COMPONENTIAL ANALYSIS OF PLANT MORPHOLOGICAL FACTORS ASSOCIATED WITH SORGHUM RESISTANCE TO SHOOT FLY ATHERIGONA SOCCATA RONDANI.

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CERTIFICATE

Mr. Subrahmanyam Darbha has satisfactorily prosecuted the course of research and that the thesis entitled **"Componential analysis of plant morphological factors associated with sorghum resistance to shoot fly *Atherigona soccata* Rondani,"** 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 **"Componential analysis of plant morphological factors associated with sorghum resistance to shoot fly *Atherigona soccata* Rondani,"** submitted in partial fulfillment of the requirements for the degree of **"Master of Science in Agriculture"** to Acharya N G Ranga Agricultural University, Hyderabad, is a record of the bonafide research work carried out by **Mr. Subrahmanyam Darbha** under my guidance and supervision The subject of the thesis has been approved by the students'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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Subrahmanyam Darbha

DECLARATION

I declare that this thesis entitled "**Componential analysis of plant morphological factors associated with sorghum resistace to shoot fly *Atherigona soccata* Rondani.**" 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

Investigation on the "Componential analysis of plant morphological factors associated with sorghum resistance to shoot fly Atherigona soccata Rondani," *was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Patancheru, Andhra Pradesh, India during kharif '96 using genotypes with varied breeding history.*

The experiment in a completely randomized block design was conducted to study the performance of land races and breeding lines for several morphological traits [mesocotyl length, seedling vigor, glossy score, 4th leaf parameters (length, width, drooping depth), trichomes on the 5th leaf surface (abaxial and adaxial)] and leaf surface wetness, related to shoot fly resistance and the inter-relationships among these factors were quantified to determine the contribution of each of the factor(s) to shoot fly resistance in sorghum using path coefficient analysis.

Genotypes IS 18551 (shoot fly resistant source), ICSV 705 (bred restorer), SPSFR 94031 B and SPSFPR 94005 B (B lines) performed consistently and were found to be most resistant to shoot fly, of all the genotypes studied. Shoot fly resistant sources and land race restorers performed similarly and grouped together. Other genotypes fell into different groups. Some with common parentage were included in distinct groups (trichome-full and trichome-nil lines).

Leaf surface wetness (LSW) had strong correlation with egg count and deadheart per cent. High glossy intensity and high trichome density on adaxial surface also played a significant role in reducing the oviposition and subsequent deadheart per cent.

Path analysis for egg count indicated high direct contribution from LSW (0.55) followed by

trichome density on adaxial surface (-0.28) and glossiness (0.26) in sowings 1 and 2 respectively. Indirect effects of LSW via glossy score and trichomes on adaxial surface are most significant (0.37 and -0.33 in first sowing and 0.19, -0.17 in second sowing respectively). The direct effects for deadheart per cent was contributed more by LSW (0.37) in the first sowing and glossy score (0.45) in the second sowing. Glossy score (0.37), trichome on adaxial surface (-0.24) and leaf drooping depth (-0.16) followed in that order in the first sowing. LSW, seedling vigor, trichome density contributed 0.37, -0.17 and -0.04 respectively in the second sowing. Indirect effects for deadhearts indicate that glossy score via LSW (0.24 in both sowings) and LSW via glossy score (0.21, 0.30 in sowings 1 and 2 respectively were very effective. Trichomes on adaxial surface via LSW contributed -0.22 in the first sowing.

Therefore, this particular experiment not only reiterated the better performance of shoot fly resistant sources and land race restorers but also, reconfirmed resistance in some of the resistant B lines, that can be utilizcd in breeding programs for improving shoot fly resistance. Further, it also brought about that, resistance to shoot fly is a complex trait resulted from the direct and indirect effects of several other factors, in addition to LSW, glossy score and trichome density through the early growth stage and that this complexity is further broadened with different locations and seasons.

Introduction

Chapter I

INTRODUCTION

Sorghum bicolor (L.) Moench is one of the most important Cereal crops in Asia, Africa, and Latin America and provides food, feed and forage. In India it is the third most important cereal crop after rice and wheat. Three quarters of the world's acreage that is devoted to sorghum production is located in Africa and India, which together contribute one thirds of the world's production. However, grain yields are generally low and range from 500-800 Kg/ha owing partly to insect pest damage. It is damaged by over 150 insect species of which sorghum shoot fly (*Atherigona soccata* Rond.) is one of the most important insect pest species distributed in almost all sorghum growing areas of India. Damage by shoot fly is caused due to feeding by the maggot, which upon hatching crawls down the central whorl, feeds on the growing point and results in the death of central shoot leaf referred to as "deadheart".

In rainfed agriculture, manipulation of sowing date to avoid pest damage is almost not possible. Conventional methods for the control of shoot fly are neither practical nor cost effective for the small and marginal farmers. Introduction of newly developed high yielding hybrids that are highly susceptible to shoot fly has added to the problem (Jotwani, 1981). Use of pest resistant cultivars, a realistic approach to pest management along with moderate application of insecticides is especially useful under subsistence farming conditions of the semi-arid tropics. Unfortunately, these newly developed cultivars often fail to meet the challenges due to heterogeneous pest populations, resistance to only a single pest and also due to their inability to compete with the commonly used hybrids and varieties, and consequently are rejected by the farming community. So, crop improvement programmes should result in development of varieties with sustained

potential for increased yields with improved inputs by offering multiple resistance, if possible. In this context, host-plant resistance assumes a great role in efforts to increase the production and productivity of sorghum.

The factors that determine the resistance of host plants to insect establishment include the presence of structural barriers, allelochemicals and nutritional imbalance. Although, various workers have attempted to classify the mechanisms of resistance, the terms defined by Painter (1951)- non-preference, antibiosis and tolerance were widely accepted. Non-preference for oviposition is considered as a primary mechanism for shoot fly resistance in sorghum (Krishnananda, *et al.*, 1970, Pradhan 1971, Soto 1974, Sharma *et al.*, 1977, Sharma and Rana 1983, Raina *et al.*, 1984, Unnithan and Reddy 1985), but under no choice conditions the resistant and susceptible varieties are equally damaged (Soto, 1974; Taneja and Leuschner, 1985). Under glass house conditions, none of the varieties are highly resistant (Jotwani and Srivastava, 1970), and non-preference is substantially reduced with a high shoot fly density (Singh and Jotwani, 1980a).

Shoot fly resistance is associated with some seedling characters. The wild species of sorghum that are immune to shoot fly have a high trichome density on the lower surface of the leaves (Bapat and Mote, 1982). Although the direct influence of trichomes on behaviour of the shoot fly needs to be established, the importance of trichomes on the under surface of leaves has been reported by several workers (Blum, 1968; Maiti and Bidinger, 1979; Maiti et al. 1980; Taneja and Leuschner, 1985). Most of these lines resistant to shoot fly also exhibit the glossy leaf character during the seedling stage (Blum, 1972; Maiti and Bidinger, 1979; Taneja and Leuschner, 1985a; Omori, *et al.*, 1988). Glossy leaves may possibly affect the quality of light reflected from leaves and influence the orientation of shoot flies towards their host plants. Glossy

leaves may also influence the host selection by means of chemicals present in the surface waxes and/or leaves. Rapid growth of seedlings may retard the first instar larvae from reaching the growing tip. In contrast, slow growth due to poor seedling vigour, low fertility or environmental stress increases shoot fly incidence (Taneja and Leuschner, 1985a: Patel and Sukhani, 1990a). Shoot fly resistant lines have rapid plant growth (Mote *et al.*, 1986), greater seedling height and hardness (Singh and Jotwani, 1980b) and have longer stems and internodes and short peduncles (Patel and Sukhani, 1990a). Tall sorghum genotypes have more shoot fly eggs compared to dwarfs. Tall genotypes had longer mesocotyl, slightly more glossiness, longer leaves and more trichomes compared to dwarf genotypes. Long and erect leaves with less drooping depth can be utilized as a simple and reliable selection criterion for the identification of shoot fly resistant genotypes (Vijayalakshmi, 1993). Differences in surface wetness of the central shoot between resistant and susceptible genotypes suggest leaf moisture as important for the movement of the larva to the growing point and deadheart formation (Nwanze *et al.*, 1992).

All the above mentioned plant morphological characteristics viz., seedling vigour, trichomes on the leaf surface, glossy leaf trait, leaf parameters, leaf surface wetness (LSW), etc., and their association with resistance to shoot fly have been observed separately. In order to obtain a clear picture of their inter-relationships and contributory role to resistance in the breeding lines of sorghum, an attempt was made to study :

1) the performance of land races and breeding lines for the traits related to shoot fly resistance.
2) the quantitative inter-relationships among these traits and determine the contribution of each of the factor(s) to shoot fly resistance in sorghum.

Review of Literature

Chapter II

REVIEW OF LITERATURE

Sorghum shoot fly, *Atherigona soccata* Rondani, is a major seedling pest of sorghum and the management involves cultural practices, host plant resistance and chemical control. Considering the success met with in research involving the development of insect resistant crop cultivars of major food crops, in addition to substantial reduction in pesticide application for pest management by identifying the host plant resistance mechanisms that contribute to the most viable and widely applicable tactic of Integrated Pest Management (IPM), a holistic review has been made to further the understanding on plant morphological factors associated with sorghum resistance to shoot fly for successful implementation of pest management programs.

2.1 Shoot fly, *Atherigona soccata* Rondani, - a serious seedling pest on sorghum

The genus *Atherigona* is a large one and unfortunately many of the species are difficult to determine. Pont (1972) Deeming (1971, 1972) and van Emden (1940) used the shape of the trifloiate process and the hypogial process to identify males. Females are much more difficult to distinguish from other species. The female *Atherigona soccata* Rondani, is a fairly robust insect with triangular or circular spots on two or three abdominal tergites (fig.1 D). Two regular cones dominate the centre of the eigth tergite of the ovipositor (T 8) (fig.1 B). The tergite is often uniformly black though the posterior portion in some insects is lighter. The free sclerite is narrow and long. A fine dark line characterises the seventh tergite (T 7) with a lighter brown area surrounding the posterior half (cricket bats). The sixth tergite is small, square and without sharp edges. The crown of the cephalad portion of sternite seven (S 7) is the best characteristic to

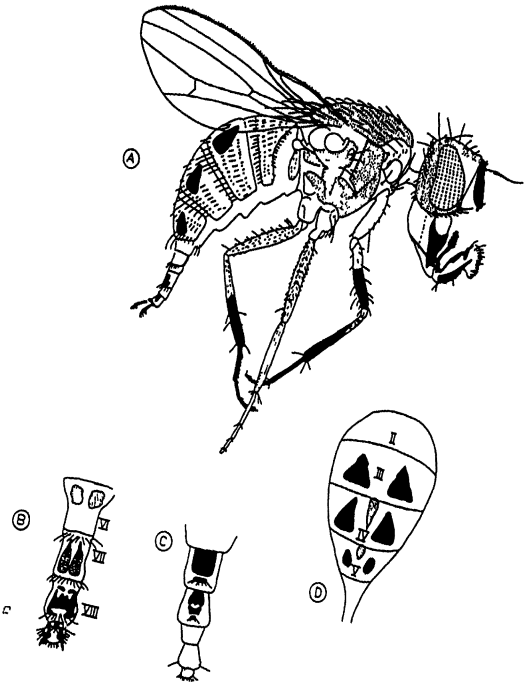


Fig. 1 *Atherigona soccata*

a) Female. Note black antennae and maxillary palp.

b) Ovipositor tergite. The broad double central cones of T VIII are unique features of this species.

c) Ovipositor sternites. The "crown" of the cephalad portion of S VII is a useful distinguishing characteristic.

d) Abdominal Pattern. The black spots may be triangular or circular, but never crescent shaped. The median vittae is often present in T II and T III. One or both of the black spots of T III may be absent.

separate *A. soccata* from the very similar *A. oryzae* (Fig 1 C). The black antennae and a maxillary palp black atleast at the base are useful confirmation that the female considered may be placed as *A. soccata.*

2.2 Distribution

Shoot fly *Atherigona soccata* Rond. is an important pest of sorghum in Asia, mediterranean Europe, and Africa. Its occurrence is clearly related to the distribution of sorghum crop (Reyes *et al.*, 1984). It has not been reported in America and Australia. It is one of the most destructive and important seedling pest of sorghum in East Africa (Reddy, 1984). Recently, it has been reported that shoot fly infestations occured at Bonka Dryland Agricultural Research station (BDARS), Somalia, (Lavign 1988)

2.3 Biology

Shoot fly *Atherigona soccata* attacks sorghum from 5 to 25 days after seedling emergence. The adult fly lays white, elongated, cigar-shaped eggs singly on the undersurface of the leaves, parallel to the midrib. The eggs hatch in 1-2 days, and the larvae crawl to the plant whorl and then move downward between the folds of the young leaves till they reach the growing point. They cut the growing point and feed on the decaying leaf tissues, resulting in deadheart formation. As a result of shoot fly attack, plant stand is greatly reduced. The death of the main shoot often results in the production of tillers, which often serve as a mechanism of recovery resistance and produce productive panicles. However, the tillers are also attacked under high shoot fly pressure. Larval stage lasts for 8-10 days. In general, the shoot fly completes its life cycle in 17-21 days.

2.4 Early studies on screening for resistance to shoot fly

Screening for resistance to shoot fly, was for the first time conducted by Ponnaiya (1951 a, b). He screened 214 varieties of which 15 were relatively less damaged by the shoot flySystematic work on screening for identifying sources of resistance was initiated in the sixties under the All India Co-ordinated Sorghum Improvement Project (AICSIP). More than 10,000 varieties from the world germplasm collection were screened at different locations. A number of screening programs were undertaken in other countries like Nigeria, Uganda, Israel and Thailand. The search for sources of resistance to shoot fly through field evaluation of thousands of varieties of the world sorghum colletion has been made by Singh *et al.*, (1968), Pradhan (1971), Young (1972), Rao *et al.*, (1978), Jotwani and Davies (1980). However, none of the cultivars selected as resistant were found to be satisfactory because, the level of resistance was low to moderate. Singh *et al.*, (1981) reported that a high level of shoot fly resistance is available in purple pigmented plant types. Singh *et al.*, (1986) also reported that several cultivars were resistant to both shoot fly and stem borer. Some of those varieties viz., IS 1054, IS 1151, IS 3541, IS 5469 and IS 5490 provided most stable source of resistance to shoot fly. But, the resistant varieties were generally poor agronomic types, susceptible to lodging, photosensitive, late maturing and low yielding. Studies on screening for resistance to shoot fly were conducted at ICRISAT using interlard fish meal technique. Taneja and Leuschner (1984) reported that about 14,000 germplasm lines were screened so far, and only 42 lines have been found less susceptible for over five seasons.

The factors that determine the resistance of host plants to insect establishment include the presence of structural barriers, allelochemicals and nutritional imbalance. Although, various workers have attempted to classify the mechanisms of resistance, the terms defined by Painter

(1951)- non-preference, antibiosis and tolerance were widely accepted. The present work is restricted to the study of non-preference/antixenosis in relation to the plant morphological characters (mesocotyl length, early seedling vigour, glossy leaf trait at seedling stage, trichomes on the leaf lamina, leaf length, breadth, drooping depth and leaf surface wetness that are probably associated with sorghum resistance to shoot fly.

Resistance as cumulative effect of plant morphological factors, non-preference and antibiosis has been reported by Rana *et al.*, (1981).

2.4.1 Non-Preference or Antixenosis

Studies on sorghum resistance by Ponnaiya (1951a, 1951b) and Rao and Rao (1956) did not result in detection of ovipositional non-preference by the shoot fly in resistant cultivars. However, the oviposition was significantly less on resistant varieties compared to susceptible ones, in a screening trial conducted by Jain and Bhatnagar (1962). Blum (1967) and Jotwani *et al.*, (1971) suggested that resistance in the field was primarily due to non-preference for oviposition.

Blum (1969), Soto (1974), Narayana (1975) Sharma *et al.*, (1970), Singh *et al.*, (1981), Singh and Jotwani (1980a) and Mote *et al.*, (1986) reported that non-preference for oviposition was evident when evaluated under low shoot fly population. But, break down of this mechanism under heavy shoot fly population was observed by Singh and Jotwani (1980a) and Borikar *et al.* (1982).

The preference of susceptible cultivars for egg laying i.e., higher number of eggs per plant and plant with eggs was reported by Jotwani *et al.*, (1971), Teli *et al.*, (1983), Unnithan and Reddy (1985) and Taneja and Leuschner (1985). Jotwani *et al.*, (1971) also reported that an

average of less than one egg per seedling on resistant cultivars (IS 1054, IS 5369, IS 5470, IS 5655 and IS 5801) compared to a maximum of 5.73 eggs per seedling on the susceptible variety swarna (CSV 1).

