STUDY OF THE INTERRELATIONSHIP OF IMPORTANT TRAITS CONTRIBUTING TO THE RESISTANCE OF SHOOT FLY IN *Sorghum bicolor* (L.) Moench

By

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CERTIFICATE

Ms. Kavitapu Vijayalakshmi has satisfactorily prosecuted the course of research and that the thesis entitled **STUDY OF THE INTERRELATIONSHIP OF IMPORTANT TRAITS CONTRIBUTING TO THE RESISTANCE OF SHOOT FLY IN *Sorghum bicolor* (L.) Moench** 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 her for a degree of any University.

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This is to certify that the thesis entitled **"Study of the interrelationship of important traits contributing to the resistance of shoot fly in *Sorghum bicolor* (L.) Moench"** submitted in partial fulfilment of the requirements for the degree of **'Master of Science in Agriculture'** of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bonafide research work carried out by **Ms. Kavitapu Vijayalakshmi** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

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

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K. Vijaya Lakshmi

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DECLARATION

I declare that this thesis entitled **STUDY OF THE INTERRELATIONSHIP OF IMPORTANT TRAITS CONTRIBUTING TO THE RESISTANCE OF SHOOT FLY IN *Sorghum bicolor* (L.) Moench** 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

Investigations on the interrelationships of important traits that contribute to shoot fly (*Atherigona soccata* Rondani) resistance in sorghum genotypes selected earlier emperically for shoot fly resistance were carried out at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India in the 1991-92 postrainy and 1992-93 rainy seasons in shoot fly infested and uninfested conditions.

The experiment was conducted in completely randomised block design with ten tall and ten dwarf genotypes originating from the same pedigree or pedigrees of related parents. Data recorded on various morphological, agronomic traits and shoot fly resistance parameters (percentage plants with eggs, number of eggs/100 plants, deadheart percentage) were subjected to statistical analyses to estimate mean performance, genetic variances for different traits, the direct and indirect effects of various morphological, and agronomic traits on shoot fly parameters.

Emperical selection for shoot fly resistance and grain yield was effective as the tall lines, SPSF 1128 and 1169 and the dwarf lines, SPSF 1170 and 1101 in the postrainy season, and the tall lines, SPSF 1029 and 1118, and the dwarf lines SPSF 1014 and 1126 in the rainy season showed shoot fly resistance with desirable grain yield. Grain yield under infestation was reduced by 14 per cent in the talls, and 18 per cent in the dwarfs in the postrainy season, while the reduction was 70 per cent in the talls, and 61 per cent in the dwarfs in the rainy season when compared to the yield potential under uninfested condition. The talls were superior (12 per cent in infested and 7 pe cent in uninfested condition) to the dwarfs in the postrainy season, while the dwarfs were superior (25 per cent in infested, and 3 per cent in uninfested condition) in the rainy season.

Shoot fly infestation with infestor row/fish meal technique was extremely high in rainy season and moderate in postrainy season. Heritabilities for various traits and their genetic gains were high under moderate (about 85 per cent deadhearts in the susceptible checks) infestation. The tall genotypes were slightly more vigorous and glossy and had long, broad, and droopier leaves with more dense trichomes and higher ovipositional preference (in postrainy season) than dwarf genotypes. At maturity dwarfs were significantly short compared to tall genotypes while there were no differences in their heights in the early stage of development in both the seasons.

Path analyses indicated that selection should aim to reduce drooping depth (perhaps without reducing leaf lenghth), and increase glossiness intensity and early plant height in talls to further enhance the levels of shoot fly resistance. In dwarfs, increasing trichome density, glossiness intensity and leaf length (without increasing droopiness or reducing early plant height) would be desirable. However, the correlations and heritability studies indicated that undue emphasis should not be placed on increasing trichome density (in dwarfs) or reducing the leaf droopiness (in talls) to increase shoot fly resistance as this might lead to reduced grain yields. Therefore, the traits shown to be neutral such as glossiness, early plant height and vigour should be given more emphasis in the selection in both talls and dwarf groups.

Thus, the study showed the need to have separate selection schemes to breed dwarf (female) lines and tall (restorer) lines in sorghum.

INTRODUCTION

CHAPTER I

INTRODUCTION

The shoot fly, *Atherigona soccata* Rondani has been reported as a pest on sorghum from almost all sorghum growing (*Sorghum biocolor* L Mocnch) areas of the world i.e. in Asia, Africa and Mediterranean Europe. Its occurance has not been recorded in America and Australia (Young and Teetes, 1977). In India high yielding hybrids are highly susceptible to shoot fly infestation which often results in severe damage (Rao and Rao, 1956, Jotwani and Srivastava, 1970).

Conventional methods for the control of shoot fly are not practical or cost effective for subsistence farmers. Resistant cultivars are a realistic alternative to chemical control, if they are able to compete economically with the commonly used hybrids and varieties.

The difficulty in recognizing the genetic variation in the host species limited the potential of plant breeding for pest resistance. Ponniaya (1951a) first attempted to screen 214 sorghum lines for shoot fly resistance. Later, Starks (1970) developed a field screening methodology for host plant resistance and the resistance sources that existed have been partly used by the breeders.

Blum (1967) and Jotwani *et al.* (1971) suggested that resistance to shoot fly in sorghum was due to ovipositional non- preference. The factors responsible being trichomes on the abaxial surface (Maiti and Bidinger, 1979) and glossy leaves - pale green smooth and shining leaves (Agarwal and House 1982) but the efficacy of this mechanism was reduced under heavy shoot fly population pressure (Singh and Jotwani, 1980a). Singh and Jotwani (1980b) and Raina *et al.* (1981) presented direct evidence of antibiosis in some selected cultivars and Doggett *et al.* (1970) identified recovery resistance/tolerance which is also promising.

Several factors associated with resistance are in the promising land races that have been selected over a period of time for shoot fly resistance, but in general, are not desirable agronomically. These resistant lines are tall and therefore susceptible to lodging and are photosensitive, late maturing and low yielding. They have been utilised in breeding programmes in an attempt to transfer the resistance to new high yielding cultivars. A number of varieties released for commercial cultivation have been developed by incorporating the resistant genes from one or more of the land races. This work resulted in developing high yielding and shoot fly resistant varieties (ICRISAT, 1989).

The present study was initiated to generate information that taller sorghums may possess greater resistance to shoot fly and yield potential than the shorter ones now widely grown for grain production (Singh and Rana, 1986). The degree of resistance and yield increase depended on the parental height. The relationship between height and yield has been established by several investigators (Graham, 1967). However, these investigations were carried out with lines that differed genetically and were divergent for other characters as well. The lines for this present investigation were chosen in a way that they differ only for height while the genetic background for other traits is either same or varies at random.

The level of resistance to shoot fly in the germplasm is not satisfactory for kharif and rabi seasons. There is a need to identify diverse resistant sources which would help in improving the shoot fly resistance levels. An understanding into the mechanisms/traits associated with shoot fly resistance is therefore important. Knowledge of the genetics of insect resistance is as important as the mechanisms of resistance. Selection for shoot fly resistance may be more effective when based on marker traits provided if they are highly heritable and the marker traits are not themselves negatively associated. Hence, an understanding of the association among the independent traits and their effects (direct or indirect) on the dependent variable (shoot fly resistance) is of paramount importance.

Hence, the present investigation was carried out involving relatively homogeneous breeding lines, but differing for plant height with the following objectives.

1. To assess the performance of the breeding lines that were bred under emperical selection for the traits related to shoot fly resistance.

2. To quantify the inter-relationships among these traits and shoot fly resistance, and decide the most causal factor(s) contributing to shoot fly resistance in various plant height backgrounds.

3. To evaluate and determine the genetic variance for various important traits contributing to shoot fly resistance in different height groups.

4. To formulate a selection strategy for breeding for resistance to shoot fly in sorghum in different height groups.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

It has been known that early planting, increase in seed rate and removal of damaged plants, and seed or slurry treatment with carbofuran are known to reduce the damage due to shoot fly *A. soccata* on sorghum. However, under severe infestation their utility was found reduced (Vedamoorty *et al.*, 1963, Jotwani and Young, 1972). These methods of control, particularly chemical seed treatment, are not practical for subsistance farmers. Therefore it is important to breed shoot fly resistant sorghum varieties with high yield which can be used as a major component in an integrated pest management scheme for the control of this pest.

2.1 VARIABILITY FOR RESISTANCE TO SHOOT FLY IN SORGHUM GERMPLASM

Ballard and Ramachandra Rao (1924) first reported *A. soccata* as a pest species on sorghum. Twenty years later Ponnaiya (1951a) initiated the study by planting a collection of 214 sorghum types and selecting 15 local cultivars which were relatively less infested than others and thus reported the existence of resistance to shoot fly in sorghum. Rao and Rao (1956) tested 42 varieties of sorghum and identified 14 which showed useful resistance to shoot fly. Jain and Bhatnagar (1962) screened 196 varieties and found 8 varieties which showed no damage by shoot fly. Singh *et al.* (1968), Pradhan (1971), Young (1972) at AICSIP in 1960's, Jotwani (1978), Rao *et al.* (1978), Jotwani and Davies (1980) at ICRISAT in 1970's and 1980's have evaluated world germplasm sorghum collection in search of sources of resistance to shoot fly. Cultivars selected by Young (1972) as promising resistant sources were not immune to shoot fly and level of resistance was low to moderate. The search for resistance continued in different parts of the world - (Blum 1965, 1968 and 1972a) in Israel, Doggett and Majisu (1965 and 1966), Doggett *et al.* (1970) in East Africa, and Harwood *et al.* (1972) in Thailand.

In India, Rao (1972) identified *maldandi* or *dagadi* types of Indian winter sorghum or the *allu* types usually mixed with *maldandi* or *dagadi* types as sources of resistance. Mostly purple pigmented plant types having greater levels of resistance were reported by Singh *et al.* (1981). The cultvars, IS 1151, IS 4776, IS 5469, IS 5470 and IS 5490 and varities CSV 5, CSV 6, SPV 8, SPV 13, SPV 14, SPV 19, SPV 29, SPV 34, SPV 70, P 37, P151, E 303 and VZM2B showed resistance to both shoot fly and stem borer, while IS 1054, IS 1082, IS 2312, IS 4646, IS 4840, IS 5469, IS 5604 and IS 5830 possessed resistance to shoot fly and mite (Singh *et al.*, 1981). An Indian local variety, Aispuri (IS 1151) has multiple resistance to shoot fly, stem borer and midge.

2.2 MECHANISMS OF RESISTANCE

All the three mechanisms, ovipositional non-preference, antibiosis and recovery resistance suggested by Painter (1951) are known to exist in sorghum for shoot fly resistance. Rana *et al.* (1981) attributed resistance to a cumulative effect of non-preference, due to some morphological factors and antibiosis.

2.2.1 Non-preference or Antixenosis

Ovipositional non-preference by the shoot fly in resistant cultivars was not detected by Ponniaya (1951a, 1951b and Rao and Rao 1956) in their studies on sorghum resistance. Jain and Bhatnagar (1962) screened 196 cultivars and first reported that resistant cultivars had significantly less oviposition compared to susceptible ones. Later, a number of workers reported non-preference for oviposition as a primary resistance mechanism for shoot fly in sorghum. Blum (1967), Jotwani *et al.* (1971), Soto (1974), Narayana (1975), Sharma *et al.* (1977), Singh *et al.* (1981), Singh and Jotwani (1980a), Mote *et al.*, (1986) and Blum (1969b) reported that non-preference was evident when evaluated under low shoot fly population. Singh and Jotwani (1980a) and Borikar *et al.* (1982) indicated that the effiency of this mechanism was reduced under heavy shoot fly population.

Jotwani *et al.* (1971), Teli *et al.* (1983), Unnithan and Reddy (1985) and Taneja and Leuschner (1985) reported that susceptible cultivars were preferred for egg laying in terms of higher number of eggs per plant and plants with eggs. Significantly, higher egg laying was observed on susceptible cultivars CSV 1 and CSH 1. Under no choice condition (in cages) oviposition was equal on both resistant and susceptible cultivars (Jotwani and Srivastava, 1970, Singh and Narayana, 1978). Taneja and Leuschner (1985) reported that more eggs were laid on resistant cultivars particularly IS 1082, IS 2122 and IS 2195 than under multiple choice conditions indicating the resistance of ovipositional non-preference under multiple choice conditions. Occasionally, ovipositional non-preference was also operative in the absence of preferred host(s) (Jotwani *et al.*, 1974; Wongtong and Palanakamjorn 1975 and Raina *et al.*, 1984). Thus ovipositional non-preference is not stable and tends to break down under no choice conditions and heavy shoot fly population.

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

The number of eggs deposited and deadhearts showed significant and positive correlation. Rana *et al.* (1975) and Sharma *et al.* (1977) indicated that varieties preferred for oviposition showed a high degree of deadheart formation and also established the group differences between susceptible and resistant varieties for deadheart percentage. Delobel (1982) concluded that the pattern of distribution of eggs differed between lines. Field and laboratory observations revealed that the placement of eggs on the leaves tended 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.

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

Raina (1982) studied the oviposition behaviour of shoot fly and reported that color, texture and width of the sorghum leaf were important factors in selection of the oviposition substrate by the female fly. Soto (1974) and Mote *et al.* (1986) reported that leaves of some of the sorghum cultivars resistant to shoot fly were pale green compared to the dark green color of susceptible cultivars. Narrowness of leaves reduced both deadhearts and egg laying as shoot fly gets less area for egg laying compared to broad leaved plants (Mote *et al.*, 1986). Bapat and Mote (1982) related leaf colour and hairiness (trichomes) as non-preference mechanisms.

2.2.2 Morphological Characters Possibly Associated with Shoot Fly Resistance

Various authors have suggested trichomes on the leaf lamina, glossy leaf trait at seedling stage, seedling vigour, seedling height, leaf length and breadth, leaf sheath hardness, and stem thickness as contributing to resistance in sorghum to shoot fly.

2.2.2.1 Leaf and Stem Characters. The leaf breadth and leaf length are different among susceptible and resistant lines of the same age. The differences in leaf width of susceptible and resistant varieties, though not statistically significant, indicate that leaves of resistant varieties are some what narrower than that of the susceptible hybrid, CSH 1 (Singh and Jotwani, 1980d). Khurana (1980) reported negative correlation of shoot fly infestation with leaf breadth and leaf length whereas Sandhu *et al.* (1986)

showed positive correlation of leaf breadth and leaf length with deadheart percentage in different varieties.

Sharma and Chaterji (1971) established a positive correlation between the hardness of the stem and the resistance to *Chilo zonellus* in maize (Swinhoe). However, Singh and Jotwani (1980d) showed that the extent of hardness of leaf sheath was high only in IS 5490 compared to other resistant and susceptible varieties to shoot fly.

Singh (1986) and Patel and Sukhani (1990) showed that stem length, ratio of stem length to stem width and length of internode were negatively significantly correlated with shoot fly oviposition and deadheart formation. Long and thin but sweet stem with longer internodes and short peduncle length can be taken as resistant sorghum genotype.

2.2.2.2 <u>Mesocotyle Length, Early Vigour and Growth of Seedlings</u>. Mesocotyle refers to the internode between the scutellar node and coleoptile node (Fahn 1974). Mesocotyle length differed significantly among the genotypes. Faster plumule growth would ensure the early emergence of seedlings. Rapid growth of seedlings might retard the first instar larva from reaching the growing point, although leaf margins might 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 vigour increased the susceptibility to shoot fly (Taneja and Leuschner 1985; Patel and Sukhani

1990).

After hatching, the larva migrates downwards towards the growing point, cuts the main shoot which dries up and turns into the characteristic deadheart. The main shoot is responsible for the growth and height of the plant. Shoot fly infestation causes suppression of growth and height of the plant.

It was observed that faster seedling growth and taller varieties were less susceptible to shoot fly (Jain and Bhatnagar (1962), Blum (1969a), Krishnananda (1969), Raghunatha *et al.* (1972), Narayana (1975) Sharma *et al.* (1977), Jotwani (1978), Mate *et al.* (1979), Khurana (1980), Singh and Jotwani (1980d), Borikar *et al.* (1981), Jadhav *et al.* (1986), Mote *et al.* (1986), Singh (1986) and Dalvi *et al.* (1990). Mate *et al.* (1979) indicated that most resistant types grew taller and had higher growth rate than susceptible ones eventhough the growth rate was not significant. However, Shivankar *et al.* (1989) provided evidence that varietal tolerance did not have definite relation so far as the height of the plant was concerned and the degree of pest incidence and relatively tolerant germplasm were found in all the categories of height ie tall > 11 feet, dwarf 4-6 feet and medium height 7-10 feet.

2.2.2.3 Trichomes. Role of trichomes as a deterring factor was suggested by Maiti and Bidinger (1979) after screening 8000 lines against shoot fly. They reported that resistant lines possessed trichomes on the abaxial surface of the leaf. The wild species of sorghum were found to be immune to shoot fly and had a high trichome density on the lower surface of the leaves (Bapat and Mote 1982). Presence of trichomes on the leaf surface was preferred to a lesser frequency both for oviposition of shoot fly and subsequent larval damage and this was reported by several workers (Blum 1968, Maiti and Bidinger 1979, Maiti *et al.*, 1980 and Taneja and Leuschner 1985). The resistant cultivars, IS 2146, IS 3962, and Is 5613 had high density of trichomes on the abaxial leaf surface while susceptible hybrid CSH 1 was found to lack trichomes.

They reported further that trichomes on the lower leaf surface might have more effect on the behaviour of the adult flies during oviposition (since eggs are laid on lower leaf surface) than on larval movement. However, the trichomes on the upper surface may interfere with larval movement and survival since larvae immediatley after hatching move on to the upper sorface and then towards the growing point. Shoot fly larvae spent little time on the leaf on which the egg was laid compared to time taken to travel from the funnel to the growing point (Nwanze *et al.*, 1990).

Moholkar (1981), Omori *et al.* (1983) and Patel and Sukhani (1990) observed positive correlation for trichome density in plants resistant to shoot fly. Jadhav *et al.* (1986) also reported negative relationship between trichome density as well as trichome length and shoot fly damage in sorghum genotypes. Agarwal and House (1982) found that the level of resistance was greater when both the glossy and trichome traits occured together.

2.2.2.4 **Glossiness**. Most of the lines resistant to shoot fly also exhibited the glossy leaf characters during the seedling stage and (Jotwani *et al.*, 1971; Blum, 1972b; Bapat *et al.*, 1975; Maiti and Bidinger, 1979; Maiti *et al.*, 1980; Bapat and Mote 1982; Omori *et al.*, 1988). Glossy leaves might possibly affect the quality of light reflected from leaves and influenced the orientation of shoot flies towards their host plants. Glossy leaves might also influence the host selection due to chemicals present in the surface waxes and/or leaves.

The association of both the glossy leaf type and trichomes with shoot fly resistance in sorghum has been supported by Maiti and Bidinger (1979). A study of four combinations, glossy leaf + trichomes, glossy leaf only, trichomes only and neither, revealed that the mean deadheart percentages were 60.7, 70.9, 83.5 and 91.3 respectively. Thus results suggested 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.

2.2.2.5 **Anatomical Characters**. Ponnaiaya (1951a) and Blum (1968) reported that the possible factors for shoot fly resistance in sorghum could be the deposition of silica bodies and lignification and thickness of the cell walls of leaf sheath. Narayana (1977) found that greatest density of dumbbell shaped silica bodies mm^{-2} of abaxial epidermis at the base of the third leaf sheath and least distance between silica bands in resistant lines must be rendering some hardness of the leaf sheath. Ponnaiya (1951a), Blum (1968) and Bothe and Porkharkar (1985) reported the appearance of silica bodies in resistant varieties from fourth leaf stage and from sixth leaf stage in susceptible ones. They suggested that the relatively late appearance of these silica bodies in the susceptible varieties made them prone to shoot fly attack over a long period.

2.2.2.6 Physiological Characters. Cultivars with high transpiration rate are preferred for oviposition (Mate *et al.*, 1988). Raina *et al.* (1981) reported that leaf moisture was important for the movement of the larva to the growing point and deadheart formation. Subsequently Nwanze *et al.* (1990); Sree (1991); Nwanze *et al.* (1992a and 1992b) indicated that physiological appearance of surface wetness of the central shoot leaf varies between the resistant and susceptible genotypes.

2.2.3. Antibiosis

Although ovipositional non-preference appears to be the primary mechanism for shoot fly resistance in sorghum, evidence of some degree of antibiosis is also available (Jotwani and Srivastava 1970; Blum 1972b; Young 1973; Soto 1974; Sharma *et al.*, 1977). Singh and Jotwani (1980b) and Raina *et al.* (1981) presented direct evidence of antibiosis in selected sorghum cultivars. The survival and development of shoot fly was adversely affected when the pest was reared on resistant varieties and the fecundity of female shoot flies was higher when raised on susceptible Swarna than on the moderately resistant lines, IS 2123 and IS 5604 (Singh and Narayana 1978).

Singh and Jotwani (1980b) found that the larval and pupal periods were extended by 8 t 15 days on resistant varieties. Not only were growth and development retarded but the survival and fecundity of the shoot fly were also adversely affected when reared on resistant varieties. According to Mote *et al.* (1986) larvae in resistant varieties were smaller while in susceptible entries they were larger and healthy. Raina *et al.* (1981) observed that the pre-oviposition period was extended from 3.1 days in the susciptible hybrid, CSH 1 to 5.6 and 6 days on the resistant varieties, IS 1082 and IS 2312 respectively. They also reported very high mortality among the first instar larvae on IS 2146, IS 2312 and IS 5613. In IS 246 and IS 2312, the larvae were usually confined to the upper region of the central shoot and larval growth rate was significantly lower. The survival rate and longevity were also significantly reduced for flies reared on IS 2146 thus showing high degree of antibiosis.

Survival and rate of larval development were dependent on the size of the host plant. Survival rate was high when seedlings were two weeks old, low in younger seedlings and lowest in 50 days old plants (Ogwaro and Kokwaro, 1981). Survival of the first instar larvae was not only dependent on the ability of the female to select a suitable oviposition site on the leaf but also ablity to penetrate the leaf sheath and travel from site of egg laying to the growing point. Delobel (1982) and Blum (1972b) found that larvae in a resistant cultivar were in the upper region of the shoot with undamaged growing point. However, Mote *et al.* (1986) found that in most resistant varieties although the growing point was partially cut off it later recovered while in susceptible ones, the growing point was completely cut and destroyed; thus showing that antibiosis contributed to resistance.

Findings of Sharma and Rana(1983) have resulted in selection criteria for antibiosis, which was found heritable in F1 and F2 generations of crosses between high yielding and resistant varieties. Rana *et al.* (1981) attributed resistance to a cumulative effect of non-preference, antibiosis and some morphological factors.

2.2.3.1 <u>Biochemical Characters</u>. Several biochemical studies on selected genotypes have shown interesting differences between susceptible and resistant genotypes. However, the role of these factors in shoot fly resistance was not clear. Similarly nitrogen, reducing sugars, total sugars, moisture and chlorophyll content of leaf were higher in susceptible cultivars than in resistant ones (Singh and Jotwani 1980c, Patel and Sukhani 1990, Mate *et al.*, 1988). Lysine is present in the leaf of susceptible cultivars but absent in all the three resistant cultivars tested (Singh and Jotwani 1980c). Shoot fly resistant lines also had more amino acids, phosphorous and total phenols (Khurana and Verma 1982, 1983).

