GENETIC VARIABILITY FOR SHOOT FLY RESISTANCE, GRAIN CHARACTERISTICS, AND YIELD IN THE POSTRAINY SEASON SORGHUMS

THESIS SUBMITTED TO

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IN GENETICS

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2015

CERTIFICATE

This is to certify that the thesis entitled **“Genetic Variability for Shoot Fly Resistance, Grain Characteristics, and Yield in the Postrainy Season Sorghums”**, submitted for the award of the degree of **DOCTOR OF PHILOSOPHY IN GENETICS**, **Osmania University**, is a bonafide record of the research carried out by **Mr. MOHAMMED RIYAZADDIN,** under my supervision and co-supervision of Prof. P.B. Kavi Kishor, Dept. of Genetics, Osmania University, Hyderabad, and no part of the thesis has been submitted for any other degree or diploma. The assistance and help taken during the course of this investigation and the sources of literature referenced have been fully acknowledged.

Date:
Place: Hyderabad

(Dr. Hari Chand Sharma)
Supervisor
Principal Scientist -Entomology

CERTIFICATE

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DECLARATION

I**, MOHAMMED RIYAZADDIN,** registered in the **Department of Genetics**, **Osmania University**, Hyderabad, have completed the research thesis entitled **“Genetic Variability for Shoot Fly Resistance, Grain Characteristics, and Yield in the Postrainy Season Sorghums”** for the award of the degree of **DOCTOR OF PHILOSOPHY IN GENETICS,** at **Osmania University**, Hyderabad, under the supervision of Dr. H.C. Sharma**,** Principal Scientist-Entomology, ICRISAT, Patancheru, Hyderabad, and co-supervision of Prof. P.B. Kavi Kishor, Dept. of Genetics, Osmania University, Hyderabad. The doctoral research work is original and no part of the work has been submitted for any other degree or diploma.

Date: Mohammed Riyazaddin

Place: Hyderabad

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Mohammed Riyazaddin

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Abbreviations

Abbreviation	Explanation
%H	Heritability broadsense (%)
A. soccata	*Atherigona soccata*
ANOVA	Analysis of variance
CTAB	Cetyl trimethyl ammonium bromide
DAE	Days after seedling emergence
DNA	Deoxyribo nucleic acid
ECV	Environmental coefficient of variation
FCR	Folin ciocalteu reagent
GA%	Genetic advance as percent mean
GCA	General combining ability
gca	General combining ability effects
GCV	Genotypic coefficient of variation
HPLC	High performance liquid chromatography
HPR	Host plant resistance
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
LSD	Least significance difference
PCoA	Principal co-ordinate analysis
PCR	Polymerase chain reaction
PCV	Phenotypic coefficient of variation
RCBD	Randomized complete block design
SAT	Semi-arid tropics
SCA	Specific combining ability
sca	Specific combining ability effects
SSR	Simple sequence repeat
TSS	Total soluble sugars

LIST OF PUBLICATIONS

1. **Riyazaddin Mohammed.**, Polavarapu B. Kavi Kishor, Are Ashok Kumar, Belum V. S. Reddy, Rajendra S. Munghate and Hari C. Sharma., (2015) "Mechanisms and Diversity of Resistance to Sorghum Shoot Fly, *Atherigona soccata*". **Plant Breeding Journal (accepted)**.
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3. **Riyazaddin Mohammed.**, Are Ashok Kumar, Ramaiah Bhavanasi, Rajendra S. Munghate, Polavarapu B. Kavi Kishor and Hari C. Sharma., (2015) "Inheritance of Resistance to Sorghum Shoot Fly, *Atherigona soccata* in Sorghum, *Sorghum bicolor*". **PLOS ONE (submitted)**.
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5. **Riyazaddin Mohammed.**, Are Ashok Kumar, Suraj P. Sharma, Polavarapu B. Kavi Kishor and Hari C. Sharma., (2015) "Molecular Diversity and Biochemical Components of sorghum exhibiting resistance/susceptibility to Shoot Fly, *Atherigona soccata*." **Journal of Plant Research (submitted)**.

ABSTRACT

Sorghum shoot fly, *Atherigona soccata* is one of the important pests of postrainy season sorghums. Combining insect resistance with desirable agronomic and morphological traits is important to increase sorghum productivity. Of the several methods for pest control, host plant resistance is one of the major components for controlling shoot fly damage in sorghum.

Evaluation of 90 sorghum genotypes for resistance to shoot fly, *A. soccata* across seasons indicated that RHRB 12, ICSV 713, ICSV 25026, ICSV 93046, ICSV 25027, IS 33844-5, Giddi Maldandi, and RVRT 3 were resistant to shoot fly damage in the postrainy season, while ICSB 463, Phule Anuradha, RHRB 19, Parbhani Moti, ICSV 705, PS 35805, IS 5480, IS 5622, IS 17726, IS 18368, IS 34722, RVRT 1, ICSR 93031, and Dagidi Solapur showed resistance in the rainy season, suggesting season-specific expression of resistance to *A. soccata*. ICSB 461, ICSB 463, Phule Yasodha, M 35-1, ICSV 700, ICSV 711, ICSV 25010, ICSV 25019, ICSV 93089, IS 18662, Phule Vasudha, IS 18551, IS 33844-5, and Barsizoot had fewer deadhearts than plants with eggs across seasons, suggesting antibiosis as one of the components of resistance to shoot fly in these genotypes. Five genotypes exhibited resistance to shoot fly and had high grain yield across seasons.

Among the selected 30 genotypes, ICSB 433, ICSV 700, SPV 1359, Phule Chitra, ICSV 705, ICSV 25019, ICSV 25022, ICSV 25026, ICSV 25039, PS 35805, IS 2123, IS 2146, Akola Kranti, Phule Vasudha, ICSV 93046, IS 18551, and RVRT 2 suffered significantly lower shoot fly damage than the susceptible check, Swarna across seasons. ICSB 433, ICSV 700, ICSV 25019, ICSV 25022, ICSV 25026, ICSV 25039, PS 35805, Akola Kranti, and IS 18551 possessed antixenosis for oviposition and antibiosis components of resistance across seasons.

Correlation, path and stepwise regression analyses indicated that leaf glossiness, seedling vigor, trichome density, oviposition and leafsheath pigmentation were associated with expression of resistance/susceptibility to shoot fly, and these traits can be used to select shoot fly resistant sorghums. The environmental coefficient of variation (ECV) and phenotypic coefficient of variation (PCV) for shoot fly resistance and morphological traits was quite high, indicating season specific expression of resistance to sorghum shoot fly. High

broadsense heritability, genetic advance and genotypic coefficient of variation (GCV) suggested the predominance of additive nature of genes controlling shoot fly resistance, and that pedigree breeding can be used to transfer shoot fly resistance genes into high yielding cultivars.

Based on the *per se* performance, the 30 sorghum lines exhibiting moderate levels of resistance to shoot fly were genotyped using 38 SSR markers to measure genetic diversity. Genetic diversity analysis placed the test genotypes into four groups, suggesting that the sources of resistance to shoot fly are genetically diverse. The average polymorphic information content was 0.45, indicating existence of high level of genetic diversity in the sorghum lines used in this study. A total of 150 alleles were observed with an average of 3.95 alleles per locus. The average heterozygosity level per locus was 0.05. The diversity based on the morphological and shoot fly resistance traits using principle co-ordinate analysis also placed the test genotypes into four different groups, suggesting that the genotypes tested for shoot fly resistance were morphologically diverse.

Biochemical composition (carbohydrates, proteins, polyphenols and tannins) indicated that there was considerable variability in the biochemical constituents in the sorghum genotypes tested. High amounts of tannins, polyphenols and proteins were observed in the shoot fly resistant genotypes with lower amounts of total carbohydrates when compared to the susceptible check, Swarna. HPLC finger prints of 30 sorghum genotypes generated altogether 55 different peaks with varying retention times and peak areas. The phenolic compounds kaempferol and salicylic acid were present in IS 18551, but absent in the susceptible check, Swarna, and the genotypes exhibiting susceptibility to shoot fly. The genotypes showing moderate levels of resistance to shoot fly also possessed these traits in varying concentrations. 3, 4-dihydroxy benzoic acid was observed in the susceptible check Swarna (9.6 µg/100mg of plant sample), it was absent in the resistant check, IS 18551. The genotypes ICSB 433, ICSV 700, SPV 1359, Moulee, Phule Chitra, Phule Anuradha, ICSV 705, ICSV 93046 and RVRT 2 possessed most of the peaks at the same retention time as in IS 18551. Though, a few of the peaks with similar retention times were observed in both the resistant and susceptible genotypes, but the peak areas were greater in the genotypes showing moderate levels of resistance to shoot fly.

Based on the *per se* performance, and molecular, biochemical and morphological diversity, 10 genotypes were selected for full diallel crossing. Genetic analysis was carried out on a set of 10 X 10 diallel crosses involving 10 selected genotypes (45 direct crosses and their reciprocals) during the rainy and postrainy seasons.

The significant GCA and SCA mean squares for most of the shoot fly resistant, morphological and agronomic traits across seasons indicated the presence of both additive and dominance type of gene action in inheritance of these traits. The significant reciprocal mean squares for combining ability for oviposition, leaf glossy score, trichome density, days to 50% flowering, plant height, 100 seed weight, panicle compactness, panicle shape and glume color suggested the influence of cytoplasmic factors in inheritance of these traits.

ICSV 700, Phule Anuradha, ICSV 25019, PS 35805, IS 2123, IS 2146 and IS 18551 were glossy with high plant vigor, and had leafsheath pigmentation and high trichome density on the abaxial and adaxial leaf surfaces. These genotypes exhibited resistance to shoot fly damage across seasons. ICSV 700, ICSV 25019, PS 35805, IS 2123, IS 2146 and IS 18551 exhibited significant and negative *gca* effects for oviposition, deadheart incidence, and overall resistance score. The *gca* effects for leaf glossiness, plant vigor, and leafsheath pigmentation were also significant, suggesting the potential of these traits for use as a selection criteria to breed for resistance to shoot fly, *A. soccata*.

Higher sca variance (σ^2s) and dominance variance (σ^2d), and lower predictability ratios than the gca variance (σ^2g) and additive variance (σ^2a) for shoot fly resistance traits and grain yield indicated the predominance of dominance type of gene action. Trichome density, leaf glossiness score, plant vigor score, days to 50% flowering, plant height and 100 seed weight with high additive variance, predictability ratio, and GCA/SCA showed predominance of additive type of gene action.

The predominance of dominance type of gene action for shoot fly resistance traits indicated that heterosis breeding is ideal for improving shoot fly resistance in sorghum. The predominance of additive nature of gene action for leaf glossy score, plant vigor, leafsheath pigmentation and trichome density suggested that recombination breeding with pedigree method can be used for incorporating these traits in high yielding sorghum cultivars. Variation in expression of shoot fly resistance across seasons was due to non-additive genetic components of the traits conferring shoot fly resistance. Crosses with significant positive or negative *sca* effects for shoot fly resistance suggested that hybridization is necessary to increase the levels of shoot fly resistance. Parents involved in the crosses with significant specific combining abilities can be utilised in the hybrid breeding process. The genotypes with good general combining ability for shoot fly resistance and high grain yield can be used in developing the shoot fly-resistant cultivars for sustainable crop production.

INTRODUCTION

Sorghum, *Sorghum bicolor* (L.) Moench, an annual diploid C_4 plant, is the fifth most important grain crop after maize, rice, wheat and barley. It is a staple food for over 750 million people in Africa, Asia and Latin America (CAC 2011). It is cultivated on marginal, fragile, and drought-prone environments in the semi-arid tropics (SAT), and India is the third largest sorghum grower in the world with an area of 6.18 m ha, production of 5.28 million tons, and an average productivity of 854.4 kg ha^{-1} (FAO 2014).

Sorghum is a multipurpose crop and is traditionally grown for food and fodder purposes. In view of decreasing demand for sorghum grain produced during rainy season (Kharif) as a food crop, it is increasingly diverted for various alternatives such as animal and poultry feed, and potable alcohol from grain. Of late, sweet sorghums with juicy stalks and high sugar content are emerging as a potential alternative feed stock for ethanol production to meet the increased demand for ethanol following government of India's policy to blend petrol with ethanol, with the twin objective of reducing air pollution and reduce the crude oil imports.

Several biotic and abiotic constraints influence the production and productivity of sorghum. Among the biotic constraints, insect pests are one of the major factors influencing the grain yield in sorghum, and result in losses of over $1,000 million in grain and forage yield (ICRISAT 1992, 2007). Nearly 32% of the actual produce of sorghum is lost because of insect pests in India (Borad and Mittal 1983). More than 150 insect pests damage sorghum from seedling to harvesting stage, of these, sorghum shoot fly, *Atherigona soccata* (Rondani) is one of the major insect pests of sorghum (Sharma 1993). Sorghum shoot fly, *A. soccata* infests the sorghum plant from 7 to 30 days after seedling emergence (DAE) (Nwanze *et al* 1990; Vadariya 2014). Under humid conditions, shoot fly females lay elongated cigar shaped eggs on the abaxial surface of the leaf, parallel to the leaf midrib (Padmaja *et al* 2010). After egg hatching, the maggot crawls to the central whorl of the leaves, reaches the growing point, cuts the central leaf, and feeds on it. As a result, the central whorl dries off and gives a typical deadheart symptom (Deeming 1972) (Fig. 1). The maggot feeds on the decaying tissue of the central whorl (Ponnaiya 1951). Sorghum shoot fly completes its life cycle in 17-21 days.

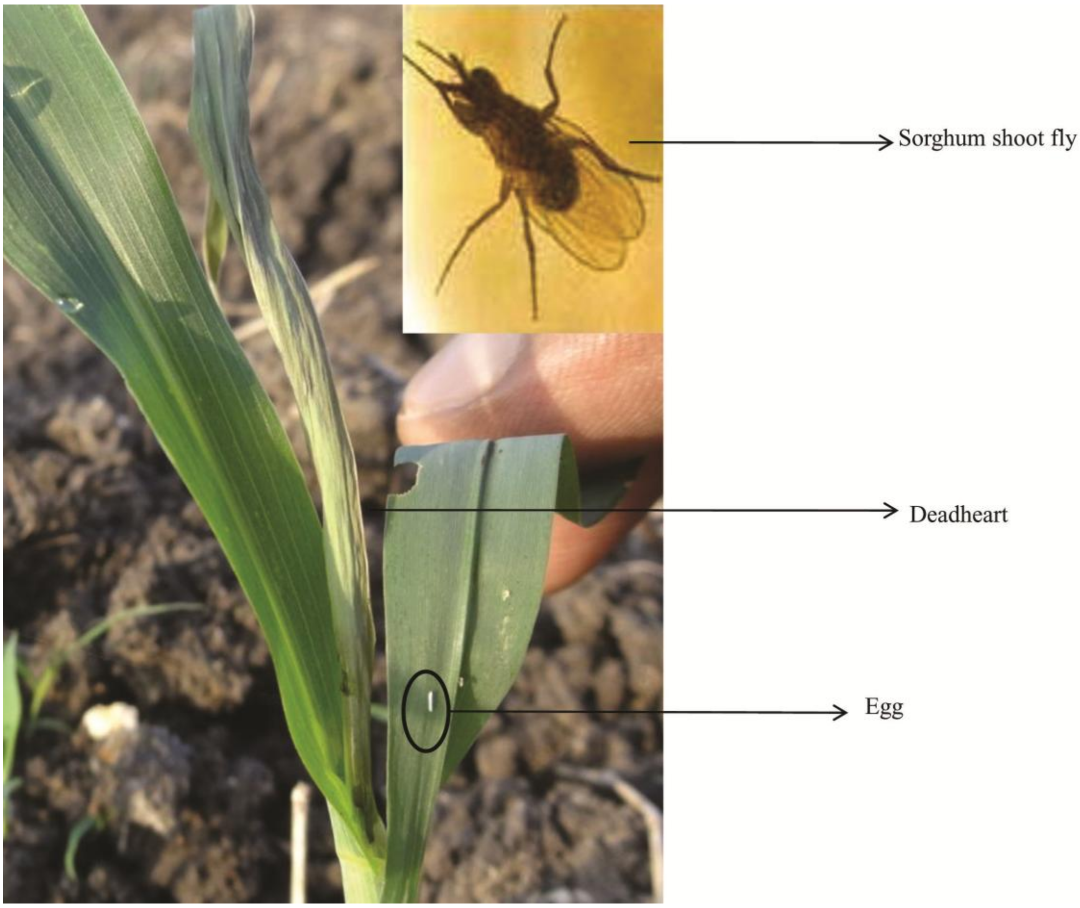


Fig. 1: Shoot fly deadheart bearing an egg under surface of the leaf

Inset: Sorghum shoot fly, *Atherigona soccata*.

Shoot fly population begins to increase in July; peaks in August-September, and declines thereafter, infestations are high when sorghum plantings are staggered due to erratic rainfall (Sharma 1985). Shoot fly infestations are normally high in the postrainy season crop planted in September to October. Temperatures above 35^{o}C and below 18^{o}C, and continuous rainfall reduce shoot fly survival (Jotwani 1978).

Shoot fly infestation decreases plant stand, and also causes severe losses in grain and fodder yield. Losses due to shoot fly damage can be reduced by using resistant varieties, timely sowing, seed treatment with systemic insecticides, and need based application of foliar sprays during the seedling stage (Sharma 1985). However, planting times in the SAT are dependent on the onset of rains, while the cost of insecticides restricts the poor farmers from applying them (Sharma 1993). Therefore, host plant resistance (HPR) can be exploited as one of the most effective means of keeping shoot fly populations below the economic threshold levels (Sharma 1985).

Postrainy sorghums are very crucial for food and fodder security in the drought prone areas of semi-arid regions, as there is no alternative crop which could be grown during this season (Gorad *et al* 1995), when only meager amounts of the annual rainfall are received during this period. Postrainy season sorghums are mainly used as food while the stalks are used as fodder. There has been a significant decline in the area under grain sorghums, and dual purpose cultivars are being preferred because of problem of grain moulds during the rainy season (Reddy *et al* 2012). Postrainy season sorghums are grown both for grain as food and the stalks as fodder for livestock under drought prone conditions.

Development of cultivars with resistance to shoot fly is one of the important goals of sorghum improvement programs in India. Genetic analysis based on phenotypic data has demonstrated that inheritance of sorghum shoot fly resistance is complex, polygenically inherited, and has high G x E interactions (Rana *et al* 1975; Agrawal and Abraham 1985; Singh *et al* 2004; Aruna and Padmaja 2009; Aruna *et al* 2011a). Despite the breeding efforts made over the past three decades by utilizing the available sources of shoot fly resistance, the level of resistance achieved in the cultivars so far is quite low.

Although considerable progress has been made in enhancing the grain yield potential of the rainy season sorghums, the genetic gains in breeding for high yield under postrainy season is limited. Many breeding programs mostly focus on the variability generated by crossing the germplasm originated from India, which has a narrow genetic base. Apart from the need to have shoot fly resistance and tolerance to drought, the sorghum productivity under low temperature is quite low. Also, grain characteristics such as, bold and lustrous grain with thin pericarp is important to fetch good market price. Therefore, there is a need to improve postrainy season sorghums for resistance to shoot fly, tolerance to terminal moisture stress and insensitivity to low temperature during crop growth. Therefore, the present studies were planned to identify a set of diverse lines with resistance to shoot fly and high grain yield and assess the genetic variability and inheritance of these traits (grain yield, size and quality traits, and resistance to shoot fly) with adaptation to the postrainy season.

Objectives

1. Characterize shoot fly-resistant lines and improved genotypes for stability of resistance, and adaptation to postrainy season (grain yield, grain size and quality traits).
2. To understand mechanisms of resistance and assess genetic diversity of shoot fly-resistant lines and improved genotypes with adaptation to postrainy season.
3. To understand the nature and inheritance of shoot fly resistance and adaptation to postrainy season (grain yield, size and quality traits).

REVIEW OF LITERATURE

2.1 Origin of sorghum and insect pest incidence affecting its sustainability

Sorghum, *Sorghum bicolor* (L.) Moench has evolved across a wide range of environments in Africa, exhibits a great range of phenotypic diversity and numerous resistances to abiotic and biotic stresses. It is originated in equatorial Africa, and is widely distributed throughout the tropical, semi-tropical, and arid regions of the world. The seed or caryopsis of sorghum provides a major source of calories and protein for millions of people in Africa and Asia. Sorghum is recognized as a highly productive, drought tolerant, C_4 photosynthetic cereal that provides food, feed, fuel, fiber, and energy. Sorghum is rich in starch, a major storage form for carbohydrates which makes up about 60 - 80% of normal kernels and has excellent potential for industrial applications (Zhang *et al* 2003; Elmoneim *et al* 2004; Claver *et al* 2010). Sorghum is the dietary staple of the people living in more than 30 countries of the semi-arid tropics, thus being one of the most familiar foods in the world. It is mostly grown as a subsistence dry land crop by resource limited farmers under traditional management conditions in the SAT regions of the Africa, Asia and Latin America, which are frequently drought-prone and characterized by fragile environments.

Yield and quality of sorghum produced worldwide is affected by a wide array of biotic and abiotic constraints (FAO 1995; ICRISAT 2004; Nadia *et al* 2009). Postrainy season sorghums grown under receding moisture conditions, are exposed to peak shoot fly populations between September to October. Shoot fly infestation decreases plant stand, and also causes severe losses in grain and fodder yield. Increase in shoot fly deadhearts by 1% results in a loss of 143 kg grain yield/ha, and 90 - 100% damage has been reported under delayed sowings (Hiremath and Renukarya 1966; Chundurwar and Karanjkar 1979; Dhaliwal *et al* 2004). The world wide yield loss due to shoot fly has been estimated to be over 274 million US$ (Sharma 2006). The pest is especially serious in the late-sown crops, but also infests early sowings when the preceding dry season is interrupted by frequent rain showers (Nimbalkar and Bapat 1987).

Developing high-yielding rainy or postrainy season-adapted varieties/hybrids is the major objective of sorghum improvement programs. Though considerable efforts have been made to develop hybrids with wider adaptability to different production environments, the results are not encouraging (Madhusudana *et al* 2003). The grain yield in the rainy season sorghums has increased significantly, but the genetic gains in the postrainy season sorghums have been quite low because of the severity of shoot fly damage and drought stress (Kumar *et al* 2011). The cultivars grown during the postrainy season must have moderate levels of resistance to shoot fly, but none of the newly developed varieties or hybrids have been able to replace the landrace cultivar, Maldandi (M 35-1) (Sharma 1993), which possesses acceptable grain and fodder quality (Sanjana Reddy *et al* 2009; Reddy *et al* 2012). Efforts have been made to transfer shoot fly resistance into cytoplasmic male-sterile and restorer lines to produce shoot fly resistant hybrids (Sharma *et al* 2005), but the expression of resistance to shoot fly varies with insect density across the environments (Sharma and Nwanze 1997; Dhillon *et al* 2005; Ashok Kumar *et al* 2008), male-sterility system (Dhillon *et al* 2006a; Umakanth *et al* 2012), and expression of different components of shoot fly resistance (Doggett *et al* 1970; Raina *et al* 1981; Sharma and Nwanze 1997; Kamatar *et al* 2003; Dhillon *et al* 2005, 2006b; Sivakumar *et al* 2008). As a result, expression of resistance to shoot fly varies between the rainy and the postrainy seasons (Aruna *et al* 2011a; Reddy *et al* 2012), suggesting the need for developing cultivars with adaptation to different seasons.

Shoot fly infestation leads to heavy crop loss due to decrease in grain and fodder yields. Losses due to shoot fly damage can be reduced by using resistant varieties, following good cultural practices, timely planting, and timely application of proper insecticides (Sharma 1985). However, planting times in the SAT are dependent on the onset of rains, while the cost of insecticides restricts the poor farmers from applying them (Sharma 1993). Therefore, HPR is one of the most effective means of keeping shoot fly populations below economic threshold levels. Plant resistance to sorghum shoot fly appears to be a complex character, and depends on the interplay of number of componential characters, which finally sum up in the expression of resistance to shoot fly (Dhillon 2004). A number of genotypes with resistance to shoot fly have been identified, but the levels of resistance are low to moderate (Jotwani 1978; Taneja and Leuschner 1985; Sharma *et al* 2003). In India, shoot fly has attained the status of a principal pest mainly because of introduction of improved sorghum varieties and hybrids susceptible to this insect, their continuous cropping, ratooning and narrow genetic variability (Singh and Rana 1986). The sorghum cultivars to be grown during the postrainy season must have moderate to high levels of primary or recovery resistance to shoot fly (Sharma 1993). Phule Yasodha, Phule Chitra and Parbhani Moti, which have moderate levels of resistance to shoot fly, have been adopted by the farmers in certain areas. However, the levels of resistance to shoot fly in the identified sources varies with insect density and across environments (Sharma and Nwanze 1997; Dhillon *et al* 2005).

2.2 Host plant resistance

Resistance of plants to insects enables a plant to avoid or inhibit host selection, inhibit oviposition and feeding, reduce insect survival and development, and tolerate or recover from injury from insect populations that would cause greater damage to other plants of the same species under similar environmental conditions (Smith 1989). HPR is one of the important components of integrated pest management systems and can be effectively utilised in developing the cultivars with insect pest resistance (Sharma 1993). HPR along with natural enemies and cultural practices is a central component of any pest management strategy. Host plant resistance to insects is an effective, economical, and environment friendly method of pest control. The most attractive feature of HPR is that farmers virtually do not need any skill in application techniques, and there is no cash investment by the resource poor farmers.

2.3 Mechanisms of resistance to sorghum shoot fly, *Atherigona soccata*

Plant resistance to sorghum shoot fly appears to be a complex trait and depends on the interplay of a number of component characters (Dhillon 2004). Shoot fly resistance is associated with the combined expression of morphological and shoot fly resistant traits along with the favourable environmental factors. Three different types of resistance mechanisms were seen in the shoot fly resistant sorghums viz., oviposition non-preference (antixenosis), antibiosis and tolerance (Soto 1974; Sharma *et al* 1992). Oviposition is a biological response which to a large extent is influenced by the genotype of the host plant (Sharma *et al* 1990a). The female shoot flies were able to select precisely their oviposition sites through a succession of probing movements of the anterior tarsae and of the ovipositor and is almost strictly monophagous, which was influenced by the physical and morphological characteristics of the host genotypes (Ogwaro 1978; Prokopy and Owens 1978).

Sorghum shoot fly, *A. soccata* prefer to lay eggs on the susceptible cultivars than on the resistant ones which is identified as oviposition non-preference (antixenosis) and is the primary mechanism of resistance to shoot fly (Taneja and Leuschner 1985; Sharma and Nwanze 1997; Dhillon *et al* 2005; Sivakumar *et al* 2008; Siva *et al* 2011). The shoot fly-resistant genotypes had significantly lower oviposition as compared to susceptible ones (Jain and Bhatnagar 1962). Oviposition of shoot fly was affected by the seedling density (Davies *et al* 1976; Davies and Reddy 1981) and also dependant on the type of the genotypes used (Singh and Narayana 1978).

When shoot fly lays eggs on the resistant cultivars, the larval and pupal periods were extended by 8 - 15 days, as a result the time taken for one life cycle to complete, was drastically increased and hence decreases the shoot fly damage (Jotwani and Srivastava 1970; Narayana 1975; Singh and Jotwani 1980a; Raina *et al* 1981; Sharma and Nwanze 1997; Dhillon *et al* 2005; Sivakumar *et al* 2008). This is antibiosis mechanism of resistance where the critical stages of shoot fly were affected. Survival of shoot fly larvae depends on the ability of the female to select for oviposition leaf of suitable position (Delobel 1982) and also on the size/thickness of the host plant for easy penetration of the shoot fly maggot into the leafsheaths of the central whorl. The most critical biological events in sorghum shoot fly, *A. soccata* were egg-hatching, first instar larva, pupariation, eclosion and post-eclosion phases and were time bounded, any lapse in completion of an event prevented the insect from advancing to the next phase of life cycle and eventually proved fatal (Kalaisekar *et al* 2013).

