative correlations were exhibited between this trait and yield score (only in kharif) and deadheart percentage (in rabi and over seasons) .

In general, trichomes either on adaxial or abaxial surfaces of the leaf produced an apparent effect in the reduction of shoot fly deadheart percentage.

4.6.1.6 **Plant Height:** Plant height was negatively correlated with yield score, eggs per plant and deadheart percentage (in rabi), yield score and deadheart percentage (over seasons).

4.6.1.7 **Yield Score:** Interestingly, significant positive correlations were noticed between this character and eggs per plant (in rabi and over seasons), and deadheart percentage only in rabi season. This relationship coincided with the general expectation that less damaged plants give more yield.

4.6.1.8 **Eggs Per Plant:** Eggs per plant was strongly and positively correlated with deadheart percentage in rabi season while this effect was not apparent in kharif. This was another indicator of instability across seasons.

4.6.2 Correlation Among 9 Characters

Estimation of the correlations among nine characters of parents and hybrids was done in rabi season to determine the degree of correlation of the additional character (leaf surface wetness) with other characters (Table 14).

4.6.2.1 **Deadheart Percentage**: Interestingly, significant positive correlations were noticed between deadheart percentage and glossy score, yield score and eggs per plant (for both parents and hybrids), vigour score and leaf surface wetness (only for parents). Deadheart percentage was significantly and negatively associated with lower surface trichomes and plant height (for both parents and hybrids) and with upper surface trichomes (only for parents).

4.6.2.2 **Leaf Surface Wetness (LSW)**: Highly significant positive correlations were noticed for LSW with; vigour score, glossy score, yield score, eggs per plant and deadheart percentage among parents only, whereas LSW was negatively correlated with trichomes on both surfaces and plant height in parents also. In respect of hybrids, estimates were small in magnitude.

The results of correlations among leaf characters (glossiness, trichome density on both surfaces and LSW) indicated that those characters correlated to each other. Resistant lines (males) had glossy leaf, more trichomes and a low LSW score, whereas it was the opposite (non-glossy, without trichomes and a high LSW score) for susceptible male-sterile lines and hybrids (some hybrids had few

Table 14. Correlation coefficients among 9 characters of sorghum parents (24) and hybrids (48) in rabi (1992-93).

		Glossy score	Upper surface trichomes	Lower surface trichomes	Plant height	Yield score	Eggs/ plant	Leaf surface wetness	% Dead heart
Vigor score	P	0.80**	-0.77**	-0.74**	-0.89**	0.74**	0.59**	0.74**	0.68**
	H	0.43**	-0.06	-0.06	-0.79**	0.62**	0.23	0.02	0.22
Glossy score	P		-0.94**	-0.90**	-0.73**	0.62**	0.92**	0.93**	0.95**
	H		-0.23	-0.21	-0.34*	0.39**	0.39**	-0.14	0.52**
Upper surface trichomes	P			0.86**	0.67**	-0.57**	-0.88**	-0.89**	-0.89**
	H			0.43**	0.10	-0.29*	-0.12	0.05	-0.27
Lower surface tricohmes	P				0.65**	-0.47*	-0.83**	-0.86**	-0.88**
	H				0.01	-0.14	-0.27	-0.03	-0.33*
Plant height	P					-0.80**	-0.54**	-0.75**	-0.65**
	H					-0.63**	-0.33*	0.00	-0.34*
Yield score	P						0.46*	0.61**	0.49*
	H						0.45**	0.07	0.56**
Eggs/plant	P							0.87**	0.96**
	H							0.17	0.77**
Leaf surface wetness	P								0.90**
	H								-0.01

*,** Significant at probability 0.05 and 0.01 respectively.

trichomes).

4.6.3 Path Coefficient Analysis

Path coefficient analyses were carried out to understand the influence of direct and indirect effects of seven and eight characters associated with shoot fly resistance in kharif and rabi respectively on deadheart percentage (independent trait).

4.6.3.1 Direct and Indirect Effects of 7 Characters on Deadheart Percentage: Direct and indirect effects of vigour score, glossiness, trichomes, plant height, eggs per plant and yield score on deadheart percentage were estimated in kharif and rabi. Pooled over seasons was also computed (Table 15).

Eggs per plant exerted highest positive direct effect (0.53) on deadheart percentage during rabi season whereas it was low and negative in kharif (-0.13) followed by yield score (0.32, 0.14) in rabi and kharif respectively. Vigour score exhibited negative direct effect on deadheart percentage in both seasons and pooled over seasons (-0.48, -0.30, -0.32). Glossy score showed considerable positive direct effect, other traits (trichomes and plant height) exhibited low negative direct effects on deadheart percentage.

4.6.3.2 Direct and Indirect Effects of 8 Characters on Deadheart Percentage in Rabi: To know the contribution of leaf surface wetness to the deadheart percentage, the direct effects of this trait as well as the other seven characters

Table 15. Direct and indirect effects of different characters on % of shoot fly dead heart in kharif (K) 1992, and rabi(R) 1992-93, and pooled(P) over seasons.