Oviposition was equal on both resistant and susceptible cultivars under no choice condition (absence of preferred host) Jotwani and Srivastava, 1970; Singh and Narayana 1978, but, less frequently, ovipositional non-preference was also observed in the absence of preferred host(s) (Jotwani *et al.*, 1974; Wongtong and Palanakamjorn 1975 and Raina *et al.*, 1984).

The association of ovipositional non-preference with leaf position has been studied. Laboratory studies by Ogwaro (1978) in Kenya revealed high ovipositional preference for the second leaf followed by third, first and fourth leaves. However, under field conditions, the third leaf was highly preferred followed by second, fourth, fifth, sixth and seventh leaves. In India, Davies and Seshu Reddy (1990) found that the fifth and fourth leaves were preferred in that order for oviposition in the field. Contrarily, oviposition on fourth followed by fifth 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).

Mowafi (1967) reported an inverse relation between the production of deadhearts in the infested seedlings and the distance between the site of oviposition to the base of the leaf blade. A significant and positive correlation was observed between the number of eggs deposited and deadhearts (Sharma *et al.*, 1977). Group differences between susceptible and resistant variety for deadheart percentage were established by Rana *et al.*, (1975) which indicated that varieties preferred for oviposition showed a higher degree of deadheart percentage.

The pattern of distribution of eggs differed between lines, under both field and laboratory conditions and observations revealed that the placement of eggs on the leaves tend to be random

or slightly aggregated rather than regular thereby suggesting that the site of oviposition by a particular female is little or not determined by the presence of other eggs (Delobel, 1982).

Behavioural resistance studies 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 was very short (Raina *et al.*, 1984). In addition, eggs were laid on non-preferred cultivars, only after laying several eggs on alternate susceptible CSH 1 seedlings. As none of the known resistant cultivars were completely non-preferred for egg laying, non-preference appears to be a relative term (Sharma and Rana, 1983).

Ovipositional behaviour of shoot fly was studied by Raina (1982) and reported that colour, texture and width of the sorghum leaf played an important role in selection of the site of oviposition by the female fly. Leaves of some of the sorghum cultivars resistant to shoot fly were pale green compared to the dark green colour of the susceptible cultivars (Soto, 1974 and Mote *et al.*, 1986). Narrow leaves had both, fewer deadhearts and egg laying as shoot fly has less area for egg laying compared to broad leaved plants (Mote *et al.*, 1986). Colour of the leaf and its hairness (Trichomes) were considered as non-preference mechanisms (Bapat and Mote 1982).

2.5 Possible morphological characters associated with shoot fly resistance

Mesocotyl length, early seedling vigor, seedling height, leaf sheath hardness, trichomes on the leaf lamina, glossy leaf trait at seedling stage etc, have been suggested by various authors as contributory factors for resistance in sorghum to shoot fly.

2.5.1 Mesocotyl length and Early seedling vigour

Mesocotyl length refers to the internode between the scutellar node and coleoptile node

(Fahn 1974). Mesocotyl length differs significantly among the genotypes. Faster plumule growth ensures the early emergence of seedlings. Quick growth of the seedlings might retard the first instar larva from reaching the growing point, although leaf margins may be cut without causing deadheart.

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 vigor and increased the susceptibility to shoot fly (Taneja and Leuschner 1985; Patel and Sukhani 1990).

2.5.2 Leaf Characters

2.5.2.1Trichomes

Blum (1967, 1968), Langham (1968) and Narayana (1975) observed small prickle hairs on the abaxial epidermis of the first, second and third leaf sheaths in some resistant varieties, which deter penetration of the young larvae. Blum (1967, 1968) attributed this to a distinct lignification and thickening of cell walls enclosing the vascular bundle sheaths within the central whorl of young leaves at the third leaf sheath.

Maiti and Bidinger (1979) suggested trichomes as a deterring factor, after screening 8000 lines against shoot fly. They concluded that resistant lines possessed trichomes on the abaxial surface of the leaf. Bapat and Mote (1982) reported that wild species of sorghum were found to be immune to shoot fly and had a high trichome density on the abaxial surface of the leaves. Several authors (Blum 1968, Maiti and Bidinger 1979, Maiti *et al.*, 1980 and Taneja and Leuschner 1985) reported the less frequent preference, for both oviposition of shoot fly and subsequent larval damage due to presence of trichomes.

Resistant cultivars IS 2146, IS 3962 and IS 5613 had a high density of trichomes on the abaxial leaf surface while susceptible hybrid CSH 1 was found to lack trichomes. Further, they reported that the behaviour of the adult flies during oviposition might be affected to a greater extent than the larval movement (as eggs are laid on the lower leaf surface) because of the presence of trichomes on the abaxial leaf surface. However, the trichomes on the upper surface may interfere with larval movement and survival, since larvae immediately after hatching move on to the upper surface and then towards the growing point. Shoot fly larvae spend little time on the leaf on which the egg was laid compared to the time taken to travel from the funnel to the growing point (Nwanze *et al.*, 1990).

A positive correlation for trichome density in plants resistant to shoot fly was observed by Moholkar (1981), Omori *et al.*, (1983) and Patel and Sukhani (1990). Jadhav *et al.*, (1986) reported negative relationship between trichome density as well as trichome length and shoot fly damage in sorghum genotypes.

Karanjkar *et al.*, (1992) studied the relation between sorghum plant characters and percentage of eggs laid on plants (14 DAE) and reported a positive correlation with the number of deadhearts. Leaf trichome density and plant height were negatively correlated with the number of deadhearts.

Kishore (1992) identified that hairiness of midrib and ligule, stout stem and small internodes of SPV 1015 affected the establishment of the immature stages of both shoot fly and stem borer.

Agarwal and House (1982) found that the level of resistance was greater when both the glossy and trichome traits occurred together. A high level of significance and negative correlation between shoot fly egg laying and trichomes and glossy traits was reported by Omori *et al.*,

(1983). Maiti and Gibson (1983) observed trichome density and concluded that, it is a possible factor in resistance, but correlation of deadheart percentage with the density of trichomes was low and non-significant. They suggested that glossy expression in seedling sorghum can be utilized as a single and reliable selection criterion for shoot fly resistance.

2.5.3 Leaf Glossiness

Most resistant varieties have been found to have glossy (pale green smooth and shining leaves) expression in the seedling stage (Jotwani *et al.*, 1971; Blum, 1972; Bapat *et al.*, 1975; Maiti and Bidinger, 1979; Maiti *et al.*, 1980; Bapat and Mote 1982; Omori *et al.*, 1988).

A large proportion (84%) of the glossy lines (accounting for less than 1% of sorghum germplasm) is peninsular Indian in origin, but some are from Nigeria, Sudan, Ethiopia, North Cameroon, Kenya, Uganda, South Africa and Mexico. Most of them belong to durra group and some others to taxonomic groups such as guinea, caudatum and bicolor (Maiti *et al.*, 1984). Glossy leaves might possibly affect the quality of light reflected from and influence the orientation of shoot flies towards their host plants. Glossy leaves also might influence the host selection due to chemicals present in the surface waxes and/or leaves.

The association of both glossy leaf type and trichomes with shoot fly resistance in sorghum has been supported by Maiti and Bidinger (1979). A study on four combinations, glossy leaf + trichomes, glossy leaf alone, trichomes alone and neither, revealed that the mean deadheart percentages were 60.7, 70.9, 83.5 and 91.3 respectively. These results suggest that each of the two traits contributed to the resistance and that the glossy leaf character contributed more than did trichomes and that the combination of the two traits was more effective than either of the traits alone.

originates from atmospheric condensation or from the plant was described by Sree *et al.*, (1994).

The earliest report on the utilization of the morning dew by freshly hatched larvae to glide down until they reach the leaf sheath was by Rinvay, (1960).

Freshly hatched shoot fly larvae when placed on sorghum leaves in the laboratory, repeatedly fell down unless the plants were moistened with a fine spray of water (Blum 1963).

The coincidence of the time of hatching with the presence of moisture on the leaf, a condition favourable for movement of larvae to the base of leaf was reported by Raina (1981).

The affect of seedling age on the susceptibility to sorghum shoot fly which was highest when seedlings were 8-12 day old, which corresponds to high moisture accumulation on the central leaf (the path of the larvae as it moves down towards the growing point after hatching) was reported by Nwanze *et al.*, (1990).

Sree (1991) studied the effects of environmental factors, micro-climate variables of annual and diurnal fluctuations of LSW, shoot fly populations and crop damage and reported surface wetness of leaf (adaxial surface) as a condition favorable for the movement of freshly hatched larvae to the base of central shoot for producing "deadheart".

The relation between epicuticular wax and wetness of the central whorl leaf of young seedlings was worked out by Nwanze *et al.*, (1992). They reported that the density of wax crystals decreased from the third to the seventh leaf stage, and was related to both seedling age and leaf position. Water droplets on susceptible genotypes with dense wax crystals showed spreading at the edges, indicating a tendency to wet easily. In resistant genotypes with less dense wax crystals, the droplets remained intact and did not spread.

Soman *et al.*, (1994) reported that the differences in soil matric potential affected plant water status, which in turn had profound affects on the production of water droplets on the

central whorl of CSH 5 and that an understanding of the mechanism by which water is transferred to the leaf surface would enhance breeding for resistance to shoot fly.

Radioactive labelling methods using tritium and carbon-14 confirmed the physical and physiological evidence that LSW originates from the plant was reported by Sivaramakrishnan *et al.*, (1994).

Materials and Methods

Chapter III

MATERIALS AND METHODS

Experiments for the study of some plant morphological features along with inter-relationships among them and their role in resistance to sorghum shoot fly, *Atherigona soccata* Rondani were conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Patancheru, Andhra Pradesh during kharif 1996.

3.1 Sorghum genotypes

Altogether thirty sorghum genotypes representing glossy and non-glossy resistant and susceptible lines, susceptible non-glossy maintainer lines, mapping parents, resistant B lines (short and tall), resistant land races (tall and medium tall), resistant bred lines (short and tall) and isogenic pairs were selected for the study (Table 1).

3.2 Experimental design

Two field experiments, early in the season and during the peak infestation of shoot fly were conducted in Kharif 1996. All the test entries were planted in a randomised block design with three replications for each genotype. Recommended agronomic practices were followed for raising the crop. In the early sown trial, field infestation of shoot fly was enhanced by sowing CSH-1 (susceptible hybrid) in four rows, 21 days prior to the planting of the test entries, and placing moist fish meal packets 500 g each within the infestor rows to have sufficient fly pressure.

Each genotype was planted in plots of 1.5 x 4.0 m (2 rows of 4 m length, ridges 75 cm

Table 1: Diverse sorghum genotypes selected for studying the morphological factors associated with shoot fly resistance in kharif '96.

Shoot fly resistance sources:	IS 1046, IS 1054, IS 1057, IS 18551, IS 18729, IS 24756
B lines:	SPSFR 94001 B, SPSFR 94003 B, SPSFR 94007 B, SPSFR 94031 B, SPSFPR 94002 B, SPSFPR 94005 B
Land race restorers:	ICSR 90002, ICSR 93009, ICSR 93010, ICSR 93011, ICSR 93031
Bred restorers:	ICSV 705, ICSV 712, ICSV 88088
Glossy lines:	GD 55161, GD 55173
Non-Glossy lines:	GD 55162, GD 55174
Trichome-full lines:	GD 55290, GD 55296
Trichome-nil lines:	GD 55255, GD 55295
Susceptible cultivar:	CSH 1

apart). Plots were sown at approximately 100 plants/row of 4 m and 10 DAE thinned to spacing of 5 cm between plants. As there was no appearance of deadhearts due to shoot fly damage prior to thinning, care was taken to thin only on the basis of position of seedlings in the row.

All the cultural practices such as interculture, weeding etc. were carried out to maintain a weed-free crop in both the trials in Kharif 1996.

3.3 Observations

Observations on plant morphological factors viz., mesocotyl length, seedling vigor, leaf glossiness, leaf length, leaf width, leaf drooping depth, trichomes on leaf surface (abaxial and adaxial) leaf surface wetness (LSW) were recorded. In addition, data on egg laying, ovipositional preference and deadhearts was recorded for both the dates of sowing.

3.3.1 Mesocotyl length

Length of the mesocotyl as an indication of early seedling vigour and as a parameter which enhances the emergence of seedlings from soil, was recorded on ten randomly selected seedlings per genotype under laboratory conditions as it was not possible to measure the length under field conditions due to variation in the depth of placement of seed and availability of moisture. Sowing was takenup in petri-plates in the laboratory. Seeds were made to germinate on blotter paper holders (made by placing a 1 mm thick pieces of filter papers). A fixed quantity (5 ml) of distilled water was used for each petri-plate using a measuring cylinder. Entries were tested in three replicates with the seedlings germinated at a room temperature of 27± 2 ^{0}c. The length of mesocotyl was measured on ten seedlings per genotype on the 5th day after placing in the petri-plates.

3.3.2 Seedling vigor

The objective of scoring for seedling vigor on a 1 to 9 scale (where, 1 = most vigorous and 9 = least vigorous) 7 DAE is to estimate rapidly and efficiently the seedling vigor of a large number of lines. The visual scoring system used is a relative one, based on the range of variability for seedling size in the material being scored. The individual ratings are based on individual plots within the experiment which serve as reference for scoring all entries. The following factors enter into the assessment of seedling vigor: height, pseudostem thickness, spread of leaf canopy and/or the length and breadth of the individual leaves.

3.3.3 Leaf glossiness

Glossy lines have light yellow green leaves with a shiny surface appearance in sunlight (may be related to chlorophyll content and epicuticular wax). Non-glossy "normal" sorghum lines have dark green and generally broad and pendant leaves. Leaves may be broad, semi-broad or narrow depending on genotypes. Seedlings in glossy lines are generally erect and leaves are stiff, but broad and slightly pendant leaves are also not uncommon (Maiti 1993). Variation in glossy trait was scored on 1 to 9 scale (where, 1 = glossy and 9 = non-glossy) at 10 DAE.

3.3.4 Leaf Parameters

Total leaf length, droopy leaf length, greatest width and the drooping depth of genotypes were recorded during Kharif 1996. The total leaf length was measured with the help of a scale from the base of the leaf to the tip after straightening the leaf. The length of the droopy leaf is the straight line distance between leaf base tip of a drooped leaf while drooping on the plant. This was measured with the help of the scale from the leaf base to the leaf tip without

straightening the leaf. The maximum perpendicular distance between the drooping leaf and the observed length was considered as drooping depth. Leaf width was recorded at the center of the leaf.

The measurements were recorded on 4th leaf at 14 DAE on five randomly chosen plants per plot per genotype.

3.3.5 Trichomes

To study the variation in leaf trichome density (abaxial and adaxial surfaces) the central portion of the 5th leaf from 3 randomly selected and tagged plants was collected by taking cotyledonous leaf as 1st leaf. The leaf bits were processed by adopting standard procedure (Maiti, 1977) with slight modifications in clearing the leaves for observation of leaf trichomes under microscope. Leaf segments (approximately 1 cm^2) were placed in 20 cc acetic acid and alcohol solution (2:1) in small glass vials (2cm diameter, 7.5 cm high) overnight. Then, they were transferred into 20 cc lactic acid (90%) in stopper vials. Cleared leaf segments (one day later) were stored for later examination.

For microscopic examination, the segments were mounted on a slide in a drop of lactic acid and observed under a microscope at 100x magnification. The trichomes on adaxial and abaxial surfaces of 5th leaf were counted in randomly selected microscopic fields and expressed as trichome density /mm^2.

3.3.6 Egg Counts

Number of shoot fly eggs on eight seedlings (4 seedlings per row consisting of 40 plants) was recorded 14 DAE in both the sowings. For studying the ovipositional preference and the leaf

most preferred for egg laying, egg counts were made separately on 4th and 5th leaves at 14 DAE. This was done by considering cotyledonary leaf as the 1st leaf and expressed in percentage after arriving at the number of eggs on a particular leaf for 100 plants /genotype.

3.3.7 Deadhearts

Deadheart counts were recorded at three intervals namely, at 14, 21 and 28 DAE and expressed in percentage of deadhearts from the total number of plants /plot.

3.3.8 Leaf Surface Wetness (LSW)

Surface wetness of leaf was quantitatively assessed on all cultivars by using a blotting paper technique described below. Observations were recorded in milligrams during 03.00 to 07.00 hrs on 10 day old seedlings in a plastic tray experiment.