Some of the sorghum genotypes exhibits an inherent ability of producing side tillers, a mechanism known as the recovery resistance/tolerance after the main shoot was killed by sorghum shoot fly, *A. soccata*. Recovery resistance/tolerance can be useful for selecting shoot fly resistant sorghums which is associated with good yield from tillers, and heritability was fairly high (Doggett *et al* 1970). Shoot fly-resistant genotypes had significantly less tiller deadhearts than the susceptible ones and can compensate for yield loss under heavy shoot fly infestation (Rana *et al* 1985; Siva 2008).

Several physico-chemical traits confer resistance to shoot fly, *A. soccata*. Morphological, agronomic and biochemical factors influence genotypic susceptibility to shoot fly. Leaf glossiness (Blum 1972; Maiti and Bidinger 1979; Sharma 1993; Dhillon *et al* 2005, 2006c; Sivakumar *et al* 2008), leafsheath pigmentation, plant vigor (Blum 1972; Taneja and Leuschner 1985; Jayanthi *et al* 2002) and trichome density (Maiti and Bidinger 1979; Mote *et al* 1986; Dhillon *et al* 2005; Sivakumar *et al* 2008) are the major morphological factors associated with resistance to shoot fly, *A. soccata*.

2.4 Genetic diversity and biochemical components associated with resistance to shoot fly, *A. soccata*

2.4.1 Sorghum genome and genetic diversity of sorghum genotypes

Sorghum has a complex diploid genome, with 20 chromosomes (2n). Its genome size is approximately 740 Mb, distributed among ten chromosomes (n) (Peterson *et al* 2002). It is a model species for tropical grasses, having the 'C_4' photosynthetic pathway which increases the efficiency of CO_2 fixation in plants, and is a logical complement to the 'C_3'grass, *Oryza sativa* L. (Kresovich *et al* 2005; Paterson *et al* 2009). Microsatellite markers are among the most popular genetic markers due to their characteristic features such as high polymorphism, co-dominance, abundant informativeness, convenience of assay by PCR, and distribution throughout the genome. A large number of SSR loci have also been genetically mapped in several agronomically important species, including sorghum (Brown *et al* 1996; Taramino *et al* 1997; Ramu *et al* 2009; Srinivas *et al* 2008, 2009; Li *et al* 2009; Sivakumar *et al* 2008; Satish *et al* 2009, Aruna *et al* 2011b). There is considerable information available on genetic linkage maps and molecular markers associated with different traits in sorghum. High density genetic maps available for sorghum (Klein *et al* 2000; Bowers *et al* 2003; Mace *et al* 2008) have recently been complemented by the aligned genome sequence (Paterson *et al* 2009), permitting *in-silico* mapping of many additional markers and genes (Yonemaru *et al* 2009; Li *et al* 2009; Ramu *et al* 2009, 2010; Mace and Jordan 2010).

Estimation of genetic diversity in a crop species is prerequisite for its improvement. The variability in sorghum germplasm is an invaluable input for sustaining and improving sorghum productivity (Emmanuel *et al* 2012). Genetic diversity within and between populations is routinely assessed using morphological, biochemical and molecular techniques. Though morphological characterization has been traditionally used to assess genetic variation, the genetic information provided by morphological characters is often limited and expression of quantitative traits is subjected to strong environmental influence (Rao 2004; Mondini *et al* 2009). Molecular markers are becoming increasingly attractive in molecular breeding and diversity assessment (Powell *et al* 1996; Rana and Bhat 2004). DNA markers provide an opportunity to characterize genotypes and to measure genetic relationships more precisely than other markers. The morphological and the molecular diversity present in the genotypes plays a crucial role in crop improvement. The use of germplasm with distinct DNA profiles helps to generate breeding populations with a broad genetic base.

2.4.2 Biochemical components of resistance to shoot fly, *A. soccata*

In natural ecosystems, plants face a large number of antagonists, and thus, have evolved multiple defense mechanisms by which they are able to survive under different biotic and abiotic stresses (Ballhorn *et al* 2009). Different resistance mechanisms confer resistance to the insect pests, such as construction of polymeric barriers to damage and the synthesis of enzymes that degrade pathogen cell wall (Hammond-Kosack and Jones 1996); production of reactive oxygen species (ROS) (De Gara *et al* 2003); alterations in the cell wall constitution; accumulation of secondary metabolites (Benner 1993; Bennett and Wallsgrove 1994; Heath 2000; Agrios 2005); activation and/or synthesis of defense peptides and proteins (Castro and Fontes 2005). In addition, plants employ specific recognition and signaling systems enabling rapid detection of pest invasion and initiation of vigorous defensive responses (Schaller and Ryan 1996). Once infected, some plants also develop immunity to subsequent microbial attacks (Putnam and Heisey 1983; Putnam and Tang 1986; Elakovich 1987; Bernays 1989).

Plants produce a high diversity of natural products or secondary metabolites for protection against herbivores and microbial pathogens on the basis of their toxic nature and repellence to herbivores and microbes. Some of them are also involved in defense against abiotic stresses (e.g. UV-B exposure) and are important for communication of plants with other organisms, but are insignificant for growth and developmental processes (Hagerman and Butler 1981; Rosenthal 1991; Schafer and Wink 2009; Hassanpour *et al* 2011). A large number of secondary metabolites in plants have a role in direct plant defense (Moraes *et al* 2008).

Antibiosis resistance operates mainly through secondary metabolites produced in the plant. Host plant resistance to insects is often mediated by chemicals produced by the host plant that act as attractants, repellents, oviposition and feeding stimulants, feeding deterrents, and/or affect the development and survival of insects. It is now generally accepted that plant resistance against insects (as well as to other organisms) are, to the greatest extent, chemical in origin (Bernays and Chapman 1978; Kubo and Hanke 1985).

All the three mechanisms of resistance *viz.*, antixenosis, antibiosis, and recovery resistance operate in sorghum for resistance to shoot fly (Sharma and Nwanze 1997).

Phenolic compounds such as, 3-deoxyanthocyanidins or allelo-chemicals (*p*-hydroxybenzoates, *p*-coumarates, and flavonols) are involved in sorghum plant resistance to various biotic stresses (Lo *et al* 1999; Weston et al 1999; Weir *et al* 2004). The leaf surface constituents are an interface between the shoot fly and the host plant (Ogwaro 1978; Chamarthi *et al* 2011), and physiological and biological changes in terms of secondary metabolites during the seedling stage have a profound effect on sorghum plant interactions with shoot fly (Singh *et al* 2004; Chamarthi *et al* 2011). Odors emanating from crops also play a role in the orientation of insect pests towards their host plants and in recognition of these plants as sites for feeding and oviposition (Visser 1986; Nwanze *et al* 1998; Bruce *et al* 2005). The percentage of nitrogen, reducing sugars, total sugars, moisture, and chlorophyll content of leaves have been reported to be higher in the shoot fly-susceptible cultivars than in the resistant ones (Singh and Jotwani 1980b; Patel and Sukhani 1990). A smooth amorphous wax layer and sparse wax crystals characterize shoot fly-resistant and moderately resistant genotypes, while susceptible genotypes possess a dense mesh of crystalline epicuticular wax (Nwanze *et al* 1992). Highly waxy leaves also retain more water as droplets than non-waxy leaves and vice-versa (Nwanze *et al* 1990; Sree *et al* 1994). Chemicals present on the surface of sorghum seedlings play an important role in host plant resistance/susceptibility to insects (Sharma and Nwanze 1997).

Although many notable successes have been achieved through conventional breeding in the improvement of plant resistance to insects, the breeding process is often slow and laborious, and sufficient levels of resistance have not been achieved due to the quantitative nature of the traits conferring resistance to shoot fly damage (Tao *et al* 2003). Many breeding programs, however, deal with the variability generated from crosses within the germplasm originating from India, which has narrow genetic variability. Given the economic impact of shoot fly in sorghum production, improvement of commercial cultivars for resistance to this pest is one of the major goals in sorghum breeding programs in India (Satish *et al* 2009). Selecting parents with diverse genetic base and contrasting phenotypes to identify morphological and biochemical components conferring resistance to shoot fly resistance sorghums is most important.

2.5 Nature and inheritance of shoot fly resistance, agronomic and morphological traits

Most of the plant breeding programs aim to increase the yielding ability of crop plants. There are several constraints that influence the sorghum grain yield. In sorghum apart from other factors, insect pests are the major constraints for grain yield loss arising from crop damage. So, developing sorghum with insect resistance will favor the productivity. In sorghum the major yield losses is observed with shoot fly, *A. soccata* damage. Inorder to develop shoot fly resistant varieties, information on various quantitative traits that contribute to shoot fly resistance, and as well as high grain yield will be most useful in planning and successful implementation of the breeding program. Hybridization is one of the means of obtaining increased yield and exploitation of heterosis is proving an efficient approach for improvement of sorghum.

The mode of inheritance or the genetic properties of the sorghum inbred lines exhibiting resistance to shoot fly can be assessed by using diallel mating method. Diallel is defined as a method of crossing each of several individuals with two or more others, inorder to determine the relative genetic contribution of each parent to specific characters in the offspring. Following the concept of general combining ability (GCA) and specific combining ability (SCA) of Sprauge and Tatum (1942), several methods were developed for estimating constants (components of means) and performing the analysis of variance for tests of hypotheses. Griffing (1956) provided detailed procedures for the analysis of variance and estimation of effects under two models (I fixed; II random) and four methods, described according to the nature of entries in the diallel analysis: 1. parents, F_1's and reciprocals; 2. parents and F_1's; 3. F_1's and reciprocals; 4. Only F_1's. Gardner and Eberhart (1966) and Gardner (1967) presented a method for the analysis of diallel crosses among a fixed set of varieties; actually it is applicable to any fixed set of materials (varieties, composites, families *etc.*,) provided that they are in Hardy-Weinberg equilibrium.

Studies on nature of gene action for shoot fly resistance have suggested that inheritance of resistance traits is complex, polygenically inherited, and involves many resistance mechanisms (Rana *et al* 1975; Agrawal and Abraham 1985; Singh *et al* 2004). Because of the poor understanding of inheritance of shoot fly resistance, sorghum improvement for resistance to this pest have not been very effective (Doggett *et al* 1970). Combining ability studies provide useful information on selection of suitable parents for effective hybridization program. Information on combining ability is needed to identify better combiners and develop superior hybrids that would be helpful in understanding the nature of gene action and inheritance of quantitative traits (Goyal and Kumar 1991; Singh and Chaudhry 1985). Diallel crosses have been widely used in genetic research to investigate the inheritance of important traits among a set of genotypes. The estimates of combining ability are useful to predict the relative performance of different lines in hybrid combinations. The information on the nature and magnitude of gene action is important in understanding the genetic potential of a population, and deciding the breeding procedure to be adopted in a given population (Prabhakar and Raut 2010). Though several researchers worked on shoot fly inheritance with importance to shoot fly traits has ended up with lower genetic gains.

Although, considerable progress has been made in identifying shoot fly resistant sorghums but the gains at the farmers' fields are low. This is because of the lack of knowledge on inheritance of the agronomic and morphological characteristics, which are associated with expression of resistance to shoot fly in the postrainy season sorghums. The postrainy season sorghum with good agronomic and morphological traits fetches high economic gains to the farmers. An understanding of the inheritance of morphological and agronomic traits will be helpful in combining the genes for shoot fly resistance and desirable agronomic and grain characteristics to increase production and productivity of postrainy season sorghums.

Therefore, it is crucial to identify the sorghum genotypes with different resistance mechanisms to increase the levels and diversify the basis of resistance to this insect. Hence, the present studies were undertaken to identify the lines with diverse mechanisms of resistance to shoot fly, with adaptation to the postrainy season, and can be used in breeding to diversify the basis of resistance to shoot fly, *A. soccata* and also to understand the *per se* performance of the hybrids and nature of gene action of shoot fly resistance, agronomic and morphological traits, and their inheritance to study the general and specific combining abilities of parents and crosses, respectively, to develop appropriate season specific strategies for sorghum improvement.

MATERIALS AND METHODS

3.1 Experimental material

The experiments were conducted during the 2010 postrainy to 2013 rainy and postrainy seasons, at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Telangana, India (latitude 17.53 ^{o}N, longitude 78.27 ^{o}E and altitude of 545 m).

The test material consisted of a diverse array of 90 sorghum genotypes comprising of germplasm accessions, landraces, breeding lines and commercial cultivars with adaptation to postrainy season in India. These 90 genotypes were evaluated in two replications in randomized complete block design (RCBD) during 2010 postrainy and 2011 rainy seasons. Of these, 30 sorghum genotypes were selected based on their resistant/susceptible reaction to shoot fly, *A. soccata* and were screened in three replications in randomized complete block design during 2011 postrainy and 2012 rainy season. The test genotypes were sown in two rows of 2.0 m length, with a row to row spacing of 75 cm and a spacing of 10 cm between the plants within a row. One set of the test material was grown under protected conditions to record the morphological and agronomic traits by spraying cypermethrin and placing carbofuran granules into the central whorl of the seedlings.

Based on the *per se* performance of the 30 genotypes in the field and as well as on their genetic diversity based on SSR markers, 10 sorghum genotypes exhibiting high levels of resistance (ICSV 25019, PS 35805, IS 2123, IS 2146, and IS 18551) or susceptibility (CSV 15 and Swarna) to shoot fly were selected for the crossing program. These genotypes were used for crossing in a full diallel fashion i.e., crossing in all possible combinations including reciprocals, during the 2012 postrainy season, to test the hybrid vigor of crosses and combining abilities, and the reciprocal effects of the parental genotypes. The crossing of 10 selected parents in a full diallel fashion generated 45 direct crosses, and 45 reciprocal crosses (90 F_1's). The 10 parents and 90 F_1's were sown in three replications in a randomized complete block design (RCBD). The test genotypes were sown in the field in 2.0 m row length, a spacing of 10 cm in-between the plants within a row, and row to row spacing of 75 cm. Parents were sown in two rows each, and the F_1's in single row. One set of replicated trial was raised under protected conditions during the 2013 rainy and postrainy seasons to record the morphological and agronomic traits. In all these experiments Swarna was used as a susceptible check and IS 18551 as the resistant check for comparing the performance of the sorghum genotypes for resistance to shoot fly.

Postrainy season sorghums are typically grown under receding moisture on deep to shallow black soils (Vertisols) between September to February. A basal dose of fertiliser (Ammonium phosphate @ 100 kg ha^{-1}) was applied for raising the crop. The seeds were sown with a two cone planter at a depth of 5.0 cm below the soil surface. Thinning was carried at 7 days after seedling emergence before the onset of shoot fly incidence, and 35 – 40 plants were retained in each plot. Interlard fish-meal technique (Fig. 2) was used to increase the shoot fly incidence in the test material (Soto 1974; Sharma *et al* 1992). Interculture was carried out at 15 and 30 DAE, earthingup and application of urea at 100 kg/ha was done at 30 DAE and the field was irrigated after every 20 days of interval in postrainy season, hand weeding was done whenever necessary, but there was no insecticide application in the experimental block.

3.2 Observations

3.2.1 Shoot fly damage parameters: Data were recorded on plants with shoot fly eggs and number of shoot fly eggs at 14 DAE, and shoot fly deadhearts at 21 DAE and expressed as the percentage of plants with shoot fly eggs and deadhearts and number of eggs per 100 plants. Overall resistance score was recorded on 1 – 9 scale before harvesting (1 = plants with <10% deadhearts and uniform tillers and harvestable panicles, and 9 = plants with >80% deadhearts, and a few or no productive tillers) (Sharma *et al* 1992).

3.2.2 Morphological characteristics: Data were recorded on leaf glossiness, leafsheath pigmentation, and seedling vigor at 7 - 10 DAE, and trichome density on abaxial and adaxial leaf surfaces at 14 DAE. Data were also recorded on waxy bloom, plant color, inflorescence exsertion, inflorescence compactness, inflorescence shape, glume color, grain lustre, grain color, total soluble sugars, endosperm texture, grain subcoat, glume coverage and endosperm color (IBPGR and ICRISAT 1993). Leaf glossiness was evaluated visually on a 1 – 5 scale at 10 - 12 DAE (fifth leaf stage), when the expression of this trait is most apparent, in the early morning hours, when there was maximum reflection of light from the leaf surface (1 = highly glossy, and 5 = non-glossy) (Sharma and Nwanze 1997). The leafsheath pigmentation was visually scored on a 1 – 3 rating scale at 7 DAE (Dhillon *et al* 2006c). Seedling vigor was recorded at 10 DAE on 1 – 3 scale (1 = highly vigorous, and 3 = poor plant vigor) (Sharma and Nwanze 1997). The density of trichomes on both the

Fig. 2: Interlard fishmeal technique

surfaces of leaf was recorded at 12 DAE by taking a 2.5 cm^2 portion from the center of the fifth leaf (Maiti and Bidinger 1979). The leaf samples were taken from three plants at random and placed in acetic acid and alcohol (2 : 1) in stoppered glass vials (10 ml capacity) for 24 h to clear the chlorophyll, and subsequently transferred into lactic acid (90%) as a preservative. The leaf sections were mounted on a glass slide in a drop of lactic acid, and observed at 10X magnification under a stereomicroscope. The trichomes on the abaxial and adaxial leaf surfaces were counted and expressed as numbers of trichomes in a 10X microscopic field.

Waxy bloom was visually scored on 1 - 3 scale (1 = slightly waxy, and 3 = completely waxy) at the flag leaf stage of the crop. Plant color was evaluated visually on a 1 – 2 scale (1 = pigmented - non tan, and 2 = non pigmented - tan); inflorescence exsertion was scored on a 1 – 4 scale (1 = panicle fully exserted, and 4 = panicle recurved); inflorescence compactness on a 1 – 3 scale (1 = loose inflorescence, and 3 = compact inflorescence); inflorescence shape on a 1 – 4 scale (1 = erect inflorescence, and 4 = elliptic inflorescence); glume color on 1 – 6 scale (1 = white glume, and 6 = purple glume); glume coverage on a 1 – 9 scale (1 = 25% grain covered with glumes, and 9 = glumes longer than the grain); leaf midrib color on 1 – 4 scale (1 = white colored midrib and 4 = brown colored midrib); awns as 1 = absence of awns, 2 = presence of awns; grain lustre as 1 = non lustrous grain, 2 = lustrous grain; and grain color on a 1 – 5 scale (1 = white colored grain and 5 = buff colored grain). Data on endosperm texture was recorded on a 1 – 5 scale (1 = completely corneous endosperm, and 5 = completely starchy endosperm); grain subcoat was evaluated on 1 – 2 scale (1= absence of subcoat, and 2 = presence of subcoat); and endosperm color on a 1 – 3 scale (1 = white colored endosperm, and 3 = red colored endosperm) (IBPGR and ICRISAT 1993). Total soluble sugars (TSS), was recorded with the help of hand refractometer (ATAGO® Master – α, Cat. no. 2311, Brix 0.0 ~ 33.0 %). For this purpose, the plant at physiological maturity stage was cut with secateurs at the centre of the 4th internode, and squeezed to extract the juice. A drop of this juice was placed on to the hand refractometer, and the value of TSS was recorded.

3.2.3 Agronomic characteristics: The data on agronomic traits (days to 50% flowering, plant height, agronomic score, 100-seed weight, and grain yield) were also recorded. The data on days to 50% flowering was recorded when half the panicle, and nearly 50% of plants in the plot had attained the anthesis stage. Plant height of three plants was taken at maturity, which were selected at random within a plot. Agronomic desirability was recorded at crop maturity on a 1 – 5 scale (1 = good productive potential and ability to withstand insect damage, and 5 = poor productive potential and prone to insect damage). Data on 100 seed weight and grain yield was recorded after harvesting. The scoring of all these traits was tabulated and described in Table 1.

3.3 Floral description and emasculation of sorghum panicle

3.3.1 Floral biology

Sorghum is preponderantly a self pollinating crop and 2.0 – 10.0% (or more) of natural cross pollination was observed depending on the genotype. The inflorescence of sorghum is raceme (Fig. 3) which consists of one or several spikelets. The racemes vary in length according to the number of nodes and the length of internodes. The panicle consists of primary rachis, and secondary rachis which inturn bear the spikelets (Fig. 4a). The spikelet usually occurs in pairs, one being sessile and the second borne on a short pedicel, except the terminal sessile spikelet, which is accompanied by two pedicellated spikelets (Fig. 4b). Androecium consists of one whorl of three stamens. The anthers are attached at the base of the ovule by a very fine filament and are versatile and yellowish. Gynoecium is centrally placed and consists of two pistils with one ovule from which two feathery stigmas protrude (Fig. 4c, d, e).

3.3.2 Pedicelled spikelets: These are much narrower than the sessile spikelets, usually lanceolate in shape. They posses only androecium (anthers) but occasionally consists of rudimentary ovary and empty glumes (Fig. 4b).

3.3.3 Sessile spikelets: These are perfect flowers and are green in color and changes to different colors until maturity. The sessile spikelets consist of both androecium and gynoecium (fertile) (Fig. 4b).

Anthesis starts at the tip of the panicle two days after the complete emergence of the panicle, and continues successfully downwards over a period of 4 – 5 days. Anthesis takes place first in the sessile spikelets from top to bottom of the inflorescence. The anthesis of the pedicellate spikelets starts when the anthesis of the sessile spikelets is half the way. The flowering phase of the pedicellate spikelets overtakes that of sessile spikelets before they reach the base of the inflorescence (Maiti 1996). Anthesis occurs during morning hours, and frequently occurs just before and after the sunrise. Maximum anthesis is observed between 0600 to 0900 hrs.

Table 1. Sorghum descriptor (ICRISAT, Patancheru, 2011 – 2014).

S. no.	Plant trait	Description	Score
1.	**Leaf glossy score**	Highly glossy	1
		Glossy	2
		Moderately glossy	3
		Slightly glossy	4
		Non glossy	5
2.	**Leafsheath pigmentation**	Highly pigmented	1
		Medium	2
		Non pigmented	3
3.	**Seedling vigor**	High	1
		Intermediate	2
		Low	3
4.	**Leaf midrib color**	White	1
		Dull green	2
		Yellow	3
		Brown	4
5.	**Waxy bloom**	Slightly present	1
		Medium	2
		Completely Present	3
6.	**Plant colour**	Pigmented	1
		Non pigmented	2
7.	**Plant height**	Height of three randomly selected plants	Cms
8.	**Awns**	Absent	1
		Present	2
9.	**Inflorescence exsertion**	Fully exserted	1
		Medium	2
		Poor exsertion	3
		Panicle recurved	4
10.	**Panicle compactness**	Loose	1
		Semiloose	2
		Compact	3

11.	**Panicle shape**	Erect	1
		Drooping	2
		Oval	3
		Elliptic	4
12.	**Glume color**	White	1
		Mahogany	2
		Red	3
		Red black	4
		Black	5
		Purple	6
13.	**Glume coverage**	25% Grain covered	1
		50% Grain covered	3
		75% Grain covered	5
		Grain fully covered	7
		Glumes longer than Grain	9
14.	**Grain color**	White	1
		Yellow	2
		Red	3
		Brown	4
		Buff	5
15.	**Grain lustre**	Absent	1
		Present	2
16.	**Grain subcoat**	Absent	1
		Present	2
17.	**Endosperm texture**	Completely corneous	1
		Intermediate	3
		Completely starchy	5
18.	**Endosperm color**	White	1
		Yellow	2
		Red	3

*Source IBPGR and ICRISAT 1993.

Fig. 3: Inflorescence of sorghum.

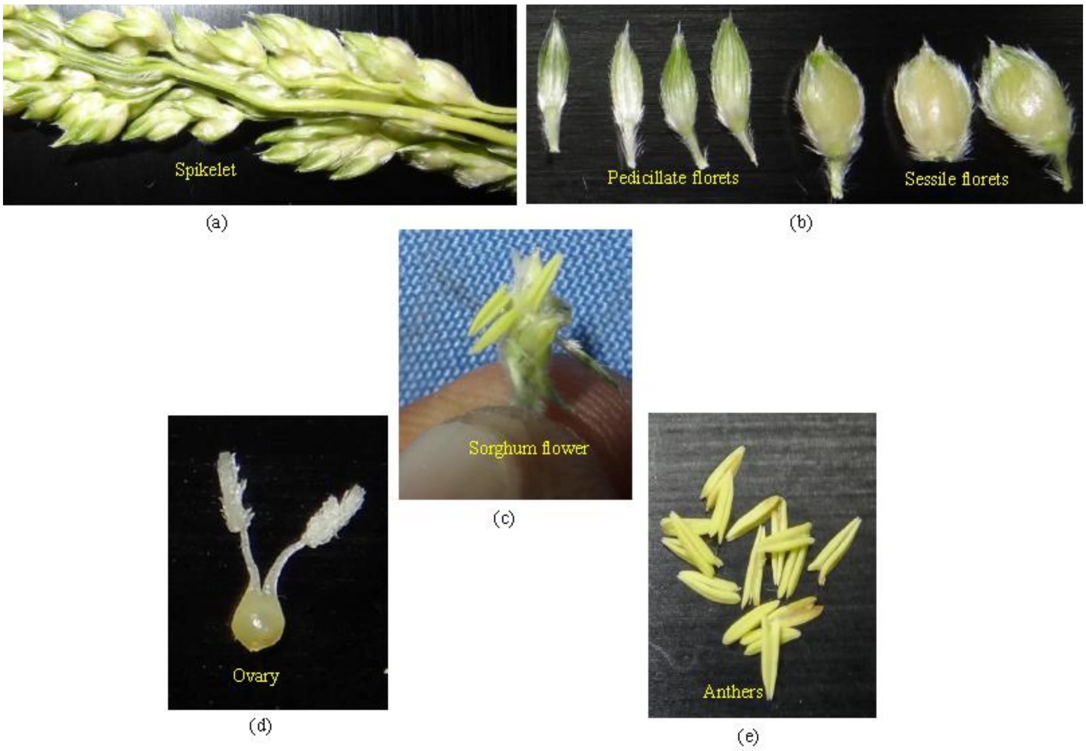


Fig. 4: Floral description of sorghum.

3.3.4 Emasculation procedure

The process of removal of anthers from the sessile florets is known as emasculation. This is a technique used in the self pollinated crops to make crosses between selected plants.

3.3.5 Materials Scissors, forceps, secateurs, butter paper bags, stapler, marking pen

3.3.6 Procedure Suitable panicle from the desired parental genotype that has just started anthesis is selected. The florets that have already started anthesis were removed using secateurs/scissors. The florets from the lower portion of the panicle were also removed leaving about 250 - 300 florets in the central portion of the panicle for emasculation. The pedicellate florets were also removed. The sessile florets were grasped into the thumb and index finger and now slowly insert a forceps between the glumes below the middle portion of the floret and lift the forceps outwards pushing the anthers out of the florets (Fig. 5a, b, and c). Gradually the other sessile florets were also emasculated and once all the florets were emasculated, cover the panicle with butter paper bag with the date of emasculation written on it and staple it.

3.3.7 Pollination of the emasculated florets

The pollination of emasculated florets was done two days after emasculation by collecting the viable pollen from the required male parent in a butter paper bag and dusting the same on to the emasculated florets. This was usually done during the morning hours of anthesis. After dusting the pollen, again the panicle is covered with butter paper bag (Fig. 5d) with details of pollen parent and date of pollination written on it. Once the seed setting starts, the butter paper bag was removed and stapled to the same panicle below the florets (Fig. 5e). Now the panicle is covered with bird scaring nylon bag inorder to avoid bird damage.

3.4 Molecular characterization of selected sorghum genotypes

SSR marker analysis was carried out using 38 polymorphic SSR markers to identify the genetically diverse sorghum genotypes.

3.4.1 Assessment of genetic diversity of shoot fly-resistant lines using SSR markers

Thirty-eight SSR markers were used to assess the genetic diversity of the 30 selected sorghum genotypes with resistance to shoot fly. SSR markers usually consist of di- or tri-nucleotide sequence repeats. These are also known as the microsatellite markers, are co-

Fig. 5: Procedure of emasculation.

dominant in nature, and distributed throughout the genome. These are more informative while dealing with the heterozygotes.