2.2.4 Tolerance or Recovery Resistance

Plants recover by producing tillers which produce grain after the main culm is destroyed by shoot fly. This type of resistance was referred to as tiller survival (Blum 1969a) or recovery resistance (Doggett *et al.*, 1970). The varieties, Serena and Nematare recovered well even when more than 90% of the main culm had been killed. Blum (1972a) reported that resistant cultivars of sorghum had a higher rate of tiller survival than susceptible cultivars.

However, tolerance can be greatly influenced by the growth condition of the plant and thus may not always be predicted at various locations, particularly those with irregular patterns of rainfall. Under Indian conditions, the tillers of susceptible varieties are repeatedly attacked and significant differeces between resistant and susceptible varieties for tiller survival are maintained. Sharma *et al.* (1977) indicated that tall seedlings and higher plant recovery were charecteristics of resistant varieties whereas Shivankar *et al.* (1989) indicated that the varietal tolerance did not have definite relation so far as the height of the plant was concerned as the relatively tolerant germplasm came from all the categories of height factor (dwarf, moderate and tall). Tiller development consequent to deadheart formation in the main shoot and subsequent survival and recovery depended on the level of primary resistance. Varieties with high recovery resistance appeared to yield more under shoot fly infestation (Rana *et al.*, 1985). Recovery resistance does not appear to be a useful mechanism particularly when shoot fly populations progressively increase as the rainy season advances.

2.3 ROLE OF HEIGHT GENES IN SORGHUM ADAPTATION

In sorghum, four major genes and a modifying complex were responsible for elongation of the internodes (Quinby and Karper, 1954). Tallness was found to be partially dominant to dwarfness. Significant environment x height and cultivar x height interactions indicated that the relative differences between short and tall isogenic lines depended upon environment and genetic background of the individual lines. However, tall lines as a group produced higher yields and longer leaf blades and sheaths than dwarf lines (Campbell *et al.*, 1975).

Tall local races were preferred for fodder/forage purpose, but these generally had less harvest index (Rao,1982). Also, most of the shoot fly resistant lines identified were found in tall background (Borikar and Chopde, 1981). Hybrids from the tall male parents differed from those of the short male parents in essentially the same characteristics as those in which the lines themselves differed. The hybrids from the tall male parents exceeded those from the short male parent in height, leaf length, and yield characteristics (Schertz, 1973).

Eventhough resistant lines for shoot fly are from tall background, efforts are being made to transfer resistance into short seed parents/female lines/male sterile lines. As reviewed earlier, reports by Singh (1986) and Patel and Sukhani (1990) suggested that shoot fly resistance was associated with early fast growth/long internodes in some cases. It is therefore important to understand the role of dwarfing genes in the context of sorghum adaptation in general and shoot fly resistance in particular.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

All the field and laboratory experiments on the assessment of various morphological traits related to 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 (hereafter referred to as IC) during post-rainy season of 1991-92 and rainy season of 1992-93.

3.1 SORGHUM GENOTYPES

The plant materials consisted of 10 tall and dwarf sorghum pairs which were at F_6 or above. The members in a given pair were chosen from the pedigrees of the same parents for the first eight pairs. The members in the last two pairs originated from the pedigrees of similar parents. All these were the target selections of the crosses made between shoot fly resistant lines and high yielding but susceptible B-lines. These were obtained through emperical selection for shoot fly resistance which was based on percentage deadhearts among the families from F_3 to F_5 generations - a part of the IC on-going shoot fly resistant seed parents breeding program.

Members in each pair were characterised as tall and dwarf and they differed by at least 40 cm during the late 1991 rainy season plantings (Plate 1). Thus, materials in the tall and dwarf groups are homogenous except for

Plate No. 1. Tall (rear ground) and dwarf (fore ground) sorghum genotypes selected for shoot fly resistance.

plant height. Added to each group are one shoot fly resistant and one susceptible genotype in respective height backgrounds. The particulars of these genotypes are given in Table 1.

3.2 EXPERIMENTAL DESIGN

Two field trials, one uninfested and the second infested with shoot fly were conducted both in the postrainy and rainy seasons simultaneously. Both uninfested and infested trials were planted in a randomised complete block design with four replications each. Recommended agronomic practices were followed for raising the crop. In the infested trial, shoot fly infestations were by natural shoot fly populations which were enhanced however, by sowing CSH-1 (a susceptible hybrid) in four rows, 21 days prior to the planting of the test entries at every 30 rows of test material. Moist fish meal packets of 500 g each were placed within the infestor rows to attract shoot flies (Starks 1970). Sowing of the experiments were done four to six weeks later than the normal planting period to have sufficient fly pressure in the infested trial. In the rainy season 1992, the uninfested experiment was sown prior to infested experiment to facilitate the crop escape from shoot fly attack and to allow normal expression of the crop.

Each genotype was planted in plots of 4.5 x 4.0 m (i.e. 6 rows of 4 m length, ridges 75 cm apart). Plots were seeded at approximately 100 plants/row of 4 m and 10 DAE thinned to spacing of 5 cm between plants. Deadhearts due to shoot fly damage did not appear prior to thinning and so

Table 1. Characteristics of 10 pairs of sorghum genotypes of F_6 generation used to study the interrelationship of morphological traits related shoot fly resistance.

Talls			Dwarfs		
Sorghum genotype	Pedigree	Height (m)	Sorghum genotype	Pedigree	Height (m)
SPSF 1017	(ICSB 51 x ICSV 705)-10-4	1.9	SPSF 1014	(ICSB 51 x ICSV 705)-9-5-3	1.1
SPSF 1029	(ICSB 102 x ICSV 705)-6-1	1.6	SPSF 1028	(ICSB 102 x ICSV 705)-1-5	1.05
SPSF 1055	[(ICSB 51 x ICSV 705) PS19349B]-5-1	1.8	SPSF 1052	[(ICSB 51 x ICSV 705) PS19349B]-3-2	1.4
SPSF 1079	(ICSB 102 x PS 18822-4-1)-1-2	1.65	SPSF 1080	(ICSB 102 x PS 18822-4-1)-2-1	1.4
SPSF 1118	[(ICSB 37 x ICSV 705) PS19349B]-4-2	1.6	SPSF 1120	[(ICSB 37 x ICSV 705) PS19349]-11-2	1.3
SPSF 1127	[(ICSB 51 x ICSV 705) PS19349B]-4-2	1.5	SPSF 1126	[(ICSB 51 x ICSV 705) PS19349]-3-1	1.4
SPSF 1128	[(ICSB 51 x ICSV 705) PS19349B]-10-1	1.6	SPSF 1125	[(ICSB 51 x ICSV 705) PS19349]-3-4	1.5
SPSF 1169	(PS x 1345)-9-4	1.7	SPSF 1170	(PS x 1345)-9-5	1.25
SPSF 1103	(PS 14413 x ICSV 112)-1-5-2-2	2.2	SPSF 1101	(PS 21303 x SPV 386)-1-3-2	1.5
SPSF 1105	(PS 14413 x ICSV 112)-1-7-2-2	2.0	SPSF 1094	(PS 21194 x ICSV 1)-3-2-1	1.0
IS 18551	Resistant check	2.3	ICSV 705	Resistant check	0.9
ICSV 112	Susceptible check	1.6	296B	Susceptible check	1.0

(Source: Cereals Program, ICRISAT)

care was taken to thin only on the basis of seedling position in the row.

All the cultural practices such as interculture, irrigation (only in postrainy season, rainy season - rainfed crop), weeding etc. were carried out to maintain a weed-free crop in both the trials in both seasons. The plant protection measures during postrainy season were as follows:

The uninfested experimental crop was protected against shoot fly and stem borer by spraying chemical insecticides. Initially, at 14 DAE carbofuran granules (Furadon 3G) were applied at the rate of about 10 granules per plant in the whorls. Later at 28 DAE, two sprays of endosulfan (700 g a.i./ha) were given at an interval of 10 days to control stem borer.

Mites were controlled both in infested and uninfested trials by spraying dimethoate (300 g a.i./ha) at flowering stage.

During the grain filling stage both the infested and uninfested trials were protected against head bugs by spraying carbaryl (1 kg a.i./ha) twice at an interval of six days.

During the postrainy season both infested and uninfested trials received a total of tour irrigations (20-25 days between irrigations).

During the rainy season the plant protection measures were as follows:

After sowing both in infested and uninfested trials, pre-emergence weedicide, atrazine (500 g a.i./ha) mixed with contact herbicide paraquat (250 g/ha) was sprayed to control weeds.

Uninfested trial was protected from shoot fly damage by spraying cypermethrin (100 g a.i./ha) at seedling stage and at grain filling stage the crop was protected from shoot bugs by spraying dimethoate (300 g/ha) twice at an interval of 5 days.

Infested experiment was protected from shoot bugs during vegetative growth period by spraying dimethoate (300 g/ha) thrice at an interval of 4 days between sprays.

In addition both infested and uninfested trials were protected from head bug damage by spraying carbaryl (1 kg a.i./ha) twice with a gap of 10 days between sprays.

One irrigation was given for uninfested trial during the 1992 rainy season to avoid stress during grain filling period because the tillers from deadhearts matured very late after the rains had stopped.

3.3 OBSERVATIONS

Observations on morphological traits namely days for emergence, mesocotyl length, seedling vigour, glossiness, plant height, leaf length, width, drooping depth, trichomes, days to 50% flowering, days to physiological maturity, plant height at maturity and grain yield were recorded both in the uninfested as well as shoot fly infested trial in the postrainy and rainy seasons. These observations were confined to middle four rows leaving one row on either side as guard rows for each genotype. In the infested trial, in addition, data on egg laying and deadheart counts were also recorded.

3.3.1 Seedling Emergence

Although all genotypes were sown on the same day, owing to differences in germination and seedling vigour differences in days to seedling emergence were recorded.

3.3.2 Mesocotyl Length

Mesocotyl length which intends to show the initial vigour of the seedlings and also enhances the emergence of seedlings from soil was recorded on ten randomly selected seedlings per plot per genotype. For this purpose seedlings were dug out eight days after sowing and the mesocotyl length was measured.

In rainy (1992) season to avoid the field variation due to difference in depth of seed placement and available moisture at different depths (rainfed crop) mesocotyl length of seedlings were measured under controlled conditions by taking sowing in petri plates in the lab. Seeds were germinated on blotter paper holders made by placing a 1 mm thick piece of blotter paper between two thinner pieces of filter paper. These were placed in a vertical position in slots in plexiglass rack in 230 x 120 x 100 mm plastic boxes, which were filled to a depth of 75 mm with distilled water. The filter paper extended 3 mm above the upper edge of the blotter paper and 4 mm below the blotter paper to provide a wick to keep the seeds moistened. Seeds were placed at the upper edge of the blotter paper between the filter papers. Each box held 24 such blotter paper holders. Entries were tested in four replicates, with seeds germinated in an incubator maintained at 30°C. On the 5th day, the length of mesocotyl were measured in 10 seedlings per genotype.

3.3.3 Seedling Vigour

Seedling vigour was scored on 1-5 scale where 1=more vigorous and 5=least vigorous and was recorded at 7 DAE.

3.3.4 Seedling Height

Seedling height was measured from soil surface to the whorl of unopened leaf and was recorded at 10, 17, 23 and 28 DAE in postrainy season and 7, 12, 17 and 22 DAE in rainy season. Ten randomly selected seedlings plot^{-1} from the central four rows were utilised to record the height.

Plant height at maturity from soil surface to the tip of the panicle was measured for ten randomly selected plants.

3.3.5 Leaf Parameters

Total leaf length, droopy leaf length, greatest width and drooping depth of genotypes were recorded during the 1992-93 rainy season. 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 (Fig. 1). The length of the droopy leaf is the straight line distance between leaf base and 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 (C) distance between the drooping leaf and the observed length was considered as drooping depth. The leaf curvature was obtained after subtracting the total length and observed length of leaf. Leaf width was recorded at the centre of the leaf.

The measurements were recorded for 3rd, 4th, and 5th leaves at 14 DAE in the rainy season randomly for five plants $plot^{-1}$ for each genotype.

3.3.6 Trichomes

In order to study the variation in leaf trichome density, the central portion of 3rd, 5th, and 7th leaves from 3 randomly selected and tagged plants were collected taking cotyledonous leaf as 1st leaf. The leaf bits were processed by adopting standard procedure (Maiti, 1977) with minor modifications for clearing the leaves for the 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 (2 cm diameter,

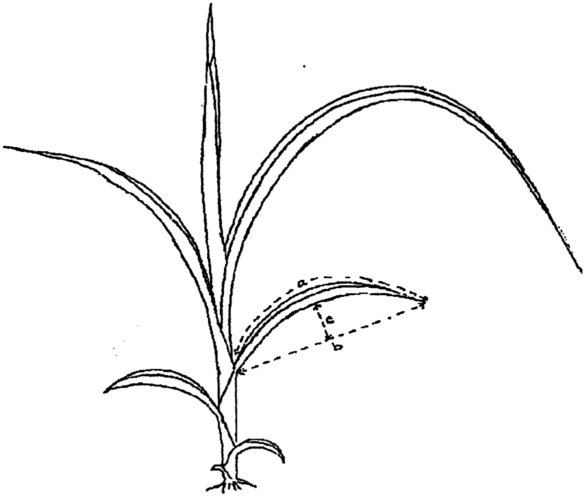


Figure 1. Methodology adapted to measure the leaf parameters.
(a) Total leaf length;
(b) Observed length of drooped leaf;
(c) Drooping depth.

7.5 cm high) overnight. Thereafter, they were transferred into 20 cc lactic acid (90%) in stoppered vials. Cleared leaf segments (approximately 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 stereo-microscope at 15x and 10x magnification. The trichomes on adaxial and abaxial surfaces of 3rd, 5th and 7th leaves were counted through randomly selected microscopic fields and expressed as trichome density mm^{-2}.

3.3.7 Days to 50% Flowering

When 50% of plants in the middle four rows were at 50% anthesis, the total number of days from sowing to anthesis was considered as days to 50% flowering. This was recorded in both uninfested and infested trials.

3.3.8 Days to Physiological Maturity

Sorghum seed is considered physiologically mature when the hilum darkens. When 50% of the panicles have seeds with dark hilum, then the number of days from sowing to this stage was recorded as physiological maturity. These observations were recorded in both infested and uninfested trials.

3.3.9 Grain Yield

At maturity, the total number of plants in the middle four rows and number of productive tillers $plant^{-1}$ and grain yield were recorded after proper drying.

After threshing, from each plot three samples of 100 grains each were weighed separately and mean weight of these were taken as 100 grain weight (seed mass).

3.3.10 Egg Counts

Number of shoot fly eggs on 100 selected seedlings (i.e. 25 seedlings/row) were recorded twice at an interval of 7 days in the infested trial. In the postrainy season, counts were made in each sorghum genotype at 21 and 28 DAE and in the rainy season 14 and 21 DAE. A seven days delay in the egg counts in the former was given because of delayed emergence of seedlings during winter. Total number of plants with eggs were recorded and number of eggs per hundred plants was calculated.

During 1992-93 rainy season, to study the ovipositional preference and also the leaf most preferred for egg laying, egg counts were made separately on 3rd, 4th, 5th, 6th, and 7th leaves at 14 DAE. This was done by taking cotyledonary leaf as the 1st leaf and expressed in percentage after arriving at number of eggs on particular leaf for 100 plants per genotype. The second egg count was recorded only as eggs per 100 seedlings when both the deadhearts and tillers appeared at 21 DAE without considering eggs per leaf.

3.3.11 Deadhearts

Deadheart counts were made twice a week after each egg count both in postrainy and rainy seasons. Deadhearts were expressed in percentage by recording total number of deadhearts and total number of plants $plot^{-1}$ (of four rows).

3.3.12 Harvesting

After the second deadheart count, final thinning was done taking care to thin only on the basis of seedling position in the row to a spacing of 11 cm between plants disregarding whether or not the plant was infested. Total number of plants/plot were recorded immediately after thinning and the healthy plants were tagged for future identification.

In each plot, the panicles from healthy plants were harvested separately. Productive tillers from deadhearts were noted and harvested separately. Later these were threshed separately and grain yield per plot from healthy plants and productive tillers of deadhearts were recorded and total yield $plot^{-1}$ was calculated by adding yield from healthy plants and productive tiller of deadhearts.

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 analysed by following the randomised complete block design analysis. The analysis was based on the following linear model given by Fisher (1938).

$$Y_{ij} = \mu + b_i + t_j + e_{ij}$$

Where,

Y_{ij} = performance of j^{th} genotype in i^{th} block

μ = general mean

b_i = true effect of i^{th} block

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

e_{ij} = random error.

Restrictions are, $\Sigma^r_{i=i} b_i = 0$ and $\Sigma^t_{j=i} t_j = 0$

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

ANNOVA - 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

t = number of treatments (genotypes)

3.4.2 Variability Studies

The genotypic and phenotypic variances and coefficients of variation for each variable were calculated using the formula given by Singh and Chaudhary (1977).

Genotypic variance = $\sigma^2 g$ = (TMSS-EMSS) ÷ r

Where,

TMSS = Treatment mean sum of squares

EMSS = Error mean sum of squares

r = Number of replications

Phenotypic variance = $\sigma^2 p = \sigma^2 g + \sigma^2 e$

Where,

$\sigma^2 g$ = Genotypic variance

$\sigma^2 e$ = Environmental variance

Genotypic coefficient of variation (GCV) = $(\sigma^{-2}g \times 100) \div \overline{x}$

Phenotypic coefficient of variation (PCV) = $(\sigma^{-2}p \times 100) \div \overline{x}$

Where,

$\sqrt{\sigma^{-2}g}$ = Genotypic standard deviation

$\sqrt{\sigma^{-2}p}$ = Phenotypic standard deviation

$\overline{x}$ = General mean of the character

3.4.3 Estimates of Heritability (Broad Sense) and Genetic Advance

Heritability in broad sense (ratio of genotypic variance to phenotypic variance) was estimated using the formula given by Allard (1960).

$$H^2 = (\sigma^{-2}g \times 100) \div \sigma^{-2}p$$

Where,

H^2 = Heritability in broad sense

$\sigma^{-2}g$ = Genotypic variance

$\sigma^{-2}p$ = Phenotypic variance

Expected genetic gain or improvement was computed by the formula suggested by Allard (1960).

$$E(GA) = K \times \sqrt{\sigma^{-2}p} \times H^2$$

Where

D(GA) = Expected genetic advance

K = Selection differential at 5% selection pressure i.e. 2.06 (constant)

$\sqrt{\sigma^{-2}p}$ = Phenotypic standard deviation

H^2 = Heritability in broad sense

Genetic advance as percentage of mean

$$= (E(GA) \times 100) \div \bar{x}$$

Where $\bar{x}$ = Mean of the character

3.4.4 Estimates of Correlation Coefficients and Path Coefficient Analysis

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

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

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 and Y
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 upto $r_{15}Y$ were written and path coefficients viz., direct and indirect effect were calculated.

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

RESULTS

CHAPTER IV

RESULTS

4.1 MEAN PERFORMANCE

The means for seedling emergence, mesocotyl length, seedling vigour and glossiness of tall and dwarf of sorghum genotype pairs, which were selected earlier for shoot fly resistance evaluated in postrainy season and rainy season during 1991-92 are presented in Table 2.

4.1.1 Seedling Emergence

The seedling emergence among the tall genotypes in postrainy season varied between 6.8 and 7.8 days. Among the tall genotypes, SPSF 1128 emerged late (7.8 days) and was significantly different from other genotypes. However, both the susceptible and resistant tall checks emerged earlier than other tall genotypes. Among the dwarf genotypes, the emergence varied between 6 and 8 days. The genotypes SPSF 1052 and 1094 emerged in 6.0 days and significantly early whereas SPSF 1028 and 1120 emerged late (8 days) compared to other genotypes. The susceptible check 296B emerged late (7.3 days) compared to the resistant check ICSV 705 (6 days).

In the rainy season, seedling emergence in the tall group ranged between 4 and 6 days. Among all the genotypes in the tall group, SPSF 1055 emerged significantly late (6 days). However, both resistant (IS 18551) and susceptible (ICSV 112) checks in the group emerged earlier than other genotypes.

Table 2. Seedling emergence, mesocotyl length, early seedling vigour, glossiness in tall and dwarf sorghum genotypes selected for shoot fly resistance.

Genotype	Seedling emergence(DAS)		Mesocotyl length(cm)		Seedling vigour[2]		Glossiness[3]	
	PR	R	PR	R[1]	PR	R	PR	R
TALL								
SPSF 1017	7.0	5.5	1.1	4.7	3.0	3.3	3.3	3.0
SPSF 1029	7.0	5.0	0.5	6.1	2.0	1.3	2.0	1.3
SPSF 1055	7.0	6.0	1.2	7.6	3.3	3.8	3.0	3.0
SPSF 1079	7.0	5.0	0.9	8.6	2.8	2.5	2.3	1.3
SPSF 1118	6.8	5.3	0.8	4.8	2.8	3.8	2.5	3.0
SPSF 1127	7.3	5.0	1.6	3.8	1.3	3.0	3.8	4.5
SPSF 1128	7.8	5.0	1.0	7.4	3.0	2.8	2.3	2.8
SPSF 1169	7.0	5.3	0.6	5.2	2.0	2.8	1.7	2.0
SPSF 1103	7.0	5.0	1.3	6.7	1.8	2.5	2.0	2.0
SPSF 1105	7.0	4.8	1.3	5.9	1.0	3.0	1.2	2.3
IS 18551(R)	6.0	4.0	0.8	9.2	1.0	2.3	1.0	1.0
ICSV 112(S)	6.0	4.0	0.8	6.3	2.0	2.0	5.0	5.0
Mean	6.9	5.0	1.0	6.3	2.1	2.7	2.5	2.6
CD(P=0.05)	0.37	0.41	0.21	0.83	0.80	0.83	0.78	0.78
DWARF								
SPSF 1014	7.0	5.3	0.4	5.4	2.8	2.8	3.5	3.0
SPSF 1028	8.0	5.8	1.0	4.7	2.3	3.5	2.5	3.3
SPSF 1052	6.0	4.8	1.6	7.5	2.3	2.8	2.5	2.0
SPSF 1082	7.0	5.0	0.9	6.4	2.5	3.3	1.5	2.5
SPSF 1120	8.0	5.5	0.7	5.6	2.3	3.0	3.3	2.8
SPSF 1126	7.0	5.0	0.7	6.4	2.3	3.0	1.8	2.3
SPSF 1125	7.3	5.0	0.8	6.3	2.0	3.5	3.0	3.3
SPSF 1170	7.0	5.0	1.3	4.9	2.0	2.8	2.3	1.8
SPSF 1101	7.0	5.0	0.6	5.0	3.5	3.0	2.5	2.3
SPSF 1094	6.0	5.3	0.6	4.5	2.8	2.8	2.0	2.3
ICSV 705(R)	6.0	5.0	0.6	7.4	1.3	2.0	1.5	1.0
296B (S)	7.3	5.0	0.7	4.7	2.0	4.0	5.0	5.0
Mean	7.0	5.0	0.8	5.7	2.3	2.9	2.6	2.7
CD(P=0.05)	0.28	0.52	0.16	0.10	1.02	0.98	0.70	0.87
Tall/Dwarf CD(P=0.05)	0.33	0.45	0.19	0.94	0.89	0.87	0.70	0.80

1 Mesocotyl length measured 5DAS under lab condition
2 On a scale of 1-5 where 1=Most vigorous and 5= Least vigorous
3 On a scale of 1-5 where 1=More glossy and 5= Non glossy
PR - Postrainy; R - Rainy

In the dwarf group the emergence of genotypes in rainy season varied between 4.8 and 5.8 days and among them SPSF 1028 emerged significantly late (5.8 days) whereas other genotypes were at par with the resistant (ICSV 705) and susceptible (296B) checks (5 days).