3.3.8.1Quantitative assessment of LSW:

The above mentioned cultivars were raised in plastic trays(1.5x1.0 ft) outside the glass house. All the thirty entries were split into three sets of ten each and an interval of two days was allowed for each set for convenience during observation. LSW was estimated by weighing a strip (1 x 1 cm) of filter paper (Watman no.4), excising the un-expanded central whorl leaf, expanding it on a double side adhesive tape followed by absorbing the moisture on the leaf and re-weighing immediately on a mettler balance (model A.E. 160). The difference in weight was equivalent to the amount of surface moisture on the leaf.

3.4 Statistical analysis

Fisher's method of analysis of variance (ANOVA) and standard error were applied for analysis and interpretation of data. F value was determined at P = 0.05 critical difference (C.D).

3.4.1 Analysis of Variance

To test the differences among genotypes in the experiments conducted, the data obtained for each character was analyzed by following the randomized complete block design analysis. The analysis was based on the following linear model given by Fisher (1983).

$$Y_{ij} = u + b_i + t_j + e_{ij}$$

Where,

Yij = performance of jth genotype in i^{th} block

u = general mean

bi = true effect of i^{th} block

tj = true effect of j^{th} genotype, and

eij = random error.

Restrictions are, $E^{r}_{i=1} b_i = 0$ and $E^{t}_{j=1} t_j = 0$

Analysis of variance based on this linear model leads to breakup into the following variance components.

ANOVA TABLE

Source	D.F.	M.S.S	F
Replications	(r-1)	Mr	Mr/E
Treatments	(t-1)	Mt	Mt/E
Error	(r-1)(t-1)	E	
Total	(rt-1)		

Where, r = number of replications and t = number of treatments (genotypes)

3.4.2 Estimates of Correlation Coefficients and Path Coefficient Analysis

Phenotypic correlations were determined using the formula suggested by Singh and Chaudhary (1977).

$r(X_1X_2)$ = $(Cov.X_1.X_2) / [V(X_1) . V(X_2)]$

Where,

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

$Cov.(X_1X_2)$ = Co-variance between X_1 and X_2

$V(X_1)$ = Variance of X_1

$V(X_2)$ = variance of X_2

X_1 and X_2 = Two related variables

The test of significance of correlations was carried out by referring to "r" table values of Fisher and Yates (1963) at (n-2) d.f. at one per cent and five per cent levels, where, "n" denotes the number of genotypes tested.

The path coefficients were obtained by solving the following simultaneous equations as suggested by Dewey and Lu (1959).

$$r_1Y = P_1 + P_2Yr_{12} + P_3Yr_{13} + ...+PK_4r_1K$$

where,

r_1Y = Simple correlation coefficient between X_1 and Y

P_1Y = Direct effect of X_1 on Y through X_2

P_2Yr_{12} = Indirect effect of X_1 on Y through X_2

P_3Yr_{13} = Indirect effect of X_1 on Y through X_3

r_{12} = Correlation coefficient between X_1 and X_2

r_{13} = Correlation coefficient between X_1 and X_3

PK_4r_1K = Indirect effect of X_1 on Y through K variable

In the same way equations for r_2, r_3Y up to $r_{15}Y$ were written and path coefficients viz., direct and indirect effects were calculated.

The direct and indirect effects were shown by a path diagram. In the path diagram, the single arrow lines represent the direct influences as measured by phenotypic and genotypic path coefficients and the double arrow lines indicate mutual association as measured by genotypic and phenotypic correlation coefficients.

Results

Chapter IV

RESULTS

4.1 Mean Performance

4.1.1 Seedling Characters

The mean performance of the seedling characters viz., mesocotyl length and seedling vigor in two plantings during kharif '96 are presented in Table 2.

4.1.1.1 Mesocotyl length

Mesocotyl lengths were measured from seedlings raised under laboratory conditions (since germination in the field was not uniform due to differences in depth of placement of seed and the availability of moisture at different depths). Mesocotyl length among all genotypes varied between 3.03 mm (IS 18729) and 19.77 mm (CSH 1) with a mean performance of 11.47 mm. Genotypes CSH 1, GD 55296, IS 18551, IS 24756, SPSFR 94031 B, ICSR 93009, ICSR 90002 and GD 55255 had long (19.77 to 16.13 mm) mesocotyl and were significantly different from most others. On the other hand genotypes IS 18729, ICSV705, ICSR 93010, SPSFR 94003 B, IS 1057, IS 1046, ICSV 712 had a very short (3.03 to 5.96 mm) mesocotyl length. However, an overall consideration of the performance indicates a significant variation among the diverse genotypes (Table 2) considered for the experiment.

4.1.1.2 Seedling vigor

Seedling vigor was scored on a 1-9 scale and square root transformed with the values ranging from 1-3 where, 1 is most vigorous and 3 is least vigorous. Seedling vigor among all

Table 2: Mesocotyl length and early seedling vigor in the sorghum genotypes selected for shoot fly resistance in kharif '96.

Genotypes	Mesocotyl length (mm)	Seedling vigor (1-9 scale) sowing 1	sowing 2
IS 1046	05.53	4.00 (2.00)	3.96 (1.98)
IS 1054	10.65	3.00 (1.73)	3.65 (1.91)
IS 1057	05.05	4.00 (2.00)	2.64 (1.62)
IS 18551	18.61	2.85 (1.68)	3.32 (1.82)
IS 18729	03.03	5.63 (2.37)	4.65 (2.15)
IS 24756	17.50	6.32 (2.51)	3.65 (1.91)
ICSV 705	03.78	5.32 (2.30)	5.00 (2.23)
ICSV 712	05.96	5.97 (2.44)	4.65 (2.15)
ICSV 88088	10.33	4.97 (2.22)	2.94 (1.71)
ICSR 90002	16.20	6.32 (2.51)	3.00 (1.73)
ICSR 93009	16.22	4.32 (2.07)	2.31 (1.52)
ICSR 93010	03.82	4.89 (2.21)	3.96 (1.98)
ICSR 93011	14.56	4.28 (2.06)	3.65 (1.91)
ICSR 93031	10.77	4.97 (2.22)	3.00 (1.73)
GD 55161	11.87	5.89 (2.46)	5.00 (2.23)
GD 55162	09.12	6.92 (2.63)	5.32 (2.30)
GD 55173	06.25	6.32 (2.51)	5.00 (2.23)
GD 55174	09.88	7.66 (2.76)	5.00 (2.23)
GD 55255	16.13	5.59 (2.36)	4.00 (2.00)
GD 55290	13.00	4.97 (2.22)	4.00 (2.00)
GD 55295	15.57	6.30 (2.50)	2.94 (1.71)
GD 55296	18.80	5.29 (2.30)	4.32 (2.07)
296 B	12.87	7.33 (2.70)	5.00 (2.23)
SPSFR 94001 B	13.27	6.66 (2.58)	4.28 (2.06)
SPSFR 94003 B	04.68	7.33 (2.70)	6.32 (2.51)
SPSFR 94007 B	10.34	7.00 (2.64)	5.32 (2.30)
SPSFR 94031 B	16.90	6.32 (2.51)	4.65 (2.15)
SPSFPR 94002 B	13.66	4.97 (2.22)	5.00 (2.23)
SPSFPR 94005 B	10.11	4.58 (2.13)	5.32 (2.30)
CSH 1	19.77	5.32 (2.30)	3.65 (1.91)
Mean	**11.47**	**5.54 (2.32)**	**4.20 (2.03)**
CD (P=0.05)	**06.93**	**1.69 (0.38)**	**0.89 (0.23)**

values in parenthesis are square root transformed on 1-3 scale

genotypes in the first planting ranged from 1.68 (IS 18551) to 2.76 (GD 55174) with a mean of 2.32. Resistant land race IS 18551 was most vigorous (1.68) followed by IS 1054 (1.73), a moderately resistant variety from the same source. GD 55174, 296 B, SPSFR 94003 B, SPSFR 94007 B, and GD 55162 were least vigorous and recorded almost equally (2.76 to 2.62).

Vigor in the second planting was higher compared to the first and recorded an overall mean performance of 2.03. ICSR 93009 (1.52), a land race restorer was the most vigorous while genotypes IS 1057, ICSV 88088, ICSR 90002, and ICSR 93031 were also vigorous but did not differ significantly from ICSR 93009 (Table 2). SPSFR 94003 B was the least vigorous of all the genotypes and recorded 2.51. Incidentally, this genotype happens to be one of the least vigorous performers in the first planting. All other genotypes were moderately vigorous.

4.1.2 Leaf Parameters

The means for the leaf parameters viz., leaf length,width and drooping depth in the selected sorghum genotypes for shoot fly resistance in kharif '96 are given in Table 3.

4.1.2.1 Length

The length of the fourth leaf among all the genotypes ranged from 13.34 to 27.44 cm with a mean of 21.37 cm. Land race restorer, ICSR 93009 recorded highest length of 27.44 cm and land race source, IS 18729 had a length of 13.34 cm. Most of the other genotypes were significantly different from each other (Table 3).

4.1.2.2 Width

Width varied between 1.04 cm (IS 18729) and 2.06 cm (SPSFR 94001 B) with an overall

Table 3: **Length, width and drooping depth of 4th leaf in sorghum genotypes selected for shoot fly resistance in kharif '96.**

Genotypes	Leaf length (cm)	Leaf width (cm)	Drooping depth (cm)
IS 1046	22.97	1.54	11.44
IS 1054	24.91	1.80	13.86
IS 1057	24.75	1.62	13.64
IS 18551	20.99	1.31	08.72
IS 18729	13.34	1.04	02.29
IS 24756	19.14	1.53	05.54
ICSV 705	22.00	1.51	09.87
ICSV 712	21.44	1.74	10.44
ICSV 88088	20.61	1.66	08.45
ICSR 90002	22.44	1.71	07.61
ICSR 93009	27.44	1.73	17.38
ICSR 93010	24.35	1.59	14.30
ICSR 93011	23.63	1.54	13.25
ICSR 93031	24.77	1.66	14.14
GD 55161	18.68	1.64	07.10
GD 55162	18.09	1.66	06.66
GD 55173	17.55	1.16	08.62
GD 55174	17.23	1.43	06.84
GD 55255	21.53	1.71	07.97
GD 55290	24.79	1.72	09.63
GD 55295	22.37	1.86	09.33
GD 55296	22.94	1.84	08.60
296 B	16.01	1.24	07.05
SPSFR 94001 B	22.72	2.06	10.33
SPSFR 94003 B	17.62	1.30	08.25
SPSFR 94007 B	22.38	1.76	09.22
SPSFR 94031 B	21.67	1.55	11.85
SPSFPR 94002 B	23.60	2.03	09.99
SPSFPR 94005 B	22.51	1.46	10.78
CSH 1	18.79	1.47	09.00
Mean	**21.37**	**1.59**	**9.73**
CD	**1.26**	**0.11**	**1.33**

mean of 1.59. Most of the genotypes were highly significant among each other (Table 3).

4.1.2.3 Drooping depth

Drooping depth followed length of the leaf in most of the genotypes i.e., more the length of the leaf, higher is the drooping depth. Most of the genotypes were significantly different from each other. ICSR 93009 (17.38 cm) and IS 18729 (2.29 cm) recorded highest and lowest drooping depths respectively with a mean depth (9.73) for all the genotypes (Table 3).

4.1.3 Glossiness

Glossiness was also recorded on a 1-9 scale and square root transformed with values ranging from 1 to 3 where, 1 is most glossy and 3 is least or non-glossy. The glossiness among all the genotypes ranged from 1.80 (IS 18551) to 2.70 (CSH 1) with an overall mean of 2.28. Resistant land race source IS 18551 was the most glossy (1.80) of all the lines and was significantly different from others. SPSFPR 94005 B (1.98) was almost glossy as IS 18551 (1.80) while genotypes ICSV 705, SPSFR 94031, IS 1046, IS 1054, IS 1057, ICSR 93031, GD 55290 and GD 55295 were on a par with each other. Susceptible hybrid CSH 1 recorded least (2.70) and was non-glossy (Table 4).

The mean performance for glossiness among all the genotypes for the second planting was 2.26 which was almost equal to that of the first planting (2.28). Glossiness among all genotypes ranged from 1.91 (ICSV 705) to 2.70 (296 B). The genotypes ICSV 705, GD 55173, ICSV 88088, IS 18551, SPSFR 94003 B and SPSFR 94031 B were the most glossy and differed significantly from most other genotypes whereas, 296 B and a susceptible hybrid CSH 1 were the least or non-glossy among all the genotypes

Table 4: Glossy Score in the Sorghum genotypes selected for shoot fly resistance in kharif '96.

Genotypes	Glossy score in 1-9 scale	
	sowing 1	sowing 2
IS 1046	4.62 (2.15)	4.32 (2.07)
IS 1054	4.65 (2.15)	4.32 (2.07)
IS 1057	4.65 (2.15)	5.66 (2.37)
IS 18551	3.26 (1.80)	3.96 (1.98)
IS 18729	5.26 (2.29)	5.26 (2.29)
IS 24756	7.00 (2.64)	6.66 (2.58)
ICSV 705	4.32 (2.07)	3.65 (1.91)
ICSV 712	5.59 (2.36)	4.62 (2.15)
ICSV 88088	4.97 (2.22)	3.89 (1.97)
ICSR 90002	6.32 (2.51)	7.00 (2.64)
ICSR 93009	4.97 (2.22)	5.29 (2.30)
ICSR 93010	5.32 (2.30)	4.97 (2.22)
ICSR 93011	4.97 (2.22)	4.97 (2.22)
ICSR 93031	4.65 (2.15)	4.62 (2.15)
GD 55161	6.00 (2.44)	6.00 (2.44)
GD 55162	5.66 (2.37)	5.66 (2.37)
GD 55173	5.26 (2.29)	3.65 (1.91)
GD 55174	5.66 (2.37)	5.32 (2.30)
GD 55255	5.66 (2.37)	5.97 (2.44)
GD 55290	4.65 (2.15)	6.66 (2.58)
GD 55295	4.65 (2.15)	6.32 (2.51)
GD 55296	5.59 (2.36)	5.00 (2.23)
296 B	6.66 (2.58)	7.33 (2.70)
SPSFR 94001 B	4.97 (2.22)	4.97 (2.22)
SPSFR 94003 B	6.30 (2.50)	3.96 (1.98)
SPSFR 94007 B	5.66 (2.37)	5.32 (2.30)
SPSFR 94031 B	4.32 (2.07)	3.96 (1.98)
SPSFPR 94002 B	4.97 (2.22)	4.97 (2.22)
SPSFPR 94005 B	3.96 (1.98)	4.52 (2.12)
CSH 1	7.33 (2.70)	7.00 (2.64)
Mean	**5.28 (2.28)**	**5.22 (2.26)**
CD	**1.47 (0.33)**	**1.52 (0.34)**

values in parenthesis are square root transformed on 1-3 scale.

4.1.4 Trichomes

The trichomes on abaxial (lower) and adaxial (upper) surfaces of 5th leaf were counted in randomly selected microscopic fields and expressed as trichome density /mm^2 after transformation [log (x+1)]. The trichome density (number/mm^2) on fifth leaf, both adaxial and abaxial surfaces was highly significant and is presented Table 5.

The trichome density on the adaxial (upper) surface was significantly higher than that of the abaxial (lower) surface in all the genotypes. Although it is difficult to set a cut off limit for the trichome density to offer resistance, it is possible that the genotypes with higher trichome density may offer more resistance by impeding larval movement. Genotypes ICSV 712, SPSFR 94001 B, SPSFR 94007 B, SPSFPR 94002 B, SPSFR 94031 B, ICSV 88088 and GD 55296 had a higher trichome density (96.66 to 70.45) compared to other genotypes.

There were no trichomes on the abaxial surface of fifth leaf of most of the genotypes. ICSV 712 and ICSV 88088 recorded highest trichome density (35.34 and 18.96) on the abaxial surface among all the genotypes. Higher trichome density on the abaxial surface may offer resistance by non-preference to shoot fly oviposition.

4.1.5 Leaf Surface Wetness (LSW)

Surface wetness of leaf was recorded in milligrams under glass house conditions during 03.00 to 07.00 hrs on 10 day old seedlings raised in plastic trays.

Results (Table 5) indicate that the variability among the most of the genotypes was non-significant and surface wetness of leaf is very high in susceptible genotypes and favoured attraction of shoot fly for oviposition and subsequent deadheart formation. The overall mean LSW on all genotypes considered was 4.36 mg. Genotypes IS 18551, ICSV 705, ICSV 712,

Table 5: Trichome density (adaxial and abaxial surfaces) of 5th leaf and leaf surface wetness in sorghum genotypes selected for shoot fly resistance in kharif '96.