3.4.2 Laboratory procedures

3.4.2.1 Extraction of DNA from the sorghum seedlings

The 30 selected genotypes were grown in pots in the glasshouse. Sampling of the plant material was done one week after seedling emergence. The extraction of DNA from the sampled material was done using CTAB method (Mace *et al* 2003) with slight modifications. The procedure adopted for 96-well plate mini-DNA extraction is as follows.

1) DNA sample preparation

- Steel balls (4 mm in diameter and 2 numbers per extraction tube), pre-chilled at –20°C for about 30 minutes, were added to the 12 x 8 well strip extraction tubes with strip caps (Marsh Biomarket, USA) that were kept on ice.
- Before starting DNA extraction, 3% CTAB buffer was preheated at 65°C in a water bath (Precision Scientific model: shaking water bath 50).
- The plant samples of 30 genotypes were collected from the glasshouse grown plants by cutting them into small pieces. The samples were then (approximately 30 mg) transferred to extraction tubes fitted in a box.

2) Grinding and extraction

To each extraction tube containing the leaf sample and pre chilled steel balls, 450 µl of preheated 3% CTAB buffer was added. Grinding was carried out using a Sigma Geno-Grinder (Spex Certiprep, USA) at 500 strokes per minute for 2 minutes. It was repeated until the leaf strip pieces were sufficiently macerated. After the first round of grinding, the boxes were checked for leakage by taking them out from the Geno-Grinder and shaken for proper mixing of leaf tissue with buffer. After proper grinding, the box with the tubes was fixed in a locking device and incubated at 65°C in a water bath for 10 minutes with occasional shaking.

3) Solvent extraction

450 µl of chloroform : isoamyl alcohol (24 : 1) mixture was added to each tube, tubes were inverted twice and the samples centrifuged at 6200 rpm for 10 minutes (Sigma Laboratory

Centrifuge 4K15C with QIAGEN rotor model NR09100: 2 x 120 g). After centrifugation, the aqueous layer (approximately 300 µl) was transferred to a fresh tube (Marsh Biomarket).

4) Initial DNA precipitation

To each tube containing aqueous layer, 0.7 volumes (approximately 210 µl) of cold (kept at –20°C) isopropanol was added. The solution was carefully mixed and the tubes were kept at –20°C for 10 minutes. The samples were centrifuged at 6200 rpm for 15 minutes, and the supernatant decanted under the fume hood and pellets were dried.

5) RNase A treatment

In order to remove co-isolated RNA, pellets were dissolved into 200 µl of low salt $T_1E_{0.1}$ buffer and 3 µl of RNase A. The solution was incubated at 37°C for half an hour or overnight at room temperature.

6) Solvent extraction

After overnight incubation, 200 µl of phenol : chloroform : isoamyl alcohol (25 : 24 : 1) was added to each tube, mixed and centrifuged (same as earlier) at 5000 rpm for 10 minutes. The aqueous phase in each tube was transferred to a fresh tube (Marsh Biomarket) and 200 µl of chloroform : isoamyl alcohol (24 : 1) was added to each tube, mixed and centrifuged at 5000 rpm for 10 minutes. The aqueous layer was transferred to fresh tube (Marsh Biomaket).

7) DNA precipitation

Add 15 µl (approximately 1/10th volume) of 3.0 M sodium acetate (pH 5.2) and 300 µl (2 volumes) of absolute ethanol (kept at –20°C) were to each of the tubes and the mixtures were subsequently incubated in a freezer (–20°C) for 5 minutes and the tubes were centrifuged at 6200 rpm for 15 minutes.

8) Ethanol wash

After centrifugation, the supernatant was carefully decanted from each tube in order to ensure that the pellet remained inside the tube. Subsequently, 200 µl of 70% ethanol was added to each of the tubes, followed by centrifugation at 5000 rpm for 5 minutes.

9) Final re-suspension

The supernatant was carefully decanted and pellet allowed to air dry for one hour. Dried pellets were re-suspended in 100 µl of $T_{10}E_1$ buffer and kept overnight at room temperature to dissolve completely. The re-suspended DNA samples were stored at 4°C.

3.4.2.2 Quantification and normalization of DNA

The DNA obtained from the above procedure was used to check its quality and as well as the quantity. In order to check the quality, gel electrophoresis was carried out using 0.8% agarose gels stained with ethidium bromide. Each well of the agarose gel was loaded with 5 µl of sample containing 3 µl distilled water + 1 µl orange dye + 1 µl DNA sample and the gel was allowed to run at 100 V for 5 minutes. After completing the electrophoresis run, DNA banding patterns on the gel were visualized under UV light. A smear of DNA indicated poor quality whereas a clear band indicated good quality DNA. Samples of poor quality DNA were re-extracted. The DNA was normalized to 2.5 ng/µl concentration with visual comparison by loading DNA samples with the standard λ DNA molecular weight markers (2.5ng/µl, 5ng/µl, 10ng/µl) on 0.8% agarose gel (Fig. 6).

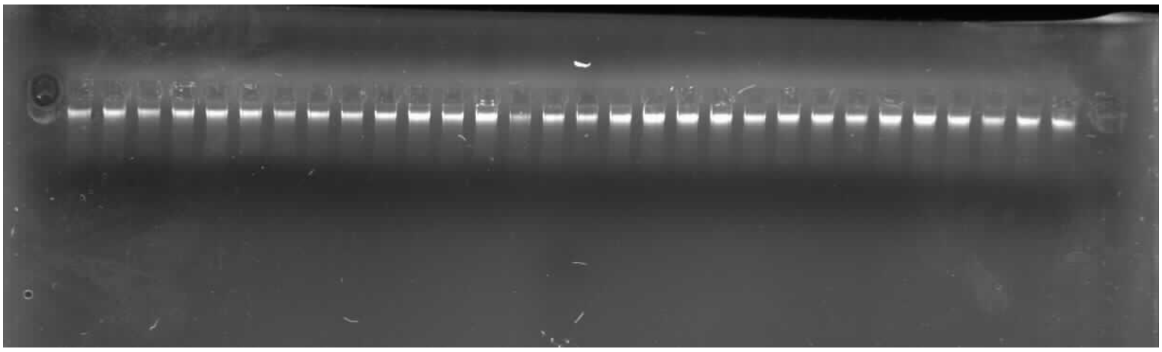


Fig. 6: Agarose gel-electrophoresis of isolated DNA samples of 30 sorghum genotypes.

3.4.3 Selection of SSR markers for diversity analysis

Primer pairs for the SSR markers used were previously defined by Kong *et al* (2000) and Bhattramakki *et al* (2000) for the *Xtxp* series from Texas A&M University; Schloss *et al* (2002) for the *Xcup* series of EST-SSRs from mapped cDNA probe sequences and Mace *et al* (2009) for the *Xgpsb* and *XmSbCIR* series from GenoPlante and CIRAD. The pre determined SSR markers were selected based on their polymorphism and their location. The 38 SSR markers distributed all over the genome (10 chromosomes) of the sorghum were selected for diversity analysis (Table 2).

Table 2. Characteristics of 38 SSR markers used in the diversity analysis of sorghum genotypes showing resistance/susceptibility to sorghum shoot fly, *A. soccata* (ICRISAT, 2011-12).

S. no.	Marker	Repeat motif	Chromosome number	Forward primer sequence 5'-3'	Reverse primer sequence 3'-5'
1	Xcup53	(TTTA)$_{5}$	1	GCAGGAGTATAGGCAGAGGC	CGACATGACAAGCTCAAACG
2	mSbCIR306	(CATG)$_{3}$(GT)$_{7}$	1	ACATGGGGAGGAAGATGA	GCTATTCAGGAGCCATGC
3	gpsb089	(TG)$_{9}$	1	ATCAGGTACAGCAGGTAGG	ATGCATCATGGCTGGT
4	mSbCIR286	(AC)$_{9}$	1	GCTTCTATACTCCCCTCCAC	TTTATGGTAGGATGCTCTGC
5	mSbCIR238	(AC)$_{26}$	2	AGAAGAAAAGGGGTAAGAGC	CGAGAAACAATTACATGAACC
6	Xcup63	(GGATGC)$_{4}$	2	GTAAAGGGCAAGGCAACAAG	GCCCTACAAAATCTGCAAGC
7	mSbCIR223	(AC)$_{6}$	2	CGTTCCAATGACTTTTCTTC	GCCAATGTGGTGTGATAAAT
8	sb6-84	(AG)$_{14}$	2	CGCTCTCGGGATGAATGA	TAACGGACCACTAACAAATGATT
9	Xisep0310	(CCAAT)$_{4}$	2	TGCCTTGTGCCTTGTTTATCT	GGATCGATGCCTATCTCGTC
10	mSbCIR276	(AC)$_{9}$	3	CCCCAATCTAACTATTTGGT	GAGGCTGAGATGCTCTGT
11	Xcup14	(AG)$_{10}$	3	TACATCACAGCAGGGACAGG	CTGGAAAGCCGAGCAGTATG
12	Xtxp114	(AGG)$_{8}$	3	CGTCTTCTACCGCGTCCT	CATAATCCCACTCAACAATCC
13	Xcup61	(CAG)$_{7}$	3	TTAGCATGTCCACCACAACC	AAAGCAACTCGTCTGATCCC
14	Xcup11	(GCTA)$_{4}$	3	TACCGCCATGTCATCATCAG	CGTATCGCAAGCTGTGTTTG
15	Xtxp012	(CT)$_{22}$	4	AGATCTGGCGGCAACG	AGTCACCCATCGATCATC
16	Xtxp021	(AG)$_{18}$	4	GAGCTGCCATAGATTTGGTCG	ACCTCGTCCCACCTTTGTTG
17	Xtxp136	(GCA)$_{5}$	5	GCGAATAGCATCTTACAACA	ACTGATCATTGGCAGGAC
18	Xtxp015	(TC)$_{16}$	5	CACAAACACTAGTGCCTTATC	CATAGACACCTAGGCCATC
19	mSbCIR329	(AC)$_{9}$	5	GATCTTCACCAGGAACAGG	ATGAGAGGAAAACATTGCTG
20	sb4-72	(AG)$_{16}$	6	TGCCACCACTCTGGAAAAGGCTA	CTGAGGACTGCCCCAAATGTAGG

Table 2. (Cont..)

S. no.	Marker	Repeat motif	Chromosome number	Forward primer sequence 5'-3'	Reverse primer sequence 3'-5'
21	Xtxp265	$(GAA)_{19}$	6	GTCTACAGGCGTGCAAATAAAA	TTACCATGCTACCCCTAAAAGTGG
22	Xtxp057	$(GT)_{21}$	6	GGAACTTTTGACGGGTAGTGC	CGATCGTGATGTCCCAATC
23	Xtxp145	$(AG)_{22}$	6	GTTCCTCCTGCCATTACT	CTTCCGCACATCCAC
24	mSbCIR246	$(CA)_{7}$	7	TTTTGTTGCACTTTTGAGC	GATGATAGCGACCACAAATC
25	msbCIR300	$(GT)_{9}$	7	TTGAGAGCGGCGAGGTAA	AAAAGCCCAAGTCTCAGTGCTA
26	Xtxp278	$(TTG)_{12}$	7	GGGTTTCAACTCTAGCCTACCGAACTTCCT	ATGCCTCATCATGGTTCGTTTTGCTT
27	SbAG-B02	$(AG)_{35}$	7	CTCTGATATGTCGTTGTGCT	ATAGAGAGGATAGCTTATAGCTCA
28	gpsb148	$(TC)_{3}(CA)_{5}$	7	CAACCACAAACCAAGAG	ATAGAAATGGGGTGGAG
29	gpsb123	$(CA)_{7}(GA)_{5}$	8	ATAGATGTTGACGAAGCA	GTGGTATGGGACTGGA
30	gpsb067	$(GT)_{10}$	8	TAGTCCATACACCTTTCA	TCTCTCACACACATTCTTC
31	mSbCIR240	$(TG)_{9}$	8	GTTCTTGGCCCTACTGAAT	TCACCTGTAACCCTGTCTTC
32	Xtxp273	$(TTG)_{20}$	8	GTACCCATTTAAATTGTTTGCAGTAG	CAGAGGAGGAGGAAGAGAAGG
33	Xtxp010	$(CT)_{14}$	9	ATACTATCAAGAGGGGAGC	AGTACTAGCCACACGTCAC
34	sb5-206	$(AC)_{13}(AG)_{20}$	9	ATTCATCATCCTCATCCTCGTAGAA	AAAAACCAACCCGACCCACTC
35	Xcup02	$(GCA)_{6}$	9	GACGCAGCTTTGCTCCTATC	GTCCAACCAACCCACGTATC
36	Xtxp141	$(GA)_{23}$	10	TGTATGGCCTAGCTTATCT	CAACAAGCCAACCTAAA
37	mSbCIR262	$(CATG)_{3}$	10	GCACCAAAATCAGCGTCT	CCATTTACCCGTGGATTAGT
38	mSbCIR283	$(CT)_{8}(GT)_{8}$	10	TCCCTTCTGAGCTTGTAAAT	CAAGTCACTACCAAATGCAC

3.4.4 Polymerase chain reaction (PCR) amplification

PCR reactions were conducted in 96 well plate in a GeneAmp PCR system 9700 Perkin Elmer (Applied Biosystem, USA) DNA thermocycler. For separation of amplicons using capillary electrophoresis M-13 tailed, and direct flourophore labelled primers were used. The M-13 tailed forward primer from each primer pair was labeled with different flourophores, FAM™ (Blue), VIC^{TM} (Green), NED™ (Yellow) and PET^{TM} (Red) (Applied Biosystems) before amplification. The reactions were performed in volumes of 5 µl. A touchdown PCR program was used to amplify the DNA fragments. The polymerase chain reaction was performed in 5 µl reaction volume as follows (Table 3**)**.

Table 3. PCR protocol used in DNA amplification.

Component	Stock concentration	Volume
DNA	2.5 ng/µl	1.0 µl
Primers	2.0 pm/µl	1.0 µl
$MgCl_2$	10.0 mM	1.0 µl
dNTPs	2.0 mM	0.3 µl
Buffer	10X	0.5 µl
Enzyme	0.5 U/µl	0.2 µl
(AmpliTaq Gold®, Applied Biosystems, USA)		
Water		1.0 µl
	Total	**5.0 µl**

3.4.4.1 Reaction conditions for the PCR program

Initial denaturation was done for 4 minutes at 94°C (to minimize primer dimer formation and to activate the Taq polymerase), subsequently 10 cycles of denaturation for 10 seconds at 94°C, 35 cycles (40 cycles for M-13 labelled primers) of annealing at 61°C to 52°C for 20 seconds (the annealing temperature for each cycle being reduced by 1°C) and extension at 72°C for 30 seconds. The last PCR cycle was followed by a 20 minutes extension at 72°C to ensure amplification to equal lengths of both DNA strands (Smith *et al* 1995).

3.4.5 Fragment analysis

The amplified PCR products were separated by capillary electrophoresis using ABI prism of 3730XL automatic DNA sequencer (Applied Biosystems Inc.). The capillary electrophoresis technique has a resolution of less than 2 bp, and hence, can be used to clearly distinguish polymorphisms of less than 2 bp. Moreover, as this technique is a fluorescence based detection system, it dispenses with the need for radioactive or laborious manual polyacrylamide gel screening techniques. Prior to electrophoresis, multiplexing was done *i.e.,* the amplified products of primers labeled with different dyes or same flourophores-labeled primers with non-overlapping amplicons (in terms of size), were pooled. Multiplexing of numerous fragments and poolplexing of numerous samples increased the throughput of this technique. For multiplexing, 1.0 µl of each of the amplified products were pooled, and each of the pooled PCR products then mixed with 0.25 µl of GeneScan LIZ 500 internal size standard (Applied Biosystems) and 7.0 µl of Hi-Di formamide (Applied Biosystems). The final volume was made upto 12 µl with sterile distilled water. This final product was then denatured for 5 minutes at 95°C (Perkin Elmer 9700, Applied Biosystems) and cooled immediately on ice for ABI runs.

3.4.5.1 Fragment size fractionation

The denatured DNA amplicons were separated using capillary electrophoresis with the help of an automatic DNA sequencer ABI 3730XL. In this technique, as the DNA migrates through the detection cell, the capillaries are simultaneously illuminated from both sides of the array by an argon-ion laser. To accomplish this, a beam from a single laser source is split using a series of mirrors to form a dual pathway. The fluorescent emissions are then spectrally separated by a spectrograph and focused onto a charged couple device, which are then converted to digital information that is processed by the “collection software”. The fluorescent internal size standard in each capillary eliminates variability. The capillary runs on ABI 3730XL were performed using “Microsatellite Default” analysis method and “Genemapper-POP7” run module. The fragments were separated on a 36 cm capillary array using POP7 as a separation matrix.

3.4.5.2 Data processing

For genotyping the samples electrophoresed on ABI 3730XL, automatic DNA sequencer GeneMapper® v 4.0 software was used. The GeneMapper® v 4.0 software provides a series of automatic fragment sizing, allele scoring, bin-building and autopanelizer algorithms.

3.4.5.3 Statistical parameters

3.4.5.3.1 Summary statistics

Summary statistics for all the markers was derived using PowerMarker v 3.25 software (Liu and Muse 2005). This software uses the following formulas to calculate different parameters:

3.4.5.3.2 Major allele frequency

$$\text{Major allele frequency} = \frac{\text{Num ber of genotypes having major allele}}{\text{Total number of genotypes}} \text{ x } 100$$

3.4.5.3.3 Gene diversity

Gene diversity, often referred to as expected heterozygosity, is defined as the probability that two randomly chosen alleles from the population are different. An unbiased estimator of gene diversity at the l^{th} locus is:

$$H_e = (1 - \sum_{i=1}^{n} P_i^2)/(1 - \frac{1+f}{n})$$

Where $P_i = i^{th}$ allele frequency, f = inbreeding coefficient, n = number of individuals

3.4.5.3.4 Heterozygosity

Heterozygosity is the proportion of heterozygous individuals in the population. At a single locus it is estimated as:

$$H_i = 1 - \sum_{i=1}^{k} P_i$$

Where $P_i = i^{\text{th}}$ allele frequency.

3.4.5.3.5 Polymorphism information content

As per Botstein *et al* (1980), polymorphism information content (PIC) was estimated as

$$PIC = 1 - \left[\sum_{i=1} P_i^2\right] - \left[\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} 2P_i^2 P_j^2\right]$$

Where P_i and P_j are the frequencies of i^{th} and j^{th} alleles

3.4.5.3.6 Dissimilarity matrix

Processed data from AlleloBin was directly used for calculating the dissimilarity matrix using DARwin 5.0 software (Perrier *et al* 2003). Dissimilarity was calculated by pair- wise simple matching using the following formula as follows:

$$d_{ij} = 1 - \frac{1}{L}\sum_{i=1}^{L} \frac{m_i}{\pi}$$

Where d_{ij} = dissimilarity between units *i* and *j*, L = number of loci, π = ploidy, m_i = number of matching alleles for locus *i*.

3.4.5.3.7 Factorial analysis

Principal coordinate analysis (PCoA) is a member of the factorial analysis family working on distance matrices and is related to multidimensional scaling methods (MDS). It considers the high dimensional space defined by the distances between units two by two. The output is a list of coordinates of each unit on each axis that are sufficient to exhibit the main structure of the data. Factorial methods aim mainly to give an overall representation of diversity and are not really affected by individual effects. The simple- matching dissimilarity matrix was used to perform the factorial analysis using DARwin 5.0 software

3.4.5.3.8 Dendrogram/Tree construction

The un-weighted neighbor joining (NJ) method as implemented in DARwin 5.0 software was used to generate dendrogram using the simple-matching dissimilarity matrix to determine the aggregation of the accessions into clusters. Un-weighted neighbor joining gives a same unitary weight to all units.

3.5 Biochemical components associated with resistance to sorghum shoot fly, *A. soccata*

3.5.1 Biochemical constituents of sorghum genotypes

Thirty test genotypes were sown in the glasshouse. Sampling was done at 12 - 14 DAE *i.e.,* at 5th leaf stage. The biochemical constituents of the sorghum genotypes such as total sugars, total phenols, protein content, condensed tannins and flavonoids were estimated from the lyophilized plant material. HPLC finger prints were generated to detect the flavonoids present in the plant material to identify the biochemical components that influence the insect pest attack.

3.5.2 Lyophilization and grinding of the samples

Lyophilization, is a process of freeze drying the plant material with intact biochemical constituents. For this purpose the plant samples were collected at 12 - 14 DAE. Nearly 15 - 20 plants were collected for each genotype grown in the glasshouse at the fifth leaf stage. The plant material obtained was placed in the trays of the lyophilizer (ThermoSavant). Freeze drying was initiated, when the temperature reached -50°C with a pump pressure of 350 mbar. This freezing temperature and pressure dries the samples with intact biochemical components in the plant material. Lyophilization of the material was carried out for 24 – 48 h. The lyophilized plant material was powdered in a blender, stored in desiccators and used whenever necessary.

3.5.3 Estimation of carbohydrates by Anthrone method

Carbohydrates are important components of storage and structural materials in the plants. They exist as free sugars and polysaccharides. The carbohydrate content can be measured by hydrolysing the polysaccharides into simple sugars by acid hydrolysis *i.e.,* Anthrone reagent method (Hedge and Hofreiter 1962). The powdered plant samples (100 mg each) were taken in the boiling test tubes and 5.0 ml of 2.5 N HCl was added. These test tubes were kept in the boiling water bath for 3 h. After 3 h the test tubes were cooled to room temperature, and add sodium carbonate (Na_2CO_3) in the test tubes until the effervescence ceased. The volume was made upto 100 ml, and centrifuged. The supernatant was taken and added Anthrone reagent to aliquots, and boiled again for 8 minutes. The conc. H_2SO_4 present in the Anthrone reagent reacts with carbohydrates causing dehydration to form furfural. Furfural so formed, condenses with the Anthrone reagent to form a blue-green colored complex, which is colorimetrically measured at 630 nm. A standard curve was prepared by using known concentrations of glucose. From the standard graph, the concentration of the carbohydrates present in the plant material was estimated by using the following formula.

$$Amount\ of\ carbohydrate\ present\ in\ the\ sample\ (\%mg) =$$

$$\frac{Sugar\ \ value\ \ from\ \ the\ grap\,h\ (mg)}{Aliquot\ \ sample\ \ (0.5\ or\ 1\ ml)}\ X\ \frac{Total\ \ weig\,ht\ of\ extract\ \ (ml)}{Weig\,ht\ of\ sample\ \ utilised\ \ (mg)}\text{X 100}$$

3.5.4 Estimation of proteins by Lowry’s method

Protein content in the sorghum genotypes was colorimetrically estimated by Lowry’s method (Lowry *et al* 1951). In this method, 500 mg of lyophilized plant material was ground in a mortar and pestle in 5 ml of buffer. Centrifuged the contents and used the supernatant for protein estimation. Pipetted out different aliquots (0.1 ml) of samples and made up the volume to 1 ml with distilled water, added 5 ml of solution C, mixed well, and incubated the sample at the room temperature for 10 minutes. Then added 0.5 ml of FCR, mixed well, and incubated at room temperature in dark for 30 minutes. Color developed in the test tubes was read colorimetrically at 660 nm. Proteins react with the alkaline copper present in Folin Ciocalteu Reagent (FCR) to give a blue colored complex. A standard graph was prepared from the known concentrations of the BSA solution. The concentration of protein present in the test genotypes was calculated using the standard graph, and the results were expressed as mg/g or mg/100 g sample or percentage.

3.5.5 Estimation of total phenols

Total phenols were estimated by using Bray and Thorpe (1954) method. Weighed 500 mg of the lyophilised leaf sample and ground it with 80% ethanol in a mortar and pestle. Centrifuged the homogenate at 10,000 rpm for 20 minutes, saved the supernatant and re-extracted the residue with five times the volume with 80% ethanol. Collected and pooled the supernatants. Evaporated the supernatants to dryness and dissolved the residue in a known volume of distilled water (5 ml). Different aliquots of the sample was pipetted out into the test tubes, made up the volume to 3 ml with distilled water and added 0.5 ml of FCR. After 3 minutes, added 2 ml of 20% Na_2CO_3 solution to each test tube. Mixed thoroughly and placed the test tubes in a boiling water bath for one minute. Cooled the test tubes to room temperature and recorded the absorbance at 650 nm. A standard curve was prepared using different concentrations of catechol. The concentration of the phenols in the test samples were obtained from the standard curve of catechol and expressed as mg phenols/100 mg material.

3.5.6 Estimation of tannins by vanillin hydrochloride method

Tannins were estimated by vanillin hydrochloride method (Robert 1971). For this 100 mg of lyophilised plant material was extracted in 50 ml of methanol and kept in continuous swirling for 20 - 28 h. After 28 h, centrifuged the contents and collected the supernatant. Pipetted out different aliquots of the sample and added 5 ml of vanillin hydrochloride reagent. Vanillin reagent will react with any phenol that has an unsaturated resorcinol or pholoroglucinol nucleus, and forms a colored substituted product. Mixed the contents and incubated it at room temperature for 20 min. Absorbance was recorded at 550 nm. A standard graph was prepared from the known concentrations of the catechin. From the standard graph, the amount of catechin was calculated i.e., tannin in the sample as per the absorbance values and expressed the results as catechin equivalents.

3.5.7 HPLC fingerprints of sorghum flavonoids

3.5.7.1 Extraction of phenols

Phenols were extracted and analyzed by the method of Hahn *et al* (1983) with slight modifications. Lyophilized sorghum samples were ground in 5 ml of methanol in mortar and pestle. After homogenizing the leaf samples in methanol, sonication was carried out for 30 minutes. The samples were centrifuged at 5000 rpm for 10 minutes. Collected the supernatant and discarded the pellet/cell debris. The supernatant was partitioned with 5 ml of hexane in a separation funnel, and this step was repeated three times. The methanol extracts were transferred to the rotavapor and the extract was reduced near to dryness and re-dissolved in 3 ml of HPLC grade methanol.

3.5.7.2 Preparation of samples for HPLC analysis

The methanol extracts were filtered through millipore filters with a pore size of 0.45 µm. The filtered samples were transferred to the HPLC vials for separation.

3.5.7.3 HPLC procedure/protocol

The samples and standards (20 µl) were chromatographed singly and in mixtures on a Waters Sunfire C_{18} column (4.6 X 250 mm) with 5 µm pore size. A Waters High

Performance Liquid Chromatography (HPLC) 2695 separations module (alliance) system consisting of a PCM 11 reciprocating piston pump and a 2996 photodiode array detector in the range of 190 to 800 nm was used in a gradient elution mode. Multistep gradient solvent system of 2% acetic acid (A) and 2% acetic acid-acetonitrile (B) was used for separation.

The protocol for the separation of the compounds was as follows.

Running time	2% Acetic acid (A%)	Acetic acid-acetonitrile (B%)
0.00	95.00	5.00
10.00	95.00	5.00
17.50	85.00	15.00
31.00	85.00	15.00
41.00	50.00	50.00
45.00	50.00	50.00
50.00	85.00	15.00
55.00	95.00	5.00

3.6 Statistical analysis

The data were subjected to analysis of variance (ANOVA) using GenStat® 13th version (GenStat 2010). Significance of the differences between the genotypes was judged by F-test, while the genotypic means were compared by least significant difference (LSD) at $P \leq 0.05$. Simple correlations were calculated using GenStat and Excel, scatter plot and regression analyses using excel, stepwise regression using SAS 9.2 (SAS Institute Inc. 2004) and path coefficient analyses were performed by GENRES (GENRES 1994) and OPSTAT statistical software packages, principal co-ordinate analysis (PCoA) using GenStat, to quantify the genotypic response across seasons, and identify the traits associated with resistance/susceptibility to shoot fly, *A. soccata*. The genetic parameters, *viz.*, Environmental Coefficient of Variation (ECV), Genotypic Coefficient of Variation (GCV), Phenotypic Coefficient of Variation (PCV), Broadsense Heritability (%H) as percentages and Genetic Advance percent of mean (GA%) were calculated by using the formulae based on mean sum of squares. Diallel analysis was carried out according to the Griffing's method 1 and model 1 (Griffing 1956), which partitions the total variation into the general combining ability (GCA) effects that provide the genetic nature of the parents, specific combining ability (SCA) effects, and genetic parameters that provide information about the performance of hybrids, and type of gene actions using Windowstat (Indostat services 2004) software.