		VS	GS	UST	LST	PH	YS	E/PL	%DH
Vigor score	K	-0.48	0.11	0.004	-0.01	0.05	0.05	0.05	-0.23
(VS)	R	-0.30	0.11	0.001	0.01	0.08	0.20	0.12	0.22
	P	<u>-0.32</u>	0.15	0.000	0.01	0.07	0.28	-0.01	0.19
Glossy score	K	-0.27	0.20	0.040	-0.01	0.04	0.07	0.06	0.13
(GS)	R	-0.13	0.25	0.004	0.02	0.04	0.13	0.21	0.52
	P	-0.17	<u>0.28</u>	0.004	0.03	0.05	0.37	-0.004	0.57
Upper surface	K	0.02	-0.07	-0.11	0.04	-0.01	-0.05	-0.01	-0.19
trichomes	R	0.02	-0.06	-0.02	-0.04	-0.01	-0.09	-0.06	-0.27
(UST)	P	0.00	-0.12	<u>-0.01</u>	-0.05	-0.01	-0.14	-0.01	-0.34
Lower surface	K	0.05	-0.03	-0.05	-0.08	-0.004	-0.05	-0.01	-0.02
trichomes	R	0.02	-0.05	-0.01	-0.10	-0.001	-0.05	-0.14	-0.33
(LST)	P	0.03	-0.09	-0.004	<u>-0.10</u>	-0.002	-0.12	-0.01	-0.29
Plant height	K	0.29	-0.10	-0.020	0.004	-0.08	-0.04	-0.02	0.04
(PH)	R	0.23	-0.09	-0.002	-0.001	-0.11	-0.20	-0.17	-0.34
	P	0.23	-0.14	-0.001	-0.002	<u>-0.11</u>	-0.26	-0.01	-0.29
Yield score	K	-0.17	0.10	0.040	-0.03	0.02	0.14	0.03	0.13
	R	-0.18	0.10	0.005	0.01	0.07	0.32	0.24	0.56
	P	-0.19	0.22	0.003	0.03	0.06	<u>0.47</u>	0.01	0.60
Eggs/plant	K	0.20	-0.10	-0.010	0.01	-0.02	-0.03	-0.13	-0.07
(E/PL)	R	-0.07	0.10	0.002	0.03	0.04	0.14	0.53	0.77
	P	0.03	-0.01	0.001	0.01	0.01	0.07	<u>0.08</u>	0.19

The underlined figures denote direct effect.
Residual effect for kharif = 0.91
Residual effect for rabi = 0.53
Residual effect for pooled = 0.73

(mentioned above) during rabi season were estimated for both parents and hybrids (Table 16).

Eggs per plant (0.62, 0.55) for parents and hybrids respectively exerted highest positive effect on deadheart percentage followed by glossy score (0.36 and 0.23) and yield score for hybrids (0.32). Upper and lower surface trichomes, plant height and LSW showed low direct effect on deadheart percentage.

4.7 STABILITY ANALYSIS

The pooled analysis of variance and stability analysis were carried out for lines, testers and hybrids across two seasons and three sets for characters associated with shoot fly resistance. The results are presented in Table 7.

The pooled analysis of variance showed significant differences across seasons for vigour score, plant height and deadheart percentage. Among sets, glossiness and yield score exhibited significance. Also significant differences were noticed for upper surface trichomes, glossiness and eggs per plant between males (lines) across seasons. Between females (testers) among seasons significant differences were found for plant height, yield score and eggs per plant whereas no significant differences were noticed for hybrids across seasons.

Table 16. Direct and indirect effects of different characters on shoot fly deadheart for parents(P) and hybrids(H) in rabi (1992-93).

		VS	GS	UST	LST	PH	YS	E/P	LSW	%DH
Vigor score (VS)	P	-0.07	0.28	-0.090	0.10	0.17	-0.07	0.37	-0.001	0.68
	H	-0.28	0.10	0.001	0.01	0.07	0.20	0.13	-0.002	0.22
Glossy score (GS)	P	-0.06	0.36	-0.120	0.12	0.14	-0.06	0.57	-0.002	0.95
	H	-0.12	0.23	0.003	0.02	0.03	0.13	0.22	0.010	0.52
Upper surface trichomes (UST)	P	0.06	-0.34	0.120	-0.12	-0.13	0.06	-0.54	0.002	-0.89
	H	0.02	-0.05	-0.010	-0.04	-0.01	-0.09	-0.07	-0.004	-0.27
Lower surface trichomes (LST)	P	0.05	-0.32	0.110	-0.14	-0.12	0.05	-0.51	0.001	-0.88
	H	0.02	-0.05	-0.010	-0.10	0.00	-0.05	-0.15	0.003	-0.33
Plant height (PH)	P	0.07	-0.26	0.080	-0.09	-0.19	0.08	-0.34	0.001	-0.65
	H	0.22	-0.08	-0.002	0.00	-0.09	-0.20	-0.18	0.000	-0.34
Yield score (YS)	P	-0.05	0.22	-0.070	0.06	0.15	-0.10	0.28	-0.001	0.49
	H	-0.17	0.09	0.004	0.01	0.06	0.32	0.25	-0.006	0.56
Eggs/plant (E/P)	P	-0.04	0.33	-0.110	0.11	0.10	-0.05	0.62	-0.001	0.96
	H	-0.06	0.09	0.002	0.03	0.03	0.15	0.55	-0.010	0.77
Leaf surface wetness (LSW)	P	-0.05	0.33	-0.110	0.12	0.14	-0.06	0.54	-0.002	0.90
	H	-0.01	-0.03	-0.001	0.00	0.00	0.02	0.09	-0.090	-0.01

The underlined figures denote direct effect.
Residual effect for parents = 0.18
Residual effect for hybrids = 0.52

DISCUSSION

CHAPTER V

DISCUSSION

The sorghum shoot fly (*Atherigona soccata* Rond.) is a major pest of sorghum in Asia causing severe damage to the seedlings and is an important factor limiting the use of higher yielding varieties and hybrids.