Genotypes	Trichome density/ mm²		LSW
	adaxial	abaxial	(mg)/ seedling
IS 1046	00.00 (00.00)	00.00 (00.00)	5.56
IS 1054	51.33 (03.95)	05.35 (01.84)	4.80
IS 1057	41.83 (03.75)	04.29 (01.66)	3.88
IS 18551	47.10 (03.87)	02.12 (01.13)	1.64
IS 18729	00.00 (00.00)	00.00 (00.00)	4.87
IS 24756	00.00 (00.00)	00.00 (00.00)	5.32
ICSV 705	61.20 (04.13)	06.94 (02.07)	1.65
ICSV 712	96.66 (04.58)	35.34 (03.59)	1.96
ICSV 88088	72.27 (04.29)	18.96 (02.99)	5.16
ICSR 90002	00.00 (00.00)	00.00 (00.00)	6.10
ICSR 93009	40.63 (03.72)	03.42 (01.48)	3.86
ICSR 93010	28.16 (03.37)	08.76 (02.27)	4.45
ICSR 93011	38.54 (03.67)	02.95 (01.37)	4.20
ICSR 93031	52.46 (03.97)	05.44 (01.86)	3.45
GD 55161	00.95 (00.66)	00.00 (00.00)	4.87
GD 55162	02.49 (01.25)	00.00 (00.00)	5.64
GD 55173	56.55 (04.05)	02.22 (01.16)	4.86
GD 55174	50.50 (03.94)	03.31 (01.46)	5.87
GD 55255	00.00 (00.00)	00.00 (00.00)	4.70
GD 55290	32.04 (03.49)	09.18 (02.32)	3.95
GD 55295	00.00 (00.00)	00.00 (00.00)	5.16
GD 55296	70.45 (04.26)	00.54 (00.43)	4.85
296 B	00.00 (00.00)	00.00 (00.00)	6.87
SPSFR 94001 B	82.54 (04.42)	08.07 (02.20)	4.20
SPSFR 94003 B	41.07 (03.73)	09.70 (02.37)	2.65
SPSFR 94007 B	80.03 (04.39)	03.18 (01.43)	4.00
SPSFR 94031 B	74.01 (04.31)	07.11 (02.09)	2.04
SPSFPR 94002 B	76.99 (04.35)	06.25 (01.98)	3.10
SPSFPR 94005 B	25.55 (03.27)	00.00 (00.00)	2.86
CSH 1	00.54 (00.43)	00.00 (00.00)	8.25
Mean	**37.88 (02.73)**	**05.09 (01.19)**	**4.36**
CD (P= 0.05)	**13.55 (00.37)**	**07.46 (00.53)**	**2.45**

values in parenthesis are log transformed

SPSFR 94031 B, SPSFPR 94005 B, SPSFPR 94002 B and ICSR 93031 recorded less than 3.5 mg of LSW. The genotype 296 B and susceptible hybrid CSH 1 recorded 6.87 and 8.25 mg LSW respectively.

4.1.6 Resistance parameters

4.1.6.1 Egg laying

Oviposition of shoot fly was recorded in kharif '96 for two dates of sowing by counting eggs (on eight plants plot^{-1}) at weekly intervals from 14 to 28 DAE. Results are expressed as mean number of eggs on eight plants for all the intervals together after square root transformation. The genotypes 296 B and IS 24756 recorded highest egg count followed by GD 55290, GD 55296, GD 55255 and IS 18729. Genotypes IS 18551 (1.35) and SPSFR 94031 (1.17) were least preferred for oviposition by the shoot fly (Table 6).

Egg count was considerably higher in second sowing (late July and August) than in the first. Susceptible hybrid CSH 1 (5.22) recorded maximum egg count followed by IS 24756 (5.02).

Genotypes SPSFR 94031 B, ICSV 88088, SPSFPR 94002 B and IS 18551 were consistent in having least preference for egg laying by the shoot fly (Table 6).

4.1.6.2 Deadhearts

Deadhearts were also recorded at weekly intervals from 14 to 28 DAE and expressed in per cent deadhearts from the total number of plants plot^{-1} after square root transformation. Susceptible hybrid CSH 1, and the pure lines, IS 24756 and 296 B resulted in highest per cent of deadhearts in the first sowing and were significantly different from other genotypes. On the contrary the genotypes IS 1054, IS 18729 and IS 18551 recorded lowest per cent deadhearts

Table 6: Shoot fly oviposition and deadheart per cent in selected sorghum genotypes for resistance in kharif '96.

Genotypes	Sowing 1		Sowing 2	
	Egg count	Deadheart %	Egg count	Deadheart %
IS 1046	07.46 (2.73)	43.70 (6.61)	16.31 (4.03)	33.34 (5.77)
IS 1054	03.85 (1.96)	16.50 (4.06)	09.59 (3.09)	20.08 (4.48)
IS 1057	03.77 (1.94)	22.97 (4.79)	08.59 (2.93)	28.73 (5.36)
IS 18551	01.83 (1.35)	20.89 (4.57)	06.98 (2.64)	15.97 (3.99)
IS 18729	08.75 (2.95)	59.64 (7.72)	21.45 (4.63)	40.22 (6.34)
IS 24756	10.44 (3.23)	74.92 (8.65)	25.23 (5.02)	51.81 (7.19)
ICSV 705	03.21 (1.79)	30.59 (5.53)	07.23 (2.68)	13.44 (3.66)
ICSV 712	03.73 (1.93)	40.78 (6.38)	09.53 (3.08)	25.31 (5.03)
ICSV 88088	05.56 (2.35)	43.43 (6.59)	05.66 (2.37)	24.20 (4.91)
ICSR 90002	07.41 (2.72)	69.54 (8.33)	11.45 (3.38)	50.34 (7.09)
ICSR 93009	06.05 (2.46)	37.60 (6.13)	12.50 (3.53)	32.11 (5.66)
ICSR 93010	05.81 (2.41)	41.64 (6.45)	14.00 (3.74)	20.21 (4.49)
ICSR 93011	05.53 (2.35)	37.91 (6.15)	12.13 (3.48)	33.44 (5.78)
ICSR 93031	06.50 (2.55)	44.13 (6.64)	10.65 (3.26)	17.80 (4.21)
GD 55161	06.72 (2.59)	51.57 (7.18)	12.25 (3.50)	30.94 (5.56)
GD 55162	07.48 (2.73)	62.46 (7.90)	12.21 (3.49)	27.44 (5.23)
GD 55173	06.48 (2.54)	42.12 (6.49)	11.81 (3.43)	14.11 (3.75)
GD 55174	05.09 (2.25)	51.34 (7.16)	12.64 (3.55)	36.56 (6.04)
GD 55255	08.79 (2.96)	59.77 (7.73)	11.77 (3.43)	23.98 (4.89)
GD 55290	08.87 (2.97)	40.73 (6.38)	18.88 (4.34)	35.90 (5.99)
GD 55295	07.77 (2.78)	64.65 (8.04)	19.63 (4.43)	40.97 (6.40)
GD 55296	08.81 (2.96)	62.11 (7.88)	19.20 (4.38)	44.93 (6.70)
296 B	10.76 (3.28)	70.43 (8.39)	18.41 (4.29)	37.29 (6.10)
SPSFR 94001 B	07.92 (2.81)	39.36 (6.27)	07.28 (2.69)	20.01 (4.47)
SPSFR 94003 B	02.70 (1.64)	27.40 (5.23)	08.62 (2.93)	10.76 (3.28)
SPSFR 94007 B	06.16 (2,48)	44.39 (6.66)	08.00 (2.82)	17.85 (4.22)
SPSFR 94031 B	01.37 (1.17)	27.12 (5.20)	04.71 (2.17)	12.67 (3.55)
SPSFPR 94002 B	05.22 (2.28)	32.32 (5.68)	06.77 (2.60)	16.94 (4.11)
SPSFPR 94005 B	02.32 (1.52)	26.71 (5.16)	11.27 (3.35)	20.17 (4.49)
CSH 1	07.83 (2.79)	80.57 (8.97)	27.29 (5.22)	57.63 (7.59)
Mean	**05.89 (2.41)**	**46.20 (6.63)**	**12.91 (3.56)**	**28.99 (5.21)**
CD (P=0.05)	**04.58 (0.93)**	**17.09 (1.34)**	**05.98 (0.82)**	**13.37 (1.18)**

values in parenthesis are square root transformed.

among all genotypes (Table 6).

Although the egg count was higher in the second planting, deadhearts were less, as the season coincided with heavy rains and resulted in wash out of eggs. CSH 1 and IS 24756 again recorded maximum deadheart percentages.

4.1.6.3 Eggs on different leaves

Preference for egg laying by shoot fly between 4th and 5th leaves was observed and results indicated clearly that, fourth leaf was preferred to fifth in both the plantings. The mean of eggs laid on fourth leaf during first planting was 2.59 in contrast to only 2.26 on the fifth leaf (Table 7). Likewise, the mean of eggs on fourth and fifth leaves for second planting were 5.63 and 4.93 respectively (Table 7).

4.2 Group analysis

A cluster program was used to group the thirty genotypes based on their performance across all the traits for resistance, in two plantings. Genotypes that performed most closely across seedling vigor, glossy leaf trait, leaf parameters, trichomes on the leaf surfaces (abaxial and adaxial) and leaf surface wetness, considered for shoot fly resistance were put under a group followed by the next best group, until a desired number of groups is arrived (Table 8). The historical background of genotypes was taken into consideration for deciding upon the number of groups desired.

Group analysis indicated high significance among groups and non-significance within the groups for almost all the morphological factors in both the plantings (Tables 9, 10 and 11).

Table 7: Shoot fly oviposition on fourth and fifth leaves in sorghum genotypes selected for resistance in kharif '96.

	Egg count on eight plants /plot			
	Sowing 1		Sowing 2	
Genotypes	4th leaf	5th leaf	4th leaf	5th leaf
IS 1046	3.67 (2.66)	2.33 (2.33)	07.33 (5.00)	06.00 (3.33)
IS 1054	2.00 (1.33)	1.33 (1.33)	04.67 (4.00)	02.67 (2.00)
IS 1057	1.67 (1.33)	1.00 (1.00)	03.67 (2.67)	03.00 (2.67)
IS 18551	1.00 (1.00)	0.67 (0.66)	03.33 (2.67)	02.00 (1.33)
IS 18729	3.33 (2.66)	3.33 (2.00)	08.33 (4.00)	06.67 (3.33)
IS 24756	4.67 (3.66)	3.67 (2.33)	11.67 (6.00)	09.33 (4.33)
ICSV 705	2.00 (1.33)	0.67 (0.66)	03.33 (3.00)	02.33 (1.67)
ICSV 712	1.67 (1.33)	1.00 (0.66)	04.00 (3.00)	03.33 (2.67)
ICSV 88088	1.67 (0.66)	2.33 (1.33)	02.33 (1.33)	02.33 (1.67)
ICSV 90002	3.33 (2.33)	2.67 (1.66)	09.67 (6.00)	07.67 (5.00)
ICSV 93009	2.67 (2.33)	2.33 (1.33)	05.00 (3.33)	04.67 (2.33)
ICSV 93010	2.33 (1.66)	2.33 (1.33)	06.00 (3.00)	04.67 (2.67)
ICSV 93011	2.33 (2.00)	2.00 (2.00)	04.33 (2.67)	05.33 (4.33)
ICSV 93031	3.00 (2.33)	2.00 (1.66)	03.33 (1.33)	04.67 (3.00)
GD 55161	2.67 (2.66)	2.67 (2.33)	05.33 (2.67)	04.33 (2.33)
GD 55162	3.33 (2.00)	2.67 (2.33)	04.67 (2.33)	04.67 (2.33)
GD 55173	2.67 (1.33)	3.33 (2.00)	05.33 (4.33)	05.00 (5.00)
GD 55174	2.00 (1.66)	1.67 (1.66)	04.67 (3.67)	04.67 (4.00)
GD 55255	3.33 (2.33)	3.00 (2.33)	08.00 (5.00)	06.67 (4.67)
GD 55290	3.67 (3.00)	3.67 (3.00)	08.33 (6.00)	06.67 (4.67)
GD 55295	3.33 (2.00)	3.00 (2.66)	09.00 (5.00)	07.67 (4.67)
GD 55296	3.67 (2.33)	3.00 (2.66)	07.33 (5.33)	08.67 (4.67)
296 B	4.33 (3.66)	4.00 (2.33)	08.33 (5.00)	06.67 (4.67)
SPSFR 94001 B	3.00 (1.66)	3.67 (3.00)	02.67 (2.33)	02.67 (1.33)
SPSFR 94003 B	1.00 (0.66)	0.67 (0.66)	02.67 (1.67)	03.67 (1.67)
SPSFR 94007 B	2.00 (1.66)	2.33 (2.00)	03.00 (2.00)	03.33 (2.00)
SPSFR 94031 B	1.00 (1.00)	0.67 (0.66)	02.33 (1.33)	01.67 (1.33)
SPSFPR 94002 B	2.33 (1.33)	2.33 (2.33)	03.00 (1.67)	02.67 (1.67)
SPSFPR 94005 B	1.00 (1.00)	0.67 (0.33)	04.67 (3.67)	04.33 (3.33)
CSH 1	3.00 (2.00)	2.67 (2.66)	12.67 (6.33)	10.00 (7.00)
Mean	**2.59 (1.90)**	**2.26 (1.77)**	**(5.63)**	**04.93 (3.19)**
CD (p= 0.05)	**1.72 (1.36)**	**1.82 (1.50)**	**(2.50)**	**02.32 (1.70)**

values in parenthesis are number of leaves on which eggs were found.

Table 8: Biological grouping of genotypes based on cluster analysis, for first and second sowings.

Sowing 1

Group 1:	IS 1046, IS 1054, IS 1057, ICSR 93009, ICSR 93010, ICSR 93011, ICSR 93031, GD 55290
Group 2:	ICSV 712
Group 3:	ICSV 88088, GD 55296, SPSFR 94001 B, SPSFR 94007 B, SPSFPR 94002 B
Group 4:	IS 24756, 296 B, CSH 1
Group 5:	ICSR 90002, GD 55161, GD 55162, GD 55255, GD 55295
Group 6:	IS 18729
Group 7:	GD 55173, GD 55174, SPSFR 94003 B
Group 8:	IS 18551
Group 9:	ICSV 705, SPSFR 94031 B, SPSFPR 94005 B

Sowing 2

Group 1:	IS 1046, IS 1054, IS 1057, ICSR 93009, ICSR 93010, ICSR 93011, ICSR 93031
Group 2:	IS 24756, 296 B, CSH 1
Group 3:	ICSR 90002, GD 55290, GD 55295, GD 55296
Group 4:	ICSV 712, ICSV 88088
Group 5:	SPSFR 94001 B, SPSFR 94007 B, SPSFPR 94002 B
Group 6:	IS 18729
Group 7:	GD 55161, GD 55162, GD 55174, GD 55255
Group 8:	IS 18551, SPSFR 94031 B
Group 9:	ICSV 705, GD 55173, SPSFR 94003 B, SPSFPR 94005 B

Table 9: **Group analysis showing means and standard errors for the group performance across the morphological and shoot fly parameters in kharif '96 (1st planting).**

Morphological factors	GRP1	GRP2	GRP3	GRP4	GRP5	GRP6	GRP7	GRP8	GRP9
Msctl									
means	09.95	05.96	13.28	16.71	13.78	03.03	06.93	18.61	10.26
s.e	00.86	02.43	01.08	01.40	01.08	02.43	01.40	02.43	01.40
Sdvg									
means	02.06	02.44	02.39	02.51	02.48	02.37	02.66	01.68	02.32
s.e	00.04	00.13	00.26	00.07	00.06	00.13	00.07	00.13	00.04
Glscr									
means	02.19	02.36	02.28	02.64	02.37	02.29	02.39	01.80	02.04
s.e	00.04	00.01	00.05	00.06	00.05	00.01	00.06	00.01	00.06
Llnth									
means	24.70	21.44	22.45	17.98	20.62	13.34	17.47	20.99	22.06
s.e	00.15	00.44	00.20	00.25	00.20	00.44	00.25	00.44	00.25
Lwdth									
means	01.65	01.74	01.87	01.41	01.71	01.04	01.29	01.31	01.51
s.e	00.01	00.04	00.01	00.02	00.01	00.04	00.02	00.04	00.02
Ldd									
means	13.45	10.44	09.32	07.19	07.70	02.29	07.90	08.72	10.83
s.e	00.16	00.47	00.21	00.27	00.21	00.47	00.27	00.47	00.27
Triab									
means	01.60	03.59	01.80	00.00	00.00	00.00	01.66	01.13	01.38
s.e	00.09	00.26	00.11	00.15	00.11	00.26	00.15	00.26	00.15
Triad									
means	03.24	04.58	04.34	00.14	00.38	00.00	03.91	03.87	03.90
s.e	00.05	00.16	00.07	00.09	00.07	00.16	00.09	00.16	00.09
LSW									
means	04.27	01.96	04.26	06.81	05.29	04.87	04.46	01.64	02.18
s.e	00.30	00.86	00.38	00.49	00.38	00.86	00.49	00.86	00.49
Eggcnt									
means	03.25	02.87	03.36	03.76	03.48	03.64	03.05	02.56	02.64
s.e	00.08	00.23	00.10	00.13	00.10	00.08	00.13	00.08	00.13
% Ddhrt									
means	05.90	06.38	06.61	08.67	07.83	07.72	06.29	04.57	05.30
s.e	00.16	00.47	00.21	00.27	00.21	00.47	00.27	00.47	00.27
no. of reps	24	03	15	09	15	03	09	03	09