RESULTS

4.1 Experiment 1: Preliminary screening of 90 sorghum genotypes for resistance to shoot fly, *A. soccata* in the postrainy season sorghums

4.1.1 Expression of resistance to sorghum shoot fly, *A. soccata* across seasons

The genotypic and environment interactions were significant ($P < 0.001$) for percentage of plants with shoot fly eggs and eggs per 100 plants, plants with shoot fly deadhearts, and overall resistance score (Table 4a). However, the mean sum of squares for environment effects, were relatively higher than the genotypic effects, suggesting that environment has a considerable bearing on expression of resistance to *A. soccata*.

There were significant differences between the genotypes for number of shoot fly eggs per 100 plants, percentage plants with shoot fly eggs and deadhearts, and overall resistance score in both the seasons (Table 4b). The genotypes Phule Yasodha, Phule Chitra, M 35-1, ICSV 702, ICSV 707, ICSV 711, ICSV 25006, ICSV 25010, ICSV 25022, ICSV 25039, IS 1104, IS 2123, IS 2146, IS 2312, IS 4646, IS 5470, IS 5604, Akola Kranti and IS 18551 were not preferred for egg laying, and suffered lower deadheart incidence (15 to 51% deadhearts) as compared to the susceptible check, Swarna (86% plants with deadhearts). These genotypes also exhibited better tolerance (recovery resistance) to shoot fly damage (overall resistance score < 4.5). RHRB 12, ICSV 713, ICSV 25026, ICSV 25027, ICSV 93046, IS 33844-5, Giddi Maldandi, and RVRT 3 exhibited resistance to shoot fly in the postrainy season; while ICSB 463, Phule Anuradha, RHRB 19, Parbhani Moti, ICSV 705, IS 5480, PS 35805, IS 5622, IS 17726, IS 18368, RVRT 1, IS 34722, ICSR 93031and Dagidi Solapur showed resistance to shoot fly damage in the rainy season. The genotypes ICSB 461, ICSB 463, ICSV 700, Phule Yasodha, M 35-1, ICSV 711, ICSV 25010, ICSV 25019, ICSV 93089, IS 18662, Phule Vasudha, IS 18551, IS 33844-5, and Barsizoot had less number of plants with shoot fly deadhearts than the number of plants with eggs, suggesting that these genotypes have antibiosis mechanism of resistance to *A. soccata*.

The genotypes ICSB 463, ICSV 700, Phule Yasodha, Phule Chitra, CSV 18R, ICSV 707, ICSV 711, ICSV 713, ICSV 25019, ICSV 25039, ICSV 93089, IS 5480, IS 2146, IS 2312, IS 4646, IS 5604, IS 5622, IS 18662, Akola Kranti, Phule Vasudha, RVRT 2, Giddi Maldandi, M 35-1-19, RVRT 3, Dagidi Solapur, IS 33844-5 and IS 18551 were glossy with

Table 4a. Mean sum of squares of analysis of variance, of sorghum genotypes evaluated for resistance to shoot fly, *Atherigona soccata* (ICRISAT, Patancheru, 2010 postrainy and 2011 rainy seasons).

Source of variation	df	Plants with shoot fly eggs (%)	Total number of shoot fly eggs/ 100 plants	Shoot fly deadhearts (%)	ORS
Replication	1	48.40	351.00	659.40	1.59
Genotype	89	1442.80**	14921.00**	1655.90**	7.37**
Season	1	7316.60**	101144.00**	6324.50**	8.08**
Genotype*Season	89	285.20**	4771.00**	308.80**	1.82**
Error	178	186.50	1832.00	172.80	0.88
Total	358				

** Mean sum of squares significant at 0.01 probability level; ORS, Overall resistance score.

Table 4b. Evaluation of sorghum genotypes for resistance to sorghum shoot fly, *Atherigona soccata* in the postrainy season sorghums (ICRISAT, Patancheru, 2010-2011).

Genotype	Number of shoot fly eggs/100 plants		Plants with shoot fly eggs (%)		Shoot fly deadhearts (%)		ORS	
	2010 PR	2011 R	2010 PR	2011 R	2010 PR	2011 R	2010 PR	2011 R
ICSB 433	114.0	64.0	30.3	57.5	37.5	50.0	6.5	5.5
ICSB 461	100.0	94.0	60.2	77.2	52.3	74.2	7.5	5.0
ICSB 463	65.0	66.0	47.1	58.3	40.7	51.0	5.5	4.0
ICSV 700	139.0	67.0	44.6	58.3	37.6	55.6	5.5	4.5
Phule Yasodha	82.0	61.0	53.7	56.1	34.3	38.6	5.0	4.0
Macia	189.0	117.0	57.1	78.0	61.7	77.3	7.0	6.5
ICSV 745	146.0	97.0	81.5	81.6	83.3	76.6	7.0	6.5
Mouli	109.0	79.0	61.8	62.1	58.3	62.7	5.5	6.0
Phule Chitra	66.0	48.0	48.2	45.2	50.8	49.5	4.5	4.5
NTJ 2	270.0	137.0	82.5	89.2	73.3	87.5	7.5	6.0
Phule Anuradha	54.0	32.0	46.1	32.3	59.5	27.3	5.5	3.5
RHRB 12	61.0	93.0	36.4	70.7	39.8	73.6	5.5	5.0
RHRB 19	114.0	36.0	65.1	36.0	58.5	41.0	4.5	4.0
M 35-1	86.0	51.0	51.6	46.1	36.6	41.1	4.5	5.0
Parbhani Moti	109.0	51.0	53.3	41.3	56.9	39.8	4.0	5.0
CSV 18R	73.0	73.0	54.0	57.9	63.6	60.6	5.0	4.5
CSV 15	213.0	131.0	82.5	89.5	73.2	91.6	6.0	6.0
ICSV 702	70.0	44.0	38.2	38.8	37.7	46.1	5.0	3.5
ICSV 705	98.0	56.0	53.0	51.9	48.5	42.7	6.0	3.5
ICSV 707	68.0	77.0	20.0	64.2	20.1	50.7	4.5	4.5
ICSV 711	87.0	60.0	45.8	55.0	36.3	43.7	5.0	4.0
ICSV 713	92.0	66.0	41.6	62.3	41.6	59.9	5.0	4.5
ICSV 714	137.0	102.0	64.7	78.7	51.0	75.6	5.5	3.5
ICSV 25006	36.0	43.0	48.5	23.7	43.4	45.4	4.5	5.0
ICSV 25010	83.0	69.0	40.0	69.2	31.1	46.5	5.5	3.0
ICSV 25019	41.0	80.0	38.1	67.7	19.4	59.3	6.5	4.0
ICSV 25022	40.0	37.0	39.9	33.9	34.4	41.8	4.5	3.5
ICSV 25026	55.0	63.0	36.2	54.4	48.7	50.0	4.5	3.0
ICSV 25027	129.0	60.0	45.6	49.0	35.9	58.5	5.0	5.5
ICSV 25039	82.0	39.0	18.5	34.1	31.5	43.4	5.5	3.5
ICSV 93089	62.0	55.0	47.2	55.1	31.4	39.2	6.0	6.5
IS 5480	90.0	35.0	54.4	33.4	43.3	37.2	5.5	4.0
PS 35805	55.0	36.0	18.4	38.9	15.4	24.3	7.0	3.0

Table 4b. (Cont..)

Genotype	Number of shoot fly eggs/100 plants		Plants with shoot fly eggs (%)		Shoot fly deadhearts (%)		ORS	
	2010 PR	2011 R	2010 PR	2011 R	2010 PR	2011 R	2010 PR	2011 R
IS 1044	139.0	100.0	60.7	81.8	59.3	70.3	6.5	4.0
IS 1104	79.0	44.0	28.3	38.5	38.1	38.8	3.5	4.0
IS 2123	79.0	30.0	27.0	25.6	24.7	20.3	3.5	4.0
IS 2146	52.0	56.0	44.6	45.8	39.1	40.4	4.0	4.5
IS 2312	49.0	36.0	34.1	35.5	35.9	27.2	4.5	4.0
IS 4646	56.0	43.0	25.3	44.3	28.3	25.5	5.0	3.0
IS 5470	46.0	54.0	27.1	54.2	21.6	19.2	4.0	3.0
IS 5604	84.0	36.0	33.8	36.2	33.9	15.0	4.0	4.0
IS 5622	69.0	37.0	51.7	37.0	62.5	33.9	4.5	5.0
IS 17726	88.0	35.0	60.6	33.6	56.2	32.3	5.0	5.0
IS 18368	75.0	63.0	63.9	51.9	65.4	41.3	6.5	5.0
IS 18662	87.0	76.0	65.4	62.6	47.4	33.5	4.5	5.0
Akola Kranti	66.0	38.0	35.6	37.6	28.2	32.7	4.5	4.5
Phule Vasudha	96.0	66.0	53.6	60.6	44.7	50.4	4.5	4.5
ICSV 93046	93.0	83.0	42.5	67.5	37.5	58.3	5.5	4.0
IS 10023	231.0	109.0	70.0	90.7	45.8	89.3	8.0	6.0
IS 11189	293.0	248.0	77.0	96.0	75.5	96.0	7.0	6.5
IS 11200	325.0	143.0	88.6	92.7	80.5	92.9	5.5	6.0
IS 11469	133.0	144.0	62.0	91.4	81.4	91.4	6.0	7.5
IS 11510	534.0	123.0	59.2	92.5	86.3	96.7	6.0	7.5
IS 12195	178.0	106.0	83.3	93.1	71.8	89.1	6.0	7.0
RVRT 1	70.0	84.0	81.6	64.2	70.2	57.1	6.5	6.0
IS 38162	148.0	177.0	80.9	97.3	84.5	95.7	8.0	7.0
IS 23891	118.0	167.0	60.4	90.2	77.4	89.6	6.1	8.5
IS 23930	178.0	139.0	90.8	93.2	80.9	94.7	7.5	8.0
IS 23999	94.0	84.0	92.8	68.0	87.8	66.7	8.0	7.0
IS 27954	136.0	116.0	72.9	82.5	92.3	87.0	8.5	8.0
IS 28102	53.0	123.0	81.2	89.5	69.9	100.0	5.7	8.5
IS 28792	177.0	143.0	68.5	89.5	72.4	88.1	7.5	7.0
IS 31705	191.0	153.0	83.3	91.4	92.8	93.1	5.7	9.0
IS 41204	95.0	169.0	47.6	96.8	75.4	95.3	7.1	8.0
IS 41207	150.0	139.0	100.0	93.9	83.3	90.4	5.7	9.0
IS 34722	276.0	100.0	81.5	67.6	69.6	66.1	6.0	5.0
IS 34723	225.0	156.0	83.3	95.6	87.5	89.9	6.0	7.5

Table 4b. (Cont..)

Genotype	Number of shoot fly eggs/100 plants		Plants with shoot fly eggs (%)		Shoot fly deadhearts (%)		ORS	
	2010 PR	2011 R	2010 PR	2011 R	2010 PR	2011 R	2010 PR	2011 R
IS 34724	109.0	165.0	68.5	90.4	78.8	88.9	6.0	7.0
IS 34725	140.0	150.0	69.0	93.3	62.0	89.1	8.1	6.5
IS 34726	194.0	174.0	94.2	94.0	78.1	91.0	6.0	6.0
IS 34727	454.0	175.0	71.5	92.3	78.6	89.6	5.5	5.5
IS 34728	258.0	140.0	67.5	84.1	62.5	82.6	7.0	7.5
RVRT 2	114.0	71.0	42.9	58.3	39.6	65.5	4.5	5.0
IS 34730	128.0	132.0	65.1	87.7	63.8	86.2	4.5	6.0
IS 34731	252.0	197.0	73.8	89.5	47.9	88.1	4.5	6.5
IS 33844-5	50.0	103.0	53.8	63.4	43.5	55.9	5.5	5.5
Giddi Maldandi	158.0	104.0	50.8	74.7	53.4	68.3	4.5	6.5
Barsizoot	100.0	82.0	67.2	70.8	44.8	62.5	5.5	5.0
M 35-1-19	118.0	149.0	59.7	93.4	37.5	93.4	4.5	8.0
ICSR 93031	135.0	42.0	77.8	38.6	74.4	38.6	7.0	5.0
ICSB 52	157.0	180.0	77.5	94.7	67.6	94.7	8.0	9.0
RVRT 3	85.0	85.0	53.6	68.4	48.6	58.9	5.0	4.0
ICSB 24002	301.0	182.0	71.4	96.5	62.3	96.8	6.0	9.0
ICSB 38	93.0	130.0	59.5	89.8	48.6	87.3	8.0	9.0
Dagidi Solapur	161.0	76.0	51.0	59.6	68.5	53.4	4.5	5.5
296 B	125.0	113.0	72.2	81.6	79.1	83.2	7.0	6.0
ICSR 92003	123.0	133.0	80.3	92.8	85.2	87.4	7.5	6.0
DJ 6514	76.0	196.0	77.7	98.7	66.7	100.0	5.0	6.5
IS 18551 (*R*)	76.0	25.0	51.0	25.0	42.2	24.7	4.5	4.5
Swarna (*S*)	223.0	146.0	71.2	89.7	58.7	86.7	8.0	6.5
Mean	**128.92**	**95.43**	**58.4**	**67.42**	**55.5**	**63.85**	**5.73**	**5.54**
SE ±	**37.83**	**19.81**	**10.34**	**8.87**	**10.98**	**7.32**	**0.74**	**0.59**
Vr (89, 89)	**5.16****	**6.27****	**3.37****	**6.41****	**3.20****	**11.14****	**2.83****	**7.70****
LSD (P 0.05)	**106.34**	**55.66**	**29.04**	**24.93**	**30.86**	**20.57**	**2.08**	**1.66**

** F test significant at P 0.01; R, rainy season; PR, postrainy season, ***(R)***, resistant check; ***(S)***, susceptible check; SE, standard error; Vr, variance ratio; ORS (Overall resistance score) 1 = plants with uniform tillers and harvestable panicles, and 9 = plants with a few or no productive tillers.

pigmented leafsheath and high trichome density with plant vigor (Table 5). Some of these genotypes exhibited resistance to shoot fly damage across seasons, with a few exceptions.

4.1.2 Association between the parameters measuring expression of resistance to shoot fly, *A. soccata*

Number of shoot fly eggs per 100 plants and percentage plants with shoot fly eggs (r = 0.94** and 0.59**, respectively, for rainy and postrainy seasons) and deadhearts (r = 0.92** and 0.52**) [*, ** correlation coefficients significant at P 0.05 and P 0.01, respectively] were correlated significantly and positively (Data not shown). The overall resistance/susceptibility score was significantly and positively correlated with eggs per 100 plants (r = 0.73** and 0.36**, for rainy and postrainy season, respectively), plants with eggs (r = 0.67** and 0.51**) and deadheart incidence (r = 0.73** and 0.52**). Plants with shoot fly eggs were also positively correlated with deadheart incidence (r = 0.93** and 0.84**).

4.1.3 Association of morphological traits with expression of resistance to sorghum shoot fly, *A. soccata*

The correlation coefficients between the agronomic and morphological traits with expression of resistance to shoot fly, *A. soccata* revealed that 100 seed weight, leafsheath pigmentation, seedling vigor score, leaf glossiness score, waxy bloom, plant color, grain color, endosperm texture and endosperm color were significantly and positively correlated with resistance/susceptibility to shoot fly damage in both the seasons (Table 6). Trichomes on abaxial and adaxial leaf surfaces, inflorescence exsertion, grain covering by the glume, grain lustre and awns were negatively and significantly correlated with resistance to shoot fly damage in both the seasons. Agronomic score and plant height showed significant and negative associations with shoot fly resistance traits during the rainy season; while grain yield exhibited a significant and positive correlation in the rainy season, and a significant and negative correlation with shoot fly resistance in the postrainy season.

4.1.4 Association of agronomic and morphological traits with resistance to shoot fly, *A. soccata*

Agronomic score and plant height were significantly and negatively correlated with leafsheath pigmentation, seedling vigor score, leaf midrib color, waxy bloom, and plant

Table 5. Morphological characteristics of sorghum genotypes evaluated for resistance to sorghum shoot fly, *Atherigona soccata* (ICRISAT, Patancheru, 2010 - 2011).

Genotype	2010 postrainy season					2011 rainy season							
	Leafsheath pigmentation[a]	Leaf glossy score [c]	Leaf midrib color [d]	Number of trichomes on abaxial surface	Number of trichomes on adaxial surface	Leafsheath pigmentation[a]	Seedling vigor score [b]	Leaf glossy score [c]	Leaf midrib color [d]	Waxy bloom [e]	Plant color [f]	Number of trichomes on abaxial surface	Number of trichomes on adaxial surface
ICSB 433	3.0	2.0	2.5	11.0	10.8	2.7	2.3	2.5	2.0	3.0	2.0	37.9	52.0
ICSB 461	3.0	4.0	2.0	13.5	44.8	3.0	2.7	3.8	2.0	3.0	2.0	22.0	26.7
ICSB 463	2.0	2.0	2.0	74.0	90.5	1.7	1.7	2.8	2.0	2.7	2.0	80.0	112.2
ICSV 700	1.0	2.0	2.0	70.8	106.0	2.0	1.7	2.2	2.0	1.3	1.7	87.7	106.6
Phule Yasodha	1.0	2.0	1.0	66.7	74.3	2.0	1.3	2.2	1.3	1.3	1.0	99.3	108.4
Macia	3.0	4.5	2.0	0.0	0.0	3.0	1.7	3.8	2.0	3.0	2.0	0.0	0.0
ICSV 745	3.0	4.0	1.0	0.0	0.0	3.0	2.7	4.3	2.0	3.0	2.0	0.0	0.0
Mouli	2.0	3.0	2.0	35.0	54.6	2.7	1.7	2.5	2.0	1.0	1.0	54.3	53.4
Phule Chitra	1.5	1.5	1.0	74.2	99.2	2.3	1.0	2.2	2.0	1.3	1.0	57.9	65.0
NTJ 2	3.0	4.5	2.0	7.5	14.3	2.7	2.3	4.7	2.0	3.0	2.0	12.7	15.9
Phule Anuradha	2.5	2.0	2.0	69.2	87.8	2.7	1.0	2.3	2.0	1.0	1.3	51.7	57.0
RHRB 12	1.0	2.5	2.0	8.0	16.7	1.7	1.3	2.2	2.0	1.7	1.0	31.0	40.3
RHRB 19	2.0	2.5	1.0	35.8	48.7	2.0	1.3	2.2	1.7	1.0	1.0	50.2	58.7
M 35-1	2.0	3.0	1.5	32.2	59.7	1.7	1.3	1.5	2.0	2.0	1.0	43.6	50.1
Parbhani Moti	1.5	3.0	1.5	45.3	67.3	2.0	1.3	2.8	2.0	1.3	1.0	53.0	58.4
CSV 18R	1.5	2.5	2.0	46.7	86.2	2.3	1.3	2.3	2.0	1.7	1.3	79.7	92.8
CSV 15	3.0	4.0	1.0	0.0	0.0	3.0	2.0	4.0	2.0	2.3	2.0	0.0	0.0
ICSV 702	2.0	2.5	2.0	37.5	66.0	2.7	2.3	2.3	2.0	2.7	2.0	78.0	96.8

Table 5. (Cont..)

Genotype	2010 postrainy season					2011 rainy season							
	Leafsheath pigmentation^a	Leaf glossy score ^{c}	Leaf midrib color ^{d}	Number of trichomes on abaxial surface	Number of trichomes on adaxial surface	Leafsheath pigmentation^a	Seedling vigor score ^{b}	Leaf glossy score ^{c}	Leaf midrib color ^{d}	Waxy bloom ^{e}	Plant color ^{f}	Number of trichomes on abaxial surface	Number of trichomes on adaxial surface
ICSV 705	2.0	2.5	2.0	57.5	67.7	3.0	1.7	2.2	2.0	3.0	2.0	73.1	79.8
ICSV 707	1.0	1.0	2.0	120.3	129.2	2.3	2.3	2.5	2.0	2.3	2.0	103.2	128.2
ICSV 711	2.0	2.5	2.0	108.0	155.7	3.0	2.7	2.8	2.0	3.0	2.0	128.2	146.4
ICSV 713	2.0	3.0	2.0	122.7	133.2	3.0	2.3	2.5	2.0	3.0	2.0	103.4	144.0
ICSV 714	3.0	3.0	2.0	37.5	51.2	3.0	2.7	3.0	1.7	3.0	2.0	50.3	56.6
ICSV 25006	1.5	1.5	2.0	29.7	60.2	1.7	2.3	2.3	2.0	1.7	2.0	56.3	63.0
ICSV 25010	2.0	3.5	2.0	26.3	36.5	2.7	2.3	2.8	2.0	2.7	2.0	29.7	35.4
ICSV 25019	2.0	2.0	2.0	60.8	70.7	2.7	1.7	1.5	2.0	2.7	2.0	69.2	81.7
ICSV 25022	2.0	2.0	2.0	34.7	69.8	2.7	2.7	2.0	2.0	2.3	2.0	93.3	101.8
ICSV 25026	1.5	1.5	2.0	11.0	31.5	3.0	2.3	2.7	2.0	1.7	2.0	104.3	113.2
ICSV 25027	2.0	2.0	2.0	38.8	37.0	3.0	2.0	1.3	2.0	2.0	2.0	59.1	77.2
ICSV 25039	1.5	1.5	2.0	167.5	169.0	3.0	1.7	1.3	2.0	2.3	2.0	133.9	142.8
ICSV 93089	1.0	1.5	2.0	92.5	134.3	1.7	1.0	1.0	2.0	1.7	1.0	133.0	138.9
IS 5480	2.0	1.5	1.0	57.5	82.3	2.0	1.0	2.0	1.7	1.7	1.0	73.0	91.2
PS 35805	2.5	2.0	2.0	78.3	100.5	3.0	1.3	1.0	2.0	2.7	2.0	75.7	83.3
IS 1044	2.0	4.5	1.0	11.7	21.5	2.0	1.3	4.2	1.0	1.7	1.3	30.4	35.7
IS 1104	1.5	2.0	2.0	43.5	77.3	2.7	1.3	1.3	2.0	1.0	1.0	67.3	78.1
IS 2123	1.5	1.5	1.0	39.8	64.0	2.3	1.3	1.3	1.0	1.0	1.0	41.3	50.2
IS 2146	1.5	2.0	1.0	91.2	118.5	2.7	1.0	1.3	1.3	1.0	1.0	109.7	113.1
IS 2312	2.0	1.0	1.0	55.2	80.2	1.7	1.0	1.3	1.3	1.3	1.0	55.1	72.4

Table 5. (Cont..)

Genotype	2010 postrainy season					2011 rainy season							
	Leafsheath pigmentation[a]	Leaf glossy score[c]	Leaf midrib color[d]	Number of trichomes on abaxial surface	Number of trichomes on adaxial surface	Leafsheath pigmentation[a]	Seedling vigor score[b]	Leaf glossy score[c]	Leaf midrib color[d]	Waxy bloom[e]	Plant color[f]	Number of trichomes on abaxial surface	Number of trichomes on adaxial surface
IS 4646	1.0	1.5	1.0	81.3	104.8	2.0	1.0	1.5	1.3	1.0	2.0	75.4	88.2
IS 5470	1.5	1.0	1.0	37.0	57.5	1.3	1.3	1.0	1.3	1.0	1.0	34.4	48.9
IS 5604	2.0	1.5	1.0	68.7	85.7	1.3	1.0	1.0	1.0	1.0	1.0	88.6	104.0
IS 5622	1.5	2.5	2.0	59.8	102.2	1.7	1.0	1.3	2.0	1.0	1.0	103.1	112.1
IS 17726	2.5	2.5	2.0	48.3	66.2	2.7	1.3	1.3	2.0	1.3	1.0	52.1	58.4
IS 18368	1.5	2.0	2.0	38.9	86.4	3.0	1.7	1.7	2.0	1.3	1.0	71.1	77.6
IS 18662	1.5	2.0	2.0	63.5	86.0	2.3	1.3	2.0	2.0	1.0	1.0	63.6	75.0
Akola Kranti	1.5	3.0	1.0	91.6	99.0	1.3	1.3	1.7	1.3	1.3	1.0	71.7	82.6
Phule Vasudha	1.0	2.0	1.0	77.3	96.5	1.7	1.3	1.8	1.0	1.7	1.0	91.8	98.1
ICSV 93046	2.5	2.0	2.0	57.0	102.2	2.7	2.7	2.5	2.0	1.7	2.0	117.3	117.2
IS 10023	3.0	4.5	1.5	36.7	50.6	2.3	1.7	4.7	2.0	2.7	2.0	6.7	13.3
IS 11189	1.5	4.0	3.0	0.0	0.0	1.0	1.7	4.7	2.7	2.3	1.0	0.0	0.0
IS 11200	1.5	4.5	3.0	0.0	0.0	3.0	1.0	4.7	1.0	1.0	1.0	0.0	0.0
IS 11469	1.0	4.0	1.0	0.0	0.0	1.0	2.0	4.0	1.3	2.0	1.0	0.0	0.0
IS 11510	1.0	5.0	1.0	0.3	-	2.7	1.7	5.0	1.7	2.3	1.0	0.0	0.0
IS 12195	3.0	4.5	1.0	-	0.1	3.0	1.0	3.7	1.0	2.7	1.0	0.0	0.0
RVRT 1	2.0	3.0	2.0	33.8	57.8	2.7	1.7	2.7	1.7	1.3	1.0	37.3	43.9
IS 38162	2.5	5.0	1.0	0.0	0.0	2.7	1.0	4.0	2.0	2.3	1.3	13.7	17.3
IS 23891	2.0	5.0	1.0	0.0	0.0	1.7	1.3	5.0	1.0	2.3	1.0	0.0	0.0
IS 23930	1.0	5.0	1.0	0.0	0.0	1.3	1.0	5.0	1.3	2.3	1.0	0.0	0.0

Table 5. (Cont..)

Genotype	2010 postrainy season					2011 rainy season							
	Leafsheath pigmentation[a]	Leaf glossy score [c]	Leaf midrib color [d]	Number of trichomes on abaxial surface	Number of trichomes on adaxial surface	Leafsheath pigmentation[a]	Seedling vigor score [b]	Leaf glossy score [c]	Leaf midrib color [d]	Waxy bloom [e]	Plant color [f]	Number of trichomes on abaxial surface	Number of trichomes on adaxial surface
IS 23999	1.5	5.0	1.0	0.0	0.0	1.0	1.3	5.0	1.3	2.3	1.0	4.8	5.8
IS 27954	1.5	5.0	1.0	0.0	0.0	2.3	1.0	4.7	1.3	2.3	1.0	3.7	7.3
IS 28102	2.0	5.0	1.0	36.7	50.6	2.3	1.7	4.7	1.3	2.0	1.3	2.3	3.6
IS 28792	2.0	5.0	1.0	0.0	0.0	2.0	1.0	4.7	1.3	1.3	1.3	16.8	18.2
IS 31705	2.0	5.0	1.6	-	0.1	1.7	2.3	5.0	1.0	3.0	1.0	6.2	5.6
IS 41204	1.5	5.0	1.0	0.0	0.0	1.7	1.0	4.3	1.7	1.7	1.3	6.6	8.4
IS 41207	1.0	4.0	1.0	36.7	50.6	1.0	1.3	4.7	1.7	2.0	1.3	0.0	0.0
IS 34722	2.5	4.5	1.0	0.0	0.0	3.0	1.0	3.5	1.0	2.3	1.0	5.9	12.8
IS 34723	2.0	4.0	1.0	-	0.1	2.3	1.7	4.3	1.0	1.7	1.3	0.0	0.0
IS 34724	3.0	4.5	1.0	5.2	8.8	3.0	2.3	4.5	1.0	1.3	1.0	6.1	5.3
IS 34725	1.0	5.0	1.0	0.3	-	2.0	2.0	3.8	1.3	1.3	1.0	2.9	3.1
IS 34726	1.0	4.5	1.0	0.0	0.0	1.3	1.7	4.3	1.0	1.7	1.0	5.4	6.3
IS 34727	1.0	4.0	1.0	0.0	0.0	2.0	1.3	3.7	1.7	3.0	1.0	6.6	11.2
IS 34728	1.5	4.5	1.0	0.0	0.0	2.0	1.3	4.3	1.0	3.0	1.0	0.0	0.0
RVRT 2	1.0	2.0	1.0	55.7	69.2	2.3	1.7	2.3	1.7	1.3	1.0	41.4	44.7
IS 34730	1.0	4.0	1.0	14.2	22.3	2.0	1.0	3.5	1.7	1.7	1.0	21.3	22.8
IS 34731	1.5	4.0	1.0	0.0	0.0	1.7	1.3	4.0	1.3	3.0	1.0	19.3	18.7
IS 33844-5	2.0	3.5	2.0	65.8	110.0	2.3	1.7	2.3	1.7	2.0	1.0	58.1	67.2
Giddi Maldandi	2.0	2.5	2.0	81.5	83.0	2.3	2.0	2.0	2.0	2.0	1.0	58.4	71.1
Barsizoot	1.5	3.0	1.5	37.5	85.5	2.0	2.0	1.8	2.0	1.7	1.0	24.9	32.0

Table 5. (Cont..)