Host plant resistance is most economical and an effective method of reducing losses due to insect pests in sorghum and of stabilizing its yield.

To breed resistant varieties it is necessary to know the mechanisms of resistance and their genetic control in order to optimize selection methodologies and to incorporate the resistance from resistant sources into commercially cultivated sorghum cultivars.

A systematic programme of screening for resistance to sorghum shoot fly under diverse environmental conditions has been in progress for over a decade in India, and some of the Indian varieties are reported to posses a fairly high degree of resistance (Jotwani *et al.*, 1971; Soto, 1972). At ICRISAT, resistant sources representing different taxonomic races and ecogeographical regions of the world have been identified. Genetic diversity was observed for shoot fly resistance in these sources (Agrawal and Abraham, 1985).

Resistance to shoot fly has been attributed to non-preference for oviposition (Blum, 1967) which may be due to the presence of trichomes on the leaf surfaces (ICRISAT, 1978) and the glossy leaf trait (Maiti and Bidinger, 1979). Leaf surface wetness (LSW) of the central leaf of sorghum seedlings is also associated with deadheart damage due to shoot fly (Nwanze *et al.*, 1990).

Resistance to *A. soccata* has been shown to be inherited quantitatively and to be predominantly controlled by additive gene action (Rao et al., 1974; Sharma *et al.*, 1977). However, Agrawal and Abraham (1985) reported non-additive gene effects. Heritability has been estimated as ≈ 50% for F_2 (Sharma *et al.*, 1977). Estimates of genetic coefficients of variability, heritability and genetic advance were better when shoot fly infestation was optimized (Borikar *et al.*, 1982).

The present study involved 48 hybrids developed at ICRISAT during 1991/92 by crossing 12 diverse shoot fly resistant sources (lines) to 12 male-sterile lines (testers) in three sets of 4 x 4 line x tester combinations. The study was initiated with the objective to estimate the importance of dominance in the inheritance of different characters associated with shoot fly resistance and to suggest appropriate selection strategies for shoot fly resistance breeding.

The interesting cross combinations from this study were also selected either on the basis of high per se performance (less egg laying and lower deadheart percentage) or for high gca effects of their parents.

5.1 MEAN PERFORMANCE

5.1.1 Seedling Characters

Significant differences were found between seasons for seedling characters (seedling vigour and seedling height). Most of the hybrids were more vigorous and taller in rabi than in kharif season. This was probably due to environmental variation; in rabi there were more sunshine hours during the period from emergence up to scoring (6.16 hrs/day) and lower temperatures (average mean 23.11°C) compared to 2.28 hrs and 25.39°C in kharif. In both seasons the differences among parents were significant; resistant ones (males) in line with expectations, were more vigorous and taller than susceptible male-sterile lines (females). These results were in conformity with previous ones obtained by Taneja and Leuschner (1985) and Patel and Sukhane (1990). Hybrids were also significantly more vigorous and taller than their parents, indicating the expression of heterosis in F_1.

5.1.2 Leaf Characters

Differences between seasons for leaf characters (glossiness, trichome density and LSW) were not significant. Resistant parents (with the exception of IS 18533 and IS 5801) were significantly more glossy, had significantly more trichomes and lower LSW scores than suceptible male-sterile lines (females). Similar results were reported by several workers (Blum, 1968, 1972; Maiti and Bidinger, 1979; Maiti *et* *al.*, 1980; Raina, 1981; Taneja and Leuschner, 1985; Omori *et al.*, 1988; Nwanze *et al.*, 1990).

Hybrids were significantly worse than their resistant parents for leaf characters, but they were slightly better than the susceptible parents, indicating incomplete dominance for these characters. Among hybrids, differences were significant for leaf characters in rabi (for glossiness in set 1, trichomes in sets 1 and 3, and LSW in set 1). Hybrids produced when IS 18533 and IS 5801 (non-glossy and with few trichomes) were used as pollinators were completely non-glossy, trichomeless and with high LSW score.

5.1.3 Yield Score

Hybrids in kharif (all sets) and in rabi (set 1) had significantly lower yield score (favourable) than their parents. This result was in line with prediction, suggesting the appearance of heterosis.

An unexpected observation was that resistant parental lines were found to have lower yield score than susceptible male-sterile lines (elite, high-yielding lines) indicating that the severe shoot fly damage on susceptible parents negatively influenced their yield scores.

5.1.4 Shoot Fly Parameters

The susceptible parents had significantly more egg laying in rabi (for all sets) and in kharif (set 1), and higher percentages of deadhearts (in both seasons for all sets) compared to the resistant parental lines, indicating that susceptible parents were more preferred by shoot fly for egg laying (1.0 egg/plant in kharif and 0.75 eggs/plant in rabi). The hybrids also had more egg laying (1.10 and 0.91 eggs/plant in kharif and rabi respectively) and deadheart percentages than the resistant parents and slightly more than the susceptible ones due to their vigour.

Although the difference between seasons for hybrids was not significant for egg laying (the difference between kharif and rabi was 0.19 eggs per plant) it was for deadheart percentage (the difference was 23.61%). Parents followed a similar pattern for egg laying; the difference between seasons (0.43 eggs/plant) was not significant, but it was for deadheart percentage (the difference was 36.72%). This result revealed the strong seasonal effects on the genetic control of shoot fly resistance. Similar results were obtained by Jotwani and Srivastava (1970) and Farah (1992), who suggested that fluctuation in shoot fly incidence was due to meteorological factors such as temperature and relative humidity, which appeared to be convenient for shootfly survival during kharif season; the minimum relative humidity and the average minimum temperature were 72.73% and 21.53°C respectively in kharif compared to 43% and 13.57°C in rabi.