Table 10: **Group analysis showing means and standard errors for the group performance across morphological and shoot fly parameters in kharif '96 (2nd planting).**

Morphological factors	GRP1	GRP2	GRP3	GRP4	GRP5	GRP6	GRP7	GRP8	GRP9
Msctl									
means	09.51	16.71	15.89	08.15	12.42	03.03	11.75	17.75	06.20
s.e	00.89	01.36	01.18	01.67	01.36	02.37	01.18	01.67	01.18
Sdvg									
means	02.04	02.51	02.38	02.33	02.48	02.37	02.54	02.10	02.41
s.e	00.05	00.07	00.06	00.09	00.07	00.13	00.06	00.09	00.06
Glscr									
means	02.19	02.64	02.29	02.29	02.27	02.29	02.39	01.94	02.21
s.e	00.04	00.06	00.05	00.08	00.06	00.11	00.05	00.08	00.05
Llnth									
means	24.69	17.98	23.13	21.02	22.90	13.34	18.88	21.33	19.92
s.e	00.16	00.25	00.22	00.31	00.25	00.44	00.22	00.31	00.22
Lwdth									
means	01.64	01.41	01.78	01.70	01.95	01.04	01.61	01.43	01.36
s.e	00.01	00.02	00.02	00.02	00.02	00.04	00.02	00.02	00.02
Ldd									
means	14.00	07.19	08.79	09.44	09.85	02.29	07.10	10.28	09.38
s.e	00.17	00.27	00.23	00.33	00.27	00.47	00.23	00.33	00.23
Triab									
means	01.50	00.00	00.68	03.29	01.87	00.00	00.36	01.61	01.40
s.e	00.07	00.10	00.09	00.13	00.10	00.18	00.09	00.13	00.09
Triad									
means	03.21	00.14	01.94	04.43	04.39	00.00	01.46	04.09	03.80
s.e	00.05	00.07	00.06	00.09	00.07	00.13	00.06	00.09	00.06
LSW									
means	04.31	06.81	05.02	03.56	03.77	04.87	05.27	01.84	03.01
s.e	00.32	00.50	00.43	00.61	00.50	00.86	00.43	00.61	00.43
Eggcnt									
means	03.19	03.76	03.57	03.03	03.32	03.64	03.39	02.50	02.88
s.e	00.09	00.13	00.12	00.17	00.13	00.24	00.12	00.17	00.12
% Ddhrt									
means	05.83	08.67	07.66	06.48	06.20	07.72	07.49	04.88	05.60
s.e	00.18	00.27	00.23	00.33	00.27	00.47	00.23	00.33	00.23
no.of reps	21	09	12	06	09	03	12	06	12

Table 11: Group analysis indicating the significance of genotypes within the groups in kharif '96 (sowings 1 and 2).

Morphological factors		GRP1	GRP2	GRP3	GRP4	GRP5	GRP6	GRP7	GRP8	GRP9
Msctl	1	0.00*	_	0.10	0.13	0.16	_	0.30	_	0.00*
	2	0.00*	0.12	0.39	0.19	0.56	_	0.16	0.61	0.25
Sdvg	1	0.20	_	0.08	0.13	0.71	_	0.40	_	0.90
	2	0.18	0.12	0.32	0.26	0.07	_	0.13	0.00*	0.00*
Glscr	1	0.97	_	0.77	0.74	0.26	_	0.47	_	0.75
	2	0.95	0.75	0.09	0.41	0.58	_	0.96	0.10	0.01*
Llnth	1	0.00*	_	0.00*	0.00*	0.00*	_	0.80	_	0.87
	2	0.00*	0.00*	0.00*	0.19	0.14	_	0.28	0.00*	0.00*
Lwdth	1	0.00*	_	0.00*	0.00*	0.00*	_	0.00*	_	0.87
	2	0.00*	0.00*	0.00*	0.19	0.00*	_	0.00*	0.00*	0.00*
Ldd	1	0.00*	_	0.02*	0.00*	0.00*	_	0.02*	_	0.01*
	2	0.00*	0.00*	0.01*	0.00*	0.23	_	0.35	0.00*	0.00*
Triab	1	0.00*	_	0.00*	1.00	1.00	_	0.00*	_	0.00*
	2	0.00*	1.00	0.00*	0.02*	0.01*	_	0.00*	0.00*	0.00*
Triad	1	0.00*	_	0.95	0.10	0.00*	_	0.38	_	0.10
	2	0.00*	0.03*	0.00*	0.13	0.93	_	0.00*	0.02*	0.00*
LSW	1	0.76	_	0.49	0.06	0.77	_	0.03*	_	0.45
	2	0.68	0.06	0.38	0.01*	0.63	_	0.72	0.74	0.07*
Eggcnt	1	0.34	_	0.51	0.47	0.93	_	0.14	_	0.29
	2	0.60	0.47	0.90	0.36	0.53	_	0.45	0.73	0.13
Ddhrt	1	0.00*	_	0.03*	0.68	0.51	_	0.01*	_	0.55
	2	0.00*	0.68	0.02*	0.76	0.35	_	0.59	0.34	0.19

* 'F' value significant

4.3 Correlation

Groupwise correlations were obtained for both the plantings and the groups with only one genotype were not considered for discussing the results as it does not provide a good statistical estimate.

4.3.1 Plant traits and Shoot fly parameters

Group wise correlations of plant characters with shoot fly oviposition and deadheart formation are presented in Tables 12 & 13.

4.3.1.1 Mesocotyl length

Mesocotyl length was positively correlated with number of eggs on eight plants in group 7 and 3 but significant only in group 7. A negative and non-significant correlation was obtained for group 9. Group 7 and 4 were positively correlated with deadheart percentage, but significant only in group 7.

Results in the second planting indicate a positive and non-significant correlation of mesocotyl length with egg count in group 2 and 9. A negative and significant correlation was obtained in group 4. All the groups except group 3 were positively correlated with deadhearts. However, none of the groups was significant for deadhearts in the second sowing.

4.3.1.2 Seedling vigor

Seedling vigor in the first sowing was positively correlated with egg count in groups 3 and 4, and negatively correlated in 5, 7 and 9. But, none of them were significant. Deadheart percentage was positive and significantly correlated to seedling vigor in group 1. There was a

Table 12: Groupwise correlations of morphological factors with Eggs on eight plants and Deadheart per cent in kharif '96 (1st planting).

Morphological factors	GRP1	GRP2	GRP3	GRP4	GRP5	GRP6	GRP7	GRP8	GRP9
Msctl lngth									
Eggcnt/8plnts	0.00	-0.83	0.46	-0.17	0.05	0.60	0.64*	0.98*	-0.56
Deadheart %	0.02	0.98	-0.09	0.40	-0.07	-0.99	0.70*	0.75	-0.25
Seedlingvigor									
Eggcnt/8plnts	-0.05	0.65	0.33	0.31	-0.40	0.27	-0.48	0.97*	-0.12
Deadheart %	0.65*	0.02	0.20	-0.08	0.32	0.56	0.22	0.70	0.47
Glossyscore									
Eggcnt/8plnts	0.19	-0.14	0.05	-0.62*	-0.33	0.89	-0.51	0.27	0.15
Deadheart %	0.38*	0.77	0.44	-0.20	-0.25	-0.91	-0.65*	-0.26	0.69*
Leaf length									
Eggcnt/8plnts	-0.21	0.27	-0.06	-0.39	0.20	-0.22	0.10	-0.99*	-0.22
Deadheart %	-0.20	-0.84	-0.08	0.29	0.18	0.89	-0.22	-0.78	-0.16
Leaf width									
Eggcnt/8plnts	0.00	0.25	0.20	-0.19	0.67*	-0.69	-0.44	0.97*	-0.34
Deadheart %	-0.38*	-0.84	-0.28	-0.01	0.14	0.99	0.33	0.70	-0.64*
Droopingdepth									
Eggcnt/8plnts	-0.39*	0.36	0.01	-0.46	-0.12	0.69	0.15	-0.84	-0.86*
Deadheart %	-0.14	-0.89	-0.16	0.08	0.06	-0.99	-0.61	-0.99*	-0.50
Trichomes(ab)									
Eggcnt/8plnts	0.07	-0.64	-0.15	0.00	0.00	0.00	-0.42	0.12	0.05
Deadheart %	0.07	0.99	-0.27	0.00	0.00	0.00	-0.53	-0.40	0.15
Trichomes(ad)									
Eggcnt/8plnts	-0.24	-0.93	0.00	-0.71*	-0.24	0.00	0.50	0.28	-0.07
Deadheart %	-0.35	0.93	-0.45	-0.09	-0.21	0.00	0.14	-0.25	0.02
LSW									
Eggcnt/8plnts	0.03	-0.31	-0.19	0.11	-0.02	-0.46	0.34	-0.01	-0.43
Deadheart %	-0.10	-0.40	0.35	0.07	0.27	-0.39	0.79*	0.50	-0.19

* significant at p= 0.05

Table 13: Groupwise correlations of morphological factors with Eggs on eight plants and Deadheart per cent in kharif '96 (2nd planting).

Morphological factors	GRP1	GRP2	GRP3	GRP4	GRP5	GRP6	GRP7	GRP8	GRP9
Mesocotyl length									
Eggcnt/8plnts	-0.06	0.52	0.01	-0.78*	0.03	-0.47	0.06	0.10	0.35
Deadheart %	0.17	0.49	-0.29	0.24	0.18	0.28	0.15	0.12	0.47
Seedling vigor									
Eggcnt/8plnts	0.21	-0.37	0.18	0.33	0.31	0.57	0.17	-0.53	-0.24
Deadheart %	-0.21	-0.45	-0.02	-0.05	-0.65*	-0.39	0.02	-0.37	-0.38
Glossy score									
Eggcnt/8plnts	-0.12	-0.03	-0.21	0.08	0.69*	0.91	0.41	0.21	0.22
Deadheart %	0.28	-0.68*	-0.05	-0.49	-0.24	-0.97*	-0.06	0.28	0.00
Leaf length									
Eggcnt/8plnts	-0.11	0.36	-0.01	0.26	-0.19	0.07	-0.20	-0.18	-0.13
Deadheart %	0.00	0.65*	-0.46	-0.46	-0.35	0.12	-0.23	-0.18	0.44
Leaf width									
Eggcnt/8plnts	-0.32	0.27	0.36	0.33	-0.25	0.57	-0.21	-0.29	-0.55*
Deadheart %	-0.34	0.60	-0.02	-0.54	0.01	-0.39	-0.43	-0.26	0.00
Drooping depth									
Eggcnt/8plnts	-0.10	-0.04	0.10	0.66	-0.66*	-0.57	0.13	-0.45	0.21
Deadheart %	0.00	0.16	-0.32	-0.19	0.36	0.39	0.39	-0.29	0.46
Trichomes (ab)									
Eggcnt/8plnts	-0.45*	0.00	0.11	0.30	0.01	0.00	0.11	-0.62	-0.26
Deadheart %	-0.33	0.00	-0.33	0.55	-0.17	0.00	0.23	-0.42	-0.46
Trichomes (ad)									
Eggcnt/8plnts	-0.63*	-0.28	0.17	0.32	0.01	0.00	0.10	-0.54	-0.16
Deadheart %	-0.35	0.48	-0.15	0.47	-0.02	0.00	0.29	-0.16	-0.19
LSW									
Eggcnt/8plnts	0.27	0.35	0.20	-0.79*	-0.63*	0.58	0.43	0.32	0.40
Deadheart %	0.08	0.06	0.07	0.05	0.27	-0.73	-0.24	-0.12	0.03

* significant at p= 0.05

positive correlation in groups 3, 5, 7 and 9 but, non-significant. Negative correlation was observed in group 4.

Eggs on eight plants was non-significant in all the groups although, groups 1, 4, 5 and 7 were positive and groups 2, 8 and 9 were negative in the second planting.Deadheart percentage was negatively correlated to seedling vigor in all the groups but, significant only with reference to group5.

4.3.1.2 Glossy score

Glossy score was negatively correlated to egg count in groups 4 and 7 but significant in the earlier. A significant negative correlation with deadhearts was obtained for group 7. Groups 9 and 1 were positive and significant with deadheart percentage. Glossiness in the second sowing was positive and significantly correlated only in group 5. A negative and significant correlation was observed for deadheart percentage.

4.3.1.3 Leaf parameters

Leaf length showed no significant correlation with eggs on eight plants in both the sowings. Group 2 in second planting was positive and significantly correlated with deadheart percentage.

Leaf width in first planting was positive and significantly correlated with egg count in group 5. A negative but significant correlation was obtained with egg counts in group 9 for second planting. Deadhearts in the first planting was negative but, significantly correlated in groups 1 and 9. However, there was no significant correlation between deadheart percentage and leaf width in second planting.

Leaf drooping depth was negative and significantly correlated with egg count in groups 1 and 9, and group 5 in first and second plantings respectively. There was no significant correlation between leaf drooping depth and deadheart percentage in both the sowings.

4.3.1.4 Leaf trichomes

Trichome density on abaxial surface of leaf was significant and negatively correlated with egg count only in group 1 of first planting between the two. None of the groups showed any significant correlation of trichomes on abaxial surface with deadheart percentage.

Group 4 of first planting and group 1 of second planting were significant and negatively correlated with egg count on 8 plants. All the groups in both plantings were non-significant with respect to % deadhearts.

4.3.1.5 Leaf surface wetness

A significant and negative correlation with egg count on eight plants was obtained for groups 4 and 5 in second sowing. Group 7 of first planting showed a positive and significant correlation to % deadhearts.

4.4 Overall correlations

Among the morphological factors considered for resistance to shoot fly, Glossy score, Trichomes on adaxial and abaxial surfaces, and LSW played an important role in relation to the shoot fly parameters both egg count on eight plants and deadheart %.

Glossy score was very significant and negatively correlated with shoot fly parameters in both the sowings (Table 14).

Table 14: Overall correlations of plant morphological factors with shoot fly parameters for sowings 1 and 2 in kharif '96.

Morphological factors	Sowing 1		Sowing 2	
	Egg count	Deadheart %	Egg count	Deadheart %
Mesocotyl length	0.18	0.22*	0.20*	0.30*
Seedling vigor	0.12	0.47*	-0.11	-0.30*
Glossy score	0.29*	0.50*	0.53*	0.48*
Leaf length	-0.18	-0.39*	-0.27*	-0.16
Leaf width	0.06	-0.07	-0.20*	-0.04
Drooping depth	-0.31*	-0.49*	-0.31*	-0.26*
Trichomes (abaxial)	-0.25*	-0.24*	-0.32*	-0.24*
Trichomes (adaxial)	-0.34*	-0.50*	-0.57*	-0.48*
LSW	0.39*	0.52*	0.53*	0.42*

p=0.05

* significant

Although, shoot fly prefers ovipositing on abaxial surface, trichomes on the adaxial surface had a greater significance with regard to the shoot fly parameters. The more the trichome density/mm^2 on the upper surface, the lesser was the attraction of shoot fly for oviposition and subsequent deadheart formation. Trichomes on the abaxial surface of the leaf correlated negatively and was significant with egg count and deadheart % in both sowing 1 and sowing 2.

Moisture in the central leaf whorl (LSW) also had a prominent role in relation of to the shoot fly parameters and showed a positive and significant correlation in both the sowings.

Seedling vigor was positively correlated to both egg count on eight plants and deadheart % in sowing 1 but, was significant only with deadheart %. Vigor was negatively correlated with the shoot fly parameters and was significant in relation to deadheart% in sowing2.

Leaf length showed a negative correlation with the shoot fly parameters and was significant only with % deadhearts in sowing 1 and egg count in sowing 2.