The tall and dwarf genotypes in rainy season emerged earlier by two days than in postrainy season. When comparisons of the seedling emergence of tall and dwarf genotypes in both the seasons were made there was no significant difference in emergence between the two groups.

4.1.2 Mesocotyl Length

The mesocotyl length among the tall genotypes varied between 0.5 to 1.6 cm in postrainy season. Among the tall genotypes, SPSF 1127, 1103 and 1105 had long mesocotyl (1.3 to 1.6 cm) whereas SPSF 1029 and 1169 had short mesocotyl (0.5 to 0.6 cm) and were significantly different from other genotypes (Table 2). However, both the resistant and susceptible check in the tall group had only 0.8 cm long mesocotyl. The mesocotyl length in the dwarf genotypes varied between 0.4 to 1.6 cm. The genotypes SPSF 1052 and 1170 had significantly long mesocotyl whereas SPSF 1014 had short mesocotyl.

In rainy season, mesocotyl lengths were measured from seedlings raised under lab condition (since germination in the field was not uniform because it was rainfed). Mesocotyl length in the tall group ranged between 3.8 to 9.2 cm. Among them, SPSF 1127 and 1017 measured lowest and

SPSF 1079 measured more (8.6 cm) and were significantly different from others. However, in the resistant genotype, IS 18551, mesocotyl length was very long i.e. 9.2 cm and susceptible check ICSV 112 had 6.3 cm length which was at par with other tall genotypes.

In the dwarf group, mesocotyl length varied between 4.5 and 7.5 cm in the rainy season. The genotypes, SPSF 1028, 1170 and 1094 measured lowest and were similar to the susceptible genotype 296B (4.7 cm). SPSF 1052 had long mesocotyl (7.5 cm) which was similar to the resistant check, ICSV 705 (7.4 cm) in the dwarf group.

The mean mesocotyl length of tall genotypes measured more by 0.2 cm and 0.6 cm in the postrainy and rainy seasons respectively than dwarf genotypes thus showing significant differences between the two groups in both the seasons.

4.1.3 Seedling Vigour

Seedling vigour (1-5 scale, where 1 is most vigorous and 5 least vigorous) in the tall group in the postrainy season, ranged between 1 and 3.3 and SPSF 1127 and 1105 were more vigorous and similar to the resistant genotype IS 18551 (1) (Table 2). The seedling vigour of the susceptible genotype, ICSV 112 (2), was similar to that of other tall genotypes.

In the dwarf group, the seedling vigour ratings ranged between 1.3 and 3.5. Only the resistant check, ICSV 705, was most vigorous (1.3) while

SPSF 1101 was least vigorous (3.0) and these were significantly different from other genotypes. The dwarf susceptible check 296B was at par with other dwarf genotypes.

In the rainy season, among tall genotypes vigour score ranged between 1.3 and 3.8 and SPSF 1029 was most vigorous whereas SPSF 1055 and 1118 were least vigorous in comparison to other tall genotypes (Table 2). The resistant check, IS 18551, and the susceptible check ICSV 112 recorded 2.3 and 2.0 scores respectively. In the dwarf group the vigour score ranged between 2.0 and 4.0. The genotypes SPSF 1028 and 1125 were least vigorous and were significantly different from other genotypes. The resistant check, ICSV 705 was more vigorous (2.0) and the susceptible check was less vigorous (4.0) than other genotypes.

The vigour scores of the tall group (2.1 postrainy, 2.7 rainy) and dwarf group (2.3 postrainy, 2.9 rainy) show that talls were slightly more vigorous than dwarf genotypes in both seasons but the differences were not significant.

4.1.4 Glossiness

The glossy score (1-5 scale where 1 is glossy and 5 non glossy) of tall genotypes in postrainy season ranged between 1 and 5 and the genotypes SPSF 1029, 1169 and 1105 were glossy (1.2-2.0) (Table 2). The resistant check, IS 18551, was glossy (1.0) and the susceptible check was nonglossy (5.0). In the dwarf group, also, glossy score ranged between 1.5 and 5. The genotypes SPSF 1082, 1126 and 1094 were highly glossy (1.5-2.0) and were at par with the resistant genotype, ICSV 705 (1.5). The susceptible genotype, 296B, was nonglossy (5.0) and was significantly different from all the dwarf genotypes.

In the rainy season, among tall genotypes as in the postrainy season the glossy score ranged between 1.0-5.0. The genotypes SPSF 1029, 1079, 1169, 1103 were rated glossy and were at par with the resistant check whereas SPSF 1127 was nonglossy (4.5 score) and was similar to the susceptible check, ICSV 112 (5.0), which differed significantly from other genotypes.

The differences in the glossy score between tall and dwarf groups were not significant.

4.1.5 Plant Height

The data on plant height at different growth stages in tall and dwarf pairs of sorghum genotypes recorded in postrainy and rainy season are presented in Table 3.

In the postrainy season, plant height at different DAE (days after emergence) varied between genotypes in the tall group. For example SPSF 1017 measured 2.8 cm at 10 DAE and 6.3, 9.6, 15.5 and 141 cm at 17, 23, 28 and at maturity respectively whereas SPSF 1127 recorded 4.2, 7.0, 11.1, 24.4 and 130 cm on the same DAE as the above genotype which indicated

Table 3. Plant height at different growth stages(DAE) in tall and dwarf sorghum genotypes selected for shoot fly resistance.

Genotype	Plant height at different growth stages(DAE) in cm									
	Postrainy					Rainy				
	10	17	23	28	At maturity	7	12	17	22	At maturity
TALL										
SPSF 1017	2.8	6.3	9.6	15.5	141	2.8	5.2	8.3	12.9	189
SPSF 1029	3.0	6.5	11.6	20.0	143	3.5	8.0	12.5	20.0	208
SPSF 1055	2.9	6.4	9.9	15.9	158	2.8	5.0	6.9	10.7	211
SPSF 1079	3.2	6.1	11.3	17.0	138	3.3	6.7	10.0	15.1	229
SPSF 1118	3.0	6.6	10.5	18.1	141	2.6	4.4	7.1	9.8	161
SPSF 1127	4.2	7.0	11.1	24.4	130	2.9	5.3	9.4	15.2	189
SPSF 1128	3.2	6.5	10.5	16.3	130	2.8	6.0	8.9	13.8	189
SPSF 1169	3.2	6.4	11.2	19.4	145	3.7	6.0	9.8	14.7	184
SPSF 1103	3.2	7.0	11.8	21.3	186	3.5	6.8	10.0	16.0	268
SPSF 1105	3.7	7.6	12.7	24.0	191	3.3	6.4	8.9	14.1	246
IS 18551(R)	3.6	7.5	12.9	21.4	230	4.7	7.9	10.6	16.9	294
ICSV 112(S)	3.8	6.8	10.3	20.6	131	3.8	7.4	11.4	19.7	205
Mean	3.3	6.7	11.1	19.5	155	3.3	6.2	9.5	14.9	214
CD(P=0.05)	0.50	1.05	1.98	3.41	12.35	0.59	1.05	1.67	2.87	12.8
DWARF										
SPSF 1014	3.3	6.4	10.5	18.7	114	3.0	6.6	9.5	16.7	111
SPSF 1028	3.3	6.3	11.2	19.2	100	2.9	4.4	7.0	10.9	121
SPSF 1052	3.1	6.0	11.5	18.7	144	3.1	5.9	9.6	16.1	184
SPSF 1082	3.3	6.9	11.5	18.0	128	2.8	4.9	7.8	13.4	163
SPSF 1120	3.2	6.8	11.2	17.4	125	2.7	5.6	8.4	13.8	158
SPSF 1126	3.2	6.6	11.7	17.9	126	3.2	5.8	8.6	12.4	161
SPSF 1125	3.7	6.6	7.8	21.3	138	2.5	5.3	7.8	11.3	166
SPSF 1170	3.2	6.5	10.7	20.7	106	3.3	6.3	9.2	17.0	133
SPSF 1101	2.8	6.1	9.6	15.4	130	3.1	5.9	8.7	13.4	168
SPSF 1094	3.6	6.1	10.7	19.0	94	3.0	5.8	9.5	15.5	121
ICSV 705(R)	3.6	7.1	13.2	22.1	78	3.5	7.5	11.0	16.8	116
296B (S)	3.8	6.8	8.7	21.1	100	2.2	4.2	6.7	9.8	136
Mean	3.3	6.5	10.7	19.1	115	2.9	5.7	8.6	13.9	145
CD (P=0.05)	0.57	1.13	1.58	3.31	23.7	0.48	1.03	2.06	2.76	12.8
Tall/Dwarf										
CD (P=0.05)	0.52	1.06	1.73	3.3	18.9	0.52	1.03	1.81	2.74	12.4

DAE = Days after emergence

genotypic variation in their growth. The initial plant height (before one month age of the crop) had no correlation with the height at maturity. For instance, the plant height at 28 DAE in SPSF 1127 was 24.4 cm and in SPSF 1128 it was 16.3 cm but the height at maturity was the same for both (130 cm). Also, the resistant check, IS 18551, and SPSF 1103 measured 21.4 and 21.3 cm respectively at 28 DAE, while at maturity, they varied in height (the former measured 230 cm and the latter 186 cm). Among the tall genotypes, significant variation was observed at all stages except 17 DAE in the measured plant height. The dwarf group genotypes showed similar variation to that in the tall group for the character of height at all stages. Thus, there was variation in both growth and height.

At maturity, the dwarf group was significantly less in height (78 to 144 cm) than the tall (130-231 cm) and in other early stages the differences in height were not significant.

In the rainy season, among tall genotypes there were significant differences in plant height at 7, 12, 17 and 22 DAE and also at maturity. The susceptible check, ICSV 112, in the tall group was at par with the resistant check, IS 18551, in plant height at initial stages, i.e., before one month of the crop. In the dwarf group also the trend was similar to the tall genotypes, with significant differences existing between genotypes for plant height.

The mean differences between the tall and dwarf genotypes for height in the rainy season were significant at 7, 12, 17 (DAE) and at maturity.

When tall and dwarf genotypes were considered, in each of the groups, the mean plant height was higher in rainy season in comparison to postrainy season. This indicated that season had an influenc on height plant.

4.1.6 Leaf Parameters

The means for leaf characters in tall and dwarf pairs of sorghum genotypes which were selected earlier for shoot fly resistance (rainy season 1992-93) are given in Table 4.

4.1.6.1 Length. In the tall group, the length of the 3rd, 4th and 5th leaves among the genotypes varied significantly. All the leaves (3rd, 4th and 5th) of the tall group and the susceptible check, ICSV 112, were longer compared to the resistant check, IS 18551 and other genotypes in the group.

In the dwarf group, the 3rd, 4th and 5th leaves of the susceptible check, 296B were 4.4, 7.4 and 8.3 cm and were shorter than to the resistant check, ICSV 705. Except for little variation, all the other genotypes in the dwarf group had similar leaf lengths including those of the resistant check.

When mean leaf length of 3rd, 4th and 5th leaves in tall and dwarf group were compared, all the leaves in the tall genotypes were longer than the dwarfs.

Table 4. Leaf length, width, drooping depth and leaf curvature in tall and dwarf sorghum genotypes selected for shoot fly resistance (Rainy season 1992-93).

Genotype	Leaf length			Leaf width			Drooping depth			Leaf curvature		
	3rd	4th	5th	3rd	4th	5th	3rd	4th	5th	3rd	4th	5th
TALL												
SPSF 1017	5.8	10.6	13.6	0.5	0.8	1.1	1.7	3.5	4.1	1.28	3.86	3.38
SPSF 1029	7.8	12.3	18.6	0.5	0.6	1.3	2.7	3.9	6.1	2.88	2.72	7.28
SPSF 1055	7.5	13.1	17.4	0.5	0.8	1.4	1.5	3.6	5.0	0.64	2.50	3.70
SPSF 1079	7.7	10.9	15.8	0.6	0.9	1.4	1.4	3.1	3.4	1.58	1.42	1.52
SPSF 1118	6.8	9.3	12.2	0.4	0.7	1.2	1.5	2.3	4.4	0.82	1.06	4.16
SPSF 1127	7.3	11.8	16.1	0.6	0.9	1.2	1.6	3.3	4.9	2.62	4.90	6.16
SPSF 1128	6.6	11.0	16.0	0.5	0.6	1.0	2.0	3.2	4.5	1.44	2.66	3.46
SPSF 1169	6.8	11.6	18.5	0.6	0.7	1.2	2.1	4.3	6.8	2.26	4.04	7.58
SPSF 1103	7.3	12.5	19.0	0.6	0.7	1.3	2.2	4.5	6.8	1.38	3.16	7.58
SPSF 1105	6.6	11.1	17.7	0.6	0.7	1.1	1.8	3.5	5.3	1.20	1.62	4.66
1S 18551(R)	8.2	13.8	19.6	0.5	0.6	0.8	1.7	3.0	3.6	1.50	2.90	3.10
ICSV 112(S)	9.3	16.3	22.9	0.6	1.0	1.7	3.0	5.9	8.2	1.92	6.32	11.54
Mean	7.3	12.0	17.28	0.5	0.8	1.2	2.0	3.7	5.3	1.6	3.1	5.3
CD(P=0.05)	1.5	2.05	2.63	0.16	0.20	0.33	0.67	1.31	1.55	1.23	1.92	2.62
DWARF												
SPSF 1014	5.7	9.2	13.6	0.5	0.6	1.0	1.8	3.2	4.4	0.92	2.28	3.50
SPSF 1028	6.0	9.5	13.5	0.5	0.7	0.9	1.7	3.5	5.2	1.25	2.00	2.65
SPSF 1052	7.0	11.1	15.9	0.5	0.6	1.1	2.3	4.0	5.8	1.74	3.74	6.00
SPSF 1082	5.6	10.1	14.3	0.5	0.8	1.1	1.3	2.3	3.1	1.56	3.30	3.92
SPSF 1120	7.6	11.4	15.8	0.6	0.8	1.2	2.0	3.2	4.7	0.66	1.78	4.86
SPSF 1126	6.3	10.2	14.7	0.4	0.7	1.1	1.8	3.6	4.7	1.14	2.80	4.48
SPSF 1125	5.2	8.7	14.5	0.4	0.6	0.9	1.3	2.1	3.4	1.52	2.26	4.84
SPSF 1170	7.1	12.4	18.8	0.5	0.7	1.1	2.8	4.5	7.1	1.26	3.72	7.70
SPSF 1101	6.5	10.9	15.9	0.5	0.7	1.3	1.9	3.0	2.7	0.74	1.92	3.66
SPSF 1094	6.6	11.5	17.4	0.4	0.6	1.0	1.7	3.6	5.7	0.66	2.08	6.12
ICSV 705(R)	6.5	11.6	16.9	0.5	0.7	1.2	2.0	4.0	4.5	0.72	2.02	2.96
296 B (S)	4.4	7.4	8.3	0.3	0.5	0.7	1.0	1.9	2.7	0.88	1.28	1.68
Mean	6.2	10.3	15.11	0.5	0.67	1.06	1.82	3.2	4.6	1.1	2.5	4.4
CD(P=0.05)	1.13	1.83	2.61	0.10	0.14	0.23	0.78	0.97	1.39	0.88	1.34	2.89
Tall/Dwarf												
CD(P=0.05)	1.3	1.9	2.62	0.13	0.17	0.27	0.71	1.11	1.43	0.99	1.72	2.72

4.1.6.2 **<u>Width</u>**. Leaf width in both tall and dwarf genotypes varied between 0.3 to 0.6 cm in the 3rd, 0.5-1.0 cm in 4th and 0.7-1.4 cm in the 5th leaves and the differences were not striking (Table 4). However, the mean widths of tall genotypes in all the leaves were in general higher than dwarf genotypes.

4.1.6.3 **<u>Drooping depth</u>**. Drooping depth progressively increased from the 3rd to the 5th leaf. The susceptible check (ICSV 112) in the tall group recorded significantly higher drooping depth in all the leaves compared to the resistant check as well as other genotypes (Table 4). Among the genotypes, the drooping depths varied between 1.4 to 2.7, 2.3 to 4.5 and 3.4 to 6.8 cm in the 3rd, 4th and 5th leaves respectively and the variation was significant between some of the genotypes in the tall group.

Interestingly, in the dwarf group even though there was progressive increase in drooping depth from the 3rd to 5th leaf, the susceptible check showed significantly less drooping depth in all the leaves compared to the resistant check and also other genotypes. Similar to tall genotypes, the drooping depth varied significantly among the dwarf genotypes.

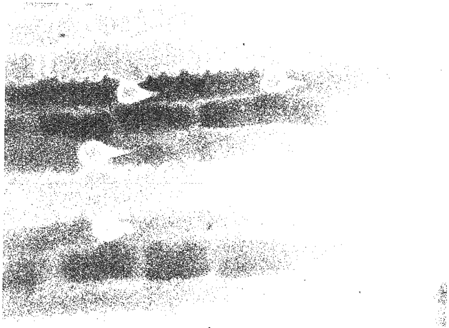
Mean drooping depth was higher in all the leaves of the tall group compared to the genotypes of the dwarf group and it was significantly distinct in the 4th and 5th leaves.

4.1.6.4 Curvature. Leaf curvature of the genotypes was found to be related with length and drooping depth of the leaf (Table 4). The susceptible genotype (ICSV 112) of the tall group recorded highest leaf curvature compared to all the genotypes in the 3rd, 4th and 5th leaves and in the 5th leaf it was as high as 11.54 cm compared to 1.5 to 7.5 cm in all other genotypes. Between genotypes, the leaf curvature varied significantly in all the leaves in most of the genotypes. Contrary to the tall group, the leaf curvature was less in the susceptible genotype in the dwarf group and it was significantly evident in the 4th and 5th leaf. Between the tall and dwarf groups, the leaf curvature was significantly high in the 3rd, 4th and 5th leaves of tall group compared to dwarf group.

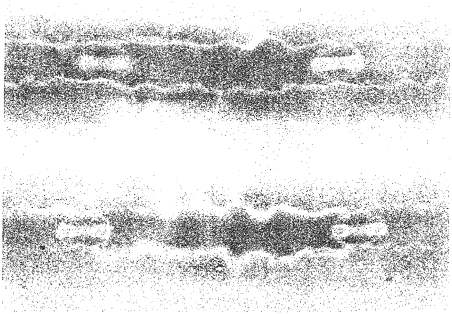
4.1.7 Trichomes

The trichome density (number mm^{-2}) on both adaxial and abaxial surfaces varied between genotypes (Plate 2a & 2b) in both tall and dwarf groups in both rainy and postrainy seasons (Table 5).

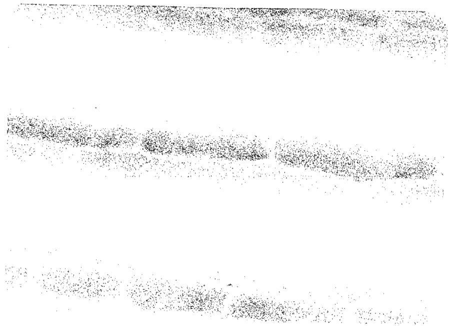
Generally, the trichome density on the adaxial surface was significantly higher than that of abaxial surface in all the genotypes except on the 3rd leaf for a few genotypes (SPSF 1127, 1128, 1169, 1103, 1105, 1052, 1125, 1101, 1094, ICSV 705). When mean trichome density was considered in between the tall and dwarf groups, the tall genotypes had a higher more number than the of dwarf genotypes except the 3rd leaf abaxial and the 5th leaf adaxial surfaces in the rainy season. The susceptible genotypes in both tall and



i

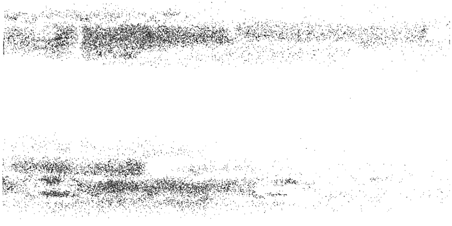


iii



ii

Plate No. 2a. Trichomes on cleared 5th leaf showing (i) high density, (ii) medium density, and (iii) no trichomes on abaxial surface.



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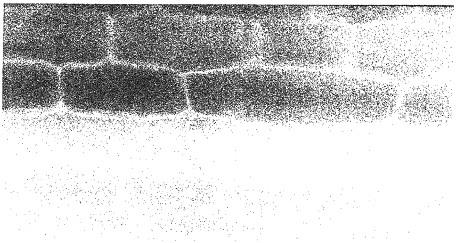
ii



iii

Plate 2b. Trichomes on cleared 5th leaf showing (i) high density, (ii) medium density and (iii) no trichomes on abaxial surface.

Table.5 Trichome density on different leaves in tall and dwarf sorghum genotypes selected for shoot fly resistance

Genotype	No. of Trichomes (mm^2)											
	Post rainy						Rainy					
	3rd		5th		7th		3rd		5th		7th	
	AD	AB	AD	AB	AD	AB	AD	AB	AD	AB	AD	AB
TALL												
SPSF 1017	30	16	201	24	250	20	45	45	386	117	389	49
SPSF 1029	14	4	99	7	229	14	20	8	81	23	133	74
SPSF 1055	27	24	118	30	146	39	10	34	83	71	212	62
SPSF 1079	145	28	183	23	366	25	269	146	678	191	606	65
SPSF 1118	10	8	191	17	205	25	52	31	171	82	390	125
SPSF 1127	12	19	195	105	657	296	12	22	80	89	953	295
SPSF 1128	15	18	95	19	91	35	16	30	152	80	259	58
SPSF 1169	35	32	224	51	206	36	41	46	264	528	564	446
SPSF 1103	8	26	73	41	104	81	8	29	32	128	279	166
SPSF 1105	12	32	137	60	229	58	14	27	73	146	295	212
IS 18551(R)	357	38	454	32	550	22	290	70	813	318	938	77
ICSV 112(S)	0	0	0	0	2	0	0	0	3	0	3	0
Mean	55	20	164	34	253	54	65	41	235	148	418	136
CD (P=0.05)	59.1	15.0	78.1	35.3	137.8	36.2	24.6	20.3	61.7	78.9	76.0	64.8
DWARF												
SPSF 1014	9	8	82	17	142	15	23	70	199	128	340	87
SPSF 1028	92	38	194	47	340	35	58	78	485	242	468	103
SPSF 1052	8	16	142	17	357	40	27	37	312	183	912	279
SPSF 1082	52	32	206	19	207	16	214	53	424	52	454	30
SPSF 1120	19	19	276	44	269	58	10	23	393	186	617	193
SPSF 1126	23	9	140	47	251	32	5	12	215	135	444	124
SPSF 1125	0	4	19	5	19	4	4	5	24	13	21	19
SPSF 1170	25	30	281	36	412	41	54	87	521	172	436	60
SPSF 1101	4	29	43	18	132	19	10	71	138	159	264	15
SPSF 1094	13	31	201	13	189	4	13	74	513	184	456	44
ICSV 705(R)	13	31	219	17	337	14	11	72	502	193	519	29
296B (S)	0	0	0	0	0	0	0	0	0	0	1	0
Mean	22	21	150	23	123	22	36	49	310	137	411	82
CD (P=0.05)	45.6	18.2	129.1	21.6	124.2	31.0	23.6	23.7	72.0	83.5	73.0	35.1
Tall/Dwarf												
CD (P=0.05)	51.5	16.9	104.4	30.2	128.1	32.4	23.5	21.3	66.7	76.7	80.4	53.1

AD - Adaxial Surface; AB - Abaxial Surface dwarf groups lacked trichomes on both the surfaces except for 1 or 2 trichomes which were rarely found on the upper surface (Table 5).