5.2 POOLED ANALYSIS OF VARIANCES

The pooled analysis of variances over sets (Table 5) revealed highly significant differences among resistant lines (males) for all characters except lower surface trichomes, eggs per plant (in both seasons), plant height and deadheart percentage (in kharif) revealing a large amount of variability among these lines.

Significant differences were noticed among susceptible male-sterile lines (females) only for yield score (in both seasons) and vigour score (in rabi), indicating that they had similar levels of shoot fly susceptibility. To differentiate among them only other traits (i.e., recovery and yield score) could be taken into consideration.

The great genetic variability among males, and absence of such variability among females were predictable, since resistant lines (males) were samples selected from large populations representing diverse sources, while the male-sterile lines were elite lines developed at the same location (ICRISAT), and with much narrower genetic background.

Among hybrids significant differences were found for all characters except eggs per plant, deadheart percentage (in rabi), upper surface trichomes, and plant height (in kharif). Non-significant differences among hybrids for egg laying and deadheart percentage in rabi, showed that hybrids also had similar level of shoot fly susceptibility. From the mean performance, hybrids in general ressembled their female susceptible parents suggesting that shoot fly susceptibility is dominant, and its inheritance is complex.

It was noticed that the mean squares due to lines for all characters except eggs per plant and deadheart percentage in kharif were higher than the corresponding mean squares due to testers. Lines also showed higher mean square for LSW than testers (Table 4), indicating greater diversity among lines which might be exploited to develop resistant varieties.

Also from the pooled analysis of variance it was noticed that mean squares due to lines x testers over seasons were lower for all characters except lower surface trichomes (in kharif) than either mean squares due to lines, testers or both, indicating that hybrids were more uniform than the parents.

5.3 NATURE OF GENE ACTION

The estimates of general combining ability variance (σ^2_{gca}) were larger than the corresponding specific combining ability variances (σ^2_{sca}) for all the characters except for vigour score, plant height and LSW. The ratios of $\sigma^2_{sca}/\sigma^2_{gca}$ were less than 1 for these characters indicating additive type of gene action, whereas non-additive gene actions were predominant for vigour score, plant height and LSW. Deadheart percentage, which is used as parameter or indicator for shoot fly susceptibility, is controlled by additive gene action. This is in confirmation of the results obtained by Rao *et al.* (1974), Balakotaiah *et al.* (1975), Rana *et al.* (1975 and 1981), Sharma *et al.* (1977), Borikar and Chopde (1981), Biradar and Borikar (1985), Nimbalkar and Bapat (1987), and Singh and Verma (1988) who found that resistance to shoot fly is inherited quantitatively and is predominantly controlled by additive gene action.

Non-preference or preference to oviposition in terms of egg laying, trichomes and glossiness are controlled by additive gene action. This appears to contradict previous studies. Sharma *et al.* (1977), Gibson and Maiti (1983) and Tarumoto (1980) studied the nature of gene action of non-preference and found that presence or absence of trichomes and glossiness were governed by single recessive genes. However, this study attempted to quantify these traits and found more complex inheritance.

In this study, seedling height was found to be controlled by non-additive gene effects, while Sharma *et al.* (1977) indicated that additive x additive gene action was predominant. It is known that plant height in sorghum is controlled by four major genes, but with many modifying genes also involved.

Previous studies at ICRISAT (1988) showed that LSW was much higher in a susceptible sorghum genotype than in a resistant one but this is the first attempt to investigate the inheritance of leaf surface wetness (LSW), and it was noted that non-additive gene effects were predominant.

The differences in identification of the nature of gene action for the different characters as suggested by Patel *et al.* (1984) are due to the gene frequencies and degree of dominance present in the material used as they influence the magnitude of the components of genotypic variance.

5.4 COMBINING ABILITY EFFECTS

The estimates of gca effects of parents (Table 8) revealed that among testers (females) ICSA 11 was the best general combiner in rabi on the basis of deadheart percentage as indicator (Table 17), while ICSA 70 was a poor combiner in both seasons for shoot fly resistance. IS 2123 and IS 5566 were also poor combiners among lines in kharif and rabi respectively.

Considering egg laying only the line IS 5801 was the best combiner in kharif (Table 18).

The estimates of gca effects of parents revealed that ICSA 49, ICSA 18, and IS 5480 were the best general combiners for seedling vigour during rabi. Among hybrids, ICSA 73 x IS 22145 in rabi showed superior sca effect.

Regarding general combining ability for glossiness, IS 18533 and ICSA 32 in kharif, ICSA 11, 18, 38, 77 and IS 22114 in rabi, were the best general combiners. The cross combinations ICSA 38 x IS 22114 and ICSA 11 x IS 2205 in rabi showed superior sca effects (Table 19).

Table 17. Testers showing superior combining ability.