In contrary to the earlier reports, leaf droopiness was negatively correlated and was significant with shoot fly parameters in both the sowings.

Mesocotyl length was positive and significantly correlated to the shoot fly parameters in sowing 2 but, was significant only with % deadhearts in sowing 1.

Leaf width did not show much importance either for egg laying by the shoot fly or deadheart formation.

4.5 Correlations among morphological factors

The correlations among morphological factors were estimated and presented in Table 15 for both sowings 1 and 2. The significant correlations between morphological traits are presented here:

Table 15: Correlation coefficients among morphological traits in sorghum genotypes selected for shoot fly resistance in kharif '96.

Sowing 1

Msctl	Sdvg	Glscr	Llnth	Lwdth	Ldd	Triab	Triad	LSW
	-0.02	0.05	0.12	0.23	-0.02	-0.21	-0.06	0.14
		0.46*	-0.49*	-0.12	-0.44*	0.03	-0.05	0.15
			-0.38*	-0.12	-0.31	0.04	-0.25	0.28
				0.65*	0.83*	0.09	0.31	-0.24
					0.35*	0.14	0.31	-0.05
						0.15	0.32	-0.21
							0.58*	-0.35*
								-0.47*

tabulated r (0.349) at 28df and at 5% significance

Sowing 2

Msctl	Sdvg	Glscr	Llnth	Lwdth	Ldd	Triab	Triad	LSW
	-0.26	0.22	0.12	0.23	-0.02	-0.21	-0.06	0.14
		-0.18	-0.50*	-0.23	-0.41*	0.05	0.12	-0.14
			-0.09	0.10	-0.22	-0.26	-0.50*	0.41*
				0.65*	0.83*	0.09	0.31	-0.24
					0.35*	0.14	0.31	-0.05
						0.15	0.32	-0.21
							0.58*	-0.35*
								-0.47*

tabulated r (0.349) at 28df and at 5% significance

Mesocotyl length had no correlation to any of the morphological factors considered. Seedling vigor was positively correlated with glossy score in the first sowing, and negatively correlated with leaf length and leaf drooping depth in both the sowings. Glossy score correlated negatively with leaf length and trichomes on adaxial surface in first and second sowing respectively, and positively with LSW.

A strong positive correlation was observed between length of the leaf and drooping depth and width. Leaf width had a positive influence on drooping depth.

Trichomes on abaxial surface was positively correlated with trichomes on adaxial surface and negatively with LSW. Trichomes on adaxial surface was also negatively correlated with LSW.

4.6 Path Coefficients

Path coefficient analysis of the dependent factors, number of eggs on eight plants and per cent deadhearts was carried out for both the sowings and the results are presented in Fig. 1 for planting 1 and Fig. 2 for planting 2.

A path diagram and coefficients of factors influencing resistance in sorghum facilitate understanding the nature of cause and effects of the system. More importantly, path diagram explains the influence of independent variables (mesocotyl length, seedling vigor, glossy score, leaf parameters, trichome density and LSW) on the dependent variables (eggs on eightplants and % deadhearts) and a composite variable that includes all other factors affecting the dependent variable in the study.

The independent variables are themselves inter-related. Consequently, each factor influences the dependent variable by a direct contribution and by acting in combination with the

other independent variables with which it is related. The residual variable X is assumed to be independent of the remaining variables.

4.6.1 Choosing dependent factors

The factors with most significant correlation (Table 14) to the dependent variables (eggs on eight plants and % deadhearts) are glossy score, leaf drooping depth, trichomes (adaxial surface) and LSW. So, the effect of independent factors mentioned above, on shoot fly egg laying and deadheart formation were examined by considering four traits at a time through path coefficient analyses.

4.6.2 Choosing combinations

The combinations of independent factors (1 to 4) with dependent factor (5) studied are given below.

	(1)	(2)	(3)	(4)
a)	Glossy score	Leaf drooping depth	Trichomes (adaxial)	Leaf surface wetness
b)	Glossy score	Seedling vigor	Trichomes (adaxial)	Leaf surface wetness

Note: The results of combination "a" is presented here for both the shoot fly parameters in sowing 1 and egg count in sowing 2. The results of combination "b" is tested for % deadhearts in sowing 2. Factors in both the combinations were chosen considering their correlation coefficients to the shoot fly parameters.

4.6.3 Path Coefficients of various factors on shoot fly parameters

The direct and indirect effects of the factors examined in the combinations mentioned above on the shoot fly parameters (no. of eggs on eight plants (eggcount) and % deadhearts) in the sorghum genotypes are given in Tables 16 to 18.

4.6.3.1 Number of eggs on eight plants (Egg count)

Combination "a" in sowing 1 explained the suitability of the morphological factors for the performance of genotypes across the shoot fly parameters (egg count and % deadhearts) to an extent of 56 and 78% (residual variabilities are 44 and 22%) respectively.

The correlation coefficients (r) of glossy score with egg counts are 0.55 and 0.66 in sowings 1 and 2 respectively. These estimates consisted of four components, the relative contribution of which are given in Tables 16 and 17. Thus, we have :-

	Sowing 1	**Sowing 2**
Egg counts (no. of eggs on eight plants) Vs glossy score	0.55	0.66
Direct effects Glossy score Vs Egg count	0.08	0.26
Indirect effects of glossiness via leaf drooping depth	0.06	0.02
Indirect effects of glossiness via trichomes (adaxial surface)	0.03	0.17
Indirect effects of glossiness via LSW	0.37	0.19
	0.55	0.66

The direct effects of glossy score in both the sowings indicates that, with other variables held constant, higher glossy score (less glossy) will attract the shoot flies for oviposition and as a result higher egg counts (decrease resistance to shoot fly). However, there may be subtle

Table 16: **Path Coefficients of glossy score, leaf drooping depth, trichomes on adaxial surface and surface wetness of leaf in sorghum genotypes (sowings 1 and 2) in relation to shoot fly oviposition and deadheart per cent.**

Glscr	Ldd	Triad	LSW	Y	Variable (Y)
0.08*	0.06	0.03	0.37	0.55	Egg count
0.33*	0.10	0.05	0.24	0.74	% Ddhrts
-0.03	-0.14*	-0.03	-0.17	-0.39	Egg count
-0.14	-0.24*	-0.05	-0.11	-0.56	% Ddhrts
-0.03	-0.04	-0.09*	-0.33	-0.51	Egg count
-0.12	-0.08	-0.16*	-0.22	-0.59	% Ddhrts
0.05	0.04	0.05	0.55*	0.72	Egg count
0.21	0.07	0.09	0.37*	0.76	% Ddhrts

Residuals:	Eggcount	% Ddhrts
	0.44	0.22

Direct effect of morphological factor on dependent variable Y

Table 17: Path Coefficients of glossy score, leaf drooping depth, trichomes on adaxial surface and surface wetness of leaf in sorghum genotypes (sowing 2) in relation to shoot fly oviposition.

Glscr	Ldd	Triad	LSW	Y	Variable (Y)
0.26*	0.02	0.17	0.19	0.66	Egg count
-0.08	-0.08*	-0.09	-0.09	-0.35	
-0.16	-0.02	-0.28*	-0.17	-0.66	
0.17	0.02	0.16	0.29	0.67	
Residuals:	Egg count				
	0.40				

Direct effect of morphological factor on dependent variable Y

Table 18: Path Coefficients of glossy score, seedling vigor, trichomes on adaxial surface and surface wetness of leaf in sorghum genotypes (sowing 2) in relation to deadheart per cent.

Glscr	Sdvg	Triad	LSW	Y	Variable (Y)
0.45*	0.03	0.03	0.24	0.77	% Ddhrts
-0.09	-0.17*	0.00	-0.06	-0.34	
-0.28	-0.02	-0.04*	-0.22	-0.58	
0.30	0.03	0.02	0.37	0.73	
Residuals	% Ddhrts				
	0.27				

Direct effect of morphological factor on dependent variable Y

indirect effects which play an important role in masking the direct influence. A strong positive influence (0.37 and 0.19 in sowings 1 and 2) was accounted indirectly by leaf surface wetness on egg counts (Table 16 & 17) as the correlations were 0.39 and 0.53, which in turn had a large direct effects of 0.55 and 0.29 in sowings 1 and 2 respectively. The indirect effects via leaf drooping depth (0.06) and trichomes on adaxial surface (0.03) were positive and contributed very little to the path system. The net effect on the path by these indirect influences is complementary and resulting in an overall correlation (0.55 and 0.66) between glossy score and egg counts in sowings 1 and 2.

4.6.3.2 Deadheart percentage

As the damage by shoot fly is ultimately expressed in a deadheart, this trait appears to be the most important and its dependence on other factors needs to be studied more carefully. In explaining the suitability of the combination of factors in "a" and "b" for the performance of genotypes across the dependent variable (deadheart %), we have the correlation coefficients (r) of glossy score with deadheart % as 0.74 and 0.77 in sowings 1 and 2 respectively. These estimates consisted of four components just as mentioned in the path for choosing combination of factors for the dependent variable egg count. The relative contribution of each of the components is given in Table 16 and 18. Thus we have,

	Sowing 1	Sowing 2
Deadheart % Vs Glossy score	0.74	0.77
Direct effect of glossy score Vs deadheart %	0.33	0.45
Indirect effect of glossiness Via leaf drooping depth	0.10	0.03
Indirect effect of glossiness Via trichomes (adaxial)	0.05	0.03
Indirect effect of glossiness Via LSW	0.24	0.24
	0.74	0.77

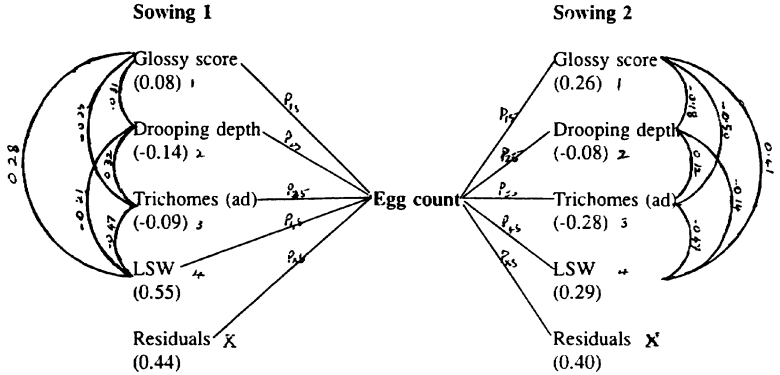
The magnitude of the unaccounted variability (residuals) in the combination of factors for sowing 1 is 22 % and the combination of factors (b) for sowing 2 is 27 %. The direct effects of the traits as given by path analysis on deadheart formation in combinations "a" and "b" for sowings 1 and 2 respectively in the order of magnitude were:

sowing 1: trichomes (ad)< drooping depth< glossy score< leaf surface wetness.

sowing 2: trichomes (ad)< seedling vigor< leaf surface wetness< glossy score.

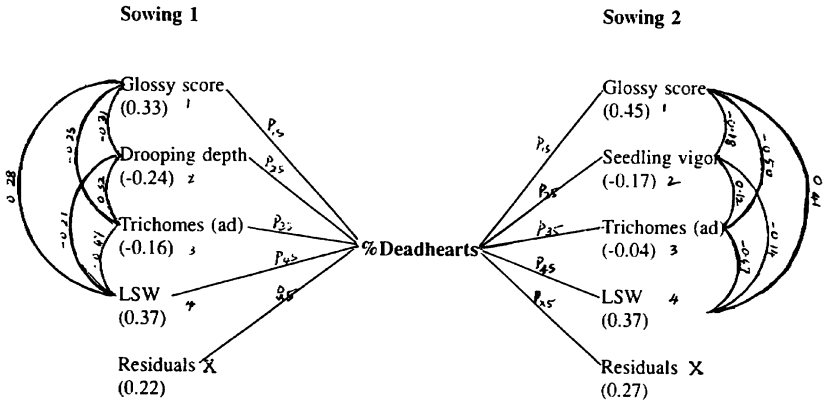
The magnitudes of the direct effects of these independent factors in combinations "a" and "b" on per cent deadhearts and correlation coefficients of morphological factors among themselves, and their inter-relationships are shown in figure 2.

Fig. 1



Path diagram and coefficients of factors influencing egg count in sorghum genotypes (sowing 1 and 2)

Fig. 2



Path diagram and coefficients of factors influencing %Deadhearts in sorghum genotypes (sowing 1 and 2)

Discussion

Chapter V

DISCUSSION

Earlier studies by Omori *et al.*, (1983), Mahad Farah (1992), Jeewad (1993) and Vijayalakshmi (1993) showed the role of some plant morphological characters on shoot fly primary resistance as measured by deadheart per cent. However, it is known that many morphological traits interact among themselves and these interactions finally contribute to the resistance, apart from the direct effect of individual traits. The present study is therefore undertaken to understand the role of interaction of a near complete set of factors on resistance. For this purpose, an array of genotypes with a varied breeding history was chosen to maximize the effects of the traits on resistance. Further, we also studied the diversity among these genotypes having supposedly diversified breeding history to help the breeder to decide on the parents for crosses in the next selection cycle to pyramid the genes for resistance.

5.1 Mean performance

All the sorghum genotypes were assessed for the morphological factors viz., mesocotyl length, seedling vigor, glossiness, leaf parameters, trichomes and LSW and shoot fly parameters-number of eggs on eight plants (indication of ovipositional non-preference) and per cent deadhearts (indication of shoot fly resistance) during kharif '96. Studies on mesocotyl length, leaf parameters, trichomes and LSW were carried out under laboratory conditions. The rest were observed under field conditions in two sowings during kharif '96.

Deadheart per cent was significantly low in genotypes IS 1054, IS 1057, IS 18551 (shoot fly resistant sources), SPSFPR 94005 B, SPSFR 94031 B, SPSFR 94003 B, SPSFPR 94002 B

(B lines) and ICSV 705 (bred restorer) in planting I. In the second planting, all the B lines including SPSFR 94002 B and SPSFR 94001 B showed less deadhearts. Genotypes IS 1054, IS 18551, ICSV 705, and ICSR 93010, ICSR 93031 (land race restorers), GD 55173 (glossy), GD 55255 (trichome-nil) also performed significantly, with lower deadheart per cent. Less susceptibility of IS 1054, IS 1057 and IS 18551 to shoot fly was reported by Taneja and Leuschner 1985.

Interestingly, egg count was low in the same genotypes that had fewer deadhearts. Genotypes SPSFR 94003 B, SPSFR 94031 B, SPSFPR 94002 B, SPSFPR 94005 B, (B lines), IS 1054, IS 1057, IS 18551, (shoot fly resistant sources), ICSV 705, and ICSV 712 (bred restorers) recorded low egg count in both the sowings. Genotypes ICSR 93010, and ICSR 93011 (land race restorers) had low egg count in first planting, although both of them showed significantly higher dedhearts. Genotypes ICSR 90002, ICSR 93031 recorded low egg count in the second planting. However, ICSR 90002 had higher deadheart percentage. Genotypes ICSR 93010 and ICSR 93031 in particular performed well for glossiness and can be utilized for transferring this trait in addition to using them as restorers. Genotypes GD 55174 (non-glossy) had significantly low egg count in the first planting but, did not result in lower deadheart per cent. None of the GD lines featured for lower egg count in the second planting. However, GD 55173 (glossy) showed resistance.

Leaf surface wetness was very less and significant in genotypes IS 18551, ICSV 705, ICSV 712 and SPSFR 94031 B. Genotypes IS 1057, SPSFR 94003 B, SPSFPR 94002 B, SPSPFR 94005 B, ICSR 93009, ICSR 93031, and GD 55290 also had a comparitively dry leaf surface. Susceptible CSH 1 and 296 B recorded more wetness of central whorl leaf. A distinctly higher LSW in susceptible cultivars (IS 1046 and CSH 1) than resistant cultivars IS 1054, IS

1057 and IS 18551) was reported by Sree (1991).

Glossiness in all shoot fly resistant sources except in IS 18729 and IS 24756 was significant and consistent in both the sowings. Among the bred restorers, only ICSV 705 was glossy in both the sowings and the other two (ICSV 712, and ICSV 88088) recorded glossiness in second sowing. B line, SPSFPR 94005 B was glossy in both plantings. Genotypes SPSFR 94001 B, SPSFPR 94002 B and SPSFR 94031 B were glossy in second and first plantings respectively. Of the glossy lines, GD 55161 and GD 55173, the later appeared glossy only in the second planting. The trichome-full lines GD 55290 and GD 55296 were significantly glossy in planting 1 & 2 respectively. Genotypes GD 55162, GD 55174 (non-glossy) and GD 55255, GD 55295 (trichome-nil) were non-glossy. Among the bred restorers, ICSR 93010 and ICSR 93031 performed significantly in the first planting.