Trichome density in general was significantly higher in the rainy season compared to the postrainy season both in the tall and dwarf groups. On the 3rd leaf, the trichome density was significantly higher on the adaxial surface in the tall group compared to dwarfs.

If adaxial surface trichomes of 5th leaf are considered important, the genotypes with more than 200 trichomes mm^{-2} may offer more resistance by impeding larval movement. The genotype with trichome density >200 in the tall group were SPSF 1017, 1079, 1118, 1127, 1169 and SPSF 1028, 1082, 1120, 1170, 1094 in the dwarf group in postrainy season and >600 in the tall group were SPSF 1017 and 1079, and in the dwarf group SPSF 1028, 1082, 1120, 1170 and 1094 in the rainy season.

4.1.8 Flowering and Maturity

Data on the days to 50% flowering and physiological maturity of both tall and dwarf genotypes during the postrainy and rainy seasons in uninfested and infested plants are presented in Table 6.

During the postrainy season, days to 50% flowering varied between 74-85 days both in uninfested and infested genotypes of the tall group. Similarly, even in the dwarf group it varied between 72-87 days both in uninfested and infested conditions except in the resistant check, ICSV 705, which flowered a little early.

Table 6. Days to 50% flowering and physiological maturity in tall and dwarf sorghum genotypes during postrainy and rainy season.

Genotype	Days to(50%) flowering				Physiological maturity (DAS)			
	Postrainy		Rainy		Postrainy		Rainy	
	UNI	IN	UNI	IN	UNI	IN	UNI	IN
TALL								
SPSF 1017	80	81	76	79(89)	108	107	105	112(123)
SPSF 1029	81	82	76	78(87)	108	107	106	112(123)
SPSF 1055	82	84	84	82(93)	108	107	118	113(125)
SPSF 1079	82	82	78	77(88)	107	107	109	111(123)
SPSF 1118	77	79	76	80(93)	107	106	108	114(123)
SPSF 1127	84	85	84	80(93)	109	107	114	112(125)
SPSF 1128	78	81	82	80(93)	109	106	111	114(123)
SPSF 1169	78	78	73	78(87)	110	107	105	109(123)
SPSF 1103	78	79	77	79(90)	101	103	106	111(118)
SPSF 1105	74	74	75	77(87)	99	100	105	111(121)
IS 18551(R)	77	77	76	79(87)	103	102	108	99(118)
ICSV 112(S)	75	78	75	77(88)	101	105	108	108(122)
Mean	79	80	78	79(89)	106	106	109	110.5(122.5)
CD(P=0.05)	3.4	2.3	2.3	1.8(2.9)	2.3	1.7	6.3	4.6(3.1)
DWARF								
SPSF 1014	80	82	74	80(90)	111	108	105	115(126)
SPSF 1028	86	87	78	82(94)	112	110	109	115(128)
SPSF 1052	75	75	73	79(88)	104	105	105	110(121)
SPSF 1082	84	86	78	79(92)	111	109	108	111(125)
SPSF 1120	76	76	76	80(90)	104	105	106	110(124)
SPSF 1126	76	77	75	80(91)	105	104	108	113(124)
SPSF 1125	82	87	82	82(92)	106	105	111	116(125)
SPSF 1170	76	74	69	75(87)	106	104	101	107(122)
SPSF 1101	81	82	78	80(90)	107	107	106	115(123)
SPSF 1094	72	72	73	78(91)	99	100	103	108(124)
ICSV 705(R)	68	70	71	70(86)	99	102	103	105(124)
296 B (S)	85	92	77	78(90)	106	105	109	114(126)
Mean	78	80	75	78(90)	106	106	106	111.6(124.3)
CD(P=0.05)	1.9	2.3	1.4	1.8(2.2)	2.1	0.8	3.2	3.1(3.0)
Tall/Dwarf								
CD (P=0.05)	2.6	2.3	1.9	1.7(2.5)	2.1	2.1	4.8	3.9(3.0)

Values in parenthesis are observations recorded based on productive tillers of deadhearts

DAS = Days after sowing

UNI = Uninfested with shoot fly

IN = Infested with shoot fly

During the rainy season, in most of the tall as well as dwarf genotypes, flowering was slightly early both in uninfested and infested conditions. However, in the tillers under infested conditions flowering was mostly late by 7-13 days in talls and 9-16 days in the dwarfs.

Physiological maturity ranged between 99-111 days both in the talls as well as the dwarfs during the postrainy season and the genotypes which flowered early, reached maturity early.

During the rainy season, maturity varied between 101 to 114 days both in the talls as well as in dwarfs. On an average, the physiological maturity was the same in the dwarfs and talls in both seasons.

4.1.9 Shoot Fly Parameters

4.1.9.1 Egg laying. Shoot fly oviposition varied between tall and dwarf genotypes and also from postrainy season to rainy season (Table 7). During the postrainy season, egg counts were made at 21 and 28 DAE due to slower plant growth whereas in the rainy season the egg counts were taken on 14 and 21 DAE.

The data clearly indicated that tall genotypes were in general preferred for egg laying compared to dwarfs and it was more evident during the postrainy season than in rainy season.

The susceptible check, ICSV 112, for the tall group recorded 93 to 97 per cent plants with eggs during the postrainy season compared to 18 to 64

Table 7. Shoot fly oviposition and deadheart per cent in tall and dwarf sorghum genotypes selected for shoot fly resistance.

Genotype	Plants with eggs at DAE (%)				Eggs/100 plants at DAE				Deadhearts(%)	
	PR		R		PR		R		PR	R
	21	28	14	21	21	28	14	21		
TALL										
SPSF 1017	34	36	87	89	36	38	149	107	34.0	91.0
SPSF 1029	64	43	91	85	82	46	178	108	49.0	86.0
SPSF 1055	37	40	89	90	43	45	157	108	46.3	91.0
SPSF 1079	48	35	85	82	54	37	137	95	41.8	81.0
SPSF 1118	27	38	85	88	31	40	135	107	41.2	87.0
SPSF 1127	21	30	89	87	23	31	167	105	20.5	88.0
SPSF 1128	40	49	91	90	48	58	175	117	42.3	91.0
SPSF 1169	33	26	90	89	35	27	171	113	31.6	89.0
SPSF 1103	41	56	93	93	44	70	184	119	48.4	91.0
SPSF 1105	32	48	91	92	36	57	182	124	40.0	88.0
IS 18551(R)	18	18	68	70	19	18	86	81	16.7	62.0
ICSV 112(S)	93	97	96	97	172	128	196	123	91.9	98.0
Mean	40.5	42.9	87.9	87.6	51.8	49.5	159.8	108.9	42.0	87.3
CD(P=0.05)	16.6	16.1	6.4	8.3	33.3	22.9	30.5	14.0	8.1	4.9
DWARF										
SPSF 1014	19	22	84	88	21	23	141	105	21.6	89.0
SPSF 1028	26	37	86	85	29	39	137	100	30.2	86.0
SPSF 1052	28	34	85	87	32	36	140	105	35.0	85.0
SPSF 1082	35	31	84	89	42	32	153	112	41.5	90.0
SPSF 1120	32	47	88	87	35	52	166	104	37.7	88.0
SPSF 1126	30	42	89	94	33	45	160	125	35.8	88.0
SPSF 1125	16	61	91	90	16	75	169	110	27.4	92.0
SPSF 1170	35	39	89	90	40	39	161	108	33.1	90.0
SPSF 1101	11	21	89	95	12	21	147	120	13.8	90.0
SPSF 1094	16	25	78	87	16	27	124	112	16.8	79.0
ICSV 705(R)	17	20	83	79	18	21	133	97	15.7	78.0
296B(S)	70	86	96	94	77	97	219	116	82.1	97.0
Mean	28	38.7	86.8	88.6	30.8	42.2	154.2	109.5	32.6	88.2
CD(P=0.05)	14.3	13.9	6.8	6.9	16.8	18.5	34.4	13.9	9.3	5.6
Tall/Dwarf										
CD (P=0.05)	15.5	14.9	6.4	7.5	26.7	20.0	31.3	13.5	8.6	5.1

PR - Postrainy ; R - Rainy
DAE - Days after emergence

per cent plants with eggs in other resistant tall genotypes at 21 DAE. There was no increase in egg laying between 21 and 28 DAE during the postrainy season in the tall group. However, the percentage plants with eggs were significantly lower in the dwarf genotypes when than in the tall groups and varied between 11-35 and 20-39 at 21 and 28 DAE respectively as against 70-86 per cent in the dwarf susceptible check 296B(S). In all the dwarf genotypes significant increase in the plants with eggs was noticed at 28 DAE compared to 21 DAE during the postrainy season.

Interestingly, during the rainy season the percentages of plants with eggs were high in all the tall (85-91%) as well as dwarf (84-91%) genotypes and the differences between the genotypes were not distinct. In general, the plants with eggs increased from 14 DAE to 21 DAE in most of the dwarf genotypes during rainy season whereas in the talls no such trend was observed.

It is clearly evident from the data that higher percentages of plants with eggs were observed during rainy season than in the postrainy season in both tall and dwarf genotypes. Even the resistant checks which recorded only 18-20 per cent plants with eggs during the postrainy season had 68-83 per cent plants with eggs in the rainy season.

Number of eggs/100 plants was relatively high in the tall genotypes compared to the dwarf genotypes during the postrainy season (Table 7). However, no significant differences in egg laying were observed between tall and dwarf genotypes during rainy season. During the postrainy season, the number of eggs/100 plants did not increase from 21 to 28 DAE in all the genotypes except in a few exceptional cases. However, in the rainy season the highest number of eggs was recorded at 14 DAE compared to 21 DAE in both tall and dwarf genotypes and the increase ranged half to one fold.

4.1.9.2 **Deadhearts**. During postrainy season, deadheart percentages were significantly more in the tall genotypes (31.6-49%) compared to the dwarf genotypes (13.8-41.5%) (Table 7). However, in the rainy season no significant differences were observed in deadhearts between the tall and dwarf genotypes and the deadheart percentage ranged as high as 81 to 91 per cent among the talls and 79 to 92 per cent among the dwarfs. In general, susceptible checks recorded highest percentages of deadhearts and resistant checks had lowest percentages of deadhearts both in the postrainy and rainy seasons (Plate 3a & 3b).

The genotypes with lower deadheart percentages in the tall group were SPSF 1017, 1027, 1169 and 1014, 1101, 1094 in the dwarf group in the postrainy season. In the rainy season, SPSF 1079, 1029 in the tall group and 1052 and 1094 in the dwarf group showed less deadhearts.

4.1.9.3 **Eggs on Different Leaves**. Shoot fly preference for egg laying on different leaves starting from 3rd to 7th leaf during rainy season clearly indicated that the 4th leaf closely followed by the 5th leaf was most highly preferred (Table 8). The order of preference for egg laying was 4th > 5th >

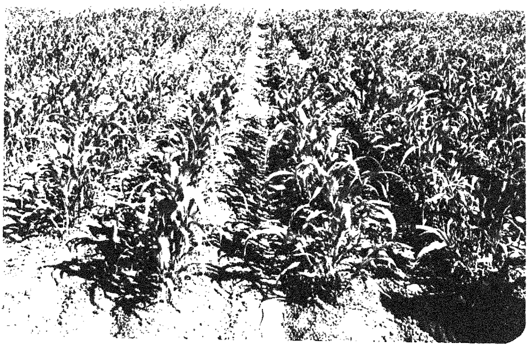


Plate No. 3a. Dwarf shoot fly resistant check ICSV 705.

Plate No. 3b. Dwarf shoot fly susceptible check 296 B.

Table 8. Shoot fly oviposition on different leaves in tall and dwarf sorghum genotypes in rainy season, 1992.

Genotype	No. of eggs in different leaves/100 plants(at 14DAE)				
	3rd	4th	5th	6th	7th
TALL					
SPSF 1017	19 (16)	59 (46)	58 (43)	11 (10)	2 (2)
SPSF 1029	22 (18)	77 (54)	66 (46)	11 (9)	2 (2)
SPSF 1055	21 (18)	65 (47)	57 (43)	11 (9)	3 (3)
SPSF 1079	26 (22)	65 (52)	40 (31)	4 (4)	2 (2)
SPSF 1118	27 (21)	71 (54)	29 (26)	6 (6)	2 (2)
SPSF 1127	15 (12)	69 (52)	60 (44)	15 (11)	2 (2)
SPSF 1128	16 (15)	74 (55)	67 (51)	15 (13)	1 (1)
SPSF 1169	19 (15)	75 (55)	64 (46)	10 (8)	3 (3)
SPSF 1103	17 (12)	63 (47)	80 (55)	21 (18)	3 (2)
SPSF 1105	9 (8)	65 (48)	83 (58)	22 (18)	3 (2)
IS18551(R)	7 (7)	34 (31)	30 (27)	13 (11)	2 (2)
ICSV 112(S)	29 (20)	92 (57)	65 (42)	8 (6)	2 (2)
Mean	18.7(15.1)	67.4(49.6)	58 (42.5)	12.2(10.1)	2.7(2.4)
CD(P=0.05)	16.8(12.9)	19.0(13.5)	23.3(15.8)	10.9(8.6)	3.6(3.0)
DWARF					
SPSF 1014	16 (12)	63 (47)	56 (41)	5 (4)	1 (1)
SPSF 1028	19 (16)	59 (45)	51 (36)	6 (5)	2 (2)
SPSF 1052	19 (18)	64 (51)	45 (36)	11 (11)	1 (1)
SPSF 1082	27 (20)	76 (53)	45 (34)	3 (3)	2 (2)
SPSF 1120	13 (11)	76 (56)	60 (42)	15 (12)	2 (2)
SPSF 1126	8 (6)	52 (41)	78 (57)	20 (16)	2 (2)
SPSF 1125	17 (14)	73 (55)	70 (48)	7 (6)	2 (2)
SPSF 1170	10 (9)	70 (53)	65 (46)	14 (10)	2 (2)
SPSF 1101	21 (16)	67 (53)	51 (39)	6 (5)	2 (2)
SPSF 1094	21 (17)	53 (41)	42 (33)	6 (5)	2 (2)
ICSV 705(R)	11 (9)	56 (44)	59 (47)	6 (6)	1 (1)
296 B (S)	23 (17)	75 (57)	92 (63)	27 (21)	2 (1)
Mean	17.3(13.6)	65.2(49.4)	59.4(43.4)	10.5(8.6)	1.4(1.3)
CD(P=0.05)	15.9(12.7)	24.1(15.3)	26.3(18.4)	10.5(8.3)	1.8(1.5)
Tall/Dwarf CD(P=0.05)	16.1(12.5)	21.0(14.0)	24.0(16.7)	10.4(8.2)	2.8(2.4)

Values in parenthesis are No.of leaves with eggs/100 plants.
DAE = Days after emergence

3rd > 6th and 7th leaf.

The egg numbers in 100 plants on the 3rd leaf ranged from 9-27 in talls and 8-27 in dwarfs, whereas on the 4th leaf they ranged from 59-75 in talls and 57-76 in dwarfs. Except in a few genotypes, slightly lower numbers of eggs were observed on the 5th leaf than on the 4th leaf in both dwarf and tall genotypes.

When individual genotypes were compared in all the genotypes including resistant and susceptible checks, highest numbers of eggs were observed on the 4th followed by 5th leaf. In most of the genotypes, irrespective of talls and dwarfs, the 3rd leaf recorded higher number of eggs than the 6th leaf.

Eggs per leaf (Table 8) were 1.1 to 1.4 in the talls and 1.2-1.4 in the dwarfs. In the tall susceptible check the eggs per leaf was 1.6 in 4th and 5th leaf and 1.5 in the dwarf susceptible check. In resistant checks, 4th and 5th leaf had 1.1 eggs/leaf in tall and 1.3 in dwarf.

4.1.10 Grain Yield Parameters

In the postrainy season, productive tillers per deadheart in tall group on an average were 1.7 plant^{-1} and in dwarf group were 1.8 plant^{-1} (Table 9). In the tall group, the genotype SPSF 1169 showed three productive tillers and SPSF 1017, 1029, 1079 and the resistant check showed one tiller each whereas other genotypes had two tillers. Similarly in the dwarf group, except

Table 9. Productive tillers and grain yield in shoot fly infested and uninfested tall and dwarf sorghum genotypes.

Genotype	Productive tillers/plant		Grain yield (t ha^{-1}) IN		Grain yield (t ha^{-1}) UNI		Yield loss(%)		100Grain weight	
	PR	R	PR	R	PR	R	PR	R	PR	R
TALL										
SPSF 1017	1	0.7	2.2	0.7	2.1	3.0	5	77	2.2	2.8
SPSF 1029	1	0.7	2.5	0.8	3.4	4.1	26	81	2.1	3.0
SPSF 1055	2	0.7	2.5	0.5	3.0	1.3	17	62	2.0	2.3
SPSF 1079	1	0.4	2.6	0.7	2.9	2.3	10	70	2.2	2.8
SPSF 1118	2	0.8	2.8	1.3	2.6	2.7	8	52	1.9	2.6
SPSF 1127	2	0.8	0.9	0.5	1.1	1.5	18	67	2.2	2.4
SPSF 1128	2	0.7	2.9	1.2	3.5	2.0	17	40	2.0	2.3
SPSF 1169	3	0.7	2.4	1.3	3.2	4.0	25	68	2.1	2.6
SPSF 1103	2	0.5	3.3	0.8	3.6	4.0	8	80	2.2	2.7
SPSF 1105	2	0.7	2.4	1.0	3.1	4.0	23	75	2.3	2.7
IS 18551(R)	1	0.7	2.4	0.7	2.7	2.2	11	68	1.9	2.0
ICSV 112(S)	2	0.6	2.9	1.3	3.7	5.0	22	74	2.2	2.7
Mean	1.7	0.6	2.5	0.9	2.9	3.0	13.7	68	2.1	2.6
CD (P=0.05)	1.0	0.2	0.5	0.3	0.7	0.7	14.9	11.6	0.3	0.2
DWARF										
SPSF 1014	2	0.8	2.7	1.5	3.4	3.4	21	56	2.2	2.8
SPSF 1028	2	1.0	2.4	1.1	2.6	2.0	8	45	2.0	3.0
SPSF 1052	2	0.6	2.7	1.1	4.0	4.1	33	73	2.2	2.4
SPSF 1082	2	0.7	1.7	0.9	2.0	2.1	15	57	1.9	2.5
SPSF 1120	1	0.4	1.6	0.6	2.0	2.2	20	73	2.3	2.7
SPSF 1126	2	0.7	2.9	1.3	3.7	3.3	22	61	2.2	2.3
SPSF 1125	2	0.9	1.6	1.1	1.5	2.9	7	62	1.3	2.5
SPSF 1170	2	0.8	2.5	1.3	3.6	4.1	31	68	2.5	2.6
SPSF 1101	2	0.9	2.7	1.7	3.5	3.7	23	54	1.7	2.4
SPSF 1094	2	0.8	2.4	1.3	2.5	3.1	4	58	2.0	2.5
ICSV 705(R)	2	0.9	2.1	1.5	2.9	3.7	28	60	2.2	2.5
296 B (S)	2	1.0	0.6	1.0	1.0	2.8	40	64	1.5	2.5
Mean	1.8	0.8	2.2	1.2	2.7	3.1	20.8	61	2.0	2.5
CD (P=0.05)	1.1	0.3	0.6	0.3	0.8	0.4	12.1	12.6	0.2	0.2
Tall/Dwarf										
CD (P=0.05)	1.0	0.2	0.6	0.3	0.7	0.6	13.5	12.3	0.2	0.2

PR - Postrainy ; R - Rainy
IN - Infested ; UNI - Uninfested

SPSF 1120 which had one, all genotypes had two productive tillers per deadheart.

In the rainy season, productive tillers per deadheart in the tall group on an average were 0.7 $plant^{-1}$ and in the dwarf group were 0.8. In the dwarf group genotypes, SPSF 1028 had one productive tiller per deadheart and was similar to the susceptible check, 296B.

Yield in infested tall group genotypes ranged between 0.9-3.3 t ha^{-1} in postrainy and 0.5-1.3 t ha^{-1} in rainy season whereas in the dwarf group, the yield ranged from 0.6 to 2.7 t ha^{-1} in the postrainy and 0.6 to 1.7 t ha^{-1} in rainy season (Table 9). In the postrainy season, mean grain yield in the tall group was higher (2.9 t ha^{-1}) under uninfested condition than that of dwarf group (2.7 t ha^{-1}) whereas in the rainy season grain yield in dwarfs was higher (3.1 t ha^{-1}) than talls (3.0 t ha^{-1}). The susceptible check ICSV 112 in the tall group ranked first for yield (3.7 t ha^{-1}) in the postrainy and 4.9 t ha^{-1} in the rainy season) under uninfested conditions.

The resistant checks IS 18551 (tall) and ICSV 705 (dwarf) yielded similarly to the susceptible tall check, ICSV 112 under infested condition in rainy and the postrainy seasons. However, there were several test entries which yielded on par or greater than the susceptible check ICSV 112 (2.9 t ha^{-1} in the postrainy and 1.3 t ha^{-1} in the rainy season) and the resistant checks. They were SPSF 1118, 1128 and 1169 in the tall group, and SPSF 1014, 1052, 1126, 120 and 1101 in the dwarf group.

Significant differences were not observed between tall and dwarf groups for the mean grain yield under infested conditions, while the genotypes which yielded high in uninfested and infested conditions in both seasons in the tall group were SPSF 1169 and 1105 (Plate 4) and in the dwarf group SPSF 1014, 1052, 1126, 1170 and 1101 (Plate 5).

During rainy season the mean yield loss due to shoot fly infestation was 13.7 per cent in talls and 20.8 per cent in dwarfs whereas in the rainy season the yield loss in tall group was 67.6 per cent and in dwarfs 60.7 per cent.

The mean seed mass (100 grain weight in grams) in the tall group was 2.1 (range 1.9-2.3 g) in postrainy season and 2.0-3.0 g in rainy season and in dwarf group (1.5-2.3 g) in postrainy and 2.3 to 5.0 g in rainy season.

4.2 GENETIC VARIABILITY STUDIES

Separate analyses of variance carried out for dwarfs and talls showed that variability among the treatments was not large for several traits particularly in the rainy season (Table 10). Hence, both talls and dwarfs were merged, and the estimates of phenotypic and genotypic coefficients of variation, heritability (broad sense) and genetic advance (percentage over mean) were estimated for the test entries (excluding the checks) in both the seasons.