Characters	Kharif			Rabi		
	1	2	3	1	2	3
Vigour score	ICSA 32 -0.83	ICSA 49 -0.78	ICSA 18 -0.63	ICSA 49 -0.79**	ICSA 18 -0.63*	ICSA 84 -0.38*
Glossy score	ICSA 32 -0.90*	ICSA 38 -0.73	ICSA 11 -0.65	ICSA 77 -1.52**	ICSA 38 -0.60**	ICSA 18 -0.48
Upper surface trichomes	ICSA 77 30.93**	ICSA 84 19.40**	ICSA 11 17.70*	ICSA 84 30.00**	ICSA 11 27.92**	ICSA 77 17.73
Lower surface trichomes	ICSA 77 2.30	ICSA 18 2.10	ICSA 70 0.27	ICSA 38 2.92	ICSA 77 1.48	ICSA 11 1.13
Plant height	ICSA 18 3.60*	ICSA 95 2.04	ICSA 32 1.38	ICSA 18 2.32*	ICSA 32 2.15*	ICSA 49 2.15*
Yield score	ICSA 32 -0.83**	ICSA 77 -0.79*	ICSA 11 -0.65	ICSA 18 -0.94**	ICSA 32 -0.75**	ICSA 84 -0.75**
Eggs/plant	ICSA 84 -0.13	ICSA 70 -0.10	ICSA 101 -0.08	ICSA 11 -0.09	ICSA 32 -0.09	ICSA 38 -0.08
% Deadheart	ICSA 49 -2.73	ICSA 38 -2.08	ICSA 101 -2.01	ICSA 11 -9.75*	ICSA 38 -6.06	ICSA 32 -4.61
Leaf surface wetness				ICSA 73 -0.75	ICSA 70 -0.35	ICSA 11 -0.15

*,** Significant at probability 0.05 and 0.01 respectively.

Table 18. Lines showing superior general combining ability.

Characters	Kharif			Rabi		
	1	2	3	1	2	3
Vigour score	IS 2205 -0.55	IS 22145 -0.52	IS 1082 -0.42	IS 5480 -0.71**	IS 5566 -0.63	IS 2205 -0.46
Glossy score	IS 18533 -1.15**	IS 22114 -0.48	IS 22145 -0.31	IS 22114 -0.85**	IS 2205 -0.31	IS 5566 -0.10
Upper surface trichomes	IS 18533 11.20	IS 22114 8.81	IS 22145 7.27	IS 18233 7.67	IS 923 6.56	IS 1082 3.75
Lower surface trichomes	IS 18533 2.85	IS 22145 1.63	IS 2123 0.27	IS 1082 2.42	IS 22145 1.48	IS 18533 1.21
Plant height	IS 22145 2.46	IS 18533 1.85	IS 2205 1.52	IS 5480 2.15	IS 5801 2.15	IS 2205 2.06
Yield score	IS 18533 -1.23*	IS 22114 -0.58*	IS 18366 -0.29	IS 2205 -0.60	IS 2123 -0.50*	IS 18366 -0.46
Eggs/plant	IS 5801 -0.25*	IS 5566 -0.14	IS 5622 -0.04	IS 1082 -0.09	IS 18533 -0.08	IS 18366 -0.07
% Deadheart	IS 22114 -7.81	IS 5622 -4.34	IS 22145 -3.03	IS 22145 -3.63	IS 18366 -3.61	IS 1082 -2.91
Leaf surface wetness				IS 18366 -0.89	IS 1082 -0.44	IS 2123 -0.34

*,** Significant at probability 0.05 and 0.01 respectively.

Table 19. Hybrids showing superior combining ability.

Characters	Kharif			Rabi		
	1	2	3	1	2	3
Vigour score	ICSA 88001xIS 5622 -1.31	ICSA 77xIS 923 -1.23	ICSA 84xIS 22114 -1.08	ICSA 73xIS 22145 -1.29*	ICSA 11xIS 2205 -0.79	ICSA 70xIS 1082 -0.71
Glossy score	ICSA 11 x IS 5622 -1.36	ICSA 77xIS 923 -1.27	ICSA 95xIS 18366 -1.02	ICSA 38xIS 22114 -0.81*	ICSA 11xIS 2205 -0.77*	ICSA 73xIS 5566 -0.73
Upper surface trichomes	ICSA 77 x IS 22145 18.49	ICSA 70xIS 2123 17.69	ICSA 84xIS 22114 16.52	ICSA 11xIS 5622 30.67**	ICSA 49xIS 18533 21.33*	ICSA 38xIS 22114 15.75
Lower surface trichomes	ICSA 18 x IS 18533 6.81	ICSA 77xIS 22145 5.20	ICSA 73xIS 5566 1.40	ICSA 38xIS 1082 8.33*	ICSA 77xIS 22145 6.77	ICSA 101xIS 923 3.94
Plant height	ICSA 38 x IS 5801 8.29	ICSA 88001xIS 5622 5.15	ICSA 18xIS 5480 3.98	ICSA 70xIS 1082 6.27*	ICSA 73xIS 22145 5.56*	ICSA 84xIS 5801 4.35
Yield score	ICSA 32x IS 1082 -0.83	ICSA 84xIS 5801 -0.83	ICSA 38xIS 2123 -0.58	ICSA 88001xIS 2205 -0.90	ICSA 11xIS 5622 -0.90	ICSA 73xIS 22145 -0.88
Eggs/plant	ICSA 38xIS 22114 -0.20	ICSA 18xIS 2205 -0.20	ICSA 49xIS 5480 -0.17	ICSA 88001x 5480 -0.14	ICSA 18xIS 18533 -0.11	ICSA 77xIS 22145 -0.11
% Deadheart	ICSA 73xIS 22145 -7.06	ICSA 70xIS 5801 -5.52	ICSA 38xIS 2123 -5.37	ICSA 18xIS 5480 -10.11	ICSA 95xIS 5566 -7.55	ICSA 18xIS 18533 -6.80
Leaf surface wetness				ICSA 101xIS 923 -1.46	ICSA 95xIS 18366 -1.28	ICSA 49xIS 2205 -1.10

*,** Significant at probability 0.05 and 0.01 respectively.