Trichome density was significantly higher on adaxial surface in at least some gentoypes of all groups (shoot fly resistant sources, B lines, land race restorers, bred restorers, glossy lines, non-glossy lines, trichome-full lines and trichome-nil lines). Bred restorers (ICSV 705, ICSV 712, and ICSV 88088) recorded high trichome density on both (adaxial and abaxial) surfaces. B lines, SPSFR 94001 B and SPSFR 94003 B showed high trichome density on abaxial surface as well. Among the trichome full lines GD 55290, GD 55296 only the later possessed significantly high trichome density on both surfaces. Trichome-nil lines (GD 55255 and GD 55295) showed absolutely no trichomes on both the surfaces.

Seedling vigor was significant in shoot fly resistant sources (IS 1046, IS 1054, IS 1057, and IS 18551) in first planting. But, only IS 1057 was vigorous in the second planting. Land race restorers ICSR 93011, ICSR 90002, and ICSR 93031 were vigorous in plantings 1 & 2 respectively. ICSR 90009 was consistently vigorous in both the plantings. Bred restorer ICSV

88088 and trichome-nil GD 55295 were also vigorous in the second planting.

Mesocotyl length was highest in the susceptible hybrid CSH 1 followed by trichome-full GD 55296 and shoot fly resistant sources IS 18551 and IS 24756. All the land race restorers had long mesocotyl length except ICSR 93010 which had shortest mesocotyl. Among the B lines, SPSFR 94001 B, SPSFR 94031 B, SPSFPR 94002 B had significantly long mesocotyl.

Leaf droopiness followed length of the leaf and a strong positive correlation was observed between the two parameters (Table 15). Very high variation was observed in the leaf parameters and all genotypes except IS 18729 were non-significant for leaf parameters and recorded slightly droopy or droopy leaves.

An overall consideration of the mean performances of different plant morphological factors of genotypes with varied backgrounds, their contribution to the shoot fly resistance indicate that genotypes from shoot fly resistant sources (IS 1054, IS 1057, and IS 18551) and B lines (SPSFR 94001 B, SPSFR 94003 B, SPSFR 94031 B, SPSFPR 94002 B, and SPSFPR 94005 B) performed well in both the sowings compared to genotypes of all other groups. Among the bred restorers only ICSV 705 performed significantly low with regard to deadheart per cent. However, it is notable that the morphological features of all the three bred restorers (ICSV 705, ICSV 712, and ICSV 88088) are significant in at least one of the plantings and contributed to shoot fly resistance.

Genotypes ICSR 93009, ICSR 93010, ICSR 93011 and ICSR 93031 though attracted more eggs, showed comparitively low deadhearts in both the sowings. Genotype ICSR 93011 had more LSW and genotype ICSR 93010 had both, more LSW and low trichome density and yet showed fewer deadhearts. A better performance with less favorable morphological factors could be due to operation of other mechanisms of resistance (tolerance and/or antibiosis).

5.2 Group performance

The performance of the genotypes across the morphological factors (mesocotyl length, seedling vigor, glossiness, leaf parameters (length, width, drooping depth), trichomes on the leaf surface (adaxial and abaxial), leaf surface wetness) studied for shoot fly resistance (in two sowings) was tested by "Biological Grouping" using a cluster program. The objective of grouping is to put together the genotypes showing similar performance for the traits considered. Grouping helps to comprehend a set of genotypes by giving an overall picture of their performance and implies that, genotypes within a group are non-significant for "F" value. Consequently, the groups differ for their performance among themselves i e., significant "F" value.

Based on the breeding backgrounds of the thirty genotypes studied, it is possible to place them under nine groups, shoot fly resistant sources, B lines, land race restorers, bred restorers, glossy lines, non-glossy lines, trichome-full lines, trichome-nil lines and susceptible lines, without using a cluster program (Table 1). But, the genotypes within a group for example, genotypes with IS numbers (shoot fly resistant sources) showed a gradation among themselves in their performance for a particular trait or a set of traits and did not allow for a clear interpretation of their performance although, they belong to the same source. A close observation on the groups made based on clustering in sowings 1 and 2 (Table 8) indicates that, genotypes group together for they show a similar performance for the traits studied. The underlying principles for their similarity in performance are 1) similarity of breeding history/ methodology and/or 2) common parent(s)/ lineage. Parentage for the genotypes used in this study is presented in Table 19. The clustering of genotypes (presented in Table 8) based on their performance, is further validated by the similarity in breeding history or common parent(s) at least in some genotypes.

The genotypes IS 1046, IS 1054, IS 1057 (shoot fly resistant sources), ICSR 93009, ICSR

93010, ICSR 93011, ICSR 93031 (land race restorers), GD 55290 (trichome-full line), were placed in one group in planting I. It can be readily seen that with the exception of GD 55290, all others belonged to the land races which were originated in India (Table 19). Genotypes IS 1054 and IS 1057 both are non-glossy, moderately resistant and resistant respectively, according to previous breeding history but, performed equally well in the present experiment. On the other hand, the known shoot fly susceptible cultivars CSH 1 and 296 B were placed together into one group in both the sowings. It is interesting to note that the land race IS 24756, originated from Nigeria, where shoot fly does not exist is also placed together with the above two lines in both the sowings. IS 24756 was never subjected to shoot fly pressure and hence had no chance of accumulating genes for resistance through natural selection.

IS 18729, the land race from Texas A & M University stood all by itself in both the sowings. It is susceptible to shoot fly but, differed from other susceptible cultivars.

Among the shoot fly resistance sources, IS 18551 and IS 18729, IS 24756 (susceptible) performed distinctly from other resistance sources and as a result were placed in three other groups (group 4,6 and 8) in the first sowing. Also, the three gentoypes originated from different countries (Ethiopia, USA, Nigeria). The later two genotypes were susceptible and performed distinctly though they are from the same continent (Africa). So, it can be concluded that, more the number of groups considered, greater are the chances of explaining the subtle variations in the performances of the genotypes. Further more, it gives a clear information about selection of parents in breeding programs. Among the resistant sources, IS 18551 can be chosen to serve as parent to incorporate shoot fly resistance, as it was most resistant and very distinctly placed in separate groups in both the sowings.

ICSR 93009, ICSR 93010, ICSR 93011, ICSR 93031 were placed together in both the

Table 19: Parentage of the genotypes evaluated for shoot fly resistance in kharif'96.

Genotypes	Parentage/ Selection from	Comments/breeding history
IS 1046	Andhra Pradesh, India	glossy, susceptible
IS 1054	Andhra Pradesh, India	non-glossy, moderately resistant
IS 1057	Maharashtra, India	non-glossy, resistant
IS 18551	Ethiopia, Africa	glossy, resistant
IS 18729	Texas, United States of America	susceptible
IS 24756	Nigeria, Africa	susceptible
ICSV 705	[(Rs/R x EN 3257-4)-1-5-1-6-1-1 x SPV 351]-3-1-2-3-3	varietal program pedigree, resistant bred line, short
ICSV 712	[(IS 5622 x CSV 4)-20-1-2-1-1-1 x ISPYT -2/E#20]-2-2-1-1-2	varietal program pedigree, resistant bred line, tall
ICSV 88088	PS 14454 x (IS 5622 x CSV 4)-6-1-1-1-1]	varietal program pedigree, resistant bred line, short
ICSR 90002	[(c-85-2 x ICSV-1) x MR-929]-1-3	varietal program pedigree
ICSR 93009	IS 33843 (Maharashtra, India)	resistant land race, tall
ICSR 93010	IS 33844 (Maharashtra, India)	resistant land race, tall
ICSR 93011	IS 18372 (Maharashtra, India)	resistant land race, medium tall
ICSR 93031	M-35-1-36 (Maharashtra, India)	resistant land race, medium tall
GD 55161	(ICSPIB/R-MFR-S12)-236-2-3-4-2-1-3-1-1	Population source selected for isogenicline dev Glossy
GD 55162	-"- -"-	-"- non-glossy
GD 55173	(ICSPIB/R-MFR-S13)-638-5-5-1-2-3-1-2	-"- glossy
GD 55174	-"- -"-	-"- non-glossy
GD 55255	(ICSPIB/R-MFR-S13)-44-7-11-2-7-5-10-9-2-9-2-11	-"- trichome-nil
GD 55290	(-"- -170)-13-18-5-9-1-1-6-7-1-1-4-1	-"- trichome-full
GD 55295	(-"- -44)-13-2-13-3-11-9-2-10-6-3	-"- trichome-nil
GD 55296	(-"- -44)-13--2-13-3-11-9-2-10-10-4-1	-"- trichome-full
296 B	(IS 3922 x Karad local)	susceptible, non-glossy, maintainer line
SPSFR 94001 B	(ICSB 37 x ICSV 705)-13-5-2-1	B line development program
SPSFR 94003 B	(PS-21303 x SPV 386)-1-3-2-2-1	-"-
SPSFR 94007 B	(ICSB 37 x ICSV 705)-13-3-2-2-1	-"-
SPSFR 94031 B	(ICSB 102 x PS 28060-3)-4-2-2-2	-"-
SPSFPR 94002 B	(ICSB 37 x ICSV 705)-13-3-2-2	-"-
SPSFPR 94005 B	(ICSB 101 x ICSV 705)7-2-3-1	-"-
CSH 1	(CK 60 A x IS 84)	Released cultivar, first hybrid released for commercial cultivation.

sowings along with some of the resistant source lines since, their performance was almost similar. Also, the resistance source lines were obtained by farmers through natural selection, while ICSR lines are resistant land races and had tall trait in common. Genotype ICSR 90002, a cross between [(c-85-2 x ICSV-1) x MR-929]-1-3 and placed separately in the two sowings.

Genotypes ICSV 712 (tall) and ICSV 88088 (short) had CSV 4 as a common parent at some stage of the breeding program and so placed together in group 4 of sowing 2. Both these genotypes were placed closely in groups 2 and 3 respectively in sowing 1.

GD 55161 and GD 55162 originated from the same parent but selected divergently for glossy and non-glossy traits. So, we expect them to fall in different groups. However, they fell in the same groups as shown by the cluster analysis i.e., in groups 5 and 7 in sowings one and two respectively. This showed that the selection was not effective.

Also, GD 55173 and GD 55174 were selected divergently for glossy and non-glossy traits. However, considering their performance, they were placed in the same group (group 7) in first planting and in groups 9 and 7 in the second sowing. This suggests that the selection in the material might have been some what effective.

GD 55255 and GD 55295 were selected against trichome character and GD 55290 and GD 55296 for trichome nature. Although they are the selections from same parents, because of effective selection history, they occupied different places due to variation in their performances in both the sowings.

SPSFR 94001 B, SPSFR 94007 B, SPSFPR 94002 B and SPSFPR 94005 B obtained from B line development program share a common parent (ICSV 705). The first three genotypes share ICSB 37 and ICSV 705 as common female and male parents, hence performed similarly and were placed in the same group 3 and 5 in sowings 1 and 2 respectively.

SPSFR 94003 B and SPSFR 94031 were selected from different crosses and showed variation in their performance and hence they were placed in different groups.

CSH 1 is a susceptible hybrid obtained by crossing CK 60 A with IS 84 which were susceptible and placed along with IS 24756 and 296 B in both the sowings. The B line 296 B is also susceptible to shoot fly.

Selection of resistant genotypes can also be made by studying the group mean performance (Table 20) for the shoot fly parameters (egg count and deadheart per cent) in sowings 1 and 2. It is evident from table 20 that, group 8 consisting of genotype IS 18551 (sowing 1) and IS 18551 and SPSFR 94031 B (sowing 2) showed highest resistance to shoot fly among all the genotypes evaluated. Grouping of SPSFR 94031 B with IS 18551 is an indication of its ability to perform equally with IS 18551. It also implies that, best shoot fly resistant lines can be developed by further studying the traits of this particular genotype (SPSFR 94031 B) and its parents.

Group 9 in both the sowings had genotypes ICSV 705 and SPSFPR 94005 B in common and performed second best with regard to deadheart per cent. However, group 5 consisting of genotypes, SPSFR 94001 B, SPSFR 94007 B and SPSFPR 94002 B showed lower egg count in second sowing than group 9. Genotype SPSFR 94031 B discussed in above paragraph was placed along with the above genotypes in group 9 in sowing 1. It is noticeable that, though the genotype has shifted its place to group 9, its competence to perform on a par with IS 18551 is evident from group 8 of second sowing. Genotypes GD 55173 and SPSFR 94003 B also were placed along with ICSV 705 and SPSFPR 94005 B in group 9 of sowing 2. Glossiness of GD 55173 and high trichome density on leaf surfaces (adaxial and abaxial) along with low leaf surface wetness in SPSFR 94003 B have contributed to better performance.

Table 20 : Mean performance of resistance parameters for the biological groups in sowing 1 and 2 in kharif '96.

Resistance parameter	GRP1	GRP2	GRP3	GRP4	GRP5	GRP6	GRP7	GRP8	GRP9
sowing 1									
Egg count									
Mean	05.98	03.73	06.73	09.67	07.63	08.75	04.75	01.83	02.30
Deadheart%									
Mean	35.64	40.78	44.32	75.30	61.59	59.64	40.28	20.89	28.14
sowing 2	**GRP1**	**GRP2**	**GRP3**	**GRP4**	**GRP5**	**GRP6**	**GRP7**	**GRP8**	**GRP9**
Egg count									
Mean	11.96	23.64	17.29	07.59	07.35	21.45	12.21	05.84	09.73
Deadheart%									
Mean	26.53	48.91	43.03	24.75	18.26	40.22	29.73	14.32	14.62

Shoot fly resistant sources IS 1046, IS 1054, IS 1057, land race sources ICSR 93009, ICSR 93010, ICSR 93011, ICSR 93031 and trichome-full have GD 55290 in first sowing and SPSFR 94001 B, SPSFR 94007 B, and SPSFPR 94002 B in second sowing also showed better performance. Reddy and Nwanze (1995) reported that gentoypes SPSFR 94002 B, SPSFR 94003 B, SPSFR 94001 B, SPSFR 94031 B, SPSFPR 94002 B, SPSFPR 94005 B, ICSV 705, ICSV 712, ICSV 88088 and IS 18551 can be utilized as parents in breeding programs to develop shoot fly resistance.

Group 4 (sowing 1) and group 2 (sowing 2) had same genotypes IS 24756, 296 B and CSH 1 were susceptible. The performance of rest of the genotypes were in between resistant and susceptible groups and requires further evaluation for their performance to shoot fly resistance.

5.3 Correlations

5.3.1 Leaf Characters Vs Shoot fly parameters

Glossiness, trichomes and leaf surface wetness are the most important factors which have a great influence on shoot fly resistance. Glossy leaves may possibly affect the quality of light reflected, which in turn may influence the host preference leading to less egg laying and deadhearts. High trichome density on the abaxial surface of the leaf leads to less preference for oviposition by shoot fly and high density on the adaxial surface may interfere with larval movement and survival leading to lesser percentage of deadhearts. Several studies in sorghum have clearly supported this view (Maiti and Bidinger, 1979; Taneja and Leuschner, 1985; Maiti 1992; Jeewad 1993 and Vijayalakshmi 1993). The accumulation of morning dew (LSW) on adaxial surface of the central whorl leaf and its utilization by the freshly hatched larvae to glide down towards the growing point for producing deadheart was well explained by Nwanze *et al.*,

1990 and Sree (1991).

The outcome of this experiment also strengthens the strong relationship between glossiness and shoot fly parameters (egg count on eight plants and per cent deadhearts) in both sowings (Table 14). Also, it is clear that, trichome density in general contributed consistently to shoot fly resistance in both the sowings. This conclusion is in agreement with the reports by Agarwal and House (1982); Maiti and Gibson (1983); Omori *et al.*, (1983); and Karanjkar *et al.*, (1992). However, it appears that the trichomes on adaxial leaf surface contributed more than did the trichomes on abaxial surface, to the shoot fly resistance, both by reducing the ovipositional preference and also by retarding the larval movement (Table 14). Although the shoot fly lays its eggs on the abaxial surface of the leaf, high trichome density on adaxial surface may intefere with its initial attempts of search for a suitable oviposition site.

Observations on LSW indicate that, there is a strong correlation between the presence of moisture in the central whorl leaf and the shoot fly parameters. A positive and significant correlation was obtained for both egg count on eight plants and per cent deadhearts in both the sowings and is in support of earlier observations by Nwanze (1990) and Sree (1991). So, a high density of trichomes on both the surfaces or on adaxial surface, glossiness and dry surface of the central whorl leaf can offer better resistance to shoot fly.