Genotype	**2010 postrainy season**					**2011 rainy season**							
	Leafsheath pigmentation^{a}	**Leaf glossy score ^{c}**	**Leaf midrib color ^{d}**	**Number of trichomes on abaxial surface**	**Number of trichomes on adaxial surface**	**Leafsheath pigmentation^{a}**	**Seedling vigor score ^{b}**	**Leaf glossy score ^{c}**	**Leaf midrib color ^{d}**	**Waxy bloom ^{e}**	**Plant color ^{f}**	**Number of trichomes on abaxial surface**	**Number of trichomes on adaxial surface**
M 35-1-19	2.0	3.0	2.0	77.2	100.3	2.7	2.3	4.3	2.7	2.3	1.7	0.0	0.0
ICSR 93031	1.5	4.0	2.0	0.0	0.0	2.7	1.7	1.8	1.7	1.0	1.0	34.9	50.8
ICSB 52	3.0	4.0	1.5	0.0	0.0	2.7	3.0	4.3	1.7	2.7	2.0	7.0	11.7
RVRT 3	1.5	2.5	2.0	72.7	77.0	2.3	2.3	2.3	1.7	1.0	1.0	41.9	41.4
ICSB 24002	2.0	5.0	2.0	0.0	0.0	2.3	3.0	4.3	2.0	3.0	2.0	3.3	3.8
ICSB 38	3.0	5.0	2.0	0.0	0.0	3.0	3.0	3.7	2.0	3.0	2.0	1.3	2.9
Dagidi Solapur	2.0	2.5	2.0	54.5	72.3	2.7	1.3	4.2	2.0	2.0	1.0	47.2	56.0
296 B	1.5	5.0	1.5	0.0	0.0	2.7	1.7	4.0	1.3	3.0	1.7	0.0	0.0
ICSR 92003	3.0	5.0	2.0	0.0	0.0	3.0	1.3	5.0	2.0	3.0	2.0	3.0	4.6
DJ 6514	2.0	3.0	1.5	0.0	0.0	3.0	3.0	4.3	1.0	3.0	1.7	0.0	0.0
IS 18551 (*R*)	1.0	1.0	1.0	102.0	127.7	1.3	1.0	1.0	1.0	1.0	1.0	92.9	101.1
Swarna (*S*)	2.0	4.0	2.0	3.2	6.5	2.7	1.7	3.8	2.0	3.0	1.7	10.4	18.6
Mean	**1.85**	**3.72**	**1.56**	**36.60**	**50.58**	**2.30**	**1.68**	**3.01**	**1.69**	**2.00**	**1.38**	**42.10**	**48.90**
SE ±	**0.29**	**0.42**	**0.15**	**10.42**	**8.83**	**0.28**	**0.29**	**0.29**	**0.19**	**0.3**	**0.13**	**9.83**	**10.47**
Vr	**4.82****	**9.62****	**11.80****	**12.72****	**27.51****	**4.57****	**4.16****	**18.96****	**4.74****	**5.94****	**11.95****	**15.51****	**17.37****
LSD (P 0.05)	**0.81**	**1.17**	**0.44**	**29.32**	**24.86**	**0.77**	**0.8**	**0.82**	**0.53**	**0.83**	**0.36**	**27.43**	**29.23**

** F test significant at P 0.01; **(*R*)**, resistant check; **(*S*)**, susceptible check; SE, standard error; Vr, variance ratio; LSD, least significant difference; [a] Leafsheath pigmentation (1 highly pigmented, and 3 non pigmented); [b]Seedling vigor score (1 highly vigorous, and 3 poor plant vigor); [c] Leaf glossy score (1 highly glossy, and 5 non glossy); [d]Leaf midrib color (1 white leaf midrib, and 4 brown leaf midrib); [e] Waxy bloom (1 slightly waxy, and 3 completely waxy); [f]Plant color (1 pigmented-non tan, and 2 non pigmented-tan).

Table 6. Association of agronomic and morphological traits with expression of resistance to sorghum shoot fly, *Atherigona soccata* in the postrainy season sorghums.

Plant traits	Number of shoot fly eggs/100 plants	Plants with shoot fly eggs (%)	Shoot fly deadhearts (%)	ORS
Agronomic traits				
Days to 50% flowering	0.31** (-0.08)	0.22* (-0.05)	0.23* (0.09)	0.09 (-0.09)
Agronomic score	-0.30** (0.04)	-0.33** (0.12)	-0.37** (0.12)	-0.20* (-0.27**)
Plant height	-0.13 (0.03)	-0.17 (0.06)	-0.16 (0.11)	-0.03 (-0.34**)
100 seed weight	0.40** (0.25*)	0.39** (0.52**)	0.40** (0.45**)	0.41** (0.16)
Grain yield	0.23* (-0.42**)	0.24* (-0.63**)	0.21* (-0.60**)	0.12 (-0.71**)
Morphological traits				
Leafsheath pigmentation	0.21* (0.08)	0.27** (0.16)	0.33** (0.13)	0.14 (0.43**)
Plant vigor score	0.35**	0.33**	0.37**	0.23*
Leaf glossy score	0.82** (0.59**)	0.84** (0.75**)	0.87** (0.76**)	0.63** (0.69**)
Leaf midrib color	-0.09 (-0.01)	-0.04 (-0.15)	0.02 (-0.17)	0.04 (0.07)
Waxy bloom	0.48**	0.53**	0.54**	0.30**
Plant color	0.21*	0.24*	0.29**	0.05
Trichome density on abaxial leaf surface	-0.72** (-0.52**)	-0.71** (-0.62**)	-0.72** (-0.66**)	-0.62** (-0.53**)
Trichome density on adaxial leaf surface	-0.72** (-0.59**)	-0.70** (-0.61**)	-0.72** (-0.68**)	-0.63** (-0.57**)
Seed/panicle traits				
Inflorescence exsertion	-0.05 (-0.28**)	-0.11 (-0.25*)	-0.14 (-0.27**)	-0.15 (-0.33**)
Panicle compactness	-0.36** (0.06)	-0.38** (-0.13)	-0.44** (-0.08)	-0.30** (-0.22*)
Panicle shape	-0.22* (0.26**)	-0.26** (0.10)	-0.32** (0.18)	-0.24* (-0.02)
Glume color	0.02 (0.37**)	0.01 (0.28**)	-0.04 (0.34**)	0.08 (0.11)
Glume coverage	-0.14 (-0.26**)	-0.13 (-0.27**)	-0.17 (-0.21*)	-0.08 (-0.27**)
Awns	-0.35** (-0.36**)	-0.42** (-0.27**)	-0.38** (-0.14)	-0.16 (-0.44**)
Grain color	0.37** (0.32**)	0.34** (0.35**)	0.35** (0.47**)	0.30** (0.27**)
Grain lustre	-0.23* (-0.15)	-0.29** (-0.31**)	-0.32** (-0.40**)	-0.24* (-0.20*)
Grain subcoat	-0.05 (0.10)	-0.06 (0.20*)	-0.05 (0.25*)	-0.11 (0.15)
Endosperm texture	0.40** (0.36**)	0.31** (0.44**)	0.33** (0.53**)	0.47** (0.14)
Endosperm color	0.34** (0.36**)	0.37** (0.36**)	0.39** (0.40**)	0.36** (0.08)

*, ** Correlation coefficient significant at P 0.05 and P 0.01, respectively.

The values outside the parenthesis are the correlation coefficients of rainy season, and there in parenthesis are for the postrainy season.

color in both the seasons (Table 7). Agronomic score was positively associated with trichome density, while plant height was positively associated with TSS during the rainy season. The 100 seed weight was positively associated with leaf glossiness in both the seasons and with TSS in the rainy season, but negatively associated with trichome density in both the seasons, and with leaf midrib color during the postrainy season. Grain yield was positively associated with seedling vigor, leaf glossiness, waxy bloom and plant color during the rainy season, and trichome density during the postrainy season contributes to high grain yield, however, leaf glossiness in the postrainy season and trichome density during the rainy season were negatively associated with grain yield.

Glume color, glume coverage, presence of awns, grain color, endosperm texture and endosperm color were positively associated with agronomic score, plant height and 100 seed weight in both the seasons; whereas glume color and endosperm color showed a negative association with grain yield in both the seasons (Table 8). Grain covering by the glumes and presence of awns exhibited a positive association with grain yield in the postrainy season, but a negative association in the rainy season suggesting, that different combination of traits contribute to high grain yield in the rainy and postrainy season.

Correlations between panicle traits with morphological traits indicated that inflorescence exsertion, glume coverage, presence of awns, and grain lustre were positively associated with trichome density, but negatively with the leaf glossiness (Table 9). Grain color, grain subcoat, endosperm texture and endosperm color showed a positive association with leaf glossiness score, but a negative association with trichome density.

4.1.5 Association of agronomic and morphological characteristics of sorghum

Agronomic score was positively associated with days to 50% flowering, plant height, 100 seed weight, but negatively associated with grain yield in the rainy season (Table 10). Plant height showed a positive association with 100 seed weight and days to 50% flowering, but a negative association with grain yield during the rainy season. The 100 seed weight was negatively associated with grain yield in the postrainy season.

Overall resistance score, leafsheath pigmentation, seedling vigor score, leaf glossiness score, leaf midrib color and waxy bloom were positively and significantly associated with each other in both the seasons (Table 11). Trichome density showed a negative association with overall resistance score, leafsheath pigmentation, seedling vigor

Table 7. Association between agronomic and morphological traits in the postrainy season adapted sorghums.

Plant traits	Leafsheath pigmentation	Plant vigor score	Leaf glossy score	Leaf midrib color	Waxy bloom	Plant color	Trichome density on abaxial leaf surface	Trichome density on adaxial leaf surface	Total soluble sugars
Days to 50% flowering	-0.26** (-0.07)	-0.05	0.21* (0.02)	-0.36** (0.11)	-0.06	-0.18	-0.06 (0.05)	-0.06 (0.05)	0.08
Agronomic score	-0.44** (-0.29**)	-0.66**	-0.34** (-0.09)	-0.42** (0.38**)	-0.72**	-0.83**	0.21* (0.05)	0.19 (0.10)	0.08
Plant height	-0.46** (-0.41**)	-0.54**	-0.16 (-0.08)	-0.45** (-0.30**)	-0.76**	-0.81**	0.05 (0.07)	0.03 (0.08)	0.28**
100 seed weight	-0.07 (-0.16)	-0.13	0.42** (0.45**)	-0.04 (-0.35**)	-0.03	-0.19	-0.34** (0.33**)	-0.36** (-0.31**)	0.41**
Grain yield	0.10 (-0.18)	0.34**	0.21* (-0.70**)	0.07 (0.06)	0.30**	0.36**	-0.09 (0.45**)	-0.08 (0.51**)	-0.01

*, ** Correlation coefficients significant at P 0.05 and 0.01, respectively.

The values outside the parenthesis are the correlation coefficients of rainy season, and there in parenthesis are for the postrainy season.

Table 8. Association between panicle/seed traits with agronomic traits in the postrainy season adapted sorghums.

Plant traits	Days to 50% flowering	Agronomic score	Plant height	100 seed weight	Grain yield
Inflorescence exsertion	-0.01 (0.01)	0.04 (0.29**)	-0.04 (-0.15)	-0.11 (-0.08)	-0.11 (0.30**)
Panilce compactness	-0.12 (0.29**)	0.14 (0.33**)	0.01 (0.03)	-0.26** (0.15)	-0.16 (0.05)
Panicle shape	0.06 (0.20*)	0.22* (0.37**)	0.13 (0.15)	-0.19 (0.12)	-0.17 (-0.08)
Glume color	0.23* (-0.07)	0.54** (0.32**)	0.48** (0.15)	0.24* (0.38**)	-0.34** (-0.37**)
Glume coverage	0.33** (0.03)	0.50** (0.24*)	0.53** (0.35**)	0.15 (-0.19)	-0.32** (0.23*)
Awns	-0.02 (0.24*)	0.46** (0.42**)	0.51** (0.49**)	0.15 (0.07)	-0.37** (0.35**)
Grain color	0.35** (-0.07)	0.23* (0.17)	0.23* (0.29**)	0.62** (0.20*)	-0.28** (-0.38**)
Grain lustre	-0.11 (-0.02)	0.06 (-0.14)	0.06 (0.07)	-0.12 (-0.20*)	-0.02 (0.33**)
Grain subcoat	-0.17 (-0.09)	-0.07 (0.07)	-0.01 (-0.08)	0.05 (0.06)	0.21* (-0.23*)
Endosperm texture	0.19 (0.19)	0.15 (0.27**)	0.32** (0.23*)	0.21* (0.41**)	-0.07 (-0.35**)
Endosperm color	0.36** (-0.17)	0.16 (0.18)	0.26** (0.21*)	0.45** (0.11)	-0.31** (-0.30**)

*, ** Correlation coefficient significant at P 0.05 and 0.01, respectively.

The values outside the parenthesis are the correlation coefficients of rainy season, and there in parenthesis are for the postrainy season.

Table 9. Association between panicle/seed characteristics with morphological characteristics in the postrainy season adapted sorghums.

Plant traits	Leafsheath pigmentation	Plant vigor score	Leaf glossy score	Leaf midrib color	Waxy bloom	Plant color	Trichome density on abaxial leaf surface	Trichome density on adaxial leaf surface	Total soluble sugars
Inflorescence exsertion	0.01 (0.08)	-0.13	-0.15 (0.36**)	0.04 (0.16)	-0.06	-0.07	0.10 (0.30**)	0.09 (0.36**)	0.05
Panicle compactness	-0.01 (-0.18)	-0.17	-0.44** (-0.11)	-0.11 (-0.10)	-0.22*	-0.06	0.33** (0.06)	0.35** (0.05)	-0.12
Panicle shape	-0.11 (-0.17)	-0.21*	-0.34** (0.11)	-0.21* (-0.16)	-0.27**	-0.1	0.24* (-0.10)	0.27** (-0.11)	-0.09
Glume color	-0.17 (-0.12)	-0.51**	0.08 (0.30**)	-0.49** (-0.38**)	-0.39**	-0.56**	-0.22* (-0.30**)	-0.22* (-0.32**)	0.20*
Glume coverage	-0.29** (-0.20*)	-0.44**	-0.12 (-0.35**)	-0.52** (-0.31**)	-0.44**	-0.37**	0.13 (0.37**)	0.10 (0.36**)	0.22*
Awns	-0.19 (-0.46**)	-0.34**	-0.37** (-0.41**)	-0.07 (-0.03)	-0.65**	-0.47**	0.34** (0.27**)	0.30** (0.35**)	0.22*
Grain color	-0.07 (-0.15)	-0.26**	0.37** (0.43**)	-0.23* (-0.30**)	0.04	-0.21*	-0.31** (-0.34**)	-0.32** (-0.38**)	0.1
Grain lustre	-0.03 (-0.03)	0.06	-0.39** (-0.24*)	0.16 (0.28**)	-0.26**	-0.11	0.34** (0.17)	0.34** (0.19)	-0.23*
Grain subcoat	0.01 (0.17)	-0.06	0.07 (0.21*)	-0.07 (-0.19)	0.01	0.11	-0.03 (-0.13)	-0.04 (-0.14)	0.15
Endosperm texture	-0.11 (-0.03)	0.06	0.29** (0.41**)	0.01 (-0.14)	-0.04	-0.28**	-0.28** (-0.25*)	-0.29** (-0.28**)	0.12
Endosperm color	0.08 (-0.31**)	-0.18	0.40** (0.27**)	-0.16 (-0.15)	-0.03	-0.13	-0.34** (-0.25*)	-0.35** (-0.28**)	0.16

*, ** Correlation coefficient significant at P 0.05 and 0.01, respectively.

The values outside the parenthesis are the correlation coefficients of rainy season, and there in parenthesis are for the postrainy season.

Table 10. Association between agronomic characteristics in the postrainy season adapted sorghums.

Plant traits	**Days to 50% flowering**	**Agronomic score**	**Plant height**	**100 seed weight**
Agronomic score	0.27** (0.03)	1		
Plant height	0.35** (0.13)	0.76** (0.50**)	1	
100 seed weight	0.20* (0.15)	0.14 (0.41**)	0.30** (0.31**)	1
Grain yield	0.20* (-0.14)	-0.54** (0.04)	-0.27** (0.14)	-0.04 (-0.49**)

*, ** Correlation coefficient significant at P 0.05 and 0.01, respectively.

The values outside the parenthesis are the correlation coefficients of rainy season, and there in parenthesis are for the postrainy season.

Table 11. Association between the morphological characteristics in the postrainy season adapted sorghums.

Plant traits	ORS	Leafsheath pigmentation	Plant vigor score	Leaf glossy score	Leaf midrib color	Waxy bloom	Plant color	Trichome density on abaxial leaf surface
Leafsheath pigmentation	0.14 (0.43**)	1.00						
Plant vigor score	0.23*	0.46**	1.00					
Leaf glossy score	0.63** (0.69**)	0.32** (0.29**)	0.31**	1.00				
Leaf midrib color	0.04 (0.07)	0.35** (0.21*)	0.36**	-0.02 (-0.15)	1.00			
Waxy bloom	0.30**	0.50**	0.60**	0.52**	0.31**	1.00		
Plant color	0.05	0.53**	0.70**	0.33**	0.45**	0.76**	1.00	
Trichome density on abaxial leaf surface	-0.62** (-0.53**)	-0.18 (-0.26**)	-0.17	-0.73** (0.72**)	0.11 (0.13)	-0.30**	-0.05	1.00
Trichome density on adaxial leaf surface	-0.63** (-0.57**)	-0.19 (-0.26**)	-0.15	-0.73**(0.77**)	0.13 (0.16)	-0.27**	-0.02	0.99** (0.96**)

*, ** Correlation coefficient significant at P 0.05 and 0.01, respectively.

The values outside the parenthesis are the correlation coefficients of rainy season, and there in parenthesis are for the postrainy season.

score, leaf glossiness score and waxy bloom in both the seasons. Trichome density on the adaxial and abaxial surfaces of the leaf was significantly correlated in both the seasons (r = 0.99** and 0.96**).

Glume color was positively associated with grain and endosperm color in both the seasons; glume coverage and presence of awns in the rainy season, and endosperm texture in the postrainy season, but negatively associated with grain lustre in the postrainy season (Table 12). The grain covering by the glumes was positively associated with awns in both the seasons, and grain color, endosperm texture and endosperm color in the rainy season. Grain color was negatively associated with grain lustre in both the seasons and positively associated with endosperm texture and endosperm color in both the seasons. Grain lustre was negatively associated with endosperm texture in the postrainy season and with endosperm color in both the seasons; while endosperm texture was positively associated with endosperm color in both the seasons.

4.1.6 Grain yield potential of different sorghum genotypes during the rainy and postrainy seasons

The mean performance of the genotypes for grain yield, and agronomic and panicle traits is given in Tables 13, 14a and 14b. The genotype IS 2123 performed well in postrainy season and yielded 3.87 t/ha, whereas CSV 15 yielded 7.10 t/ha during the rainy season. The genotypes ICSV 700, Phule Chitra, RHRB 12, RHRB 19, ICSV 707, ICSV 711, ICSV 714, ICSV 25022, ICSV 25026, ICSV 25027, IS 1044, IS 5604, IS 18662, Akola Kranti, ICSB 24002, and DJ 6514 yielded high across seasons; whereas ICSB 433, ICSB 463, Macia, ICSV 745, CSV 15, ICSV 713,ICSV 93089, IS 34726, IS 33844-5, Barsizoot, ICSB 52, ICSB 38, 296 B, ICSR 92003, and Swarna in the rainy season; Phule Yasodha, Phule Anuradha, Parbhani Moti, CSV 18R, ICSV 702, ICSV 25010, IS 1104, IS 2123, IS 2146, IS 2312, IS 5470, IS 5622, and ICSV 93046 exhibited high grain yield in the postrainy season.

Based on the relationship between grain yield of the test genotypes across seasons (Fig. 7), the genotypes ICSV 25026, ICSV 707, ICSB 24002 (quadrant IV) exhibited high grain yield in both the seasons. The genotypes CSV 15, RHRB 12, Macia, 296B, ICSR 92006, ICSV 745, Swarna, ICSB 433, IS 34726 and ICSV 714 (quadrant II) performed well in the rainy season; while IS 2123, IS 5622, IS 2312, IS 5470, IS 2146, ICSV 25027,

Table 12. Association between panicle/seed characteristics in the postrainy season adapted sorghums.

Plant traits	Inflorescence exsertion	Panicle compactness	Panicle shape	Glume color	Glume coverage	Awns	Grain color	Grain lustre	Endosperm texture
Panicle compactness	0.12 (0.23*)	1.00							
Panicle shape	0.18 (0.06)	0.87** (0.75**)	1.00						
Glume color	0.06 (-0.23)	0.23* (0.09)	0.27** (0.17)	1.00					
Glume coverage	-0.01 (-0.01)	0.20* (0.00)	0.27** (0.07)	0.49** (0.05)	1.00				
Awns	0.12 (0.39**)	0.11 (0.18)	0.07 (0.18)	0.35** (-0.12)	0.47** (0.26**)	1.00			
Grain color	-0.07 (-0.25*)	-0.09 (-0.10)	0.05 (0.20*)	0.44** (0.40**)	0.31** (0.14)	0.10 (0.09)	1.00		
Grain lustre	-0.04 (0.16)	0.16 (-0.08)	0.00 (-0.19)	-0.15 (0.37**)	-0.19 (-0.07)	0.24* (0.13)	-0.24* (0.35**)	1.00	
Endosperm texture	0.01 (0.01)	-0.28** (0.10)	-0.19 (0.24*)	0.17 (0.30**)	0.22* (-0.11)	0.14 (0.17)	0.28** (0.28**)	-0.17 (0.29**)	1.00
Endosperm color	-0.16 (-0.18)	-0.11 (-0.08)	0.02 (0.16)	0.31** (0.40**)	0.32** (-0.12)	0.05 (0.05)	0.88** (0.59**)	-0.20* (0.31**)	0.28** (0.37**)

*, ** Correlation coefficient significant at P 0.05 and 0.01, respectively.

The values outside the parenthesis are the correlation coefficients of rainy season, and there in parenthesis are for the postrainy season.

Table 13. Agronomic characteristics of sorghum genotypes evaluated for resistance to sorghum shoot fly, *Atherigona soccata* (ICRISAT, Patancheru, 2010-2011).

Genotype	2010 postrainy season					2011 rainy season				
	Days to 50% flowering	Agronomic score[a]	Plant height (cm)	100 seed weight (g)	Grain yield (t/ha)	Days to 50% flowering	Agronomic score[a]	Plant height (cm)	100 seed weight (g)	Grain yield (t/ha)
ICSB 433	85.0	2.5	153.3	1.9	1.0	69.0	1.7	216.7	2.0	4.7
ICSB 461	78.0	2.0	125.0	2.4	1.2	63.0	2.3	183.3	2.2	1.8
ICSB 463	81.0	2.0	120.0	2.3	0.9	70.7	2.0	160.0	1.4	3.1
ICSV 700	84.0	4.5	183.3	2.4	1.9	79.3	4.0	350.0	2.9	3.7
Phule Yasodha	71.5	3.5	203.3	3.6	2.1	72.7	3.7	376.7	2.6	2.8
Macia	84.0	2.5	110.0	2.5	0.8	64.0	1.7	170.0	2.5	4.7
ICSV 745	68.9	2.5	131.7	2.4	1.1	68.0	1.7	236.7	3.0	4.9
Mouli	74.0	5.0	175.0	3.4	1.5	64.3	4.7	323.3	2.0	0.8
Phule Chitra	81.0	4.5	195.0	3.6	2.2	66.3	4.3	330.0	3.0	3.1
NTJ 2	78.0	2.5	141.7	3.0	0.4	79.7	3.3	280.0	3.5	0.9
Phule Anuradha	79.0	4.0	170.0	3.7	1.9	57.0	4.3	283.3	2.9	1.6
RHRB 12	85.0	1.5	140.0	2.7	1.9	65.3	2.7	273.3	2.5	5.2
RHRB 19	78.0	3.5	195.0	3.3	2.0	70.3	4.0	330.0	2.6	4.5
M 35-1	74.5	3.5	166.7	3.5	1.6	65.3	4.3	316.7	2.1	1.6
Parbhani Moti	83.0	4.0	173.3	3.9	1.4	66.3	4.7	343.3	2.6	2.5
CSV 18R	84.0	3.5	198.3	3.7	2.4	82.0	4.7	363.3	2.5	2.1
CSV 15	75.0	3.0	145.0	2.8	1.5	65.0	2.3	276.7	2.1	7.1
ICSV 702	78.0	2.5	128.3	2.4	2.2	76.7	2.3	193.3	2.5	2.5
ICSV 705	73.0	2.0	93.3	2.1	1.1	63.3	2.7	123.3	1.8	1.4
ICSV 707	76.0	2.0	130.0	2.3	2.6	66.3	2.7	210.0	2.6	5.5
ICSV 711	78.0	2.5	148.3	2.1	2.0	68.3	4.7	206.7	2.3	3.9
ICSV 713	75.0	2.0	156.7	2.5	1.6	69.7	2.7	216.7	2.0	3.3

Table 13. (Cont..)

Genotype	2010 postrainy season					2011 rainy season				
	Days to 50% flowering	Agronomic score[a]	Plant height (cm)	100 seed weight (g)	Grain yield (t/ha)	Days to 50% flowering	Agronomic score[a]	Plant height (cm)	100 seed weight (g)	Grain yield (t/ha)
ICSV 714	77.0	1.5	120.0	2.5	1.8	65.3	1.7	183.3	2.3	4.1
ICSV 25006	78.0	4.0	141.7	3.6	1.3	62.7	2.7	213.3	2.6	1.5
ICSV 25010	75.5	2.0	103.3	2.2	2.0	62.0	2.0	133.3	1.5	1.6
ICSV 25019	73.0	2.0	103.3	2.1	1.4	63.0	2.0	123.3	2.5	2.5
ICSV 25022	79.0	2.0	126.7	2.3	2.0	76.0	2.3	240.0	2.9	3.5
ICSV 25026	79.0	2.0	133.3	2.3	2.9	76.0	2.0	220.0	2.6	4.4
ICSV 25027	72.0	3.0	165.0	2.2	2.9	68.3	2.7	273.3	2.2	3.2
ICSV 25039	84.0	2.5	138.3	1.8	1.4	73.0	3.0	216.7	1.7	2.2
ICSV 93089	75.0	3.5	156.7	3.0	1.4	64.3	4.0	290.0	3.5	3.5
IS 5480	83.0	5.0	155.0	2.4	1.6	66.3	5.0	350.0	2.1	1.8
PS 35805	72.5	2.5	91.7	2.2	1.2	70.0	3.0	96.7	1.9	2.0
IS 1044	59.0	3.5	148.3	3.0	2.0	78.0	4.0	343.3	3.3	3.1
IS 1104	79.0	4.5	178.3	3.1	2.0	64.0	5.0	300.0	2.3	1.2
IS 2123	73.0	4.5	185.0	2.7	3.9	73.0	5.0	310.0	2.2	1.2
IS 2146	77.0	4.5	166.7	2.3	2.5	66.3	5.0	293.3	1.7	1.8
IS 2312	78.0	5.0	168.3	2.4	2.8	66.3	5.0	310.0	1.6	1.3
IS 4646	69.5	5.0	173.3	2.4	1.7	76.7	5.0	356.7	-	-
IS 5470	80.0	5.0	155.0	2.7	2.8	67.7	5.0	320.0	2.1	2.3
IS 5604	80.0	4.0	186.7	2.2	2.5	79.3	4.7	336.7	2.0	3.2
IS 5622	83.0	5.0	165.0	2.6	3.4	71.0	5.0	296.7	2.0	2.1
IS 17726	74.0	4.0	171.7	3.6	1.6	64.3	4.7	296.7	2.7	2.6
IS 18368	79.0	4.0	145.0	3.8	0.8	64.3	4.0	316.7	3.2	2.4
IS 18662	78.0	5.0	160.0	3.3	1.8	67.0	5.0	316.7	3.0	3.9
Akola Kranti	85.0	4.0	190.0	3.4	1.9	78.0	4.0	390.0	3.0	3.7
Phule Vasudha	82.0	3.5	211.7	3.7	1.8	69.7	4.3	346.7	2.6	2.8

Table 13. (Cont..)