Upper surface trichomes, the testers ICSA 77, ICSA 84 and ICSA 11 were the highest combiners in both seasons. ICSA 11 x IS 5622 and ICSA 49 x IS 18533 revealed significant positive (desirable) sca effects in rabi.

For lower surface trichomes, only one cross combination ICSA 38 x IS 1082 during rabi season showed significant positive (desirable) sca effect.

Regarding the character plant height, ICSA 18 was the best general combiner among testers, in both seasons. Among hybrids, ICSA 70 x IS 1082 and ICSA 73 x IS 22145 were the superior combinations in rabi season, since taller, faster seedling growth is one of the resistance characteristics (Mate *et al.*, 1979).

In respect of yield score, the parents IS 18533, IS 22114, ICSA 32 and ICSA 77 during kharif; and IS 2123, ICSA 11, 18, 32 and 84 during rabi were the best general combiners.

The best line during kharif, IS 22114, occupied second rank for combining ability for glossiness, upper surface trichomes and yield score (Table 17). IS 18533 occupied first rank for the same characters but its combining ability for deadheart percentage was less than that of IS 22114 and also its mean performance (Table 6b) was less favourable for traits associated with shoot fly resistance (less glossiness, less trichomes and more deadheart percentage). This indicates that the characters under study contributed to shoot fly resistance but were not the only contributers.

During rabi, IS 18366 was the best overall combiner, occupying first rank in LSW trait and third rank for egg laying and yield score. This observation perhaps indicates the importance of LSW in shoot fly susceptibility.

The estimates of specific combining ability (sca) effects presented in (Table 8) show that few hybrids only in rabi exhibited significant desirable sca effects.

The fact that significant sca was recorded only in rabi suggests that expression of such characters was better in rabi when shoot fly infestation was lower and the number of eggs per plant for parents and hybrids were less (0.56 and 0.91) respectively This led to the better discrimination between the resistant lines and the susceptible ones, while in kharif due to higher infestation (0.99 and 1.10 eggs per plant for parents and hybrids respectively) even resistant lines suffered deadhearts in excess of 50%.

The hybrids ICSA 38 x IS 22114 and ICSA 18 x IS 2205 in kharif and ICSA 88001 x IS 5480 in rabi recorded highest desirable sca effects for egg laying, whereas hybrids ICSA 73 x IS 22145 in kharif and ICSA 18 x IS 5480 in rabi recorded highest desirable sca effects for deadheart percentage (Table 19).

5.5 VARIABILITY

Desirable genetic variability and selection efficiency are the important prerequisites for a successful breeding programme. Analysis of variability in F_1 hybrids for shoot fly resistance helps to predict the additional gains that can be made.

The analysis of variance in this study revealed large amounts of variability in the material for most of traits under study. The largests genotypic coefficients of variation (gcv) were exhibited by trichomes (both on upper and lower surfaces), while eggs per plant and deadheart percentage displayed relatively lower gcv. Other traits were intermediate in gcv values.

Phenotypic variances and phenotypic coefficients of variation (pcv) were found to be higher than the corresponding genotypic variance and gcv for all characters.

5.6 HERITABILITY

Heritability estimates give a measure of transmission of characters from one generation to the next generation. Heritability estimates together with gcv would give a better picture of the extent of genetic advance to be expected by selection (Burton, 1952). Heritability estimates reported in this study were broad sense estimates and hence the total genetic variance may include epistatic components rather than dominance which are not amenable for fixation through simple selection based on phenotypic performance (Johanson *et al.*, 1955), and therefore, do not necessarily indicate a greater genetic gain (Sivasubramanian and Madhavamenon, 1973).

The heritabilities estimated in this investigation varied from season to season according to the level of shoot fly infestation. Sharma *et al.* (1977) revealed that the genetics of deadheart percentage and eggs per plant is influenced by the level of shoot fly population. Heritability varied from character to character. This may be due to the initial frequencies of resistance genes in parental material (Rana *et al.*, 1981). Heritability also depends upon the type of breeding material; whether they are parents, F_1 or F_2 generations.

Heritability values were high for glossiness and trichome density traits only in the case of parents; they were in agreement with the estimates of Vijayalakshmi (1993). Intermediate heritability estimates were recorded for vigour score, plant height, yield score, eggs per plant, deadheart percentage and LSW for parents in rabi and vigour score, glossiness and yield score for hybrids also in rabi. Intermediate heritability for deadheart percentage was in conformity with the estimation of Sharma *et al.* (1977).

In respect of LSW, intermediate and low heritablity estimates were recorded for parents and hybrids respectively. The lowest estimation for LSW revealed that more environmental effects influenced this trait.

Higher heritability estimates were observed for parents than for hybrids because the hybrids derive from combinations between two parents and have different alleles of the genes controlling such characters.

Johanson *et al.* (1955) reported that heritability in association with genetic advance (GA) is more reliable in predicting the progress by selection than heritability alone because heritability estimates are subjected to genotype and environmental interactions. Glossiness and trichomes on both surfaces of the leaf exhibited highest genetic advance (% over mean) and least GA for deadheart percentage and eggs per plant. These estimates were in conformity with Vijayalakshmi's (1993) results.