Plate No. 4. Selected tall sorghum genotypes (SPSF 1105 and 1169) for shoot fly resistance based on resistance and yield.

Plate No. 5. Selected dwarf sorghum genotypes (SPSF 1101 and 1052) for shoot fly resistance based on resistance and yield.

Table 10. Coefficient of variation, heritability and genetic advance for all the morphological characters and shoot fly egg laying and deadhearts in sorghum genotypes selected for shoot fly resistance.

	Mean		CV (%) Phenotypic		CV (%) Genotypic		Heritability (broad sense)		Genetic advance (% over mean)	
	PR	R	PR	R	PR	R	PR	R	PR	R
Seedling emergence	7.1	5.2	7.6	8.4	6.8	5.1	82	37	12.7	6.4
Mesocotyl length	9.5	5.9	38.8	22.7	36.0	20.6	86	82	68.9	38.0
Seedling vigor	2.4	2.9	35.7	25.2	22.9	15.6	41	38	30.3	19.9
Glossiness	2.4	2.5	32.2	37.0	24.3	27.5	57	55	37.9	42.2
Pl.Ht. 1	3.3	3.0	14.0	14.9	8.9	8.9	41	36	11.7	11.0
2	6.6	5.8	11.2	17.6	2.1	13.7	35	61	0.8	22.0
3	10.8	8.9	13.4	19.1	8.0	12.7	35	45	9.8	17.5
4	18.9	14.1	16.8	21.4	11.9	15.9	51	55	17.6	24.3
5	135.3	177.9	18.5	23.5	17.6	22.9	91	95	34.7	46.1
Days to 50% flower UNI	79.0	76.8	5.1	5.1	4.6	4.8	81	88	8.3	9.3
IN	80.0	90.1	5.7	3.1	5.3	2.3	88	57	10.4	3.6
Days to phy. mat. UNI	106.3	107.5	3.6	4.6	3.3	3.1	86	47	6.4	4.5
IN	105.6	123.4	2.7	2.1	2.3	1.3	72	38	4.1	1.6
Productive tillers	1.8	0.7	41.6	28.4	3.4	20.0	1	49	0.6	28.9
Yield UNIN	2862	2970	32.2	32.7	26.1	30.1	66	84	43.5	56.9
IN	2372	1035	28.6	38.4	21.5	31.1	57	66	33.3	52.1
Seed mass	2.1	2.6	13.8	9.3	7.8	71.2	70	20	13.5	31.2
Plants with eggs 1	31.2	87.6	48.9	6.0	34.2	2.8	49	22	49.5	2.7
2	37.9	88.7	37.7	6.0	2.1	41.1	12	32	1.5	35.3
Eggs/100 plants 1	35.3	155.9	54.8	17.2	39.3	9.0	52	27	58.1	9.7
2	41.8	110.2	45.1	10.4	30.3	5.3	45	26	42.1	5.6
DH(%)	34.4	88.5	33.8	5.1	28.1	2.9	69	33	48.2	3.5

PR - Postrainy ; R - Rainy

UNI- Uninfested ; IN -Infested

DH(%) - Deadheart percentage

contd...

Table 10 (contd.)

		Mean		CV (%) Phenotypic		CV (%) Genotypic		Heritability (broad sense)		Genetic advance (% over mean)	
		PR	R	PR	R	PR	R	PR	R	PR	R
Trichome density											
3 rd	AD	27.7	45.2	150.3	157.3	114.6	153.6	58	95	180.1	308.8
	AB	21.1	46.5	71.7	78.3	39.7	69.9	31	80	45.4	128.8
5 th	AD	154.9	261.3	64.6	75.2	38.8	72.7	36	94	48.1	145.0
	AB	32.0	145.3	95.4	81.2	63.2	72.2	44	79	86.2	132.5
7th	AD	240.0	424.6	67.2	55.3	54.8	53.7	67	94	92.0	107.5
	AB	44.6	125.4	147.4	92.9	136.3	87.1	85	88	259.6	168.1
Leaf parameters											
Length	3rd		6.6		16.5		9.3		32		10.8
	4th		10.9		15.8		9.2		34		11.1
	5th		15.9		16.6		11.5		48		16.4
Width	3rd		0.5		21.2		9.2		19		8.2
	4th		0.7		19.7		9.7		25		10.0
	5th		1.1		19.8		9.7		24		9.8
Drooping depth	3rd		1.8		32.3		17.6		30		19.8
	4th		3.4		28.4		17.0		36		20.9
	5th		4.9		30.9		21.8		50		31.8
Curvature	3rd		1.3		68.3		38.7		32		45.3
	4th		2.6		52.6		31.8		37		39.6
	5th		4.8		53.8		32.3		37		40.4

4.2.1 Highly Heritable Traits (>80%)

The traits that fall under this group were seedling emergence, mesocotyl length, plant height at maturity, days to 50% flowering in uninfested and infested trails, days to physiological maturity and trichomes on abaxial surface of 7th leaf in the postrainy season and mesocotyl length, plant height at maturity, days to 50% flowering (uninfested), yield in the uninfested trial, trichomes on 3rd, 5th and 7th leaves adaxial surfaces and 7th leaf abaxial surface in rainy season.

4.2.2 Intermediate Heritable Traits (50-80%)

The traits that fall under this category were glossy score, plant height at 28 DAE, days to physiological maturity (infested), yield in both uninfested and infested trials, seed mass, deadheart percentage, and trichomes 3rd and 7th leaves adaxial surface in the postrainy season and glossy score, plant height at 12 DAE, 22 DAE, days to 50% flowering (infested) yield (infested), seed mass, trichomes on 3rd and 5th leaves abaxial surface in the rainy season.

4.2.3 Low Heritable Traits (<50%)

The traits in this group were seedling vigour, plant height at 10, 17, 23 DAE, percentage plants with eggs (21 and 28 DAE), number of eggs/100 plants (28 DAE), trichomes on 3rd and 5th leaves abaxial surface and 5th leaf adaxial surface in postrainy season and seedling emergence, seedling vigor, plant height at 7 and 17 DAE, physiological maturity, productive tillers, percentage plants with eggs, number of eggs/100 plants, deadheart percentage, and length, width, drooping depth, and curvature of 3rd, 4th and 5th leaves in rainy season.

4.2.4 Heritability/Season

Some traits showed distinct changes in their heritability estimates across seasons. Seedling emergence showed high heritability in the postrainy season, while low in the rainy season. Early plant height at stage 2 and 3 showed less heritability in the postrainy season than in the rainy season. Heritability was low for days to flower and to physiological maturity (under infested condition), and for shoot fly parameters such as number of eggs/plant or percentage plants with eggs and deadhearts in the rainy season. On the other hand, productive tillers were less heritable in postrainy season than in rainy season. Similarly, grain yield and trichome density (except 7th abaxial) under the postrainy season were less heritable than in the rainy season.

4.2.5 Heritability over Developmental Stages

Plant height observed in early stages (1, 2 and 3) was less heritable than that observed at maturity. In view of the lack of relationship between plant height in early stages and height at maturity, especially in dwarfs, it is important to know at which of the early stages plant height was least variable. It appeared that plant height observed at stage 4 could be most appropriate as it had above 50% heritability (Table 10). Similarly, number of eggs/100 plants taken at an early stage (21 DAE postrainy, 14 DAE rainy) was more highly heritable than in later stage (28 DAE postrainy, 21 DAE rainy) under both low and high pest infestations. In the postrainy season, 3rd leaf adaxial and 5th and 7th leaves abaxial surface trichomes were more heritable than the trichome on other surfaces. On the other hand, the adaxial trichomes of 3rd, 5th or 7th leaves were more heritable than abaxial surface trichomes in rainy season. Considering all, adaxial suface trichomes on the 3rd leaf and abaxial surface trichomes on the 7th leaf were the most appropriate for selection programs to have high genetic gain. Measurements on the 5th leaf for leaf characters proved to be most appropriate as these had higher heritability compared to others.

4.2.6 Genetic Advance (% Over Mean)

Genetic advance estimates provide a clearer picture about the expected gains due to selection as they take into account not only heritability but also the selections differential (a deviation of sample mean from the population mean). Given the selection differential, the higher the heritability, the greater would be the genetic gain. The genetic gains by and large followed a pattern similar to that of heritability for shoot fly parameters.

4.3 CORRELATION

4.3.1 Plant Traits and Shoot Fly Parameters

Correlations of plant characters with shoot fly oviposition and deadheart formation in tall and dwarf sorghum genotypes are presented in Table 11.

4.3.1.1 Seedling Emergence. Seedling emergence was negatively correlated with percentage plants with eggs, number of eggs/100 plants and deadhearts in tall group in postrainy season and positively correlated in rainy season whereas in the dwarf group it was vice versa. Thus there is no consistent relationship across the seasons. However, these correlations were not statistically significant.

4.3.1.2 Mesocotyl Length. Mesocotyl length was negatively correlated with percentage plants with eggs, number of egg/100 plants and deadhearts in the tall group in postrainy as well as in rainy season whereas in the dwarf group it was negatively correlated only in the rainy season. Again these were not statistically significant.

4.3.1.3 Seedling Vigour. Statistically significant correlations between this trait and percentage plants with eggs, number of eggs/100 plants and deadhearts were observed in rainy season in respect of genotypes in the dwarf group, while no such significant estimates were obtained in all other cases including tall and dwarf genotypes.

Table 11. Correlation of plant characters with shoot fly oviposition and deadhearts in tall (T) and dwarf (D) sorghum genotypes selected for shoot fly resistance.

Plant characters		Plants with eggs(%)				No.of eggs/100 plants				Deadhearts	
		Postrainy		Rainy		Postrainy		Rainy		(%) PR	R
		21DAE	28DAE	14DAE	21DAE	21DAE	28DAE	14DAE	21DAE		
Seedling emergence	T	-0.29	-0.25	0.26	0.27	-0.42	-0.29	0.08	0.12	-0.30	0.38
	D	0.28	0.41	-0.17	-0.29	0.27	0.41	-0.18	-0.39	0.32	-0.15
Mesocotyl length	T	-0.40	-0.01	-0.47	-0.50	-0.36	-0.00	-0.41	-0.44	-0.23	-0.56
	D	0.20	0.09	-0.16	-0.38	0.23	0.07	-0.12	-0.19	0.19	-0.27
Seedling vigour	T	0.17	0.07	-0.04	0.19	0.07	0.03	0.21	0.05	0.23	0.18
	D	-0.30	-0.34	0.66*	0.62*	-0.28	-0.34	0.67*	0.38	-0.27	0.78**
Glossiness	T	0.54	0.61*	0.51	0.62*	0.63*	0.60*	0.44	0.47	0.59*	0.64*
	D	0.59*	0.72**	0.60*	0.50	0.56	0.71**	0.68*	0.24	0.64*	0.74**
Plant height(DAE):											
10,7	T	0.00	0.16	-0.47	-0.52	0.16	0.19	-0.27	-0.38	-0.03	-0.62*
	D	0.30	0.49	-0.54	-0.44	0.27	0.53	-0.68*	-0.22	0.33	-0.70*
17,12	T	-0.29	-0.00	-0.15	-0.32	-0.17	-0.04	0.04	-0.14	-0.21	-0.38
	D	0.36	0.29	-0.46	-0.48	0.37	0.29	-0.49	-0.30	0.35	-0.50
23,17	T	-0.25	-0.26	0.04	-0.19	-0.26	-0.23	0.21	-0.06	-0.35	-0.18
	D	-0.20	-0.62*	-0.63*	-0.56	-0.19	-0.65*	-0.62*	-0.33	-0.32	-0.73**
28,22	T	-0.10	0.06	0.11	-0.09	-0.00	0.09	0.29	0.02	-0.12	-0.10
	D	0.26	0.39	-0.63*	-0.50	0.24	0.40	-0.61*	-0.40	0.24	-0.58*
At maturity	T	-0.40	-0.28	-0.45	-0.47	-0.36	0.24	-0.28	-0.31	-0.35	-0.60*
	D	-0.10	0.10	0.32	0.44	-0.08	0.12	0.23	0.44	0.03	0.32
Leaf length:											
3rd	T	-	-	-0.05	-	-	-	0.02	-	-	-0.16
	D	-	-	-0.39	-	-	-	-0.48	-	-	-0.57*
4th	T	-	-	0.08	-	-	-	0.22	-	-	0.00
	D	-	-	-0.50	-	-	-	-0.57*	-	-	-0.66*
5th	T	-	-	0.16	-	-	-	0.35	-	-	-0.01
	D	-	-	-0.56	-	-	-	-0.66*	-	-	-0.65*

Contd...

Table 11 (Contd.)

Plant characters		Plants with eggs(%) Postrainy 21DAE	Plants with eggs(%) Postrainy 28DAE	Plants with eggs(%) Rainy 14DAE	Plants with eggs(%) Rainy 21DAE	No. of eggs/100 plants Postrainy 21DAE	No. of eggs/100 plants Postrainy 28DAE	No. of eggs/100 plants Rainy 14DAE	No. of eggs/100 plants Rainy 21DAE	Deadhearts (%) PR	Deadhearts (%) R
Leaf width:											
3rd	T	-	-	0.48	-	-	-	0.49	-	-	0.36
	D	-	-	-0.43	-	-	-	-0.51	-	-	-0.32
4th	T	-	-	0.48	-	-	-	0.33	-	-	0.51
	D	-	-	-0.17	-	-	-	-0.21	-	-	-0.19
5th	T	-	-	0.62*	-	-	-	0.51	-	-	0.60*
	D	-	-	-0.38	-	-	-	0.52	-	-	-0.43
Drooping depth:											
3rd	T	-	-	0.51	-	-	-	0.64*	-	-	0.39
	D	-	-	-0.24	-	-	-	-0.42	-	-	-0.42
4th	T	-	-	0.59*	-	-	-	0.68*	-	-	0.51
	D	-	-	-0.46	-	-	-	-0.56	-	-	-0.67*
5th	T	-	-	0.69*	-	-	-	0.78**	-	-	0.60*
	D	-	-	-0.42	-	-	-	-0.41	-	-	-0.51
Leaf curvature:											
3rd	T	-	-	0.19	-	-	-	0.30	-	-	0.02
	D	-	-	0.08	-	-	-	0.02	-	-	0.26
4th	T	-	-	0.34	-	-	-	0.41	-	-	0.35
	D	-	-	-0.23	-	-	-	-0.26	-	-	-0.09
5th	T	-	-	0.58*	-	-	-	0.68*	-	-	0.51
	D	-	-	-0.28	-	-	-	-0.29	-	-	-0.24
Days to flower:											
Uninfested	T	-0.22	-0.41	0.08	0.03	-0.30	-0.45	0.01	-0.07	-0.35	0.13
	D	0.39	0.46	0.39	0.40	0.40	0.45	0.30	-0.29	0.48	0.51
Infested	T	-0.04	-0.21	-0.12	0.01	-0.12	-0.25	-0.18	-0.09	-0.13	0.05
	D	0.49	0.58*	0.17	0.50	0.45	0.59*	0.11	0.30	0.56	0.45
Phy.maturity:											
Uninfested	T	-0.23	-0.49	-0.02	-0.02	-0.29	-0.53	-0.10	-0.17	0.04	0.06
	D	0.16	0.06	0.51	0.42	0.18	0.04	0.50	0.31	0.20	0.59*
Infested	T	-0.19	-0.07	0.68*	0.64*	-0.07	-0.45	0.50	0.54	-0.01	0.74**
	D	0.05	-0.08	0.46	0.63*	0.09	-0.10	0.31	0.39	0.10	0.68*

Contd...

Table 11 (Contd.)

Plant characters			Plants with eggs(%) Postrainy 21DAE	Plants with eggs(%) Postrainy 28DAE	Plants with eggs(%) Rainy 14DAE	Plants with eggs(%) Rainy 21DAE	No. of eggs/100 plants Postrainy 21DAE	No. of eggs/100 plants Postrainy 28DAE	No. of eggs/100 plants Rainy 14DAE	No. of eggs/100 plants Rainy 21DAE	Deadhearts (%) PR	Deadhearts (%) R
Trichomes:												
3rd	AD	T	-0.33	-0.49	-0.81**	-0.85**	-0.28	-0.44	-0.82**	-0.85**	-0.46	-0.85**
	AB		-0.67*	-0.61*	-0.49	-0.55	-0.67*	-0.57*	-0.59*	-0.62*	-0.66**	-0.51
	AD	D	0.02	-0.19	-0.23	-0.04	-0.04	-0.22	-0.15	-0.06	-0.03	0.09
	AB		-0.40	-0.66*	-0.60*	-0.41	-0.37	-0.68*	-0.76**	-0.42	-0.51	-0.52
5th	AD	T	-0.70*	-0.80**	-0.84**	-0.84**	-0.64*	-0.77**	-0.85**	-0.86**	-0.79**	-0.82**
	AB		-0.62*	-0.43	-0.40	-0.39	-0.56	-0.41	-0.34	-0.33	-0.60*	-0.42
	AD	D	-0.12	-0.42	-0.67*	-0.67*	-0.10	-0.45	-0.62*	-0.53	-0.26	-0.73**
	AB		-0.10	-0.24	-0.54	-0.53	-0.10	-0.27	-0.69*	-0.46	-0.17	-0.72
7th	AD	T	-0.61*	-0.69*	-0.69*	-0.72**	-0.55	-0.68*	-0.66*	-0.73**	-0.76**	-0.67*
	AB		-0.41	-0.23	0.11	0.06	-0.35	-0.23	0.17	-0.13	-0.42	-0.06
	AD	D	-0.19	-0.51	-0.57*	-0.51	-0.16	-0.55	-0.55	-0.40	-0.32	-0.62*
	AB		-0.02	-0.16	-0.19	-0.20	-0.00	-0.20	-0.18	-0.25	-0.07	-0.22
Productive tillers		T	-0.19	-0.06	-0.05	0.03	-0.12	-0.04	0.01	0.10	-0.04	0.04
		D	-0.01	-0.18	0.19	0.13	-0.01	-0.20	0.01	0.10	-0.04	0.15
Grain yield: Uninfested		T	0.62*	0.56	0.46	0.44	0.54	0.57*	0.55	0.55	0.65*	0.35
		D	-0.47	-0.69*	-0.05	0.01	-0.45	-0.71*	-0.19	0.08	-0.56	-0.19
Infested		T	0.44	0.46	0.28	0.38	0.36	0.47	0.30	0.47	0.55	0.29
		D	-0.65*	-0.77**	-0.20	0.06	-0.64*	-0.78**	-0.44	0.17	-0.71**	-0.25
% Yield loss/ha		T	-0.52	0.49	0.15	0.03	-0.55	-0.52	0.22	0.06	-0.49	0.02
		D	-0.21	-0.37	0.18	-0.01	-0.22	-0.38	0.35	-0.01	-0.26	0.09
100 grain mass		T	0.17	0.22	0.57*	0.42	0.14	0.22	0.49	0.41	0.10	0.47
		D	-0.13	-0.54	-0.16	-0.43	-0.11	-0.59*	-0.17	-0.68*	-0.29	-0.07

* = Significant at P=0.05

** = Significant at P=0.01

4.3.1.4 Glossiness. In both postrainy and rainy seasons, glossiness was negatively correlated in general with percentage plants with eggs, number of eggs/100 plants and deadheart percentage in the tall as well as dwarf groups. The effects were significant both in tall and dwarf groups for percentage plants with eggs and deadheart percentage in both the seasons. The correlations of glossiness and eggs/100 plants were significant in rainy and postrainy seasons for the dwarf group, while in rainy season not significant only for the tall group.

4.3.1.5 Plant Height. Plant height (stage 1: 10 DAE in postrainy and 7 DAE in rainy season) were negatively correlated with number of eggs/100 plants and deadheart percentage for dwarf group in rainy season only. In all other cases they were not significant.

Correlation between plant height (stage 2: 17 DAE in postrainy and 12 DAE in rainy season) with ovipositional preference traits or with deadheart percentage were not significant in any of the cases examined.

Plant height (stage 3: 23 DAE in postrainy and 17 DAE in rainy season) showed significantly negative correlation with percentage plants with eggs, number of eggs/100 plants and deadheart percentage in rainy season only in the dwarf group. No such significant estimates were observed in any other cases.

Plant height (stage 4 : 28 DAE in postrainy and 22 DAE in rainy season) showed statistically significant positive correlation with percentage plants with eggs, number of eggs/100 plants and deadheart percentage in dwarf proup in rainy season only. In all other cases the correlations were not significant.

Plant height at maturity in the tall group showed significant negative correlation with deadheart formation in the rainy season. The correlations in the other cases were not siginificant.

4.3.1.6 Leaf Length. In the rainy season, leaf lengths of 3rd, 4th and 5th leaves were negatively correlated with deadheart percentage and the 4th and 5th leaf lengths with number of eggs/100 plants in the dwarf group. In all other cases examined, particularly in the tall group, the correlations were not significant.

4.3.1.7 Leaf Width. Leaf width (3rd, 4th and 5th) in the tall group showed positive correlation with percentage plants with eggs, number of eggs/100 plants and deadheart percentage and particularly significant for percentage plants with eggs and deadheart percentage in 5th leaf, whereas in the dwarf group the correlations were negative but without any significance.

4.3.1.8 Drooping Depth. The correlations for drooping depth for tall groups were positive and significant in all cases, except the droopyiess of the 3rd leaf with percentage plants with eggs and deadheart percentage and 4th leaf droopiness with deadheart percentage. However, in the dwarf group, correlations were negative but were not significant except 4th leaf with percentage deadhearts.

4.3.1.9 Leaf Curvature. The pattern of correlations with three shoot fly parameters were similar to that observed with drooping depth but were not siginificant except 5th leaf curvature with shoot fly egg laying (percentage plants with eggs and number of eggs/100 plants).

4.3.1.10 Days to 50% Flowering and Physiological Maturity. Days to 50% flowering and days to physiological maturity under infested conditions may get prolonged especially in the susceptible genotypes and hence usually we expect to observe positive relationship between these traits and shoot fly parameters (Table 11). However, correlations between these traits under uninfested conditions are of interest. When these were examined, the correlation between days to flower or days to maturity with shoot fly parameters were positive and large, and in one case (physiological maturity and percentage deadhearts) were significant in the dwarf group, while these were either close to zero or negative and small in magnitude in the tall group.

4.3.1.11 Trichomes. Correlations of trichome density on the adaxial and abaxial surfaces of the 3rd, 5th and 7th leaves with percentage plants with eggs, eggs/100 plants and deadheart percentage were all negative and in more than one third of cases either significant or highly significant (Table 11) indicating that high trichome density reduces shoot fly damage. Further, the following generalizations can be deduced by examining the magnitude of these correlation estimates: (i) In general, the 3rd leaf abaxial surface trichomes, 5th and 7th leaf adaxial surface trichomes produced pronounced effects in reducing the number of plants with eggs or number of eggs/100 plants or deadhearts in both rainy and postrainy seasons in both tall and dwarf groups. (ii) However, exceptions to the above general rule were the effects of 3rd leaf adaxial surface trichomes in the tall group in the rainy season on percentage plants with eggs and number of egg/100 plants. (iii) In general, such effects as deduced in (i) are less in the dwarf group than in the tall group.