Genotype	2010 postrainy season					2011 rainy season				
	Days to 50% flowering	Agronomic score[a]	Plant height (cm)	100 seed weight (g)	Grain yield (t/ha)	Days to 50% flowering	Agronomic score[a]	Plant height (cm)	100 seed weight (g)	Grain yield (t/ha)
ICSV 93046	80.0	3.5	158.3	2.4	2.0	83.0	4.0	353.3	-	-
IS 10023	75.2	4.0	156.3	5.1	0.1	67.7	4.0	180.0	3.1	1.8
IS 11189	78.2	3.5	223.3	3.0	0.4	79.0	4.3	350.0	-	-
IS 11200	85.2	3.5	205.0	3.4	0.7	86.7	4.7	423.3	2.8	1.1
IS 11469	74.0	5.0	205.0	2.4	1.2	107.8	5.0	310.0	-	-
IS 11510	65.0	4.0	156.7	3.3	0.7	92.7	5.0	300.0	-	-
IS 12195	84.9	4.0	159.6	3.2	0.5	74.0	5.0	310.0	2.8	1.1
RVRT 1	74.5	3.5	156.7	3.7	1.6	63.0	4.3	306.7	3.0	2.8
IS 38162	81.2	3.0	157.1	2.5	0.5	74.7	5.0	316.7	-	-
IS 23891	86.9	3.0	202.9	4.1	0.6	89.8	4.9	330.0	-	-
IS 23930	81.0	4.0	166.7	4.6	0.5	87.3	4.7	330.0	-	-
IS 23999	70.9	3.5	170.0	4.6	0.0	88.0	4.7	330.0	-	-
IS 27954	87.2	4.0	165.0	4.3	0.2	77.3	4.7	296.7	4.4	1.3
IS 28102	86.9	3.6	169.6	4.8	0.1	73.3	4.7	293.3	-	-
IS 28792	71.0	4.5	171.7	3.4	0.3	68.7	4.7	373.3	4.8	2.2
IS 31705	78.2	3.6	156.2	3.1	1.4	87.0	5.0	350.0	-	-
IS 41204	80.9	4.0	176.3	4.1	0.2	87.7	4.7	283.3	-	-
IS 41207	75.0	3.6	150.0	3.6	0.0	88.0	3.1	370.0	-	-
IS 34722	70.0	4.5	205.0	3.1	1.4	96.0	5.0	446.7	-	-
IS 34723	74.0	5.0	145.0	4.3	0.8	92.7	5.0	260.0	-	-
IS 34724	79.0	4.0	138.3	4.5	0.3	89.8	5.0	270.0	-	-
IS 34725	84.0	2.0	165.0	3.4	0.3	99.3	5.1	376.7	-	-
IS 34726	72.0	4.5	153.3	4.7	0.4	93.0	4.7	270.0	2.5	5.4
IS 34727	70.9	5.0	136.7	3.8	0.8	91.0	5.0	296.7	4.5	0.7
IS 34728	88.0	4.0	141.7	4.8	0.6	106.5	5.1	360.0	-	-

Table 13. (Cont..)

Genotype	2010 postrainy season					2011 rainy season				
	Days to 50% flowering	**Agronomic score^a**	**Plant height (cm)**	**100 seed weight (g)**	**Grain yield (t/ha)**	**Days to 50% flowering**	**Agronomic score^a**	**Plant height (cm)**	**100 seed weight (g)**	**Grain yield (t/ha)**
RVRT 2	73.0	4.0	186.7	3.7	1.7	63.7	4.3	333.3	2.6	1.6
IS 34730	88.0	3.0	200.0	3.7	1.1	78.3	5.0	336.7	3.1	0.4
IS 34731	83.2	5.0	143.3	4.6	0.6	95.8	5.0	306.7	-	-
IS 33844-5	80.0	4.5	148.3	3.5	1.4	67.7	4.3	303.3	2.7	3.7
Giddi Maldandi	85.0	4.0	143.3	2.9	1.5	81.0	4.3	280.0	2.3	0.1
Barsizoot	80.0	4.0	151.7	3.5	1.3	65.0	4.3	313.3	3.4	3.8
M 35-1-19	77.0	5.0	150.0	3.4	1.7	82.7	2.7	280.0	2.8	0.5
ICSR 93031	71.2	3.0	137.1	3.1	0.6	63.7	4.7	330.0	2.8	2.0
ICSB 52	78.9	3.0	123.3	3.3	0.3	71.0	1.4	176.7	3.2	3.2
RVRT 3	84.0	4.5	175.0	3.4	1.1	80.3	4.3	376.7	3.0	1.7
ICSB 24002	77.0	1.5	138.3	2.0	2.3	69.3	1.0	200.0	2.7	5.6
ICSB 38	79.0	2.0	128.3	2.8	0.5	64.7	1.3	150.0	2.3	3.9
Dagidi Solapur	86.0	3.5	116.7	2.7	1.8	73.7	4.7	306.7	2.4	1.7
296 B	79.0	2.0	105.0	2.9	0.8	62.0	1.3	200.0	2.5	5.8
ICSR 92003	84.0	5.5	115.0	2.9	0.5	64.3	1.3	203.3	3.1	5.5
DJ 6514	77.0	5.0	176.7	3.7	1.8	77.7	3.7	280.0	1.8	4.4
IS 18551 (*R*)	82.0	4.5	186.7	2.1	1.4	83.0	5.0	340.0	1.7	0.9
Swarna (*S*)	74.0	2.5	115.0	3.3	1.0	65.7	1.3	196.7	2.8	4.4
Mean	**78.22**	**3.56**	**156.2**	**3.13**	**1.37**	**74.43**	**3.83**	**284.85**	**2.59**	**2.81**
SE ±	**3.50**	**0.55**	**10.10**	**0.23**	**0.42**	**4.50**	**0.41**	**7.59**	**0.07**	**0.16**
Vr	**2.45****	**3.83****	**7.99****	**11.49****	**3.79****	**5.95****	**9.12****	**-**	**-**	**-**
LSD (P 0.05)	**9.86**	**1.54**	**28.41**	**0.65**	**1.19**	**12.55**	**1.16**	**-**	**-**	**-**

** F test significant at P 0.01; **(*R*)**, resistant check; **(*S*)**, susceptible check; ^{a}Agronomic score (1 good productive potential and ability to withstand insect damage, and 5 poor productive potential and prone to insect damage).

Table 14a. Panicle and grain characteristics of sorghum genotypes evaluated for resistance to sorghum shoot fly, *Atherigona soccata* during the rainy season (ICRISAT, Patancheru, 2010-2011).

Genotype	Total soluble sugars	Inflorescence exsertion [a]	Inflorescence compactness [b]	Inflorescence shape [c]	Glume color [d]	Glume coverage [e]	Awns [f]	Grain color [g]	Grain lustre [h]	Grain subcoat [i]	Endosperm texture [j]	Endosperm color [k]
ICSB 433	13.3	3.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	3.0	1.0
ICSB 461	9.3	1.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	2.0	3.0	1.0
ICSB 463	12.3	1.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	2.0	1.0	1.0
ICSV 700	14.0	2.0	3.0	4.0	2.0	3.0	2.0	1.0	2.0	2.0	1.0	1.0
Phule Yasodha	14.3	3.0	2.0	1.0	3.0	5.0	2.0	1.0	2.0	2.0	3.0	1.0
Macia	12.3	2.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0
ICSV 745	11.3	2.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	3.0	1.0
Mouli	13.7	2.0	2.0	1.0	2.0	3.0	2.0	1.0	2.0	2.0	3.0	1.0
Phule Chitra	13.3	1.0	2.0	1.0	1.0	3.0	2.0	1.0	2.0	2.0	1.0	1.0
NTJ 2	18.3	3.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	2.0	3.0	1.0
Phule Anuradha	14.0	1.0	2.0	1.0	3.0	3.0	2.0	1.0	2.0	2.0	1.0	1.0
RHRB 12	6.3	2.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	2.0	3.0	1.0
RHRB 19	10.0	2.0	3.0	4.0	3.0	3.0	2.0	1.0	2.0	2.0	1.0	1.0
M 35-1	7.3	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	2.0	3.0	1.0
Parbhani Moti	10.3	2.0	2.0	1.0	2.0	3.0	2.0	1.0	2.0	2.0	5.0	1.0
CSV 18R	9.3	2.0	2.0	1.0	1.0	3.0	2.0	1.0	2.0	2.0	3.0	1.0
CSV 15	17.7	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	3.0	1.0
ICSV 702	17.7	3.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0
ICSV 705	8.7	3.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0	1.0
ICSV 707	14.0	1.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	2.0	1.0	1.0
ICSV 711	8.7	1.0	2.0	1.0	1.0	3.0	1.0	1.0	1.0	2.0	3.0	1.0
ICSV 713	11.3	1.0	3.0	4.0	1.0	1.0	1.0	1.0	2.0	2.0	3.0	1.0
ICSV 714	17.7	1.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	3.0	1.0

Table 14a. (Cont..)

Genotype	Total soluble sugars	Inflorescence exsertion [a]	Inflorescence compactness [b]	Inflorescence shape [c]	Glume color [d]	Glume coverage [e]	Awns [f]	Grain color [g]	Grain lustre [h]	Grain subcoat [i]	Endosperm texture [j]	Endosperm color [k]
ICSV 25006	11.0	2.0	2.0	1.0	1.0	3.0	2.0	1.0	1.0	2.0	3.0	1.0
ICSV 25010	4.3	3.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0	1.0
ICSV 25019	10.0	3.0	3.0	4.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0
ICSV 25022	11.7	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0
ICSV 25026	13.0	3.0	2.0	1.0	2.0	3.0	2.0	1.0	2.0	2.0	1.0	1.0
ICSV 25027	10.7	2.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0
ICSV 25039	8.0	3.0	2.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0
ICSV 93089	10.3	2.0	2.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0
IS 5480	8.7	3.0	3.0	3.0	3.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0
PS 35805	7.7	3.0	3.0	4.0	2.0	1.0	1.0	1.0	2.0	2.0	1.0	1.0
IS 1044	15.3	2.0	1.0	1.0	2.0	3.0	1.0	1.0	1.0	2.0	1.0	1.0
IS 1104	11.3	1.0	2.0	1.0	3.0	3.0	2.0	1.0	2.0	2.0	3.0	1.0
IS 2123	8.3	2.0	3.0	3.0	3.0	5.0	2.0	1.0	2.0	2.0	1.0	1.0
IS 2146	10.0	3.0	3.0	3.0	3.0	1.0	2.0	1.0	2.0	2.0	3.0	1.0
IS 2312	8.0	1.0	3.0	3.0	3.0	3.0	1.0	1.0	2.0	2.0	1.0	1.0
IS 4646	17.7	2.0	3.0	4.0	4.0	7.0	2.0	1.0	1.0	-	-	-
IS 5470	11.3	2.0	3.0	3.0	3.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0
IS 5604	14.3	3.0	3.0	4.0	3.0	9.0	2.0	1.0	1.0	2.0	3.0	1.0
IS 5622	5.3	2.0	3.0	3.0	2.0	3.0	2.0	1.0	2.0	2.0	1.0	1.0
IS 17726	13.0	2.0	2.0	1.0	3.0	1.0	2.0	1.0	2.0	2.0	3.0	1.0
IS 18368	12.0	2.0	3.0	4.0	4.0	1.0	2.0	1.0	2.0	2.0	3.0	1.0
IS 18662	14.0	2.0	2.0	1.0	3.0	3.0	2.0	1.0	2.0	2.0	3.0	1.0
Akola Kranti	13.3	1.0	2.0	1.0	1.0	3.0	2.0	1.0	2.0	2.0	3.0	1.0
Phule Vasudha	15.3	1.0	2.0	1.0	3.0	5.0	2.0	1.0	2.0	2.0	3.0	1.0
ICSV 93046	12.3	1.0	2.0	1.0	1.0	5.0	2.0	1.0	2.0	-	-	-

Table 14a. (Cont..)

Genotype	Total soluble sugars	Inflorescence exsertion [a]	Inflorescence compactness [b]	Inflorescence shape [c]	Glume color [d]	Glume coverage [e]	Awns [f]	Grain color [g]	Grain lustre [h]	Grain subcoat [i]	Endosperm texture [j]	Endosperm color [k]
IS 10023	17.3	1.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0
IS 11189	9.3	3.0	1.0	1.0	-	1.0	2.0	2.0	1.0	2.0	5.0	1.0
IS 11200	15.7	2.0	1.0	1.0	4.0	5.0	2.0	3.0	1.0	2.0	5.0	3.0
IS 11469	11.3	2.0	1.0	1.0	-	-	1.0	-	-	-	-	-
IS 11510	16.0	2.0	2.0	1.0	3.0	3.0	2.0	-	-	-	-	-
IS 12195	7.3	1.0	2.0	1.0	4.0	9.0	2.0	2.0	1.0	2.0	3.0	2.0
RVRT 1	18.3	3.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	2.0	3.0	1.0
IS 38162	5.3	2.0	2.0	1.0	3.0	3.0	1.0	1.0	2.0	-	-	-
IS 23891	10.7	1.0	-	-	-	-	2.0	-	-	-	-	-
IS 23930	5.3	2.0	-	-	-	-	2.0	-	-	-	-	-
IS 23999	15.0	2.0	2.0	1.0	4.0	3.0	1.0	-	-	-	-	-
IS 27954	12.7	1.0	2.0	1.0	4.0	3.0	2.0	4.0	1.0	2.0	3.0	2.0
IS 28102	12.0	2.0	1.0	1.0	2.0	1.0	1.0	1.0	1.0	-	-	-
IS 28792	19.3	2.0	3.0	4.0	4.0	7.0	2.0	4.0	2.0	2.0	3.0	3.0
IS 31705	8.7	2.0	2.0	1.0	-	-	2.0	-	-	-	-	-
IS 41204	17.7	2.0	2.0	1.0	3.0	3.0	2.0	-	-	-	-	-
IS 41207	7.7	-	-	-	-	-	-	-	-	-	-	-
IS 34722	14.7	2.0	-	-	-	-	1.0	-	-	-	-	-
IS 34723	10.7	2.0	-	-	-	-	1.0	-	-	-	-	-
IS 34724	16.0	2.0	2.0	1.0	3.0	3.0	2.0	-	-	-	-	-
IS 34725	11.7	1.0	3.0	4.0	-	-	1.0	-	-	-	-	-
IS 34726	7.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	2.0	3.0	1.0
IS 34727	10.3	2.0	-	-	-	-	1.0	4.0	1.0	2.0	3.0	2.0
IS 34728	9.0	-	-	-	-	-	-	-	-	-	-	-
RVRT 2	16.3	2.0	2.0	1.0	3.0	3.0	2.0	1.0	1.0	2.0	3.0	1.0

Table 14a. (Cont..)

Genotype	**Total soluble sugars**	**Inflorescence exsertion [a]**	**Inflorescence compactness [b]**	**Inflorescence shape [c]**	**Glume color [d]**	**Glume coverage [e]**	**Awns [f]**	**Grain color [g]**	**Grain lustre [h]**	**Grain subcoat [i]**	**Endosperm texture [j]**	**Endosperm color [k]**
IS 34730	18.7	3.0	2.0	1.0	3.0	5.0	2.0	1.0	1.0	2.0	3.0	1.0
IS 34731	8.3	2.0	2.0	1.0	3.0	3.0	1.0	-	-	-	-	-
IS 33844-5	19.3	3.0	2.0	1.0	2.0	3.0	2.0	1.0	2.0	2.0	3.0	1.0
Giddi Maldandi	7.3	3.0	3.0	4.0	3.0	3.0	2.0	-	-	1.0	3.0	1.0
Barsizoot	13.3	3.0	2.0	1.0	2.0	3.0	2.0	1.0	2.0	2.0	3.0	1.0
M 35-1-19	13.3	1.0	2.0	1.0	1.0	1.0	1.0	-	-	2.0	3.0	3.0
ICSR 93031	8.7	2.0	2.0	1.0	3.0	1.0	2.0	1.0	2.0	-	-	-
ICSB 52	15.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	3.0	1.0
RVRT 3	15.0	1.0	2.0	1.0	3.0	3.0	2.0	1.0	2.0	2.0	1.0	1.0
ICSB 24002	8.3	1.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	5.0	1.0
ICSB 38	6.7	1.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	3.0	1.0
Dagidi Solapur	17.3	3.0	3.0	3.0	4.0	3.0	2.0	1.0	1.0	2.0	3.0	1.0
296 B	10.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0
ICSR 92003	16.3	1.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0
DJ 6514	6.0	2.0	3.0	4.0	2.0	1.0	1.0	1.0	2.0	2.0	1.0	1.0
IS 18551 (*R*)	14.7	2.0	3.0	4.0	3.0	9.0	2.0	1.0	1.0	2.0	3.0	1.0
Swarna (*S*)	5.0	2.0	2.0	1.0	3.0	3.0	1.0	1.0	2.0	2.0	3.0	1.0
Mean	**11.9**	**1.9**	**2.2**	**1.6**	**2.3**	**2.5**	**1.6**	**1.2**	**1.7**	**2.0**	**2.3**	**1.1**
SE ±	**0.4**	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**0.1**	**0.1**	**0.1**	**0.0**	**0.1**	**0.1**

(R), resistant check; ***(S)***, susceptible check; SE, standard error; [a]Inflorescence exsertion (1 panicle fully exserted, and 3 poor panicle exsertion); [b] Inflorescence compactness (1 loose inflorescence, and 3 compact inflorescence); [c]Inflorescence shape (1 erect inflorescence, and 4 elliptic inflorescence); [d]Glume color (1 white colored glume, and 6 purple colored glume); [e]Glume coverage (1 25% grain covered with glumes, and 9 glumes longer than grain); [f]Awns (1 awns absent, and 2 presence of awns); [g]Grain color (1 white colored grain, and 5 buff colored grain); [h]Grain lustre (1 non lustrous grain, and 2 lustrous grain); [i]Grain subcoat (1 absence of grain sub coat, and 2 presence of grain subcoat); [j]Endosperm texture (1 completely corneous endosperm, and 5 completely starchy endosperm); [k]Endosperm color (1 white colored endosperm, and 3 red colored endosperm).

Table 14b. Panicle and grain characteristics of sorghum genotypes evaluated for resistance to sorghum shoot fly, *Atherigona soccata* during the postrainy season (ICRISAT, Patancheru, 2010 - 2011).

Genotype	Inflorescence exertion [a]	Inflorescence compactness [b]	Inflorescence shape [c]	Glume color [d]	Glume coverage [e]	Awns [f]	Grain color [g]	Grain lustre [h]	Grain subcoat [i]	Endosperm texture [j]	Endosperm color [k]
ICSB 433	1.5	2.0	1.0	1.5	4.0	1.5	1.0	2.0	1.0	3.0	1.0
ICSB 461	1.0	1.5	1.0	2.5	1.0	1.5	1.0	2.0	1.0	3.0	1.0
ICSB 463	1.0	2.0	1.0	2.0	3.0	1.0	1.0	2.0	1.5	3.0	1.0
ICSV 700	1.5	2.0	1.0	2.0	4.0	2.0	1.0	2.0	1.0	2.0	1.0
Phule Yasodha	1.0	2.0	1.0	1.0	5.0	2.0	1.0	2.0	1.0	3.0	1.0
Macia	1.0	2.0	1.0	2.0	2.0	1.0	1.0	2.0	1.5	2.0	1.0
ICSV 745	1.0	1.5	1.0	2.5	2.0	1.0	1.0	1.5	2.0	4.0	1.0
Mouli	2.0	2.0	1.0	1.0	1.0	2.0	1.0	2.0	1.5	4.0	1.0
Phule Chitra	1.0	2.0	1.0	2.0	3.0	2.0	1.0	2.0	1.0	3.0	1.0
NTJ 2	1.0	0.9	1.9	2.0	1.0	1.0	1.0	2.0	1.5	2.0	1.0
Phule Anuradha	2.0	1.5	1.0	2.0	3.0	2.0	1.0	2.0	1.5	4.0	1.0
RHRB 12	1.0	2.0	1.0	2.5	2.0	2.0	1.0	2.0	1.0	3.0	1.0
RHRB 19	1.5	2.0	1.0	1.5	5.0	2.0	1.0	2.0	1.0	2.0	1.0
M 35-1	2.0	2.0	1.0	2.0	2.0	2.0	1.0	2.0	1.0	2.0	1.0
Parbhani Moti	1.5	2.0	1.0	2.5	2.0	2.0	1.0	2.0	1.0	5.0	1.0
CSV 18R	1.0	1.0	1.0	1.0	2.0	1.5	1.0	2.0	1.0	4.0	1.0
CSV 15	1.5	2.0	1.0	1.0	2.0	1.0	1.0	2.0	1.0	3.0	1.0
ICSV 702	1.5	2.0	1.0	2.0	2.0	2.0	1.0	2.0	1.5	3.0	1.0
ICSV 705	1.5	2.0	1.0	1.0	3.0	1.0	1.0	2.0	1.5	2.0	1.0
ICSV 707	1.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0
ICSV 711	1.0	2.0	1.0	1.0	5.0	1.0	1.0	2.0	2.0	3.0	1.0
ICSV 713	1.0	2.0	1.0	1.0	4.0	1.0	1.0	2.0	1.0	2.0	1.0
ICSV 714	1.5	2.0	2.5	1.0	1.0	1.0	1.0	2.0	1.5	3.0	1.0

Table 14b. (Cont..)

Genotype	Inflorescence exertion [a]	Inflorescence compactness [b]	Inflorescence shape [c]	Glume color [d]	Glume coverage [e]	Awns [f]	Grain color [g]	Grain lustre [h]	Grain subcoat [i]	Endosperm texture [j]	Endosperm color [k]
ICSV 25006	2.0	2.0	1.0	2.0	4.0	2.0	1.0	2.0	1.0	3.0	1.0
ICSV 25010	2.0	2.0	1.0	1.0	3.0	1.0	1.0	2.0	1.0	1.0	1.0
ICSV 25019	2.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0
ICSV 25022	1.0	1.5	1.0	2.0	2.0	1.5	1.0	2.0	1.5	2.0	1.0
ICSV 25026	1.0	2.0	1.0	2.0	3.0	2.0	1.0	2.0	1.5	2.0	1.0
ICSV 25027	1.0	2.0	1.0	2.0	4.0	1.0	1.0	2.0	2.0	2.0	1.0
ICSV 25039	2.0	2.5	2.5	2.0	4.0	2.0	1.0	2.0	1.0	3.0	1.0
ICSV 93089	1.0	1.5	1.0	1.0	4.0	2.0	1.0	2.0	1.0	2.0	1.0
IS 5480	2.0	3.0	3.0	2.5	3.0	2.0	1.0	2.0	1.0	3.0	1.0
PS 35805	2.0	2.5	2.5	1.0	2.0	1.0	1.0	2.0	1.0	2.0	1.0
IS 1044	1.0	1.5	1.0	4.0	3.0	2.0	1.0	2.0	1.0	4.0	1.0
IS 1104	2.0	2.0	1.0	2.0	4.0	2.0	1.0	2.0	1.0	4.0	1.0
IS 2123	2.0	3.0	3.0	2.0	3.0	2.0	1.0	2.0	1.0	2.0	1.0
IS 2146	2.0	3.0	3.0	2.0	4.0	2.0	1.0	2.0	1.5	4.0	1.0
IS 2312	2.0	3.0	3.0	2.0	3.0	2.0	1.0	2.0	1.0	3.0	1.0
IS 4646	1.0	1.0	1.0	5.0	7.0	2.0	1.0	2.0	1.0	1.0	1.0
IS 5470	2.0	3.0	3.0	2.0	3.0	2.0	1.0	2.0	1.0	3.0	1.0
IS 5604	1.0	3.0	3.5	3.0	9.0	2.0	1.0	2.0	2.0	3.0	1.0
IS 5622	1.5	3.0	3.0	2.0	3.0	2.0	1.0	2.0	1.0	2.0	1.0
IS 17726	2.0	2.0	1.0	1.0	3.0	2.0	1.0	2.0	1.5	3.0	1.0
IS 18368	2.0	2.5	2.0	4.5	2.0	2.0	1.0	2.0	1.0	4.0	1.0
IS 18662	2.0	2.0	1.0	3.0	5.0	2.0	1.0	2.0	1.0	3.0	1.0
Akola Kranti	1.5	2.0	1.0	1.0	3.0	2.0	1.0	2.0	1.0	5.0	1.0
Phule Vasudha	1.0	2.0	1.0	1.0	4.0	2.0	1.0	2.0	1.0	2.0	1.0
ICSV 93046	2.0	2.0	1.0	1.0	5.0	2.0	1.0	2.0	2.0	2.0	1.0
IS 10023	1.0	2.0	1.0	3.5	2.0	1.0	1.0	2.0	2.0	5.2	1.0
IS 11189	1.0	3.0	4.0	3.0	1.0	2.0	2.0	2.0	1.0	5.0	1.5

Table 14b. (Cont..)

Genotype	Inflorescence exertion [a]	Inflorescence compactness [b]	Inflorescence shape [c]	Glume color [d]	Glume coverage [e]	Awns [f]	Grain color [g]	Grain lustre [h]	Grain subcoat [i]	Endosperm texture [j]	Endosperm color [k]
IS 11200	1.0	3.0	4.0	2.5	1.0	2.0	2.0	2.0	1.0	5.0	2.0
IS 11469	1.0	1.0	2.0	3.0	3.0	2.0	3.0	2.0	1.5	5.0	3.0
IS 11510	1.0	2.5	2.0	3.0	2.0	1.0	1.0	2.0	1.0	3.0	1.0
IS 12195	1.0	1.1	1.1	4.0	5.0	2.0	2.0	2.0	1.0	4.0	1.5
RVRT 1	2.0	1.0	1.0	1.0	3.0	2.0	1.0	2.0	1.0	3.0	1.0
IS 38162	1.0	0.9	0.9	2.0	6.7	1.0	2.5	2.0	1.5	4.0	1.0
IS 23891	1.0	2.1	1.1	5.0	1.3	2.0	1.0	2.0	1.0	3.2	1.0
IS 23930	1.5	2.0	3.0	1.0	4.0	2.0	1.0	2.0	1.0	4.0	1.0
IS 23999	2.0	3.1	4.1	1.0	5.3	2.0	1.0	2.0	2.0	5.2	1.0
IS 27954	1.0	2.5	2.5	3.0	5.0	2.0	4.0	1.0	2.0	4.8	1.0
IS 28102	1.0	2.1	1.1	4.0	3.3	1.0	1.0	2.0	1.0	3.2	1.0
IS 28792	1.5	2.0	1.0	5.5	4.0	1.0	4.0	2.0	1.5	4.0	2.0
IS 31705	1.4	2.1	1.7	2.3	3.0	1.6	1.3	1.9	1.3	3.3	1.1
IS 41204	1.0	3.0	4.0	1.0	3.0	2.0	4.0	2.0	2.0	3.0	1.0
IS 41207	1.0	0.9	0.9	4.5	2.0	1.5	4.0	1.0	2.0	5.0	3.0
IS 34722	1.0	1.0	2.0	5.0	5.3	1.0	5.0	1.9	1.3	3.3	1.1
IS 34723	1.0	2.0	1.0	5.0	1.0	1.0	4.0	1.0	2.0	5.0	3.0
IS 34724	1.5	3.0	3.0	5.5	3.0	1.0	1.0	1.0	2.0	5.0	1.0
IS 34725	1.0	2.1	1.1	3.0	2.0	1.0	2.0	2.0	1.5	4.0	2.0
IS 34726	1.0	3.0	3.0	4.5	1.0	1.0	2.0	2.0	2.0	5.0	2.0
IS 34727	1.5	3.0	3.0	5.0	2.0	1.0	2.0	1.5	1.5	4.0	2.0
IS 34728	1.0	3.0	3.0	4.5	2.0	1.5	1.0	2.0	1.0	4.0	1.0
RVRT 2	1.0	2.0	1.0	2.0	4.0	1.5	1.0	2.0	1.5	3.0	1.0
IS 34730	1.0	2.5	2.0	3.0	4.0	1.5	3.0	2.0	1.5	3.0	1.5
IS 34731	1.0	3.0	3.0	4.0	1.0	1.0	1.0	2.0	1.5	3.0	1.0
IS 33844-5	2.0	3.0	3.5	1.0	3.0	2.0	1.0	2.0	1.5	3.0	1.0
Giddi Maldandi	2.5	2.0	1.0	2.5	2.0	2.0	1.0	2.0	1.0	5.0	1.0

Table 14b. (Cont..)