During rabi, GAs for shoot fly parameters (egg laying and deadheart percentage) were more. This revealed the environmental influences on such characters and confirmed that selection should be carried out under moderate infestation (rabi) and not under high infestation. Borikar *et al.* (1982) reported that estimates of GCV, heritability and genetic advance were better when shoot fly infestation was optimized. Rana *et al.* (1975) suggested selection should be done under conditions when mortalities ranged between 6.7-67 percent, whereas Borikar *et al.* (1982) suggested 24-70 percent.

5.7 CORRELATION AND PATH ANALYSIS

5.7.1 Characters Associated with Shoot Fly Deadheart

The associations between different characters under study and deadheart percentage caused by shoot fly are important to give an idea about the contribution of each one and the correlations among them.

Deadheart percentage, which is the direct damage by shoot fly, is taken as a parameter of susceptibility and it is a good indicator for preference mechanism.

The results obtained from this study revealed that deadheart percentage in hybrids was positively and significantly associated with glossy score, yield score and eggs per plant while it was negatively and significant correlated with lower surface trichomes and plant height in rabi.

In the case of the parents, highly significant correlations were observed in rabi between deadheart percentage and all the other characters. Deadheart percentage was positively associated with vigour score, glossy score, eggs per plant, leaf surface wetness and yield score and negatively associated with trichomes and plant height.

Studies by Jain and Bhatnagar (1962), Sharma *et al.* (1977), Agrawal and House (1982), Agrawal and Abraham (1985), Patel and Sukhane (1990) and Vijayalakshmi (1993) showed significant positive correlation between deadheart percentage and egg laying indicating that deadheart formation depends on oviposition preference mechanism.

5.7.2 Leaf Characters vs Shoot Fly Parameters

Leaf characters (glossiness, trichomes, LSW) are the most important traits which influence shoot fly resistance. Glossy leaf influences the host preference leading to less egg laying and lower deadheart percentage. In this study the effect of glossiness (low glossy score) was apparent in rabi, when it was negatively and significantly correlated with egg laying (r = -0.39) and deadheart percentage (r = -0.52). In kharif the opposite was noticed (significant positive correlation with egg laying). The explanation of this adverse relationship may be due to the following two reasons. First due to environmental factors: in kharif the number of cloudy days at time of shoot fly incidence was greater and on such days flies are not able to discriminate between glossy and non-glossy. The second reason is the high pressure of shoot fly in kharif: under such conditions adults have no preference for oviposition and eggs were laid everywhere.

In spite of glossiness being positively correlated with egg laying in kharif (equal numbers of eggs per plant were found on glossy lines and on non-glossy), no correlation was observed between glossiness and deadheart percentage. This may be due to higher shoot fly population in kharif season, since the competition between flies for laying was more, and in this case they had no choice.

High trichome density, particularly on the lower surface of the leaf, leads to less preference for oviposition by shoot fly. In this study trichomes also strongly and negatively correlated with deadheart percentage in the case of parents, whereas for hybrids trichomes on both surfaces were significantly correlated with deadheart percentage (r= -0.33) only in rabi. Such relations indicated that the effect of trichomes was exhibited under low to moderate pressure of shoot fly and disappeared under high pressure.

5.7.3 The Association of LSW with Other Traits

Previous studies at ICRISAT (1988) showed that LSW was much higher in a susceptible sorghum genotype than in a resistant one and larvae moved faster towards the growing point and produced deadhearts much earlier. It was also shown that the leaf surface wetness of the central shoot leaf is a more reliable parameter of resistance than glossy leaf trait or trichome density.

In this study, strong and significant positive correlations between LSW and shoot fly parameters (egg laying and deadheart percentage) were noticed only in the case of parents, (r = 0.87 and 0.90) respectively. All resistant lines (except IS 18533 and IS 5801) had values of LSW <2.5 and <36% deadhearts. In the case of parents also LSW was strongly and positively correlated with vigour score, glossy score and yield score, whereas it was negatively correlated with trichome density and plant height. It was observed that certain leaf characters (glossiness, high trichome density and low LSW score) were associated together in resistant lines.

Correlations among different characters were apparent in the case of parents because most of them governed by additive gene actions, whereas in the case of hybrids due to the recombination of genes and the contribution of the adverse alleles (which act in the negative direction), so their effect did not exhibit.

When correlations between leaf characters and deadheart percentage were partitioned into direct and indirect effects through path coefficient analysis, it was noticed that although lower surface trichomes and LSW were associated with deadheart percentage they did not contribute directly to it but they contributed through eggs per plant and glossiness.

Eggs per plant and glossiness contribute directly to deadheart percentage, indicating that the relationships between egg laying and glossiness on the one hand, and shoot fly resistance on the other hand are true, and they are more reliable parameters than other characters.

Correlation coefficients between leaf characters and deadheart percentage obtained in this study were confirmed earlier studies by several workers (Blum, 1968; Maiti and Bidinger, 1979; Maiti *et al.*, 1980; Agrawal and House, 1982; Agrawal and Abraham, 1985; Omori *et al.*, 1988; Nwanze *et al.*, 1990 and Vijayalakshmi, 1993).

5.7.3 Seedling Traits Vs Shoot Fly Resistance

Seedling vigour and seedling height give an idea about the growth rate during the early and critical stage of the plant for shoot fly incidence. They are also important selection criteria. In this study, vigour score was negatively and significantly correlated with eggs per plant in kharif (r=-0.41); that means there were more eggs on hybrids (1.10) which had lower vigour score (4.27) (more vigorous) compared with resistant and susceptible checks which were less vigorous (4.33, 5.33) and had fewer eggs (0.57, 0.73 respectively). The explanation of this relationship is probably because shoot fly adults select more vigorous and healthy host plants for oviposition. These plants perhaps emitted higher dose of chemicals (attractants) which attract the shoot fly. The observation in rabi was different, when the correlation between vigour score and egg laying was positive (although not significant) and in conformity with the result obtained by Taneja and Leuschner (1985) who reasoned that rapid growth of seedling may retard the first-instar larvae from reaching the growing point.