4.3.1.12 **Productive Tillers**. Productive tillers from deadhearts showed negative relationship in both tall and dwarf genotypes in postrainy season and positive correlation in rainy season with egg laying and deadheart formation, but they were very small and not significant.

4.3.1.13 **Grain Yield**. Grain yield showed positive but not significant (in most cases) correlation with shoot fly egglaying and deadheart percentage in both uninfesteed and infested trials in postrainy and rainy seasons in the tall group and negative significant relationship in postrainy season in the dwarf group. In rainy season same was true but with few exceptions.

4.3.1.14 **Yield Loss**. Negative correlations between percentage yield loss (t ha^{-1}) and shoot fly parameters were observed in the tall and dwarf groups in postrainy season. However, such correlations were positive in rainy season with few exceptions.

4.3.1.15 **Grain Mass**. The tall group showed positive correlations between 100 grain mass and percentage plants with eggs, number of eggs/100 plants and deadheart percentage whereas the dwarf group showed a negative trend. In most cases (exceptions were one in tall; two in dwarf group), the correlations were not significant.

4.3.2 Among Plant Characters

Correlations among plant characters (excluding days to physiological maturity) were also estimated. These are presented in Table 12 for postrainy season and Table 13 for rainy season.

The significant correlations between morphological traits are:

Seedling emergences was positively correlated with mesocotyl length in postrainy season in talls and negatively correlated in rainy season. Seedling emergence was positively related to seedling vigor in talls but not in dwarfs. Seedling emergence had positive relationship with plant height. Early emerged ones flowered early.

Mesocotyl length was correlated with glossiness intensity and plant height at maturity in talls but not in dwarfs. It had no correlation with other traits. Seedling vigour was more when they were more glossy, tall and early to flower. Seedling vigour correlation with early plant height, glossiness, and days to flower was more pronounced in dwarfs in rainy season; glossy seedlings were in general tall and early to flower.

In talls there was positive relationship for initial plant height and height at maturity in postrainy season, but not in rainy season. In dwarfs, there was strong positive correlation between glossiness intensity and early plant height

Table 12. Correlation coefficients among morphological traits in tall (T) and dwarf (D) sorghum genotypes, 1991-92 postrainy season.

		Seedling emergence (1)	Mesocotyl length (2)	Seedling vigor (3)	Glossy score (4)	Plant height at17 DAE (5)	Plant height at maturity (6)	Trichome density AD (7)	Trichome density AB (8)	Days to 50% flowering UNIN (9)	Days to 50% flowering IN (10)	Yield UNIN (11)	Yield IN (12)
(1)	T		0.39	0.36	-0.09	-0.23	-0.44	-0.30	0.31	0.46	0.47	-0.14	-0.18
	D		-0.13	0.10	0.28	-0.33	0.18	-0.02	0.47	0.67*	0.60*	-0.39	-0.30
(2)	T			-0.16	0.13	-0.04	0.07	-0.15	0.69*	0.29	0.19	-0.49	-0.42
	D			-0.22	-0.20	0.10	0.36	0.23	0.14	0.04	-0.09	0.30	0.14
(3)	T				0.34	-0.83**	-0.58*	-0.32	-0.53	0.31	0.50	0.13	0.31
	D				0.10	-0.29	0.40	0.03	-0.02	0.31	0.21	0.24	0.37
(4)	T					-0.77**	-0.71**	-0.53	-0.07	0.19	0.40	-0.19	-0.10
	D					-0.75**	-0.14	-0.70**	-0.44	0.51	0.64*	-0.46	-0.47
(5)	T						0.74**	0.43	0.29	-0.32	-0.55	0.11	-0.01
	D						-0.33	0.72**	0.49	-0.58*	-0.66*	0.48	0.42
(6)	T							0.56	0.21	-0.41	-0.59*	0.11	0.18
	D							-0.29	0.03	0.28	0.23	0.15	0.12
(7)	T								0.14	0.02	-0.17	-0.47	-0.35
	D								0.63*	-0.47	-0.64*	0.24	0.23
(8)	T									0.34	0.12	-0.67*	-0.76
	D									-0.08	-0.28	0.39	0.45
(9)	T										0.94**	-0.57*	-0.55
	D										0.96**	-0.45	-0.37
(10)	T											-0.43	-0.41
	D											-0.59*	-0.53
(11)	T												0.88
	D												0.94

UNIN = Uninfested; IN = Infested
AD = Adaxial; AB = Abaxial
* Correlation significant at P=0.05
** Correlation significant at P=0.01

Table 13. Correlation coefficients among morphological traits in tall (T) and dwarf (D) sorghum genotypes, 1992 rainy season.

		Seedling emergence (1)	Mesocotyl length (2)	Seedling vigour (3)	Glossy score (4)	Plant height at17 DAE (5)	Plant height at maturity (6)	Trichome density AD (7)	Trichome density AB (8)	Days to 50% flowering UNIN (9)	Days to 50% flowering IN (10)	Yield UNIN (11)	Yield IN (12)
(1)	T		-0.48	0.61*	-0.02	-0.66*	-0.49	-0.24	-0.04	0.43	0.61*	-0.39	-0.30
	D		-0.54	0.19	0.24	-0.31	-0.49	0.34	0.44	0.16	0.54	-0.68*	-0.28
(2)	T			-0.28	-0.55	0.19	0.67*	0.56	0.12	0.05	-0.23	-0.20	-0.19
	D			-0.43	-0.48	0.44	0.44	0.004	-0.05	-0.05	-0.38	0.28	-0.04
(3)	T				0.30	-0.98**	-0.36	-0.08	0.03	0.38	0.62*	-0.53	-0.11
	D				0.90**	-0.97**	0.23	-0.57*	-0.60*	0.72*	0.69*	-0.58*	-0.45
(4)	T					-0.22	-0.51	-0.57*	-0.47	0.32	0.46	0.01	-0.14
	D					-0.83**	-0.03	-0.64*	-0.60*	0.56	0.55	-0.52	-0.42
(5)	T						0.34	0.09	0.04	-0.41	-0.69*	0.55	0.10
	D						-0.21	0.31	0.41	-0.72**	-0.74**	0.67*	0.50
(6)	T							0.40	0.19	-0.16	-0.26	0.07	-0.34
	D							-0.37	-0.27	0.42	0.10	0.07	-0.26
(7)	T								0.51	-0.22	-0.21	-0.33	-0.25
	D								0.72**	-0.58	-0.43	-0.04	-0.05
(8)	T									-0.43	-0.15	-0.04	-0.17
	D									-0.53	-0.19	-0.17	-0.26
(9)	T										0.82**	-0.79*	-0.60*
	D										0.77**	-0.62*	-0.30
(10)	T											-0.66*	-0.20
	D											-0.77**	-0.33
(11)	T												0.62*
	D												0.67*

UNIN =Uninfested ; IN =infested

AD =Adaxial ; AB =Abaxial

* Correlation significant at P=0.05

** Correlation significant at P=0.01

in both the seasons, while it was not the case with plant height at maturity. Also there was some tendency that dwarf and glossy lines flowered early. Plant height at maturity did not show correlation with early plant height in dwarfs in both the seasons. Plant height at maturity had negative correlation with flowering in talls and positively correlated in dwarfs, whereas plant height was positively correlated to yield in both tall and dwarf in postrainy and rainy seasons except under infested trial where it was negatively correlated but not significant.

Correlations between flowering and yield suggested that earliness helped to produce more grain yields in talls in both the seasons in both uninfested and infested conditions, while in dwarfs it helped only in uninfested rainy season condition. Grain yield from the uninfested trial had significant positive correlation with yield of the infested trial in both the seasons.

The results of correlations among leaf characters, plant height in the early stage (i.e., 17 DAE), glossiness and trichome density are presented in (Table 14) for rainy season.

In talls, early plant height and trichome density (5th leaf)were not correlated while there was a positive tendency between them in dwarfs. Both in talls and dwarfs greater early plant height was associated with longer and droopier leaves. In both talls and dwarfs, glossiness intensity and trichome density were positively correlated . Leaf length and glossiness showed

Table 14. Correlation coefficients among morphological traits of tall (T) and dwarf (D) sorghum groups, 1992 rainy season.

		Plant height at17 DAE (1)	Glossy score (2)	Trichome density AD (3)	AB (4)	Leaf length (5)	Drooping depth (6)	Yield UNIN (7)
(1)	T	1.00	-0.24	0.08	0.04	0.68*	0.43	0.11
	D	1.00	-0.82**	0.43	0.48	0.70*	0.45	0.48
(2)	T			-0.55	-0.43	0.03	0.33	-0.19
	D			-0.55	-0.64**	0.87**	-0.49	-0.46
(3)	T				0.51	-0.14	-0.67*	-0.33
	D				0.72**	0.66*	0.69*	-0.04
(4)	T					0.08	-0.06	0.04
	D					0.61*	0.66*	0.17
(5)	T						0.69*	0.52
	D						0.29	0.53
(6)	T							0.77**
	D							0.46

AD = Adaxial; AB = Abaxial
UNIN = Uninfested

distinctly strong positive correlation in dwarfs, but not in talls, while glossiness did not show any relationship with leaf droopiness in talls nor in dwarfs. In talls the density on the adaxial surfaces trichome was negatively correlated with drooping depth of the leaf, while it was the opposite in dwarfs. Similarly, abaxial trichome density did not correlate with other leaf characters in talls, but did so in dwarfs. Leaf length and droopiness showed positive correlation in talls but not in dwarfs.

4.4 PATH COEFFICIENTS

Path coefficient analysis of the dependent traits, number of eggs/100 plants, percentage plants with eggs and percentage deadhearts was carried out only for the rainy season data as data on a larger number of parameters are available for rainy season experiments. Data on leaf parameters were not planned in the postrainy season experiments.

A path diagram and coefficients of factors influencing resistance in sorghum facilitate understanding of the nature of the cause and effects of the system. The path diagram shows in essence that a dependent variable (percentage plants with eggs, eggs/100 plants and deadheart percentage) is the result of other independent variables (like plant height at 17 DAE, trichome density, glossiness and leaf parameters), 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.

4.4.1 Choosing Dependent Traits

The traits with significant correlation with the dependent variable such as shoot fly egg laying (percentage plants with eggs and number of eggs/100 plants)and deadheart formation (Table 11) are seedling vigour, plant height at 17 DAE, glossiness, leaf parameters of 5th leaf, viz., leaf length, drooping depth and trichomes on adaxial and abaxial surface of leaves.

Therefore, the effect of the independent traits such as glossiness, plant height at 17 DAE and leaf parameters on shoot fly egg laying and deadheart formation were examined by considering four traits at a time through path coefficient analyses.

4.4.2 Choosing Combinations

The combinations of the independent traits (1 to 4)with dependant traits (5) examined are given below.

	(1)	(2)	(3)	(4)
A.	Plant height at 17 DAE	Glossiness	Trichome density on AB/AD	Leaf leng
B.	Plant height at 17 DAE	Glossiness	Trichome density on AB/AD	Drooping depth
C.	Plant height at 17 DAE	Glossiness	Leaf length	Drooping depth
D.	Plant height at 17 DAE	Trichome density on AB/AD	Leaf length	Drooping depth
E.	Glossiness	Trichome density on AB/AD	Leaf length	Drooping depth

Note: AB = Abaxial surface trichome density used in respect of percentage plants with eggs, and number of eggs/100 plants.
AD = Adaxial surface trichome density used in respect of deadheart percentage.

4.4.3 Path Coefficients of Various Factors on Shoot Fly Parameters

The direct and indirect efects of the traits examined in different above mentioned combinations, ie, A, B, C, D, and E on different shoot fly parameters (percentage plants with eggs, number of eggs/100 plants and deadheart percentage) in both tall and dwarf groups are given in Tables 15 to 19.

Table 15. Path coefficients of plant height, glossy score and 5thleaf trichomes and leaf length in tall and dwarf groups in relation to shoot fly oviposition and deadhearts per cent (1992 rainy season).

Height group	Plant height	Glossy score	5th leaf Trichome density AB/AD	5th leaf Leaf length	Y	Variable (Y)
	Plant height					
Tall	0.05	-0.08	-0.01	0.09	0.05	% PLEG
Dwarf	-0.41	0.06	-0.15	-0.11	-0.61	% PLEG
Tall	-0.12	-0.29	-0.19	-0.02	-0.61	EGPL
Dwarf	0.09	-0.08	-0.01	0.21	0.22	EGPL
Tall	0.02	-0.05	-0.06	-0.08	-0.18	DH %
Dwarf	-0.33	-0.50	-0.25	0.35	-0.74	DH %
		Glossy score				
Tall	-0.01	0.34	0.12	0.004	0.45	% PLEG
Dwarf	0.34	-0.07	0.20	0.14	0.60	% PLEG
Tall	0.10	0.36	0.25	0.02	0.72	EGPL
Dwarf	-0.02	0.32	0.10	0.01	0.40	EGPL
Tall	-0.004	0.22	0.39	-0.003	0.60	DH %
Dwarf	0.27	0.61	0.33	-0.43	0.76	DH %
			Trichome density			
Tall	0.002	-0.15	-0.27	0.01	-0.41	% PLEG
Dwarf	-0.20	0.05	-0.31	-0.10	-0.56	% PLEG
Tall	-0.06	-0.23	-0.39	-0.02	-0.69	EGPL
Dwarf	0.004	-0.14	-0.23	0.02	-0.33	EGPL
Tall	0.001	-0.12	-0.72	0.02	-0.82	DH %
Dwarf	-0.14	-0.33	-0.59	0.32	-0.74	DH %
				Leaf length		
Tall	0.03	0.01	-0.02	0.13	0.15	% PLEG
Dwarf	-0.29	0.06	-0.19	-0.16	-0.58	% PLEG
Tall	-0.08	-0.31	-0.24	-0.03	-0.66	EGPL
Dwarf	0.06	0.01	-0.02	0.31	0.36	EGPL
Tall	0.01	0.006	0.10	-0.12	-0.002	DH %
Dwarf	-0.23	-0.53	-0.39	0.49	-0.66	DH %

Residuals:	% PLEG	EGPL	%DH
Tall	0.72	0.38	0.29
Dwarf	0.53	0.67	0.17

% PLEG = % Plants with eggs; EGPL = Eggs/100 plants;
DH % =Deadheart per cent
AB Abaxial surface related to % PLEG ,EGPL
AD Adaxial surface related to DH %

Table 16. Path coefficients of plant height, glossy score and 5th leaf trichomes and drooping depth in tall and dwarf groups in relation to shoot fly oviposition and deadheart per cent (1992 rainy season).

Height group	Plant height	Glossy score	5 th leaf: Trichome density AB/AD	5 th leaf: Drooping depth	Y	Variable (Y)
	Plant height					
Tall	-0.30	0.01	-0.01	0.35	0.05	% PLEG
Dwarf	-0.41	-0.05	-0.16	0.01	-0.61	% PLEG
Tall	-0.14	0.01	-0.01	0.36	0.22	EGPL
Dwarf	-0.15	-0.30	-0.23	0.07	-0.61	EGPL
Tall	-0.22	-0.04	-0.04	0.12	-0.18	DH %
Dwarf	-0.38	-0.19	-0.25	0.09	-0.74	DH %
		Glossy score				
Tall	0.07	-0.05	0.15	0.27	0.45	% PLEG
Dwarf	0.34	0.06	0.21	-0.01	0.60	% PLEG
Tall	0.03	-0.03	0.12	0.28	0.40	EGPL
Dwarf	0.12	0.36	0.31	-0.07	0.72	EGPL
Tall	0.05	0.17	0.28	0.10	0.60	DH %
Dwarf	0.31	0.24	0.32	-0.09	0.78	DH %
			Trichome density			
Tall	-0.01	0.02	-0.36	-0.06	0.41	% PLEG
Dwarf	-0.20	-0.04	-0.33	0.01	0.56	% PLEG
Tall	-0.01	0.01	-0.29	-0.06	0.33	EGPL
Dwarf	-0.07	-0.23	-0.49	0.10	0.69	EGPL
Tall	-0.02	-0.10	-0.51	-0.19	0.82	DH %
Dwarf	-0.16	-0.13	-0.59	0.14	0.74	DH %
				Drooping depth		
Tall	-0.13	-0.02	0.03	0.80	0.68	% PLEG
Dwarf	-0.18	-0.03	-0.22	0.02	-0.41	% PLEG
Tall	-0.06	-0.01	0.02	0.83	0.78	EGPL
Dwarf	-0.07	-0.17	-0.33	0.15	-0.41	EGPL
Tall	-0.09	0.06	0.35	0.29	0.60	DH %
Dwarf	-0.17	-0.11	-0.40	0.20	-0.48	DH %

Residuals:	% PLEG	EGPL	%DH
Tall	0.34	0.30	0.27
Dwarf	0.53	0.37	0.20

% PLEG = Percentage Plants with eggs; EGPL = Eggs/100 plants;
DH % =Deadheart per cent
AB Abaxial surface related to % PLEG ,EGPL
AD Adaxial surface related to DH %

Table 17 Path coefficients of plant height, glossy score and 5th leaf length and drooping depth in tall and dwarf groups in relation to shoot fly oviposition and deadheart per cent (1992 rainy season).

Height group	Plant height	Glossy score	5th leaf: Leaf length	5th leaf: Drooping depth	Y	Variable (Y)
	Plant height					
Tall	0.03	-0.03	-0.40	0.44	0.05	% PLEG
Dwarf	-0.35	-0.12	-0.10	-0.04	-0.61	% PLEG
Tall	0.07	-0.03	-0.23	0.41	0.22	EGPL
Dwarf	-0.05	-0.50	-0.03	-0.03	-0.61	EGPL
Tall	-0.12	-0.06	-0.41	0.42	-0.17	DH %
Dwarf	-0.23	-0.62	-0.23	-0.11	-0.73	DH %
		Glossy score				
Tall	-0.01	0.13	-0.02	0.34	0.45	% PLEG
Dwarf	0.29	0.14	0.12	0.05	0.60	% PLEG
Tall	-0.02	0.11	-0.01	0.32	0.40	EGPL
Dwarf	0.04	0.61	0.04	0.03	0.72	EGPL
Tall	0.03	0.26	-0.02	0.33	0.60	DH %
Dwarf	0.19	0.75	-0.29	0.12	0.78	DH %
			Leaf length			
Tall	0.02	0.004	-0.58	0.71	0.15	% PLEG
Dwarf	-0.25	-0.13	-0.14	-0.06	-0.58	% PLEG
Tall	0.05	0.003	-0.34	0.65	0.36	EGPL
Dwarf	-0.04	-0.53	-0.05	-0.04	-0.66	EGPL
Tall	-0.08	0.01	-0.60	0.67	-0.004	DH %
Dwarf	-0.16	-0.65	0.33	-0.16	-0.65	DH %
				Drooping depth		
Tall	0.01	0.04	-0.40	1.03	0.68	% PLEG
Dwarf	-0.16	-0.07	-0.09	-0.10	-0.41	% PLEG
Tall	0.03	0.04	-0.23	0.95	0.78	EGPL
Dwarf	-0.02	-0.29	-0.03	-0.07	-0.41	EGPL
Tall	-0.05	0.09	-0.41	0.98	0.60	DH %
Dwarf	-0.10	-0.36	0.21	-0.26	-0.50	DH %

Residuals:	%PLEG	EGPL	%DH
Tall	0.33	0.32	0.24
Dwarf	0.58	0.47	0.34

DH % = Deadheart per cent; % PLEG = Plants with eggs; EGPL = Eggs/100 plants

Table 18. Path coefficients of plant height, trichomes, length and drooping depth of 5th leaf in tall and dwarf groups in relation to shoot fly oviposition and deadheart per cent (1992 rainy season).

Height group	Plant height	5th leaf: Trichome density AB/AD	Leaf length	Drooping depth	Y	Variable (Y)
	Plant height					
Tall	-0.04	-0.01	-0.35	0.44	0.05	%PLEG
Dwarf	-0.38	-0.16	-0.11	0.03	-0.61	%PLEG
Tall	0.01	-0.01	-0.19	0.41	0.22	EGPL
Dwarf	-0.24	-0.27	-0.22	0.18	-0.61	EGPL
Tall	-0.13	-0.03	-0.30	0.29	-0.17	% DH
Dwarf	-0.58	-0.27	0.07	0.05	-0.73	% DH
		Trichome density				
Tall	-0.002	-0.29	-0.04	-0.07	-0.41	%PLEG
Dwarf	-0.18	-0.33	-0.09	0.05	-0.56	%PLEG
Tall	0.0003	-0.25	-0.02	-0.07	-0.33	EGPL
Dwarf	-0.12	-0.56	-0.19	0.18	-0.69	EGPL
Tall	-0.01	-0.41	0.06	-0.46	-0.82	% DH
Dwarf	-0.25	-0.64	0.06	0.08	-0.73	% DH
			Leaf length			
Tall	-0.03	-0.02	-0.51	0.71	0.15	%PLEG
Dwarf	-0.27	-0.20	-0.15	0.05	-0.58	%PLEG
Tall	0.006	-0.02	-0.28	0.66	-0.36	EGPL
Dwarf	-0.17	-0.34	-0.32	0.17	-0.66	EGPL
Tall	-0.09	0.06	-0.44	0.47	-0.004	% DH
Dwarf	-0.41	-0.42	0.10	0.08	-0.65	% DH
				Drooping depth		
Tall	-0.02	0.02	-0.35	1.03	0.68	%PLEG
Dwarf	-0.16	-0.22	-0.10	0.07	-0.41	%PLEG
Tall	0.004	0.02	-0.19	0.95	0.78	EGPL
Dwarf	-0.11	-0.37	-0.20	0.27	-0.41	EGPL
Tall	-0.06	0.28	-0.30	0.68	0.60	% DH
Dwarf	-0.25	-0.44	0.06	0.12	-0.50	% DH

Residuals :	% PLEG	EGPL	%DH
Tall/	0.26	0.27	0.24
Dwarf	0.53	0.37	0.24

DH % = Deadhearts per cent; % PLEG = Plants with eggs; EGPL = Eggs/100 plants
AB/AD = AB: Abaxial surface related to egg laying;
AD: Adaxial surface related to deadhearts per cent

Table 19. Path coefficients of glossy score, trichomes, leaf length and drooping depth of 5th leaf in tall and dwarf groups in relation to shoot fly oviposition and deadhearts per cent (1992 rainy season).