Genotype	Inflorescence exsertion [a]	Inflorescence compactness [b]	Inflorescence shape [c]	Glume color [d]	Glume coverage [e]	Awns [f]	Grain color [g]	Grain lustre [h]	Grain subcoat [i]	Endosperm texture [j]	Endosperm color [k]
Barsizoot	2.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	3.0	1.0
M 35-1-19	2.5	2.0	2.0	2.0	3.0	2.0	1.0	2.0	1.5	3.0	1.0
ICSR 93031	1.0	1.9	0.9	2.0	0.7	1.0	1.0	2.0	1.0	0.8	1.0
ICSB 52	1.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	3.0	1.0
RVRT 3	1.0	2.0	1.0	2.0	3.0	2.0	1.0	2.0	1.0	5.0	1.0
ICSB 24002	1.0	1.5	1.5	1.0	1.0	1.0	1.0	2.0	1.0	5.0	1.0
ICSB 38	1.0	1.5	1.0	2.0	2.0	1.0	1.0	2.0	1.0	3.0	1.0
Dagidi Solapur	2.5	2.5	2.0	2.5	5.0	2.0	1.0	2.0	1.0	5.0	1.0
296 B	1.5	2.5	2.5	1.0	1.0	2.0	1.0	2.0	1.5	5.0	1.0
ICSR 92003	1.0	2.5	2.5	2.0	1.0	1.0	1.0	1.5	2.0	3.0	1.0
DJ 6514	2.5	2.5	2.0	1.0	3.0	2.0	1.0	2.0	1.0	4.0	1.0
IS 18551(*R*)	1.0	3.0	4.0	2.5	9.0	2.0	1.0	1.5	2.0	3.0	1.0
Swarna (*S*)	1.0	2.0	1.0	2.5	3.0	1.0	1.0	2.0	1.0	3.0	1.0
Mean	**1.40**	**2.11**	**1.70**	**2.32**	**2.99**	**1.60**	**1.34**	**1.93**	**1.30**	**3.28**	**1.14**
SE ±	**0.26**	**0.26**	**0.51**	**0.63**	**0.66**	**0.16**	**0.20**	**0.11**	**0.27**	**0.68**	**0.14**
Vr	**3.54****	**5.33****	**3.67****	**3.97****	**6.51****	**9.12****	**19.89****	**4.44****	**2.08****	**2.84****	**8.9****
LSD (P 0.05)	**0.72**	**0.72**	**1.44**	**1.78**	**1.86**	**0.44**	**0.55**	**0.30**	**0.75**	**1.92**	**0.40**

** F test significant at P 0.01; **(*R*)**, resistant check; **(*S*)**, susceptible check; SE, standard error; Vr, variance ratio; LSD, least significance difference; [a] Inflorescence exsertion (1 panicle fully exserted, and 3 poor panicle exsertion); [b]Inflorescence compactness(1 loose inflorescence, and 3 compact inflorescence); [c]Inflorescence shape (1 erect inflorescence, and 4 elliptic inflorescence); [d]Glume color (1 white colored glume, and 6 purple colored glume); [e]Glume coverage (1 25% grain covered with glumes, and 9 glumes longer than grain); [f]Awns (1 absence of awns, and 2 presence of awns); [g]Grain color (1 white colored grain, and 5 buff colored grain); [h]Grain lustre (1 non lustrous grain, and 2 lustrous grain); [i]Grain subcoat (1 absence of grain subcoat, and 2 presence of grain subcoat); [j]Endosperm texture (1 completely corneous endosperm, and 5 completely starchy endosperm); [k]Endosperm color (1 white colored endosperm, and 3 red colored endosperm).

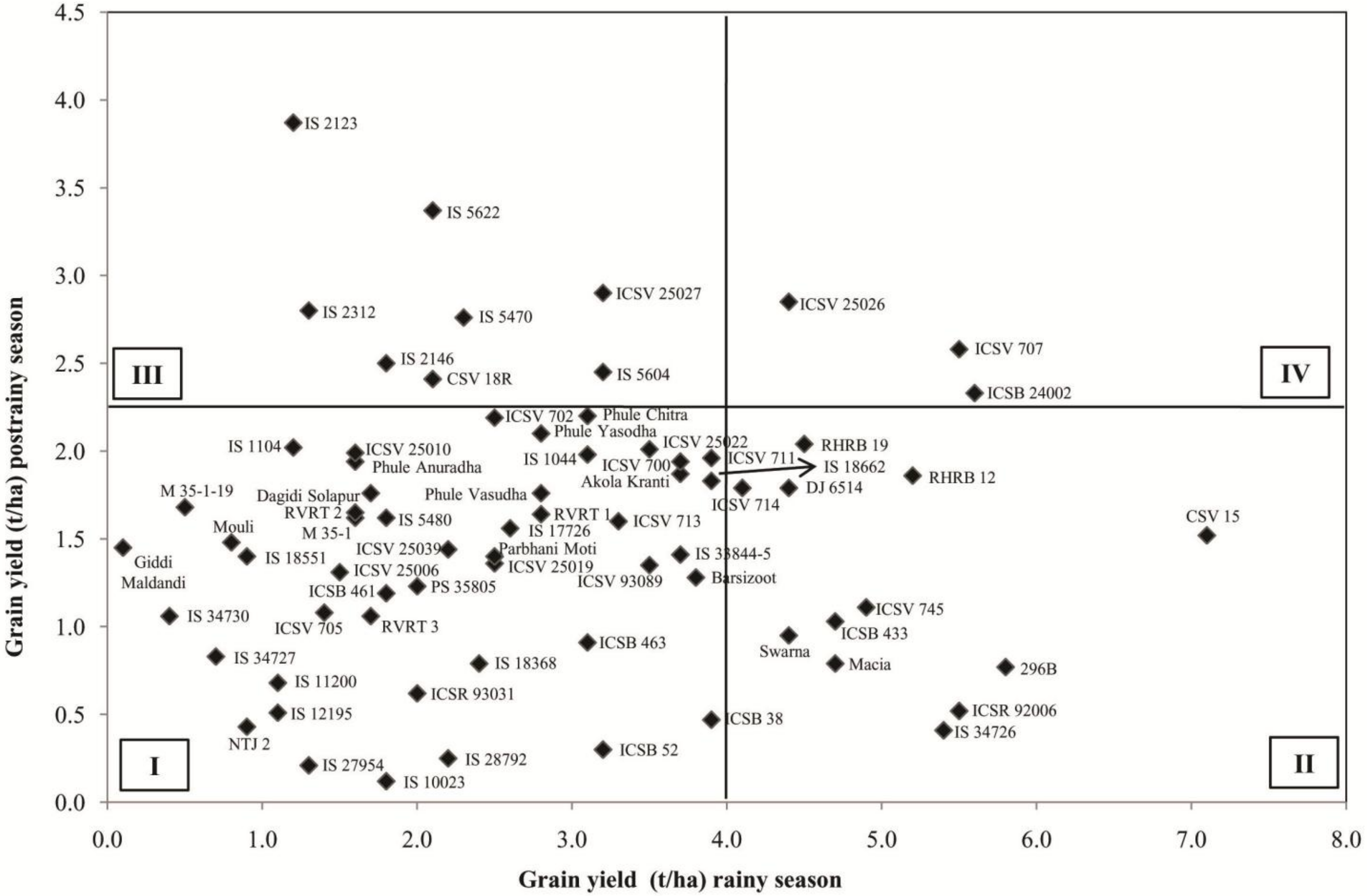


Fig. 7: Relationship between grain yield in the rainy and postrainy seasons and response of the genotypes across the seasons.

CSV 18R and IS 5604 (quadrant III) exhibited high grain yield potential in the postrainy season.

4.1.7 Direct and indirect effects of morphological traits on grain yield

Path coefficient analysis for grain yield as a dependent factor during the postrainy season revealed that trichomes on adaxial surface of the leaf exhibited positive and significant correlation with grain yield (r = 0.55**), and had the maximum direct effects (0.46), with positive indirect effects through leaf glossiness score (0.37), and negative indirect effect through trichomes on abaxial surface of the leaf (-0.52) (Table 15). Similarly, trichomes on abaxial surface of leaves showed negative direct effects (-0.54), but the indirect effects were positive through leaf glossiness score (0.35), and trichomes on adaxial leaf surface (0.45), but had a significant and positive correlation with grain yield (r = 0.48**). Leaf glossiness score showed negative direct effects (-0.47) on grain yield, and its indirect effects through other traits were also negative, except the trichomes on abaxial leaf surface (0.40). Leaf glossiness showed a negative and significant correlation with grain yield (-0.72**).

Maximum direct effects (0.53) were shown by the trichomes on adaxial leaf surface, with a significant and positive correlation with grain yield in the rainy season (r = 0.21*). The 100 seed weight showed positive direct effect (0.41), and was significantly and correlated with grain yield (r = 0.56**) (Table 16). The parameters with correlation and path coefficients in the same direction could be used to select for shoot fly resistance in the postrainy season.

Stepwise regression analysis indicated that factors contributing to grain yield and shoot fly resistance differ in both the seasons. Leaf glossiness score, 100 seed weight (test weight) and plant height explained 56.31% of the variation for grain yield [Grain yield (Y) = 2.66 + 0.01 plant height (X_1) – 0.31 test weight (X_2) – 0.35 leaf glossiness score (X_3)]; whereas plants with shoot fly eggs and trichomes on adaxial leaf surface explained 75.55% of the total variation in deadhearts during the postrainy season [Shoot fly deadhearts (Y) = 20.51 + 0.69 percentage plants with shoot fly eggs (X_1) – 0.11trichomes on adaxial surface (X_2)]. During the rainy season, none of factors accounted for a significant variation in grain yield, but the number of shoot fly eggs per 100 plants, plants with shoot fly eggs, and leaf glossiness score explained 92.03% of the variation for percentage of plants with shoot fly deadhearts [Shoot fly deadhearts (Y) = 0.44 + 10.09

Table 15. Direct and indirect effects of shoot fly resistance, morphological and seed/panicle characteristics on grain yield during the postrainy season.

Plant traits	Number of shoot fly eggs/100 plants	Plants with shoot fly eggs (%)	Plants with shoot fly deadhearts (%)	Leaf glossy score	Trichome density on abaxial leaf surface	Trichome density on adaxial leaf surface	100 seed weight	Inflorescence exsertion	Glume color	Glume coverage	Awns	Grain yield
Number of shoot fly eggs/100 plants	**0.11**	-0.10	-0.02	-0.27	0.28	-0.27	-0.05	-0.01	-0.04	0.00	-0.05	**-0.40****
Plants with shoot fly eggs (%)	0.05	**-0.19**	-0.03	-0.35	0.35	-0.30	-0.11	-0.00	-0.03	0.00	-0.03	**-0.64****
Shoot fly deadhearts (%)	0.06	-0.16	**-0.04**	-0.36	0.37	-0.33	-0.09	-0.01	-0.04	0.00	-0.02	**-0.61****
Leaf glossy score	0.06	-0.14	-0.03	**-0.47**	0.40	-0.36	-0.09	-0.01	-0.04	0.00	-0.05	**-0.72****
Trichome density on abaxial leaf surface	-0.05	0.12	0.02	0.35	**-0.54**	0.45	0.07	0.01	0.04	-0.00	0.03	**0.48****
Trichome density on adaxial leaf surface	-0.06	0.12	0.03	0.37	-0.52	**0.46**	0.07	0.01	0.04	-0.00	0.04	**0.55****
100 seed weight	0.02	-0.10	-0.02	-0.21	0.19	-0.16	**-0.20**	-0.00	-0.04	0.00	0.01	**-0.51****
Inflorescence exsertion	-0.03	0.05	0.01	0.17	-0.16	0.17	0.02	**0.01**	0.03	0.00	0.05	**0.30****
Glume color	0.04	-0.05	-0.01	-0.14	0.17	-0.16	-0.07	-0.01	**-0.12**	0.00	-0.02	**-0.36****
Glume coverage	-0.03	0.04	0.01	0.15	-0.19	0.15	0.03	0.00	-0.00	**-0.01**	0.04	**0.20**
Awns	-0.04	0.05	0.01	0.19	-0.15	0.16	-0.01	0.01	0.02	-0.00	**0.12**	**0.34****

** Correlation coefficient significant at P 0.01. The values along the diagonal are direct effects, whereas off the diagonal are for indirect effects. Residual effect = 0.62

Table 16. Direct and indirect effects of shoot fly resistance, morphological and seed/panicle characteristics on grain yield during the rainy season.

Plant traits	Plant vigor score	Leaf glossy score	Waxy bloom	Plant color	Trichome density on abaxial leaf surface	Trichome density on adaxial leaf surface	Days to 50% flowering	Plant height	100 seed weight	Grain yield
Plant vigor score	**0.16**	0.00	-0.03	0.06	0.02	-0.03	0.03	-0.02	0.02	**0.30****
Leaf glossy score	0.03	**0.00**	-0.03	0.01	0.31	-0.42	-0.15	0.00	-0.11	**-0.18**
Waxy bloom	0.08	0.00	**-0.05**	0.06	0.13	-0.15	-0.02	-0.02	-0.03	**0.17**
Plant color	0.10	0.00	-0.03	**0.10**	-0.05	0.09	0.10	-0.03	0.04	**0.39****
Trichome density on abaxial leaf surface	-0.01	-0.00	0.02	0.01	**-0.40**	0.52	0.11	-0.01	0.08	**0.19**
Trichome density on adaxial leaf surface	-0.01	-0.00	0.02	0.02	-0.39	**0.53**	0.12	-0.01	0.09	**0.21***
Days to 50% flowering	-0.01	0.00	-0.01	-0.03	0.14	-0.19	**-0.32**	0.02	-0.23	**-0.55****
Plant height	-0.08	0.00	0.03	-0.07	0.03	-0.05	-0.14	**0.04**	-0.07	**-0.40****
100 seed weight	0.01	0.00	0.01	0.01	-0.08	0.11	0.18	-0.01	**0.41**	**0.56****

*, ** Correlation coefficient significant at P 0.05 and 0.01, respectively; highlighted diagonal values are direct effects and off the diagonal are for indirect effects; Residual effect = 0.70

total number of shoot fly eggs per 100 plants (X_1) + 0.56 percentage of plants with shoot fly eggs (X_2) + 5.34 leaf glossiness score (X_3)].

4.2 Experiment 2: Screening of the selected 30 sorghum genotypes exhibiting resistance to shoot fly, *A. soccata* in the postrainy season sorghums

4.2.1 Expression of resistance to sorghum shoot fly, *A. soccata*

There were significant differences between the genotypes for deadheart formation and egg laying, with significant variance ratio at $p \leq 0.01$. Based on the shoot fly resistant traits, ICSB 433, ICSV 700, Phule Yasodha, Phule Chitra, ICSV 705, ICSV 25019, ICSV 25022, ICSV 25026, ICSV 25039, PS 35805, IS 2123, IS 2146, Akola Kranti, Phule Vasudha, ICSV 93046, IS 18551, and RVRT 2 exhibited resistance to shoot fly across seasons, with 10 - 30% plants with eggs and 0.9 – 16.0% of shoot fly deadhearts in the postrainy season and upto 90% of plants with eggs and 50.0 – 75.0% of deadhearts in the rainy season, when compared with the susceptible check Swarna (Table 17). These genotypes also exhibited tolerance to shoot fly by showing low to moderate levels of overall resistance score. Moulee, Phule Anuradha, M 35-1, CSV 18R, IS 2312, Giddi Maldandi, and RVRT 3 exhibited resistance to shoot fly only in the postrainy season, and ICSV 713 in the rainy season, which were better/onpar with the resistant check IS 18551.

The intensity of oviposition was high during the rainy season with oviposition ranging 182.6 - 265.6 eggs per 100 plants and 10.3 - 102.7 eggs per 100 plants in the postrainy season. The genotypes ICSB 433, ICSV 700, ICSV 25019, ICSV 25022, ICSV 25026, ICSV 25039, PS 35805, Akola Kranti, and IS 18551 showed antibiosis component resistance as these genotypes had lower percentage of plants with deadhearts (0.9 - 10.3% and 45.5 - 76.0% respectively, in the postrainy and rainy seasons) than the plants with shoot fly eggs (11.0 - 24.0% and 93.8 - 99.2% respectively, in the postrainy and rainy seasons). The genotypes Moulee, M 35-1, CSV 18R, Phule Vasudha, and RVRT 2 showed antibiosis mechanism of resistance only in the postrainy season, with lower shoot fly deadhearts (11.0 - 20.7%) than the plants with shoot fly eggs (10.7 - 37.0%), whereas Phule Chitra, ICSV 705, ICSV 713, IS 2123, and IS 2146 exhibited antibiosis mechanism of resistance with 60.5 - 80.8% shoot fly deadhearts, lower to that of the plants with eggs (91.8 - 99.2%) in the rainy season. These genotypes also had lower number of shoot fly eggs per 100 plants as compared to the susceptible check, Swarna, (215.5 eggs/100 plants).

Table 17. Expression of resistance to sorghum shoot fly, *A. soccata* in sorghum (ICRISAT, Patancheru, 2011-12).

Genotype	**Number of shoot fly eggs/ 100 plants**		**Plants with shoot fly eggs (%)**		**Shoot fly deadhearts (%)**		**Overall resistance score[a]**	
	2011 PR	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**
ICSB 433	31.7	216.9	23.1	94.2	10.3	74.3	6.7	3.5
ICSV 700	22.3	206.9	21.4	99.2	12.9	74.6	5.0	3.0
Phule Yasodha	39.3	222.1	29.8	99.1	15.1	84.0	4.3	6.0
Moulee	27.0	242.7	24.3	99.2	14.4	86.7	4.7	6.0
Phule Chitra	18.4	224.2	16.2	97.7	11.8	78.3	4.3	6.0
Phule Anuradha	22.6	207.5	20.7	99.2	11.8	91.1	3.7	6.7
M 35-1	29.4	249.4	26.8	99.2	13.5	86.0	4.0	5.3
Parbhani Moti	40.6	228.4	36.3	100.0	28.5	86.6	4.0	7.3
CSV 18R	32.9	213.8	31.0	99.1	18.2	89.6	4.3	5.3
CSV 15	70.8	257.8	57.6	100.0	41.9	96.5	6.3	6.7
ICSV 705	12.4	204.1	10.7	92.6	6.3	60.5	6.0	5.5
ICSV 713	47.3	206.1	37.0	97.5	27.6	73.5	6.3	3.0
ICSV 25019	17.5	218.5	14.2	93.8	6.7	54.6	5.3	5.2
ICSV 25022	15.5	198.1	13.7	99.1	7.7	77.8	4.0	3.3
ICSV 25026	18.6	182.6	14.3	98.5	5.1	68.6	3.0	2.7
ICSV 25039	12.0	202.1	11.2	95.0	0.9	57.7	2.0	3.0
PS 35805	12.6	191.6	11.0	95.2	4.4	45.5	3.0	4.8
IS 2123	20.6	245.0	17.7	98.3	12.0	80.8	3.7	3.7
IS 2146	19.8	240.0	18.8	96.9	11.6	76.8	4.0	4.3
IS 2312	10.3	196.3	8.6	98.4	5.2	84.4	3.3	3.7
Akola Kranti	26.6	224.0	24.0	97.4	9.1	72.6	4.7	6.5
Phule Vasudha	33.4	208.3	29.8	91.8	11.0	81.2	4.3	7.0
ICSV 93046	18.6	236.4	17.6	99.3	14.1	83.6	3.3	4.3
IS 18551 ***(R)***	20.1	265.6	17.4	97.5	7.1	76.0	3.3	4.2
Swarna ***(S)***	102.7	215.5	55.8	100.0	58.3	98.3	8.0	9.0
RVRT 2	36.5	204.0	26.2	99.1	15.0	83.2	4.3	8.0
Giddi Maldandi	39.9	249.6	30.7	100.0	12.5	76.5	2.7	4.8
RVRT 3	38.8	198.4	32.8	98.4	20.7	79.9	4.0	6.7
Dagidi Solapur	44.0	199.7	35.8	100.0	25.7	95.5	4.0	7.7
296 B	92.3	208.6	77.4	100.0	68.6	94.3	7.0	7.7
Mean	**32.5**	**218.81**	**26.40**	**97.86**	**16.92**	**78.96**	**4.46**	**5.36**
SE ±	**7.10**	**19.90**	**4.54**	**1.57**	**4.68**	**5.34**	**0.51**	**0.57**
Vr (58, 29)	**9.62****	**1.13**	**11.37****	**2.17****	**10.61****	**5.41****	**7.30****	**9.16****
LSD (P 0.05)	**20.11**	**NS**	**12.86**	**4.44**	**13.25**	**15.11**	**1.43**	**1.62**

** F test significant at P 0.01; ***(R)***, resistant check; ***(S)***, susceptible check; R, rainy season; PR, postrainy season; NS, non significant F value; [a]Overall resistance score (1 plants with uniform tillers and harvestable panicles, and 9 plants with a few or no productive tillers).

4.2.2 Association of morphological and agronomic traits with expression of resistance to shoot fly, *A. soccata*

Leaf glossiness score and leafsheath pigmentation were significantly and positively correlated with shoot fly damage (*r* = 0.83** and *r* = 0.42*, respectively) in the postrainy season, but negatively correlated with agronomic score across seasons (Table 18). Seedling vigor and plant color were negatively and significantly correlated (*r* = -0.43** and *r* = -0.48**, respectively) with shoot fly damage in the rainy season with non-significant contribution in the postrainy season. Trichome density in the abaxial and adaxial leaf surfaces was significantly and negatively correlated with shoot fly damage parameters across seasons. There was a significant and positive correlation between trichome density and agronomic score in the postrainy season. Endosperm texture was positively correlated with shoot fly damage parameters across seasons, with a few exceptions. Seed weight was positively correlated with shoot fly deadhearts (*r* = 0.38*) and the overall resistance score (*r* = 0.69**) in the rainy season.

Leaf glossiness score (Slope = 8.76) and leafsheath pigmentation (slope = 8.56) were positively correlated with shoot fly damage, with a positive slope (Fig. 8a and 8b). Trichome density on the abaxial (Slope = -0.29) and adaxial (slope = -0.22) leaf surfaces was negatively associated with shoot fly damage, with a negative slope (Fig. 8c and 8d).

4.2.3 Agronomic characteristics of the test sorghum genotypes

The agronomic characteristics were recorded from the test genotypes grown under protected conditions. The grain yield of Phule Yasodha, ICSV 25026, Akola Kranti and ICSV 93046 (3.4 - 5.3 t/ha and 2.5 - 3.2 t/ha in the postrainy and rainy seasons respectively) was high across seasons, and these lines also had good agronomic score (2.0 - 4.3) (Table 19). Moulee, Phule Chitra, Phule Anuradha, Parbhani Moti, CSV 18R, IS 2312, Phule Vasudha, RVRT 3, and Dagidi Solapur yielded quite high in the postrainy season with the highest grain yield of 5.3 t/ha in Phule Yasodha. The grain yield of ICSB 433, ICSV 700, M 35-1, CSV 15, ICSV 25022, and Swarna was high in the rainy season (2.3 - 4.8 t/ha). The genotypes Moulee, Phule Anuradha, M 35-1, CSV 15, ICSV 705, ICSV 25019, IS 2123, IS 2146, IS 2312, RVRT 2 and Swarna were early flowering (58.0 - 66.0 days for 50% flowering) and had a medium plant height ranging from 102.5 cm to 300 cm across seasons. The mean 100 seed weight was 2.8 g in the postrainy season and

Table 18. Association of agronomic and morphological traits with expression of resistance to sorghum shoot fly, *A. soccata* in the postrainy season sorghums.

Traits	Number of shoot fly eggs/ plant	Plants with shoot fly eggs (%)	Shoot fly deadhearts (%)	Overall resistance score	Agronomic score
Leaf glossy score	-0.22 (0.84**)	0.18 (0.83**)	0.34 (0.83**)	0.35 (0.68**)	-0.60** (-0.51**)
Leafsheath pigmentation	-0.1 (0.41*)	-0.09 (0.41*)	-0.05 (0.42*)	0.12 (-0.36)	-0.69** (-0.41*)
Seedling vigor score	-0.49** (-0.12)	-0.48** (-0.20)	-0.43** (-0.13)	-0.1 (-0.20)	-0.84** (-0.35)
Trichome density on abaxial leaf surface	-0.15 (-0.72**)	-0.45** (-0.70**)	-0.53** (-0.72**)	-0.45** (-0.76**)	0.29 (0.47**)
Trichome density on adaxial leaf surface	-0.14 (-0.77**)	-0.36 (-0.75**)	-0.47** (-0.76**)	-0.53** (-0.73**)	0.28 (0.49**)
Plant color	-0.31 (-0.06)	-0.29 (-0.03)	-0.48** (-0.01)	-0.47** (-0.23)	-0.77** (-0.27)
Panicle shape	0.37* (-0.14)	-0.13 (-0.15)	0.01 (-0.16)	-0.27 (-0.37*)	0.42* (0.66**)
Awns	0.08 (-0.25)	0.40* (-0.13)	0.32 (-0.19)	-0.01 (-0.59**)	0.70** (0.45**)
Endosperm texture	0.34 (0.42*)	0.22 (0.55**)	0.36 (0.40*)	0.54** (-0.11)	0.41* (-0.14)
100 seed weight	0.02 (-0.25)	0.19 (-0.29)	0.38* (-0.22)	0.69** (-0.05)	0.1 (-0.10)

*, ** Correlation coefficients significant at P 0.05 and 0.01 probability levels, respectively.

Values in the parenthesis are the correlation coefficients of postrainy season where as the values outside the parenthesis are correlation coefficients of the rainy season.