5.3.2 Early seedling traits Vs Shoot fly parameters

Observations on mesocotyl length showed that, the longer the mesocotyl length, the greater is the egg laying and consequently deadhearts, in both the sowings. This is in contrast to the observations by Taneja and Leuschner (1985); Patel and Sukhani (1990) who reported that, quick growth of the seedlings (longer mesocotyl length and vigorous seedling growth) might

retard the first instar larva from reaching the growing point although, leaf margins may be cut without causing deadheart. However, this may not be a dependable character due to differences in depth of sowing and the availability of moisture which was reflected in coefficient of variation of 37%. Also, the performance of genotypes for this trait may collapse with heavy infestation of shoot fly under field conditions.

Vigor was highly correlated with deadheart per cent in the first sowing. Faster seedling growth and sturdiness resulted in fewer deadhearts. Vigor was positively correlated with both the shoot fly parameters but, significant only with per cent deadhearts in first sowing. Vigor did not have any appreciable impact on the oviposition and egg count on eight plants in both the sowings. Also, vigor was negative and significantly correlated with per cent deadhearts in second sowing which was a reflection of poor growth of the seedlings due to excess moisture (heavy rains in August). Taneja and Leuschner (1985); Patel and Sukhani (1990) indicated that resistant genotypes had faster plumule growth and early emergence of seedlings.

5.3.3 Leaf Parameters Vs Shoot fly parameters

A study on the leaf parameters (leaf length, width and drooping depth) in relation to the shoot fly parameters indicate that, drooping depth followed leaf length (r= 0.83) and was negatively correlated with eggs on eight plants and per cent deadhearts. Higher drooping depth might make it difficult for the freshly hatched larvae to reach the adaxial surface of the leaf and glide down towards the growing point. Correlation between glossy score and leaf drooping depth (Table 15) implies that glossy leaves are less pendant. Maiti (1993) reported that scoring for glossiness also takes into account the erectness/ droopiness of leaves as one of the important aspects and it is not uncommon to notice broad and slightly droopy leaves yet glossy. Also, as

it is difficult to set a leaf droopy limit for resistance, we may consider a slightly droopy leaf to resist the oviposition and subsequent larval movement. However, earlier reports by Vijayalakshmi (1993) state that long and erect leaves with less drooping depth can be utilized as a simple and reliable selection criterion for identification of shoot fly resistant genotypes.

Width of the leaf is of no significance either to ovipositional preference or to the per cent deadhearts. This may be because shoot fly lays its eggs close to the midrib at middle or lower half of the leaf, irrespective of the width. Also, the eggs laid close to the midrib of the leaf may take support from the closely arranged veins adjacent to it, thereby preventing the drop down of eggs. Observations also suggest that leaf width as one of the resistant factor, may not be narrow as opposed to the observation by Singh and Jotwani (1980b) who reported that resistant varieties had slightly narrower leaves than susceptible hybrid CSH 1.

5.4 Path analysis

Path coefficient analysis proposed by Wright (1921) enables to partition the correlation coefficient into effects attributed to the direct and indirect effects of the independent variables via the association between the dependent variable.

5.4.1 Number of eggs on eight plants (Egg count)

Low egg count on eight plants per plot is a measure of ovipositonal non-preference. Earlier investigations report that fewer deadheart formation is a reflection of shoot fly resistance which is due to ovipositonal non-preference (Jain and Bhatnagar, 1962; Blum,1967; Jotwani *et al.*, 1971, Soto, 1974; Omori *et al.*, 1983; Vijayalakshmi, 1993).

The factors considered in the path for the study of ovipositonal non-preference (egg count)

in the first and second sowings are glossy score, leaf drooping depth, trichomes on adaxial surface and leaf surface wetness (Table 16 and 17). In the first sowing, path analysis showed that the contribution of LSW (0.55) to egg count far exceeded rest of the parameters studied. Leaf drooping depth (-0.14) influenced egg counts more than did trichomes on adaxial surface (-0.09) and glossy score (0.08).

In the second sowing too, LSW (0.29) was significant in affecting shoot fly oviposition. The contribution of trichomes on adaxial surface (-0.28) and glossy score (0.26) to egg count was marginally less compared to LSW (0.29). Drooping depth contributed to -0.08. However, a large proportion (0.44% and 0.40% in first and second sowings respectively) was left unexplained by the factors studied in the path. It is clear from the above that the effects of factors studied in the path for their influence on non-preference for oviposition by shoot fly are postive with regard to LSW and negative with respect to trichome density, leaf drooping depth and glossy score i.e., low leaf surface wetness, high trichome density, more glossiness and high drooping depth contributed to significant reduction in egg laying by shoot fly. It can be concluded from the magnitude of the effects, considering both the sowing that, LSW is the most important factor followed by trichomes on adaxial surface, glossy score and drooping depth.

The indirect effect of these parameters via the other factors chosen in the path in the first sowing (Table 16), indicate that, the morphological factors- glossy score, trichomes on adaxial surface and leaf drooping depth were influenced greatly by LSW (better performance of these traits in presence of LSW) and showed an indirect effect of 0.37, -0.33 and -0.17 respectively on egg count. Glossy score via leaf drooping depth and trichomes on adaxial surface showed an indirect effect of 0.06 and 0.03 respectively, which are insignificant compared to its association with LSW (0.37). The indirect effect of leaf drooping depth via glossy score and trichome density

was equal (-0.03). Trichomes on adaxial surface via glossy score and drooping depth contributed indirectly to an extent of -0.03 and -0.04 respectively. Glossy score and trichomes (0.05) and drooping depth (0.04) had little impact in influencing LSW to affect egg count. However, LSW on its own contributed 0.55 and in presence of other factors lead to an overall effect of 0.72.

In the second sowing, the indirect effects (Table 17) of glossy score, trichomes on adaxial surface and drooping depth via LSW were 0.19, -0.17 and -0.08 respectively. Glossy score interacted with trichomes on adaxial surface apart from LSW and indirectly contributed to an extent of 0.17. Trichomes on adaxial surface interacted with glossy score and contributed -0.16. The indirect effects of LSW via glossy score and trichomes on adaxial surface are almost equal, 0.17 and 0.16 respectively. Drooping depth neither influenced egg counts directly on its own nor indirectly in association with other parameters. A quick comparison of these indirect effects with those in the first sowing clearly reflects the fact that, the association of morphological factors studied in the path with LSW contributed significantly in the order of LSW via glossy score, LSW via trichome density, LSW via leaf drooping depth and have a great implication to shoot fly resistance (oviposition). Plant breeders can certainly take advantage of this favorable association of LSW with other factors especially glossy score, trichomes on adaxial surface and incorporate these traits into a single gentoype for resistance to shoot fly. Omori *et al.*, (1983) at ICRISAT considered number of eggs per plant along with glossiness and trichome density as independent variables affecting deadhearts and finally concluded that the effects of trichomes and glossiness were marginal on deadhearts as the shoot fly eggs had accounted for most of the variability in deadhearts. However, a significant reduction of the oviposition is possible by emphasizing on low LSW, high glossiness and increasing the trichome density.

5.4.2 Per cent deadhearts

Damage by shoot fly is ultimately identified by deadheart symptom which in turn reflects the level of resistance. The combination of traits, glossiness, seedling vigor trichomes on adaxial surface and LSW in the first sowing and seedling vigor instead of leaf drooping depth along with other traits considered in first sowing, were chosen in second sowing for the study of resistance (Table 16 and 18).

LSW, just as it contributed to egg count in both sowings, did influence deadhearts too in the first sowing. The direct contribution of LSW to deadheart per cent was 0.37, followed by glossy score (0.33), leaf drooping depth (-0.24) and trichome density on adaxial surface (-0.16). In the second sowing, glossy score markedly influenced deadheart per cent and showed a direct effect of 0.45. However, LSW contributed significantly to an extent of 0.37. Other factors-seedling vigor and trichomes on adaxial surface contributed -0.17 and -0.04 respectively. The morphological factors studied in the path for deadhearts in sowings 1 and 2 revealed that shoot fly resistance can be achieved by more glossiness, less LSW, high trichome density and high drooping depth. Omori *et al.*, (1983) also indicated the need to place a major emphasis on glossiness in increasing shoot fly resistance though, path analysis considered it as less important. Interestingly, seedling vigor (studied only in second sowing) contributed positively to deadheart per cent. This might be due to coincidence of peak incidence of shoot fly with the emergence of seedlings. Although, there is no report indicating a positive impact of seedling vigor on shoot fly resistance, this factor may lose effectiveness under high fly pressure, as it happened in second sowing when the eggcounts where comparitively higher than in the first sowing.

Indirect effects studied among the morphological factors in the path for deadheart per cent in first sowing (Table 16) indicate that, glossy score via LSW contributed significantly (0.24).

LSW was also profoundly influenced by glossy score (0.21). The indirect effect of LSW via drooping depth and trichome density was not significant. Both glossy trait and LSW influenced drooping depth (-0.14 and -0.11 respectively). Trichome density showed more indirect effect on deadheart per cent through LSW (-0.22) than glossy score (-0.12) and drooping depth (-0.08). In the second sowing, the indirect effect (Table 18) of glossy score via LSW was 0.24 which was exactly equal to the indirect effect of glossy trait in a similar association with LSW in the first sowing. Seedling vigor and drooping depth were inconsequential in influencing glossy score to per cent deadhearts. The indirect effects of LSW via glossy score (0.30) and, trichome density via glossy score (-0.28) and LSW (-0.22) were of considerable importance in their contribution to per cent deadhearts. The unexplained part of the path (including both direct and indirect effects) was 27% and 22% in first and second sowings respectively. Although the residuals are comparitively low and most of the components thouroughly explained their effects and interactions on deadheart per cent, further improvement in shoot fly resistance can be achieved by placing emphasis on glossy score and LSW and identifying other morphological factors which could probably play an important role. Vijayalakshmi (1993) considered height backgrounds and reported that leaf drooping depth in talls and lack of trichomes and glossiness in dwarfs were found to be more effective factors in explaining the variability than plant height, in number of eggs per 100 plants.

It can clearly be inferred from path analysis that, greater the contribution of individual factor(s) and/or the interaction among the factors chosen to form the path, higher is the possibility of explaining the residuals and inturn the influence on resistance. In other words, smaller the residuals, more are the interactions among the facotrs eg. deadhearts in first sowing and egg count in second sowing (residuals 22% and 40% respectively).

5.5 Conclusions

Mean performance of the morphological factors and their contributions to shoot fly resistance indicate that genotypes from shoot fly resistant sources (IS 1054, IS 1057, IS 18551) and almost all B lines (SPSFR 94001 B, SPSFR 94003 B, SPSFR 94031 B, SPSFPR 94002 B, SPSFPR 94005 B) performed well compared to genotypes from all other groups. Among the above genotypes IS 18551 and SPSFR 94031 B were most resistant to shoot fly in both the sowings.

The consistence of genotypes (similarity in performance with regard to the groups in which they are placed) could be due to the fact that the genotypes within a group have similar breeding history or common parent(s)/ lineage. However, it is not always true and a greater emphasis have to be given to the final performance across the traits considered, than to their backgrounds. Although, it is hypothetically true to place the genotypes according to their breeding history, virtually it may not be accomplished and the genotypes may group with cultivars having a totally different breeding history which may be due to differences in breeding methodologies followed from time to time and also the presence of genes at different loci for a particular trait. This idea might perhaps enlighten breeders about the fact that, higher levels of shoot fly resistance can be achieved by selecting the genotypes which perform markedly from the rest of the cultivars of the same group, with those better performers having a different breeding history there by emphasizing on the importance of both historical background and the ultimate performance of genotypes in deciding on the parents for crosses in resistance breeding programs.

Path analysis showed that low LSW contributed maximum to ovipositonal non-preference by shoot fly, followed by trichomes (high) on adaxial surface and glossiness (high) in sowings

1 and 2. Deadheart per cent was reduced by both LSW (low) and glossiness (high).

Indirect effects on path analysis indicated that the inter-relationships of LSW with glossy score and LSW with trichome density in that order were significant in lowering deadheart per cent. The interaction of LSW, glossy score and trichomes on adaxial surface affected oviposition non-preference by shoot fly. However, further studies have to be made on other morphological factors and some biochemical factors to understand this mechanism, as there was a large residue left unexplained.

Finally, it is important to understand and consider the integrated effects of the characters over a developmental period for shoot fly resistance, because trichome density was recorded only on 5th leaf surface, measurements for leaf parameters were taken on 4th leaf alone, oviposition was studied only on 4th and 5th leaves. But, shoot fly is known to oviposit over different growth stages, from 3rd to 7th leaf stage (Vijayalakshmi 1993). So, the overall effects of the traits on all growth stages under different seasons/locations including a large number of lines from varied backgrounds should be evaluated for clear elucidation of the influence of plant factors in sorghum resistance to shoot fly.

Summary

SUMMARY

Investigation on the "Componential analysis of plant morphological factors associated with sorghum resistance to shoot fly *Atherigona soccata* Rondani," was carried out at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Patancheru, Andhra Pradesh, India during kharif '96. The effect of morphological factors on shoot fly resistance was studied by considering thirty genotypes having a varied breeding background.

The morphological factors viz., mesocotyl length, seedling vigor, glossy score, 4th leaf parameters (length, width and drooping depth), trichomes on 5th leaf (abaxial and adaxial surfaces) and leaf surface wetness (LSW) were studied in relation to shoot fly parameters (egg count and deadheart per cent). Seedling vigor, glossy score and shoot fly parameters were studied under field conditions in two sowings during kharif '96. Mesocotyl length, leaf parameters, trichomes on the leaf surface and leaf surface wetness were studied under laboratory conditions. The data obtained was analyzed for mean performance of individual genotypes, and groups of genotypes for various factors and the study of correlations and inter-relationships of various morphological factors on shoot fly resistance parameters using path coefficient analysis.

The mean performance of all the genotypes across the morphological traits studied for shoot fly resistance indicated that shoot fly resistant sources (IS 1054, IS 1057, and IS 18551) and Bred resistant B lines (SPSFR 94001 B, SPSFR 94003 B, SPSFR 94031 B, SPSFPR 94002 B and SPSFPR 94005 B had desirable morphological features which resulted in lower deadheart per cent. Genotypes IS 18551, ICSV 705, SPSFR 94031, and SPSFPR 94005 B performed consistently in both the sowings and were found to be most

resistant to shoot fly, of all the genotypes studied.

Group performance was tested by biological grouping using a cluster program. Biological grouping placed together the genotypes with similar performance for the morphological traits and the shoot fly parameters. Similarity in performance of the genotypes was due to either similarity of breeding history/methodology, common parents or both. Shoot fly resistant sources and land race restorers performed similarly and were grouped together indicating their origin (farmers collection). Bred restorers and B lines also showed fewer deadhearts and possessed favorable morphological traits that resist shoot fly and they formed into a separate group. It is therefore suggested that, crossing of the genotypes belonging to different groups followed by selection may result in further gains for resistance to shoot fly. Even genotypes with common parents trichome-full lines (GD 55290 and GD 55296) and trichome-nil lines (GD 55255 and GD 55295) fell into different groups indicating that common parentage is not sufficient indicator to conclude that the sister lines do not differ for genes contributing to resistance.

Correlation studies indicated that presence of moisture in the central whorl (LSW) had strong correlation with egg count on eight plants and per cent deadhearts. Glossy intensity and trichome density on adaxial surface of leaf were next to LSW in lowering shoot fly oviposition and subsequent deadheart per cent. Mesocotyl length and seedling vigor did not have much impact. Among the leaf parameters only leaf drooping depth was found to be influencing both the shoot fly parameters in a negative way.

Path analysis for egg count indicated high direct contribution from LSW (0.55) followed by trichome density on adaxial surface (-0.28) and glossiness (0.26) in sowings 1 and 2 respectively. Indirect effects of LSW via glossy score and trichomes on adaxial

surface are most significant (0.37 and -0.33 in first sowing and 0.19, -0.17 in second sowing respectively). The direct effects for deadheart per cent was contributed more by LSW (0.37) in the first sowing and glossy score (0.45) in the second sowing. Glossy score (0.37), trichomes on adaxial surface (-0.24) and leaf drooping depth (-0.16) followed in that order in the first sowing. LSW (0.24 in both sowings) and LSW via glossy score (0.21, 0.30 in sowings 1 and 2 respectively were very effective. Trichomes on adaxial surface via LSW contributed -0.22 in the first sowing. All in all LSW (low) via glossy trait (high) and trichome density on adaxial surface (high) interacted favorably contributing to shoot fly resistance in both the sowings.

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