Height group	Glossy score	5th leaf: Trichome density AB/AD	Leaf length	Drooping depth	Y	Variable (Y)
Glossy score						
Tall	-0.01	0.13	-0.02	0.35	0.45	%PLEG
Dwarf	0.29	0.18	0.14	-0.01	0.60	%PLEG
Tall	0.21	0.19	-0.01	0.21	0.60	EGPL
Dwarf	0.35	0.31	0.15	-0.09	0.72	EGPL
Tall	0.21	0.19	-0.21	0.60	0.60	% DH
Dwarf	0.92	0.31	-0.47	0.01	0.77	% DH
Trichome density						
Tall	0.01	-0.30	-0.04	-0.07	-0.41	%PLEG
Dwarf	-0.18	-0.29	-0.10	0.01	-0.56	%PLEG
Tall	-0.11	-0.35	0.07	-0.43	-0.82	EGPL
Dwarf	-0.23	-0.47	-0.11	0.03	-0.69	EGPL
Tall	-0.11	-0.35	0.07	-0.43	-0.82	% DH
Dwarf	-0.51	-0.57	0.36	-0.01	-0.73	% DH
Leaf length						
Tall	-0.0004	-0.02	-0.54	0.72	0.15	%PLEG
Dwarf	-0.25	-0.17	-0.16	0.01	-0.58	%PLEG
Tall	0.006	0.05	-0.50	0.44	-0.004	EGPL
Dwarf	-0.31	-0.30	-0.17	0.12	-0.66	EGPL
Tall	0.006	0.05	-0.50	0.44	-0.004	% DH
Dwarf	-0.80	-0.37	-0.54	-0.01	-0.65	% DH
Drooping depth						
Tall	-0.005	0.02	-0.37	1.04	0.68	%PLEG
Dwarf	-0.14	-0.19	-0.10	0.02	-0.41	%PLEG
Tall	0.07	0.23	-0.34	0.63	0.60	EGPL
Dwarf	-0.17	-0.32	-0.11	0.19	-0.41	EGPL
Tall	0.07	0.23	-0.34	0.63	0.60	% DH
Dwarf	-0.44	-0.39	0.35	-0.02	-0.50	% DH

Residuals:	%PLEG	EGPL	%DH
Tall	0.26	0.21	0.21
Dwarf	0.58	0.37	0.21

DH % = Deadhearts per cent; % PLEG = Plants with eggs; EGPL = Eggs/100 plants
AB/AD = AB: Abaxial surface related to egg laying
AD: Adaxial surface related to deadhearts per cent

4.4.3.1 **Percentage Plants with Eggs**. Among the combinations from 'A' to 'E', 'D' combination explained the variability better than other combinations as the residual variability in this was less (26% in talls and 53% in dwarfs) than in others. It appeared that the traits in the 'D' combination explained the variability of the dependent variable percentage plants with eggs better in the tall group than in the dwarf group.

For 'D' combination, the path diagram and coefficients of factors influencing percentage plants with eggs in tall and dwarf sorghum genotypes are shown in Figure 2.

The correlation coefficients (r) of plant height at 17 DAE with percentage plants with eggs are 0.05 in the tall group and -0.61 in the dwarf group. These estimates consisted of four components, the relative contribution of these are given in Table 18. Thus, we have

	Tall	Dwarf
Percentage plants with eggs vs Plant height r	0.05	-0.61
Direct effects 1 vs 5	-0.04	-0.38
Indirect effects via trichome density (AB)	-0.01	-0.16
Indirect effects via the leaf length	-0.35	-0.11
Indirect effects via drooping depth	0.43	0.03
	-----	------
Total	0.05	-0.61
	-----	------

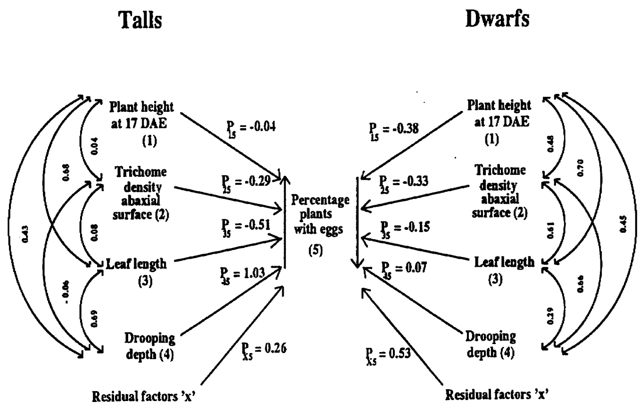


Figure 2. Path diagram and coefficients of factors influencing percentage plants with eggs in tall and dwarf sorghum genotypes

The direct effect of plant height at 17 DAE in the tall group points out that with other variables held constant, increasing plant height at 17 DAE will decrease the percentage plants with eggs (ie, increase resistance to shoot fly). However, the subtle indirect effects play a more important part and mask the direct influence. A strong positive influence (0.44) was registered indirectly by drooping depth upon percentage plants with eggs in the tall group as its correlation was r = 0.68 which in turn has a large direct effect (1.03) upon percentage plants with eggs (Table 18). Path coefficients may be greater than 1. The indirect effect (-0.01) through trichome density on abaxial surface was negative but negligible and the influence via leaf length (-0.35) was quite sizable and negative. The net effect in this system of imposing influence was that one positive effect counter balanced three negative ones, making the overall correlation between plant height and percentage plants with eggs in the tall group essentially low (0.05).

In the dwarf group, the direct effect of plant height on percentage plants with eggs while other variables are held constant, points out that increasing plant height at 17 DAE will decrease the percentage plants with eggs. Here the indirect effects were not able to mask the direct influence, and the reason might be as follows.

A strong negative correlation by leaf length (Table 18)
(r = -0.58) had small direct effect (-0.15) upon percentage plants with eggs. Whereas trichome density on abaxial surface had negative correlation lesser than leaf length (r = 0.56) but had large direct influence (-0.33) on

percentage plants with eggs. The positive direct effect of drooping depth is masked by other three negative ones and thus aggregating the overall correlation to -0.61 between plant height at 17 DAE and percentage plants with eggs in the dwarf group.

In the same pattern, the correlations of other parameters like trichome density (5th leaf) on abaxial surface, leaf length (5th leaf) and drooping depth (5th leaf) each with percentage plants with eggs in both tall and dwarf groups are presented and the estimates are given in Table 18.

An examination of the correlation components in the tall group reveals that both leaf length and trichome density have exerted greater influence indirectly. The observed correlation between leaf length and percentage plants with eggs (r=0.16) gives a misleading impression that leaf length has little to do with percentage plants with eggs. But path analysis exposed that leaf length in the tall group exerted one of the major influences in reducing the percentage plants with eggs.

Considering the correlation of the traits in the tall group on percentage plants with eggs, the traits in the order of importance were drooping depth, glossiness, trichomes, leaf length and plant height (Table 11). However, considering the path coefficient estimates eg. direct effects (Table 19), the influence of glossiness on egg laying was negligible.

In the dwarf group, correlation coefficients with percentage plants with eggs revealed that glossiness had higher correlation than trichomes, leaf length and drooping depth. Direct effect by glossiness (Table 19) also showed considerable significant contribution. So in the dwarf group along with plant height at 17 DAE, trichome density, leaf length, drooping depth, and glossiness also contributed to reduce the egg laying ie percentage plants with eggs.

The order of direct effects in 'D' combination of the independent traits with percentage plants with eggs in tall group are drooping depth > leaf length > trichome density on abaxial surface > plant height at 17 DAE and in dwarf group plant height at 17 DAE > trichome density on abaxial surface > leaf length and > drooping depth.

In the dwarfs there may be some other factors influencing the expression of shoot fly percentage plants with eggs along with the traits examined.

4.4.3.2 <u>Number of Eggs/100 Plants</u>. Among the combinations for which path analysis were carried out i.e. A to E, the combination of traits in 'E' explained the variability better than other combinations (A, B, C and D) as the residual variability with this combination was 21 per cent in talls and 37 per cent in dwarfs (Table 19). The traits in the 'E' combination, however, explained the variability of the dependent variable, number of eggs/100 plants better in the tall group than in the dwarf group.

For 'E' combination, the path diagram and coefficients of the factors influencing eggs/100 plants in tall and dwarf sorghum genotypes is shown in Figure 3.

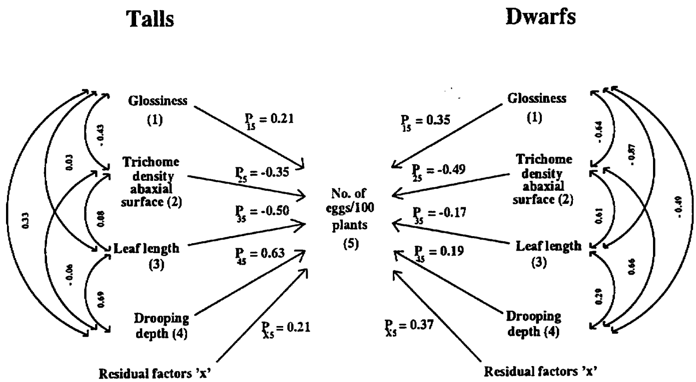


Figure 3. Path diagram and coefficients of factors influencing No. of eggs per 100 plants in tall and dwarf sorghum genotypes

The correlation coefficients (r) of glossiness with number of eggs/100 plants are 0.60 in the tall group and 0.72 in the dwarf group. The estimates of the relative contribution four components of these are given in Table 19.

In the tall group, the simple correlation coefficients of the important traits on number of eggs/100 plants in the order of magnitude are trichome density on abaxial surface (5th leaf) > drooping depth (5th leaf) > glossiness > plant height > leaf length (5th leaf).

However, the direct effects of the traits on the number of eggs/100 plants in the tall group (Figure 3) in the order of magnitude are drooping depth > leaf length > trichome density on abaxial surface > glossiness which is different from the one seen through the simple correlations mentioned as above.

In tall group if the direct effect of glossiness is considered keeping other variables constant, with increase in glossiness there is decrease in egg laying. Here also the direct effects of glossiness was masked by indirect effects as indicated earlier. Strong positive indirect (0.21) and direct (0.63) effects by drooping depth upon number of eggs/100 plants mighty be responsible boosting up the direct effects of glossiness on eggs/100 plants (Table 19). The indirect effect (0.19) through trichome density on abaxial surface was positive but the indirect effect of leaf length was negative and negligible. Thus, positive effects of drooping depth, and trichome on the abaxial leaf surface had aggravated the overall correlation between glossiness and eggs/100 plants in tall group.

Similarly, the indirect effects of the other three independent variables on the dependent variable can be readily explained from the estimates presented in Table 19.

Thus, overall, drooping depth and leaf length directly or indirectly influenced the other independent variables to give high correlation coefficients with eggs/100 plants. Drooping depth had strong positive and indirect influence which together counteract each other. This in turn leads to the negligible (-0.03) correlation coefficient of leaf length with eggs/100 plants. This was misleading and gave an impression that leaf length did not have any effect on eggs/100 plants. However, path coefficient analysis clearly demonstrated that the effects of leaf length on other variables was indeed significant.

In the dwarf group, simple correlation coefficients of important traits identified eggs/100 plants and their contribution in the order of magnitude are: glossiness > trichome density on abaxial surface > leaf length > plant height > drooping depth.

The order of direct effects of the traits in 'E' combination as seen in Figure 3, were trichome density on abaxial surface > glossiness > leaf length > drooping depth.

The correlation of glossiness on number of eggs/100 plants was 0.72. This was accounted by the direct effects of glossiness and the indirect influence of trichome density (on abaxial surface) both in equal measure and the indirect influence by leaf length, the measure of which was about half of the earlier variables (Table 19). Drooping depth had very negligible indirect effect.

The simple correlation coefficient of leaf length (5th leaf) with number of eggs/100 plants was -0.66 which was a significant correlation. However, the direct effect of leaf length was only 50% of either glossiness on trichome on abaxial surface. Thus in the dwarf group unlike in the talls the indirect influence of one trait over other was similar to that of their direct effects.

Considering the residuals in the combinations of D & E which differ only by one trait (plant height/glossiness) it was clear that glossiness played a greater role than plant height (as the former reduced the residuals by 6%) in the tall group whereas they played an equal and similar role in the dwarf group (no change in the residuals between E & D)> This indicated that in the dwarf group to reduce further the un accounted variability a combination with more than four traits (ie plant height at 17 DAE and glossiness along with three other variables ie, trichomes on the leaf surface,leaf length and drooping depth of the leaves) are required.

Thus, the above analysis on number of eggs/100 plants and percentage plants with eggs ie oviposition non-preference clearly leads to the following conclusions.

The important traits for resistance (non preference to oviposition) in the tall group are glossy seedlings with long leaves having less drooping but with trichomes on abaxial surface. Whereas in the dwarf group the selection criteria should include fast early growth (tall) glossy with moderately long leaves with minimum drooping and dense trichomes on abaxial and adaxial surface of leaves.

4.4.3.3 **Deadheart Percentage**. This is the most important dependant trait as this directly relates to shoot fly damage. As in ovipositional non-preference, the independent traits (plant height 17 DAE, glossiness, trichome, leaf length, and drooping depth) and their combinations, 'A' & 'E' were considered in explaining the variability of this important dependant variable. Considering the magnitude of the unaccounted variability, the combination of traits as given in 'E' was adjudged as the best for both tall and dwarf groups.

Considering the differences in residuals between 'D' and 'E' (tall) which have accounted different magnitude of variability in the deadhearts, but which differ by only one trait glossiness/plant height at 17 DAE, it was clear that glossiness was accounting more variability than plant height at 17 DAE in both tall and dwarf groups.

When the unaccounted variability given by 'E' and 'A' combinations, which differed by only one trait (drooping depth/plant height 17 DAE) was considered, it was clear that plant height had greater role than drooping depth in the dwarf group and in talls drooping depth had greater role than plant height.

The simple correlation coefficients of traits in 'E' combination showed that the effects in the order of magnitude were trichome on adaxial surface of 5th leaf > drooping depth > glossiness > plant height > leaf length in tall and glossiness > plant height (17DAE) > trichome on adaxial surface of 5th leaf > leaf length > drooping depth in dwarf group over deadheart percentage.

However, direct effects of the traits as given by path analysis on deadheart formation in 'E'combination in the order of magnitude were -

Tall - glossiness < trichome < leaf length < drooping depth of leaf.

Dwarf - glossiness > trichome > leaf length > drooping depth ofleaf.

Thus talls showed the reverse trend compared to the dwarfs. These traits are inter-related, one influencing the other traits. The magnitudes of the direct effects of these independent traits in 'E' combination on percentage deadhearts and correlation coefficients of traits among themselves, and their interrelationships are shown in Figure 4.

When the simple correlation coefficients are closely examined the correlations of leaf length and drooping depth with percentage deadhearts in the tall group were different in magnitude in the former and in direction in the latter when compared to those in dwarfs. However the correlations of glossiness and trichome density with percentage deadhearts were of the same magnitude and direction in both the groups (Table 19).

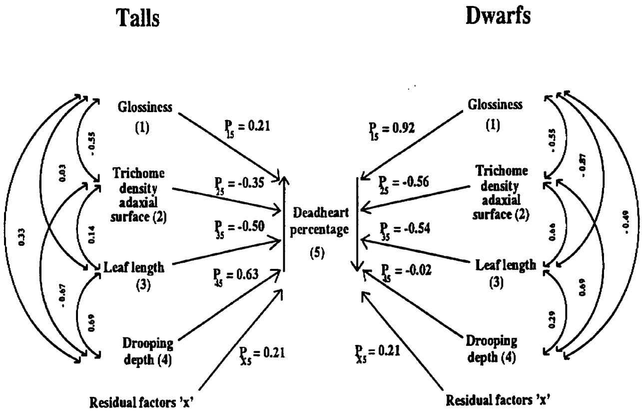


Figure 4.Path diagram and coefficients of factors influencing deadheart formation in tall and dwarf sorghum genotypes

The patterns of the direct and indirect effects of the dependent traits on percentage deadhearts in the tall group as given by path analysis were similar to those of the effects observed in the case of the dependant variable, number of eggs/100 plants as explained earlier. But, in the dwarf group, the direct and indirect effects of glossiness on percentage deadheart, unlike on numbering eggs/100 plants was more pronounced. The leaf length correlation coefficient with percentage deadheart was negative and high (-0.65). However the direct effect was positive and high (0.54) which resulted from the contribution of the indirect effects of other independent traits, mostly glossiness and trichome density.

DISCUSSION

CHAPTER V

DISCUSSION

Shoot fly *A. soccata* is one of the most important yield limiting factors in Asia in both rainy and postrainy season sorghum crops (Jotwani, 1981). Significant variability for resistance has been established among germplasm lines (Dhabolkar *et al.*, 1989), and usually the shoot fly resistant germplasm lines were tall (Singh *et al.*, 1968) and had undesirable characters, such as poor agronomic desirability, susceptibility to lodging, low yield etc. (Singh and Rana, 1986).

Breeding programs aim to transfer resistance into high yielding and adapted breeding lines or varieties, which often serve as restorers to develop hybrids in sorghum.

It has been shown that the inheritance of resistance to shoot fly is quantitative and polygenically controlled. It is expressed as a dominant trait under low shoot fly pressure and adddtive or additive x additive trait under high pressure (Borikar and Chopde, 1980).

In view of the significant heterosis known to occur in sorghum for various traits, in particular grain and fodder yields (Rao and Murthy, 1970; Quinby, 1970), hydrids are the target materials in various breeding programs. Therefore, it is imperative that resistance to shoot fly is incorporated into both the parents - female/seed parents and male parents - in order to have high yielding hybrids with shoot fly resistance under variable shoot fly pressures.

Female/seed parents are usually shorter than male parents. The latter may be similar in height to shoot fly resistant germplasm lines or the bred varieties presently available. Earlier studies suggested that fast growth was related to shoot fly resistance (Jain and Bhatnagar, 1962; Dalvi *et al.*, 1990) and that may readily be seen to be associated with height (Mate *et al.*, 1988). Hence, changes brought about in the selections in breeding short shoot fly resistant seed parents may be quite different from those of tall restorers/varieties.

The present study, involving lines selected empirically under field conditions for resistance to shoot fly including one tall and one dwarf in each pair of the same pedigree or pedigree of similar parents readily provided the scope to study such effects of selection for shoot fly resistance in dwarf and tall backgrounds.

5.1. MEAN PERFORMANCE OF TALL AND DWARF SELECTIONS

The selections in the dwarf and tall groups were assessed for various morphological traits (seedling emergence, mesocotyl length, seedling vigour, glossiness, plant height, leaf parameters, trichomes) and shoot fly parameters - percentage plants with eggs, number of eggs/100 plants (which indicates ovipositional non-preference), percentage deadhearts (which indicates shoot fly resistance), and effective tillering ability (which indicates tolerance or recovery resistance), grain yield under shoot fly infestation and grain yield potential under controlled condition. The empirical selection for shoot fly resistance resulted in talls which differed significantly from the dwarfs by 69 cm for plant height at maturity in rainy and 40 cm in postrainy season indicating that the above grouping was appropriate (Table 3).

Talls had significantly higher egg laying in general, and more percentage deadhearts in the postrainy season compared to dwarfs when there was normal shoot fly pressure (difference in percentage deadhearts between tall resistant and susceptible checks was 75 per cent), while they did not differ from the dwarfs (although they had numerically high egg laying) in the rainy season where shoot fly pressure was more (difference in percentage deadhearts was only 36 per cent). Also, egg laying was high and stable in talls over a period, while egg laying was initially less in dwarfs and increased at a higher rate up to the level of tall genotypes later on indicating that talls were more preferred by the shoot fly for egg laying. Thus, the variations in selection pressures would bring about differential effects in the selections in tall and dwarf backgrounds (Table 7).

An examination of morphological traits showed that dwarfs had significantly less mesocotyl length and less number of trichomes (3rd leaf adaxial and 7th leaf abaxial) in both the seasons than talls, while these differences were consistent, but not signigicant for various other traits including glossinesss across seasons (Table 2). However, considering the seasons separately, dwarfs had less plant height at 7 DAE and 12 DAE, less leaf length (3rd, 4th, and 5th leaves) less leaf droopiness (5th leaf) and less leaf curvature (3rd leaf) compared to the talls in rainy season. Perhaps, these might again explain the differential shoot fly infestations effects bred in tall and dwarf groups during the empirical selection.

Considering the productive tillering ability which is a reflection of recovery resistance or tolerance, the dwarfs had numerically more productive tillers both in rainy and postrainy seasons (Table 9). Sharma *et al.* (1977) in their inheritance studies also indicated that dwarfs had more tillers than tall Indian sorghums. Tillering ability was said to provide recovery resistance (Doggett *et al.*, 1970). However, this may not be a dependable character, as under persistent shoot fly attack or under unfavourable conditions, this may collapse.

Under shoot fly infested condition in postrainy season, although talls had more deadhearts and less productive tillers, they produced higher grain yield (numerically) while in rainy season, dwarfs yielded more than talls, although both groups had similar damage due to shoot fly infestation. Therefore, the observed differences in grain yield may be attributed to height genes and associated gene complexes. The observed pattern of grain yields under uninfested conditions (talls yielding more in postrainy, and dwarfs in rainy seasons) also supported the above conclusion. Furthermore studies by Casady, (1965) and Stickler and Younis (1966) showed that differences in plant height could affect the grain yield/adaptation in sorghum.

Selections with the least number of deadhearts and high grain yield under infested and uninfested conditions are shoot fly resistant high yielding lines. These lines were SPSF 1029, 1055, and 1118 in the tall group, and 1014, 1052 and 1126 in the dwarf group in the rainy season, and 1118, 1128 and 1169 in the tall group, and 1126, 1170 and 1101 in the dwarf group in the postrainy season.

5.2. TRAIT ASSOCIATIONS IN TALL AND DWARF GROUPS

The associations between morphological traits and shoot fly parameters, and also shoot fly parameters themselves, are important in formulating a breeding strategy as the correlated response influences the selection criteria (Table 11).

5.2.1 Early Seedling Traits vs Shoot Fly Parameters

Seedling emergence, mesocotyl length, early seedling vigour and early plant height (stages 1, 2, and 3) all refer to the growth rate during the early stage of the seedlings during which they are attacked by shoot fly. An understanding of the relationships of these traits in the lines obtained through empirical selection for shoot fly resistance is important and as such, an analysis would indicate what traits are brought together along with shoot fly resistance. In this study, seedling emergence and mesocotyl length did not show significant correlation either with ovipositional preference (number of eggs/100 plants or percentage plants with eggs) or with deadheart percentages in both talls and dwarfs. This indicated that these traits either did not have sufficiently strong impact on shoot fly resistance or if they had, the selection might have broken such linkages. Inheritance studies by Biradar and Borikar (1983) showed that seedlings with long basal internodes had high seedling vigour.

On the other hand, early plant height (stages 1, 2, and 3) showed strong negative correlation for oviposition in dwarf group in the rainy and the postrainy seasons, while such relations were not exhibited in talls in the rainy nor in the postrainy season. However, the impact of plant height in dwarfs in relation to deadheart percentage was seen only in the rainy season. The study also showed that early plant height did not show any relationship to the height at maturity. Shivanker *et al.*, . (1989), however, argued that such a relationship between plant height and resistance to shoot fly did not exist as relatively tolerant germplasm came from all height categories (in dwarf, moderately tall and tall). It was clear in the present investigations that plant height at maturity, as was the case with Shivanker *et al.*, . (1989), did not show any effect on shoot fly resistance.

Early seedling vigour showed strong negative correlation with egg laying and deadheart formation by shoot fly in the dwarf group particularly in rainy season which clearly indicated that high early growth rate was important in breeding for dwarf shoot fly resistant lines, and that it had a greater role in the rainy season than in the postrainy season. Mate *et al.* (1979) also indicated that most resistant types grew taller and had higher growth rate than susceptible ones even though the growth rate was not significant.

5.2.2 Leaf Characters vs Shoot Fly Parameters

Glossiness and trichomes are the most important traits which have positive influence on shoot fly resistance. High trichome density on the abaxial surface of the leaf leads to lower preference for oviposition by shoot fly and high density on the adaxial surface may interfere with larval movement and survival leading to reduced deadhearts. Glossy leaves may possibly affect the quality of light reflected from them which in turn may influence the host preference leading to less egg laying and deadhearts. Several studies in sorghum have clearly supported about this view (Maiti and Bidinger, 1979; Taneja and Leuschner, 1985).