Plant height was significantly negatively associated with eggs per plant and deadheart percentage in rabi, (r= -0.33 and -0.34 respectively). This result was as the case with Singh and Jotwani (1980a).

When correlations of vigour score and plant height with deadheart percentage were partitioned into direct and indirect effects, it was found that both traits did not contribute directly to deadheart percentage but contributed through eggs per plant and glossy traits.

5.7.4 Yield Score Vs Shoot Fly Resistance

There is no doubt that susceptibility to insects affects the ultimate yield and quality of crop plants.

In rabi, strong and significant negative correlations between yield score and egg laying and deadheart percentage (r=0.45 and 0.56 respectively) were shown. That means genotypes with less eggs and low deadheart percentage were low in yield score and are expected to give more yield. When this correlation was partitioned into direct and indirect effects, it was noticed that yield score contributed directly to deadheart percentage and also through egg laying and vigour score.

SUMMARY

CHAPTER VI

SUMMARY

The present investigation was undertaken at ICRISAT in the year 1992-93 to elicit information on the inheritance of different characters associated with shoot fly resistance and to estimate the degree of dominance for such characters.

A line x tester (partial diallel) experiment using 12 resistant lines and 12 male-sterile lines (testers) in three sets of 4 x 4 combinations was taken up for this investigation.

The resulting 48 hybrids and 24 parents along with six standard checks were planted in kharif 1992 and rabi 1992-93 at ICRISAT, Patancheru, Andhra Pradesh, India. Observations were recorded on seedling vigour, glossiness, trichome density on both sides of the leaf, seedling height, yield score, eggs per plant and deadheart percentage and leaf surface wetness (LSW).

On the basis of overall performance for different characters hybrids (mean value) were better than their parents (resistant and susceptible) only for seedling vigour and in both seasons and plant height in rabi; their vigour scores were lower than their parents and they were taller than them in rabi. For yield score and leaf characters (glossiness, trichomes and LSW) hybrids were in between the resistant and susceptible checks, and they were on par with the susceptible checks for shoot

fly parameters (egg laying and deadheart percentage).

From the analysis of variance it can be concluded that resistant lines possess high genetic diversity for all characters except eggs per plant. This genetic diversity can be utilized to develop shoot fly resistant hybrids.

From the results of gca and sca effects of parents and hybrids respectively (Table 8 and 9), only the tester ICSA 11 in rabi was the best general combiner for shoot fly resistance. The tester ICSA 70 in both seasons was a poor combiner. Although the resistant lines IS 2123 and IS 5566 were poor combiners they contributed to resistance through other traits (i.e. recovery resistance), so all lines can be exploited to improve the population in population breeding. None of the hybrids showed significant sca effects for egg laying and deadheart percentage. The hybrids ICSA 38 x IS 22114, ICSA 18 x IS 2205 (in kharif) and ICSA 88001 x IS 5480 (in rabi) recorded high desirable sca effects for egg laying, whereas the hybrids ICSA 73 x IS 22145 and ICSA 18 x IS 5480 in kharif and rabi respectively recorded highest desirable sca effects for deadheart percentage.

Based on the ratio of sca and gca variances it was noticed that both additive and non-additive types of gene action appear important for shoot fly resistance. Additive type of gene action was more important for vigour score, glossiness, upper surface trichomes, yield score, eggs per plant and deadheart percentage. On the contrary, non-additive type of gene action was found to be important for plant height and leaf surface wetness (LSW).

Correlation and heritability studies indicated that further emphasis should be placed on increasing glossiness and trichome density in selection to increase shoot fly resistance in breeding programmes.

Leaf surface wetness was intermediate and low heritable character for parents and hybrids respectively and although it was correlated with shoot fly susceptibility it did not contribute directly to deadheart percentage but contributed through other traits, i.e., eggs per plant and glossy score.

Correlation studies revealed that LSW character was closely associated with glossiness and the effects of the two characters on shoot fly resistance and oviposition non-preference cannot be separated. Therefore glossiness among all traits would be the most appropriate marker to be used in identification and selection for shoot fly resistance since it is easily identifiable.

Correlation coefficients, heritability and genetic gain towards resistance were more apparent and higher for parents and in rabi, so selection should be carried out in rabi when shoot fly infestation was lower (mortality in susceptible check 64%).

Conversion of resistant lines (agronomically unusable) to male-sterile lines through the conventional backcrossing method will allow to test the combining abilities of many high yielding varieties for shoot fly resistance.

A breeding strategy was proposed from this investigation whereby good combinering male-sterile lines (such as ICSA 11) would be mated with good combinering resistant lines (all lines under this study except IS 2123 and IS 5566 could be used). A large F_2 population would be screened under low and moderate shoot fly infestation and selected for agronomic characteristics, glossiness, trichome presence and other desired traits. Populations could be improved by using mass selection in which inferior lines with more deadhearts would be eliminated. Once the population had been improved for characters associated with shoot fly resistance it could be subjected to random mating with different resistant lines (here lines IS 2123 and IS 5566 could be added), and new cycles of recurrent selection started.

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