This study also clearly established the relationship between glossiness and deadheart formation consistently across seasons and plant height groups, while such a relationship between ovipositional non-preference and glossiness was not statistically consistent, although numerically so (Table 11).

It was also seen clearly with this material, that trichome density in general contributed consistently across plant height groups and both seasons to shoot fly resistance. However, as indicated earlier, the effect of trichomes was more strongly seen in tall groups than in dwarf groups. Secondly, trichomes on the abaxial surface of the 3rd leaf were more important than the adaxial surface trichomes, while the reverse was the case with 5th and 7th leaves. This is understandable as shoot fly lays eggs on the abaxial surface.

The 3rd leaf abaxial surface trichomes help in reducing egg laying and thereby reducing the deadhearts, while 5th and 7th leaves adaxial surface trichomes affect larval movement toward growing point resulting in less deadhearts. Studies by several workers (Moholkar, 1981; Bapat and Mote, 1982; Jadhav *et al.*, 1986) obtained similar results.

In this study, more egg laying was observed in talls than dwarfs. However, trichome density or glossiness or both did not support sufficiently greater ovipositional preferrence in talls than dwarfs. On the other hand, leaf length and droopiness consistently showed strong positive relationships in talls to shoot fly resistance parameters and particularly with deadhearts, while such relationships were either negligible or in the other direction in the dwarfs. This, however, needs to be further confirmed especially in no-choice conditions and in different seasons. An extensive literature search did not provide further research results by others in this area. It is therefore believed that this finding is the first of its kind.

5.2.3 Flowering vs Shoot Fly Parameters

Early flowering genotypes had less egg laying and deadhearts in both rainy and postrainy seasons in dwarfs indicating that fast growth/development might have enabled them to escape egg laying in the early stages. However, such relation was not strong or consistant with the talls. Again, such findings of this nature as in dwarfs are not known from the literature.

5.2.4 Grain Yield vs Shoot Fly Parameters

Shoot fly resistance and grain yield in uninfested or infested conditions were negatively correlated in talls in postrainy season while these were in reverse direction in dwarfs (Table 11). This indicatied that it is easier to breed for high shoot fly resistance and grain yields in dwarfs in postrainy season, while it is not so in talls. Occurence of more deadhearts in talls in postrainy season may support the role of other compensatory mechanisms such as recovery resistance. However, absence of high a number of productive tillers probably, as indicated earlier, negated this view. Therefore it is possible that height genes might be playing a dominant role contributing to high grain yield in talls in postrainy season. Furthermore, advantages of height (high photosynthetic rate) under stress such as postrainy season adaptation where receding soil moisture interacted with varying day light and low temperature was known earlier (Singh, 1991). Such trend (a negative correlation between shoot fly resistance and grain yield) was not however observed either in the talls or the dwarfs evaluated in this study in the rainy season. This suggested that yield increases can be brought about in both talls and dwarfs equally through breeding for shoot fly resistance in the rainy season.

Thus, the above discussion clearly suggested that breeding strategy should be separate for dwarfs and talls and for rainy and postrainy seasons.

5.2.5 Associations among Shoot Fly Parameters

The characters such as, percentage plants with eggs, number of eggs/100 plants and deadheart percentage indicate plant response in general to shoot fly attack. Information on the first two characters directly relates to preference or non-preference of the host for egg laying and this is usually referred to as ovipositional preference or non-preference. Information on percentage deadhearts gives the direct damage by shoot fly and is taken as a measure of shoot fly susceptibility or resistance. The data has been examined through correlations to see if mechanisms other than ovipositional non-preference are involved in shoot fly resistance. In this study, high and greater correlations were observed in talls (0.95^{**} in postrainy and rainy seasons) between egg laying and deadhearts than in dwarfs (0.85^{**} in postrainy and 0.79^{**} in rainy seasons). This indicated that shoot fly resistance in talls was almost entirely due to ovipositional non-preference. However, there might be greater chances of other mechanisms in addition to non-preference involved in dwarfs.

Studies by Jain and Bhatnagar (1962), Sharma *et al.*, (1977), and Patel and Sukhani (1990) showed significant positive correlation between percentage deadhearts and egg laying, indicating that deadheart formation depends on the extent of egg laying, and concluded that deadheart damage was entirely due to ovipositional non- preference in sorghum. This is the case with talls but not dwarfs in our study.

5.2.6 Correlations among Morphological Traits and Grain Yield

Earlier discussion showed that early plant height, leaf droopiness/length, trichome density and glossiness intensity contributed to shoot fly resistance in both tall and dwarf genotypes though their relative effects (in direction and magnitude) may vary between the groups (Table 11).

The host morphological traits and grain yield correlate with each other among themselves; sometimes positively and sometimes negatively. This in turn would influence their joint final effect on shoot fly resistance. Correlations among these traits are discussed below from this perspective (Table 12 and 13).

Glossiness intensity and early plant height were positively correlated among themselves, and also they did not correlate with grain yield under infested/uninfested conditions. Therefore, these traits appeared to be neutral traits which can be deployed profitably in increasing shoot fly resistance without upsetting grain yield levels in different height groups and seasons.

However, trichome density particularly 5th leaf abaxial surface, was negatively correlated with grain yield under both infested and uninfested conditions in talls in postrainy season, while in dwarfs, the relationship was positive. This suggested that boosting trichome density in talls to upgrade resistance only resulted in reduced grain yield in talls, while in dwarfs, it could be deployed as a selection criterion to improve resistance without reducing grain yields. Lack of such relationship in the rainy season between trichomes and grain yield in talls and dwarfs showed that this trait can be profitably exploited.

In dwarfs, leaf length and droopiness and trichome density were positively related. The latter two were also positively correlated with early plant height. The leaf characters association with grain yield was moderate indicating that these traits could be manipulated as neutral traits without affecting grain yield for increasing resistance. However, drooping depth had significant negative effect on grain yield (Table 14).

5.3. PATH ANALYSIS

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

5.3.1 Percentage Plants with Eggs

This is a measure of ovipositional preference. Many investigations showed that shoot fly resistance or less deadheart formation was due to ovipositional non-preference in sorghum (Jain and Bhatnagar, 1962; Blum, 1967; Rangdang *et al.*, 1970; Jotwani *et al.*, 1971; Soto, 1974; Omori *et al.*, 1983). The study of Omori *et al.*, (1983) conducted at IC included number of eggs/plant along with glossiness and trichome density as independent variables affecting deadhearts, and investigated their effects on deadhearts.

They showed that the effects of trichomes and glossiness were marginal on deadhearts, as the number of eggs had accounted most of the variability in deadhearts.

In this study, only plant characters that have been found correlating with the shoot fly parameters were examined.

Path analysis showed that drooping depth of the leaf contributed maximum in the tall group, whereas the highest contribution was by plant height in early stages in the dwarf group (Table 18). Interestingly, plant height at early stages contributed least in talls, whereas drooping depth of leaf contributed least in dwarfs. Other traits fell in between these two limits. Drooping depth of leaf accompanied by leaf length would have enhanced egg laying by providing better shaded area for shoot fly. This was explained by high egg laying in talls although they had high trichome density on the abaxial surface (see earlier discussion section 5.2.2). In the case of dwarfs, early plant height would have contributed to plant escape from oviposition thus leading to less egg laying. This was further complimented by erect and short leaves in dwarfs which would have made the site unfavorable for egg laying.

Thus, the dwarfs had less self-shading effect than talls in the early stage. The empirical selection carried out earlier in the program had therefore, manifested in bringing about these contrasting leaf characters in the two groups. This became possible probably due to the choice-screening adopted in the selection program.

To bring about further reduction in egg laying, emphasis should be placed on reducing leaf droopiness without reducing leaf length, and increasing early growth in talls, while in dwarfs, one should emphasize other traits such as trichome density.

5.3.2 Number of Eggs/100 Plants

Number of eggs/100 plants is also a measure of ovipositional preference by the pest.

As indicated earlier, the traits involved in this area are glossiness, trichomes on abaxial surface, and leaf length and drooping depth (Table 19). As with the earlier parameter, drooping depth contributed most, in talls while mostly (lack of) trichomes and glossiness in dwarfs. The pattern here was almost the same as in the previous parameter, except that glossiness was found to be a more effective factor than plant height in explaining the variability of this parameter.

Since number of eggs/100 plants and percentage of plants with eggs referred to the same phenomenon of resistance, namely, ovipositional non-preference, early plant height along with glossiness played a major role along with other traits in dwarfs for non-preference.

Emphasis should be placed, in addition to the traits mentioned earlier in relation to the response, percentage plants with eggs, on increasing the glossiness in dwarfs and dwarfs to bring about further increase in resistance. Also leaf droopiness should be reduced.

5.3.3 Percentage Deadhearts

Shoot fly damage is directly proportional to the number of deadhearts which in turn reflects the level of resistance.

The combination of traits, glossiness, trichomes on adaxial surface, leaf length and drooping depth influenced in reducing the deadheart formation (Table 19).

On deadhearts, the effects of drooping depth and glossiness formed the limits of the range in the magnitude of the effective of independent traits. In talls, drooping depth contributed most and glossiness least. On the other hand, the reverse was the case in dwarf - glossiness contributed most and drooping depth the least. The other two traits, adaxial trichome density, and leaf length fell in between these two extremes.

5.3.4 Integrated Effects of the Traits over Developmental Period

The above discussion included the results of path analysis of various independent traits measured at a particular plant development (17 DAE). For example, measurements taken on the 5th leaf were considered for trichome density and leaf parameters in the path analysis. However, shoot fly is known to lay eggs over different growth stages starting from the 3rd to 7th leaf and the cumulative effects of the traits for example, trichome density on all the leaves should therefore be expected to further contribute to the vairability of shoot fly parameters along with other traits.

Such analysis was carried out for trichomes considering their density on the 3rd, 5th and 7th leaves simultaneously along with glossiness in a combination in the path analysis. The results (Table 20) showed that the cumulative effects of trichomes on the 3rd, 5th and 7th leaves as expected, explained higher variability than any of the other combinations studied only for ovipositional preference in the dwarfs and percentage deadhearts in the talls.

Thus, the combination 'E' which included glossiness intensity, trichome density (5th leaf), leaf length and droopiness (Table 19) remained as the best when considered with all the shoot fly resistance parameters in both groups of sorghum genotypes.

Considering all these parameters and percentage plants with eggs, number of eggs/100 plants and deadheart percentage, it was clear that breeding programs should emphasise more on reducing drooping depth, perhaps without reducing leaf length, and increasing glossiness intensity and early plant height in talls. In the case of dwarfs, increasing trichome density, glossiness and leaf length (without increasing droopiness) or reducing early plant height would be desirable.

Omori *et al.*, (1983) indicated the need to place major emphasis on glossiness in increasing shoot fly resistance, although path analysis did not

Table 20. Path coefficients of glossy score, trichomes on 3rd, 5th and 7th leaves in tall and dwarf groups in relation to shoot fly oviposition and deadhearts per cent (1992 rainy season).

Height group	Glossy score	Trichome densty AB/AD 3rd	5th	7th	Y	Variable (Y)
	Glossy score					
Tall	0.05	0.18	0.23	-0.02	0.44	EGPL
Dwarf	0.29	0.33	0.02	0.04	0.68	EGPL
Tall	0.30	0.34	-0.09	0.04	0.60	% DH
Dwarf	0.36	-0.04	-0.38	0.04	0.74	% DH
		3rd				
Tall	-0.02	-0.33	-0.21	-0.03	-0.59	EGPL
Dwarf	-0.16	-0.61	-0.02	-0.03	-0.76	EGPL
Tall	-0.17	0.60	0.15	-0.23	-0.85	% DH
Dwarf	-0.04	0.35	-0.22	-0.01	-0.09	% DH
			5th			
Tall	-0.02	-0.14	-0.50	0.33	-0.34	EGPL
Dwarf	-0.17	-0.39	-0.03	-0.09	-0.69	EGPL
Tall	-0.17	-0.57	0.16	-0.24	-0.82	% DH
Dwarf	-0.23	0.13	-0.59	-0.04	-0.73	% DH
				7th		
Tall	-0.001	0.02	-0.34	0.49	0.17	EGPL
Dwarf	-0.06	0.08	-0.01	-0.19	-0.18	EGPL
Tall	0.03	-0.36	-0.10	-0.39	0.68	% DH
Dwarf	-0.22	0.06	-0.39	-0.06	-0.62	% DH

Residuals:	EGPL	DH %
Tall	: 0.53	0.18
Dwarf	: 0.28	0.23

DH % = Deadhearts per cent; EGPL = Eggs/100 plants
AB/AD = AB: Abaxial surface related to egg laying
AD: Adaxial surface related to deadhearts

show this. This conclusion was based primarily on correlations although they carried out a path analysis study. The present study, however, as showed earlier, is definitely an improvement on the earlier study, as this was more comprehensive, and, moreover, could distinguish the effects of the traits in relation to materials of different plant height backgrounds. This information is useful in breeding short statured seed parents and A-lines in sorghum hybrid program.

5.3.5 Correlation Coefficients and Path Coefficients Magnitude and Direction

Correlations of morphological traits with shoot fly parameters may be in opposite directions in tall and dwarf groups. However, path analysis clearly demonstrated that the direct effects of these independent traits on the dependent trait are in the same direction. For example, correlations of leaf length or drooping depth with percentage plants with eggs are in opposite directions in talls and dwarfs (Table 11). On the other hand, path analysis showed that their effects were in the same direction (Table 19).

Khurana (1980) showed negative correlation of shoot fly infestation with leaf breadth and leaf length whereas Sandhu *et al.*, (1986) showed positive relationship in different varieties. These contradictory observations were similar to the trend that was observed in tall (+ve) and dwarf (-ve) groups in this study. Therefore, different authors might have studied materials with different leaf lengths as found with the present materials studied.

5.5 GENETIC VARIABILITY

The genotypic and phenotypic coefficients of variability and heritability were estimated according to the formulae given by Singh and Chaudhary (1977) and expected genetic advances at 5 per cent selection intensity were estimated as given by Allard (1960).

The extent of progress that could be made through selection depends upon the extent and nature of genetic variability present in the material under study. Analysis of variability in advanced generation material bred through selection for high yield and shoot fly resistance helps to predict the additional gains that can be made. Heritability estimates give a measure of transmission of characters from one generation to the next generation and consistency in the performance of selection depends on the heritable portion of variability.

Heritability estimates reported here were only based on broad sense and hence the total genetic variance may include dominance and epistatic components which are not amenable for fixation through simple selection based on phenotypic performance (Johnson *et al.*, 1955), and therefore do not necessarily indicate a greater genetic gain (Sivasubramanian and Madhavamenon, 1973).

Estimates of heritability and additive gene action may vary according to the initial frequencies of resistant genes in parental material, the selection intensity, the generation and the level of shoot fly infestation (Rana *et al.*, 1981). The heritability estimates in this study varied from trait to trait and from season to season or pest pressure for diferent characters.

Doggett *et al.*, (1970) reported high heritability for recovery resistance. However in this study, the heritability for recovery resistance in the material tested was extremely low under low pressure in the postrainy season, and moderate under high pressure conditions in the rainy season.

Rana *et al.*, (1975) also suggested the selection under conditions when mortalities ranged between 6.7 to 67 per cent and Borikar *et al.*, (1982) under 24 to 70 per cent. Rana *et al.*, (1975) and Borikar and Chopde (1980) reported lower (about 25%) narrow sense heritability estimates for shoot fly resistance. The heritability estimates in this study, being broad sense, were slightly higher than 25 per cent.

Further, the following specific points can be deduced from the present study (Table 10).

i) Genetic gain for shoot fly resistance was of the same magnitude whether selection was based on deadheart percentage or number of eggs/plant or percentage plants with eggs.

ii) The gain for shoot fly resistance was negligible in rainy season where the pressure was high (trial mean 88 per cent deadhearts) irrespective of the type of shoot fly parameters. It was high where deadheart percentage was about 35 per cent deadhearts (trial mean) as in postrainy season.

iii) Genetic gain for shoot fly resistance based on glossiness was less than what one would get when one of the shoot fly resistant parameters form the selection criteria. This was particularly evident when shoot fly pressure was normal as in postrainy season. On the other hand, when shoot fly pressure was unusual or abnormally high, selection if based on glossiness would be more advantageous.

iv) As with glossiness, selection for early plant height, if based on the measurements taken at stage 4, would be more advantageous.

v) Genetic gain for shoot fly resistance was more effective when trichome density formed the selection criteria in the rainy season than in the postrainy season in the 3rd and 5th leaf stages. However, when the growth was advanced to 7th leaf stage, postrainy season evaluation of 7th leaf abaxial surface trichomes was more advantageous.

vi) Among the leaf parameters, leaf curvature of 3rd, 4th, and 5th leaf and also drooping depth of 5th leaf gave more genetic gain than other measurements.

Even though the infector row/fish meal technique claimed to provide adequate pressure in any given season, especially in rainy season screenings, it is unpredictable in retaining the pressure within the upper threshold limits. Therefore, to safe guard against unpredictable (high) pressures, it is important that one should also take measurements on early morphological parameters such as early plant height, glossiness, leaf characters and trichomes to enable them to be used as selection criteria to assure genetic gain in each cycle as these were shown through path analysis to have effect on the resistance parameters.

Breeding dwarf statured high yielding plants resistant to shoot fly was considered for the first time by investigating the role of different morphological traits on shoot fly resistance parameters in the tall and dwarf lines obtained by emperical selection. The results helped to conclude that

i) The empirical selection for shoot fly resistance and grain yield was effective as the lines, SPSF 1128 and 1169 in the tall group and 1170 and 1101 in the dwarf group in the post-rainy season, and the lines, SPSF 1029 and 1118 in the tall group and 1014 and 1126 in the dwarf group in the rainy season showed shoot fly resistance in desirable grain yield background.

ii) Genetic gains for resistance was high when the selection was carried out at optimum shoot fly infestation (87% in the susceptible check) such as in post-rainy season. At high infestation such as in the rainy season the selection was not effective.

iii) The influence of morphological traits on shoot fly resistance in the dwarfs differed from the talls. They both had similar plant height in early stage while they differed significantly at maturity.

iv) Considering path analysis results it was shown that breeding programs should emphasize more in reducing drooping depth, perhaps without reducing leaf length, and increasing glossiness intensity and early plant height in the talls. In case of the dwarf, increasing trichome density, glosiness intensity and leaf length (without increasing droopiness or reducing early plant height) would be desirable.

v) However, the correlation and heritability studies indicated that undue emphasis on increasing trichomes density (in the dwarfs) or reducing leaf droopiness (in the talls) should not be placed to increase shoot fly resistance in breeding programs as this might lead to reduced grain yields. Therefore, the trait shown to be neutral such as glossiness, early plant height, and early vigour should be given further emphasis in selection in both the tall and dwarf groups.

To elucidate further the role of early growth parameters such as mesocotyl length, seedling vigour, early plant height in relation to their importance in breeding dwarf shoot fly resistant lines should be investigated. Secondly, the role of leaf parameters on ovipositional preference both in the choice and no- choice conditions should be further studied. Thirdly, care should be taken to include a large number of lines, and to evaluate them in different seasons/locations including no choice conditions in future studies.

SUMMARY

CHAPTER VI

SUMMARY

Investigations on the interrelationships of important traits in sorghum that contribute to shoot fly resistance were carried out at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, in the post-rainy (1991-92) and rainy (1992-93) seasons. The effect of height on shoot fly resistance was studied by involving ten tall and ten dwarf sorghum genotypes that originated from the same pedigree or pedigrees of related parents, but underwent emperical selection for shoot fly resistance.

Shoot fly oviposition, damage to crop (% deadhearts), emergence of seedlings, mesocotyl length, seedling vigour, glossiness, plant height at various stages and trichome density of 3rd, 5th and 7th leaves on adaxial and abaxial surfaces of tall and dwarf sorghum genotypes were compared in the tall and dwarf groups and with resistant and susceptible genotypes of that group. Similarly the following parameters - leaf length, width, drooping depth and curvature, days to 50% flowering, physiological maturity and yield parameters were evaluated.

The tall and dwarf sorghum genotypes were almost similar in many of the morphological traits measured. However, both groups were significantly different for plant height at maturity in both the seasons indicating that at maturity these materials could be classified as tall and dwarf genotypes.

However, in the early stages of plant growth they were of the same height. The tall genotypes were slightly more vigorous, glossy, and had long, broad and droopy leaves with dense trichomes than the dwarf genotypes. The tall group showed significantly high egg-laying and deadhearts in the postrainy season.

Shoot fly infestation was high in rainy season and moderate in postrainy season. Under high shoot fly pressure even the resistant check showed high egg laying and deadheart formation. The tall genotypes were more preferred for egg laying than dwarf genotypes. This was due to more plant canopy leading to self-shading in early stage which created a congenial microclimate for the shoot fly by providing more shade on the lower surface of leaves. On the other hand, dwarf genotypes which had narrow moderately long leaves with slight drooping at the tip reduced the self-shading of the leaves and increased more light penetration. Hence talls were more preferred for oviposition than the dwarfs.

The trichome density was higher on the adaxial surface than on the abaxial surface and as the leaf number increased, density increased. In the rainy season the trichome density was significantly higher than in the post-rainy season.

Grain yield under infestation was reduced by 14 per cent in the talls, and 18 per cent in the dwarfs in the postrainy season, while the reduction was 70 per cent in the talls, and 61 per cent in the dwarfs in the rainy season when compared to the yield potential under uninfested condition. The talls were superior (12 per cent in infested and 7 per cent in uninfested condition) to the dwarfs in the postrainy season, while the dwarfs were superior (25 per cent in infested, and 3 per cent in uninfested condition) in the rainy season.

The morphological characters mesocotyl length, seedling vigour, glossiness intensity, trichome density, early plant height and leaf characters were correlated with shoot fly parameters but their interrelationships in the tall and dwarf groups varied. Correlation coefficients of shoot fly parameters with some traits (leaf length, width, drooping depth and curvature Vs shoot fly egg laying and deadhearts) were in reverse trend between the tall and dwarf genotypes, but the direct effects obtained in the path analyses were in the same direction in both the groups.

Heritability and genetic advance estimates of the traits in postrainy and rainy seasons indicated that high shoot fly pressure lead to low heritability and genetic gain. All the traits viz., seedling emergence, mesocotyl length, glossiness, plant height at maturity, days to 50% flowering, days to physiological maturity, grain yield, seed mass and trichomes had higher heritability than deadheart percentage in post-rainy and rainy seasons. Leaf parameters also showed higher heritability in rainy season than deadheart percentage.

Genetic advance (expressed as % over mean) was higher only for some traits such as mesocotyl length, plant height at maturity, yield, trichomes and leaf curvature.

However, the interrelationships of the traits such as trichomes showed negative relationship with grain yield. Also, leaf traits in particular droopiness was highly correlated with grain yield.

On the other hand, the correlation analyses indicated that mesocotyl length, seedling vigour, glossiness intensity, and early plant height behaved neutrally with grain yield potential (under uninfested conditions), and grain yield under infested condition in both the groups in both the seasons.

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