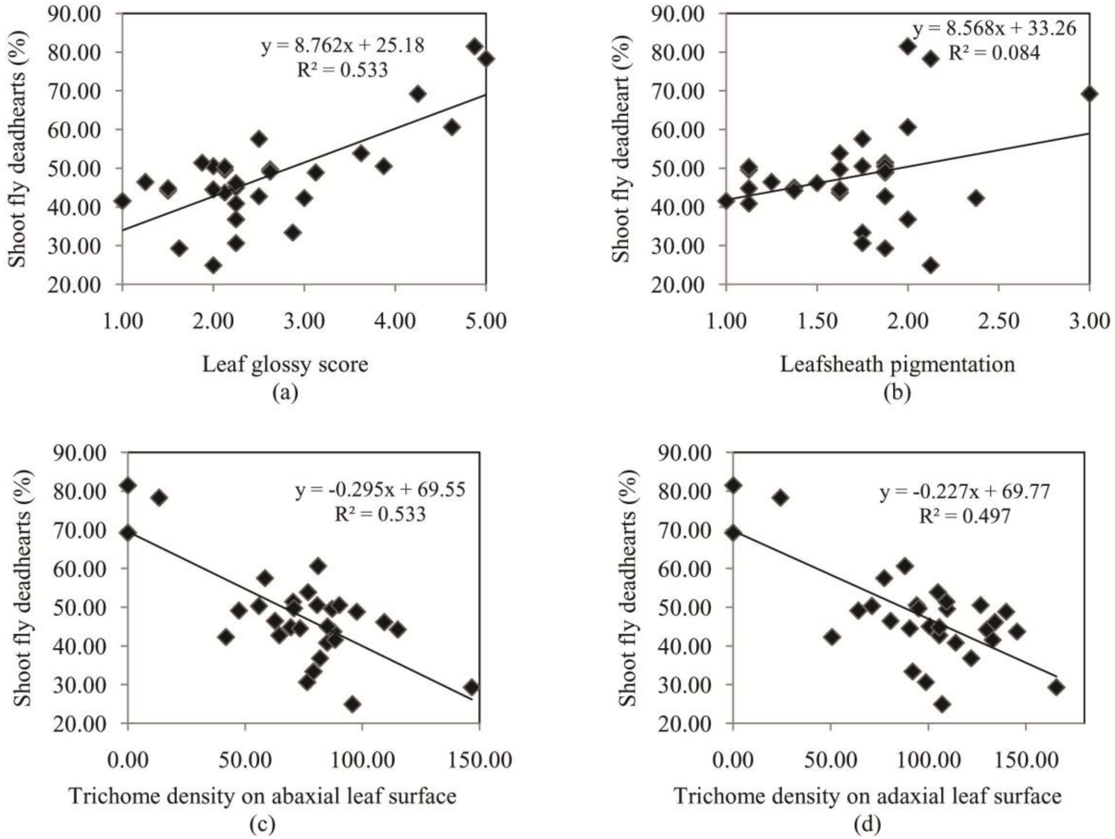


Fig. 8: Association of **(a)** Leaf glossy score, **(b)** Leafsheath pigmentation, **(c)** Trichome density on abaxial leaf surface, **(d)** Trichome density on adaxial leaf surface with resistance to shoot fly, *A. soccata*.

Table 19. Agronomic characteristics of sorghum genotypes evaluated for resistance to sorghum shoot fly, *A. soccata* (ICRISAT, Patancheru, 2011-12).

Genotype	**Days to 50% flowering**		**Plant height (cm)**		**100 seed weight (g)**		**Grain yield (t/ha)**		**Agronomic score[a]**	
	2011 PR	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**
ICSB 433	70.5	66.0	150.0	173.3	1.9	2.3	2.0	4.0	2.3	1.7
ICSV 700	69.8	75.0	237.5	333.3	2.6	2.7	2.8	2.3	3.3	4.0
Phule Yasodha	70.0	70.0	250.8	340.0	3.6	3.1	5.3	3.1	2.3	4.3
Moulee	61.0	60.0	223.3	286.7	3.4	3.0	3.7	1.8	2.7	5.0
Phule Chitra	69.8	65.0	251.7	326.7	3.2	2.8	3.6	0.5	2.7	4.3
Phule Anuradha	58.5	58.0	215.0	290.0	3.6	3.0	3.6	1.8	2.3	4.3
M 35-1	65.0	65.0	238.3	340.0	3.5	2.7	3.3	2.3	2.7	4.3
Parbhani Moti	69.8	68.0	242.5	330.0	3.9	3.1	3.8	1.1	3.0	4.0
CSV 18R	72.3	76.0	253.3	323.3	3.8	2.5	4.1	0.7	2.3	4.0
CSV 15	63.5	64.0	185.0	246.7	2.4	2.9	3.1	3.8	2.3	2.3
ICSV 705	63.5	65.0	102.5	120.0	1.8	2.4	1.7	1.5	2.3	2.0
ICSV 713	69.8	62.0	164.2	173.3	2.0	2.0	1.7	2.2	2.0	2.0
ICSV 25019	62.8	62.0	109.2	123.3	1.4	2.7	1.5	2.3	2.3	1.7
ICSV 25022	69.3	74.0	160.0	213.3	2.4	2.3	2.9	4.7	2.0	1.7
ICSV 25026	69.8	74.0	165.0	206.7	2.4	2.4	3.6	3.2	2.0	2.0
ICSV 25039	73.0	73.0	163.3	210.0	1.5	1.7	2.4	1.9	3.0	2.7
PS 35805	64.8	70.0	95.8	106.7	1.8	2.3	1.6	1.4	2.0	2.0
IS 2123	66.3	66.0	219.2	276.7	2.7	2.2	3.4	2.0	4.0	5.0
IS 2146	64.3	65.0	210.8	286.7	2.1	1.9	3.0	1.4	3.7	5.0
IS 2312	64.8	65.0	227.5	300.0	2.4	2.0	3.6	1.6	4.3	5.0
Akola Kranti	72.0	74.0	274.2	346.7	3.5	3.1	4.7	2.5	2.3	4.0
Phule Vasudha	71.3	65.0	260.0	356.7	3.5	3.1	4.3	2.0	2.3	4.3
ICSV 93046	70.0	74.0	238.3	293.3	2.7	2.7	3.4	2.8	3.0	4.0
IS 18551***(R)***	66.0	70.0	238.3	336.7	2.2	1.9	2.6	1.5	4.3	4.0
Swarna ***(S)***	63.8	58.0	137.5	166.7	3.2	3.8	2.7	4.8	1.0	1.7
RVRT 2	66.0	60.0	224.2	280.0	3.8	3.0	3.5	1.9	2.3	4.3
Giddi Maldandi	76.5	82.0	164.2	226.7	2.7	2.2	3.3	2.1	2.3	4.3
RVRT 3	68.5	70.0	261.7	326.7	3.7	2.9	3.7	0.9	2.3	4.0
Dagidi Solapur	70.8	72.0	222.5	320.0	3.4	2.5	4.1	1.3	3.3	3.4
296 B	68.5	64.0	104.2	123.3	2.5	2.0	1.7	2.1	2.0	1.7
Mean (58, 29)	**67.7**	**67.7**	**199.7**	**259.5**	**2.8**	**2.6**	**3.2**	**2.2**	**2.6**	**3.4**
SE ±	**0.7**	**1.1**	**7.3**	**14.4**	**0.1**	**0.1**	**0.4**	**0.2**	**0.4**	**0.3**

(R), resistant check; ***(S)***, susceptible check; R, rainy season; PR, postrainy season; [a]Agronomic score (1 good productive potential and ability to withstand insect damage and 5 poor productive potential and prone to insect damage).

2.6 g in the rainy season, with the highest 100 seed weight of 3.9 g in Parbhani Moti in the postrainy season, and 3.8 g in Swarna, in the rainy season.

4.2.4 Morphological characteristics of the sorghum genotypes

The genotypes Phule Yasodha, IS 2146, Akola Kranti, and Phule Vasudha exhibited leaf glossiness (1.3 - 2.5 and 1.8 - 2.3 score in the postrainy and rainy season respectively), leafsheath pigmentation (1.0 - 1.5 and 1.3 - 1.5 score in the postrainy and rainy season), high seedling vigor (1.5 - 1.8 and 1.0 - 2.3 score in the postrainy and rainy season respectively) and high trichome density on the abaxial (46.4 - 78.9 and 156.0 - 110.7 trichomes per microscopic area in the postrainy and rainy seasons, respectively) and adaxial (98.7 – 113.0 and 120.4 - 165.0 trichomes per microscopic area in the postrainy and rainy seasons, respectively) leaf surfaces and were on par with the resistant check IS 18551 (Table 20). Moulee, Phule Chitra, Phule Anuradha, M 35-1, IS 2123, IS 2312, Giddi Maldandi and RVRT 3 possessed leaf glossiness, leafsheath pigmentation, and high seedling vigor with moderate trichome density.

4.2.5 Panicle and seed characteristics of the sorghum genotypes

The data on the panicle traits and seed characteristics is given in Table 21. These traits were useful in selecting sorghum genotypes with desirable panicle and seed characteristics for developing farmer preferred cultivars with shoot fly resistance, good agronomic and seed traits, and high grain yield.

4.2.6 Path-coefficients of morphological and agronomic traits on expression of resistance to sorghum shoot fly, *A. soccata*

The direct effects and the correlation coefficients of leaf glossy score, plant vigor, trichome density on the abaxial leaf surface, plant height, and plant color were in the same direction (+ve or –ve), and hence these traits can be used as a criteria to select for resistance to shoot fly during rainy season (Table 22); whereas the direct effects and the correlation coefficients of trichome density on the adaxial leaf surface and 100 seed weight were in opposite direction, and hence these traits will not be useful for selecting the shoot fly resistant sorghums. The residual effect (0.08) of path coefficient analysis in the rainy season was very low.

Table 20. Morphological characteristics of sorghum genotypes evaluated for resistance to sorghum shoot fly, *A. soccata* (ICRISAT, Patancheru, 2011-12).

Genotype	Leaf glossy score		Leafsheath pigmentation		Seedling vigor score		Trichome density on abaxial surface		Trichome density on adaxial surface		Leaf midrib color		Waxy bloom		Plant color	
	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R
ICSB 433	2.5	3.5	2.0	2.8	2.8	2.8	28.0	55.6	50.7	50.8	2.0	2.0	3.0	3.0	2.0	2.0
ICSV 700	2.0	2.3	1.8	1.5	2.3	1.3	58.8	116.4	152.6	138.4	2.0	2.0	1.3	1.0	2.0	2.0
Phule Yasodha	2.0	2.3	1.0	1.3	1.5	1.0	63.6	110.7	98.7	120.4	1.0	1.0	1.3	1.0	1.0	1.0
Moulee	2.0	2.0	1.8	1.8	1.8	1.3	51.9	109.4	70.6	117.4	2.0	2.0	1.8	1.0	1.0	1.0
Phule Chitra	2.0	2.5	1.5	1.3	1.3	1.3	46.1	124.2	86.3	114.8	2.0	2.0	1.3	1.0	1.0	1.0
Phule Anuradha	2.3	1.5	2.0	1.8	1.0	1.0	42.9	97.9	100.3	118.2	1.0	1.0	1.8	1.0	1.0	1.0
M 35-1	2.3	3.0	1.5	1.8	1.5	1.5	40.4	101.3	79.2	110.9	2.0	2.0	2.0	1.0	1.0	1.0
Parbhani Moti	2.8	2.3	1.8	1.8	1.0	1.3	48.7	68.1	75.7	79.2	2.0	1.0	1.5	1.0	1.0	1.0
CSV 18R	3.8	3.5	2.0	1.3	1.3	1.3	43.8	109.9	96.1	113.8	1.8	2.0	1.3	1.0	1.0	1.0
CSV 15	4.8	3.8	3.0	3.0	1.0	1.3	0.0	0.0	0.0	0.0	2.0	1.0	3.0	1.0	2.0	2.0
ICSV 705	2.0	3.8	1.8	1.8	2.8	2.8	53.1	105.2	78.8	105.2	2.0	2.0	3.0	3.0	2.0	2.0
ICSV 713	3.8	4.0	2.0	1.8	3.0	3.0	22.6	157.7	53.3	200.1	2.0	2.0	3.0	3.0	2.0	2.0
ICSV 25019	2.0	2.5	1.5	2.0	2.0	2.5	40.1	112.8	76.2	121.2	2.0	2.0	3.0	2.0	2.0	2.0
ICSV 25022	2.0	3.0	2.0	1.8	2.5	2.3	46.1	82.9	103.6	107.6	2.0	2.0	3.0	2.0	2.0	2.0
ICSV 25026	2.0	2.5	2.0	2.0	2.3	2.3	55.3	108.4	116.8	127.2	2.0	2.0	3.0	2.0	2.0	2.0
ICSV 25039	1.0	2.3	1.8	2.0	2.5	3.0	122.1	171.3	171.6	159.4	2.0	2.0	3.0	2.0	2.0	2.0
PS 35805	1.8	2.3	1.8	2.5	2.8	2.8	62.3	129.2	94.0	120.3	2.0	2.0	3.0	2.0	2.0	2.0
IS 2123	1.0	1.5	1.5	1.0	1.3	1.3	49.8	75.8	74.2	87.1	1.0	1.0	1.5	1.0	1.0	1.0
IS 2146	1.3	1.8	1.3	1.5	1.5	1.0	78.9	151.2	113.0	146.9	1.0	1.0	1.8	1.0	1.0	1.0
IS 2312	1.3	1.8	1.3	1.0	1.3	1.0	48.7	90.2	100.7	110.7	1.0	1.0	1.0	1.0	1.0	1.0
Akola Kranti	2.3	2.3	1.0	1.3	1.8	1.3	46.4	123.7	99.0	128.9	1.0	1.0	1.5	1.0	1.0	1.0

Table 20. (Cont..)

Genotype	Leaf glossy score		Leafsheath pigmentation		Seedling vigor score		Trichome density on abaxial surface		Trichome density on adaxial surface		Leaf midrib color		Waxy bloom		Plant color	
	2011 PR	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**
Phule Vasudha	2.5	2.0	1.5	1.5	1.0	2.3	62.1	156.7	103.2	165.0	1.0	1.0	1.3	1.0	1.0	1.0
ICSV 93046	2.3	4.0	1.8	2.0	2.3	1.5	59.7	135.7	126.0	153.7	2.0	2.0	2.0	2.0	2.0	2.0
IS 18551 ***(R)***	1.0	1.0	1.0	1.0	1.5	1.0	68.3	108.2	139.9	125.9	1.0	1.0	1.0	1.0	1.0	1.0
Swarna ***(S)***	5.0	5.0	2.0	2.3	2.0	2.8	4.4	22.0	16.4	32.1	2.0	2.0	3.0	3.0	1.0	1.0
RVRT 2	2.3	3.0	2.0	1.8	1.8	1.5	28.2	66.3	55.4	73.1	2.0	2.0	1.5	1.0	1.0	1.0
Giddi Maldandi	2.0	2.0	1.8	1.5	1.8	1.5	55.4	91.2	83.2	97.9	2.0	2.0	3.0	2.0	1.0	1.0
RVRT 3	1.8	2.5	1.0	1.3	1.5	1.8	27.9	83.8	57.0	85.3	1.0	1.0	1.0	1.0	1.0	1.0
Dagidi Solapur	4.8	4.5	2.0	2.0	1.3	1.5	47.9	114.2	80.2	95.9	2.0	2.0	2.0	1.0	1.0	1.0
296 B	4.8	5.0	2.0	2.0	2.0	3.0	0.0	0.0	0.4	0.0	1.0	1.0	3.0	3.0	2.0	2.0
Mean	**2.4**	**2.8**	**1.7**	**1.7**	**1.8**	**1.8**	**46.8**	**99.3**	**85.1**	**106.9**	**1.7**	**1.6**	**2.1**	**1.6**	**1.4**	**1.4**
SE ±	**0.2**	**0.4**	**0.2**	**0.2**	**0.2**	**0.2**	**6.2**	**15.3**	**9.0**	**14.6**	**0.0**	**0.1**	**0.2**	**0.1**	**0.0**	**0.1**
Vr (58, 29)	**37.3****	**7.9****	**5.1****	**5.3****	**5.8****	**8.6****	**14.7****	**7.4****	**18.9****	**9.1****	**108.6****	-	**22.9****	-	**0.0**	-
LSD (P 0.05)	**0.5**	**1.0**	**0.5**	**0.6**	**0.7**	**0.7**	**17.5**	**43.2**	**25.3**	**41.4**	**0.1**	-	**0.5**	-	**0.0**	-

** F test significant at P 0.01; (***R)***, resistant check; (***S)***, susceptible check; R, rainy season; PR, postrainy season; Leafsheath pigmentation (1 highly pigmented and 3 non pigmented); Seedling vigor score (1 highly vigorus and 3 poor plant vigor); Trichome density, number of trichomes/microscopic area; Leaf glossy score (1 highly glossy and 5 non glossy); Leaf midrib color (1 white leaf midrib and 4 brown leaf midrib); Waxy bloom (1 slightly waxy and 3 completely waxy); Plant color (1 pigmented-non tan and 2 non pigmented-tan).

Table 21. Panicle and grain characteristics of sorghum genotypes evaluated for resistance to sorghum shoot fly, *A. soccata* (ICRISAT, Patancheru, 2011-12).

Genotype	Inflorescence exertion		Panicle compactness		Panicle shape		Glume color		Glume coverage		Awns		Grain color		Grain lustre		Grain subcoat		Endosperm texture		Endosperm color	
	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R	2011 PR	2012 R
ICSB 433	1.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.7	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	3.0	3.0	1.0	1.0
ICSV 700	2.0	3.0	2.0	2.0	1.0	1.0	2.0	2.0	3.7	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	2.3	1.0	1.0	1.0
Phule Yasodha	2.7	2.0	2.0	2.0	1.0	1.0	1.0	1.0	3.0	5.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	3.0	3.0	1.0	1.0
Moulee	3.0	2.0	2.0	2.0	1.0	1.0	1.3	1.0	1.7	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	3.0	5.0	1.0	1.0
Phule Chitra	2.7	3.0	2.0	2.0	1.0	1.0	1.0	3.0	1.7	5.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	1.7	3.0	1.0	1.0
Phule Anuradha	3.0	3.0	2.0	2.0	1.0	1.0	2.7	1.0	3.0	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	3.0	5.0	1.0	1.0
M 35-1	3.0	2.0	2.0	2.0	1.0	1.0	1.3	1.0	1.0	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	4.3	3.0	1.0	1.0
Parbhani Moti	3.0	1.0	2.0	2.0	1.0	1.0	1.0	1.0	1.7	1.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	3.0	3.0	1.0	1.0
CSV 18R	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	2.3	5.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	3.7	3.0	1.0	1.0
CSV 15	1.7	2.0	2.0	2.0	1.0	1.0	1.3	2.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	3.0	3.0	1.0	1.0
ICSV 705	2.3	3.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0
ICSV 713	1.0	2.0	2.0	2.0	1.0	1.0	1.3	1.0	2.3	1.0	1.3	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.3	1.0	1.0	1.0
ICSV 25019	2.0	3.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	1.7	3.0	1.0	1.0
ICSV 25022	1.0	2.0	2.0	2.0	1.0	1.0	2.0	1.0	2.3	1.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	1.7	1.0	1.0	1.0
ICSV 25026	1.0	2.0	2.0	2.0	1.0	1.0	2.0	2.0	1.7	1.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0
ICSV 25039	1.3	1.0	2.0	2.0	1.0	1.0	1.0	2.0	2.3	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	3.0	3.0	1.0	1.0
PS 35805	2.0	3.0	2.0	2.0	1.0	1.0	1.0	1.0	1.7	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	3.0	1.0	1.0	1.0
IS 2123	3.0	3.0	3.0	3.0	3.0	3.0	1.0	3.0	2.3	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	1.7	3.0	1.0	1.0

Table 21. (Cont..)

Genotype	**Inflorescence exertion**		**Panicle compactness**		**Panicle shape**		**Glume color**		**Glume coverage**		**Awns**		**Grain color**		**Grain lustre**		**Grain subcoat**		**Endosperm texture**		**Endosperm color**	
	2011 PR	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**	**2011 PR**	**2012 R**
IS 2146	3.0	3.0	3.0	3.0	3.0	3.0	2.3	2.0	3.7	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	3.0	3.0	1.0	1.0
IS 2312	3.0	3.0	3.0	3.0	3.0	3.0	1.0	2.0	2.3	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	2.3	1.0	1.0	1.0
Akola Kranti	2.7	2.0	2.0	2.0	1.0	1.0	1.3	2.0	3.0	5.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	3.7	3.0	1.0	1.0
Phule Vasudha	2.7	2.0	2.0	1.0	1.0	2.0	1.3	3.0	2.3	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	3.0	3.0	1.0	1.0
ICSV 93046	2.0	3.0	2.0	2.0	1.0	1.0	1.0	1.0	3.7	3.0	2.0	2.0	1.0	1.0	2.0	1.0	2.0	2.0	1.7	1.0	1.0	1.0
IS 18551***(R)***	1.3	3.0	3.0	3.0	4.0	4.0	1.0	2.0	9.0	9.0	2.0	2.0	1.0	1.0	2.0	1.0	2.0	2.0	2.3	3.0	1.0	1.0
Swarna ***(S)***	1.0	1.0	2.0	2.0	1.0	1.0	2.0	3.0	3.0	3.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.3	3.0	1.0	1.0
RVRT 2	3.0	2.0	2.0	1.0	1.0	1.0	2.3	3.0	1.0	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	3.0	5.0	1.0	1.0
Giddi Maldandi	3.0	3.0	3.0	2.0	4.0	1.0	3.0	3.0	2.3	5.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	3.0	5.0	1.0	1.0
RVRT 3	2.0	3.0	2.0	2.0	1.0	1.0	1.0	1.0	3.7	3.0	1.7	2.0	1.0	1.0	2.0	2.0	2.0	2.0	3.7	5.0	1.0	1.0
Dagidi Solapur	3.0	3.0	3.0	2.0	3.0	1.0	1.0	1.0	1.0	3.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	2.3	3.0	1.0	1.0
296 B	2.0	3.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	5.0	3.0	1.0	1.0
Mean (58, 29)	**2.2**	**2.4**	**2.2**	**2.1**	**1.5**	**1.3**	**1.4**	**1.7**	**2.4**	**2.9**	**1.8**	**1.8**	**1.0**	**1.0**	**2.0**	**1.9**	**2.0**	**2.0**	**2.7**	**2.8**	**1.0**	**1.0**
SE ±	**0.2**	**0.1**	**0.0**	**0.1**	**0.0**	**0.2**	**0.2**	**0.2**	**0.5**	**0.3**	**0.1**	**0.1**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.5**	**0.2**	**0.0**	**0.0**

(R), resistant check; (***S)***, susceptible check; R, rainy season; PR, postrainy season. Inflorescence exsertion (1 panicle fully exserted, 3 poor panicle exsertion); Panicle compactness (1 loose inflorescence, 3 compact inflorescence); Panicle shape (1 erect inflorescence, 4 elliptic inflorescence); Glume color (1 white glume, 6 purple glume); Glume coverage (1 25% grain covered with glumes, 9 glumes longer than the grain); Awns (1 awns absent, 2 presence of awns); Grain color (1 white colored grain, 5 buff colored grain); Grain lustre (1 non lustrous grain, 2 lustrous grain); Grain subcoat (1 absence of grain subcoat, 2 presence of grain subcoat); Endosperm texture (1 completely corneous endosperm, 5 completely starchy endosperm); Endosperm color (1 white colored endosperm, 3 red colored endosperm).

Table 22. Direct (diagonal) and indirect (off the diagonal) effects of agronomic and morphological traits on expression of resistance to shoot fly, *A. soccata* (Plants with deadhearts) in sorghum across seasons.

Traits	Leaf glossy score	Leafsheath pigmentation	Plant vigor score	Trichome density on abaxial leaf surface	Trichome density on adaxial leaf surface	Plant height	Plant color	100 seed weight	Shoot fly deadhearts
Leaf glossy score	**0.47 (0.16)**	0.11 (-0.07)	-0.04 (0.00)	0.33 (-0.04)	-0.24 (0.03)	-0.24 (0.03)	-0.10 (0.03)	-0.04 (0.08)	**0.34 (0.83**)**
Leaf sheath pigmentation	0.25 (0.10)	**0.20 (-0.11)**	-0.04 (-0.00)	0.28 (-0.02)	-0.23 (0.02)	-0.33 (0.06)	-0.16 (0.13)	-0.03 (-0.04)	**-0.05 (0.42*)**
Plant vigor score	0.24 (-0.01)	0.11 (-0.02)	**-0.08 (-0.03)**	0.02 (0.00)	-0.03 (-0.01)	-0.45 (0.09)	-0.17 (0.21)	0.05 (-0.22)	**-0.43* (-0.13)**
Trichome density on abaxial leaf surface	-0.20 (-0.112)	-0.07 (0.05)	0.00 (-0.00)	**-0.78 (0.05)**	0.53 (-0.05)	0.13 (-0.02)	0.01 (-0.01)	0.07 (-0.08)	**-0.53** (-0.72**)**
Trichome density on adaxial leaf surface	-0.20 (-0.11)	-0.09 (0.05)	0.00 (-0.00)	-0.75 (0.05)	**0.56 (-0.05)**	0.14 (-0.04)	-0.00 (0.00)	0.07 (-0.05)	**-0.48** (-0.76**)**
Plant height	-0.20 (-0.03)	-0.12 (0.05)	0.06 (0.02)	-0.19 (0.01)	0.14 (-0.02)	**0.56 (-0.13)**	0.18 (-0.19)	-0.08 (0.24)	**0.45** (-0.21)**
Plant color	0.17 (0.02)	0.13 (-0.05)	-0.05 (-0.02)	0.02 (-0.00)	0.00 (-0.00)	-0.39 (0.09)	**-0.26 (0.28)**	0.10 (-0.25)	**-0.48** (0.02)**
100 seed weight	0.07 (0.04)	0.02 (0.01)	0.02 (0.02)	0.20 (-0.01)	-0.13 (0.01)	0.16 (-0.10)	0.09 (-0.21)	**-0.28 (0.34)**	**0.38** (0.22)**

*, ** correlation coefficients significant at P 0.05 and 0.01, respectively; Residual effect = 0.08 (0.03).

The values outside the parenthesis are path coefficients for the rainy season and those inside the parenthesis are path coefficients for the postrainy season.

Path coefficient analysis with shoot fly deadhearts as a dependant factor indicated that the direct effects and the correlation coefficients of leaf glossiness, plant vigor, trichomes on abaxial leaf surface, plant height, and plant color were in the same direction (+ve or –ve), and hence, these traits can be used as a criteria to select for resistance to shoot fly during postrainy season. However, the direct effects and the correlation coefficients of leafsheath pigmentation, and trichomes on abaxial leaf surface were in opposite direction, and hence these traits will not be useful to select for resistance to shoot fly during the postrainy season. Lower residual effect of 0.03, was observed in the postrainy season.

4.2.7 Genetic parameters for shoot fly resistance and morphological traits

The genetic parameters for shoot fly resistance and morphological traits (Table 23) revealed that shoot fly oviposition differed across the seasons, with high levels of heritability (74.19%) and genetic advance (113.94%) in the rainy season; whereas these estimates were low during the postrainy season. Shoot fly deadhearts, leaf glossiness, leafsheath pigmentation, plant vigor, and the trichome density on the abaxial and adaxial leaf surfaces exhibited high broadsense heritability and genetic advance indicating that these traits had high heritability. The genetic parameters of shoot fly deadhearts varied across seasons with high heritability (76.22%) and genetic advance (154.30%) in the rainy season. The PCV percentage of leaf glossiness, leafsheath pigmentation, oviposition, and trichome density was high indicating the seasonal influence of these traits, with resistance to shoot fly. However, high GCV percentage, broad sense heritability and genetic advance suggested the predominance of additive nature of genes controlling shoot fly resistance, and there is a good possibility of breeding for shoot fly-resistant sorghums.

4.3 Diversity of sorghum genotypes exhibiting resistance to shoot fly, *A. soccata*

4.3.1 Genotypic diversity of the sorghum genotypes for shoot fly, *A. soccata*

The principal co-ordinate analysis based on shoot fly resistance traits placed the test genotypes into three different groups (Fig. 9a). The shoot fly susceptible genotypes (CSV 15, Swarna and 296 B) were placed in group I; while the genotypes showing resistance to shoot fly (ICSV 700, Phule Yasodha, Moulee, Phule Chitra, Phule Anuradha, M 35-1, Parbhani Moti, CSV 18R, ICSV 713, ICSV 25022, IS 2123, IS 2146, IS 2312, Akola

Table 23. Genetic parameters of the shoot fly resistance and morphological traits in sorghum.

Traits	Plants with shoot fly eggs (%)	Number of shoot fly eggs/plant	Shoot fly deadhearts (%)	Leaf glossy score	Leafsheath pigmentation	Plant vigor score	Trichome density on the abaxial leaf surface	Trichome density on the adaxial leaf surface
ECV	29.81 (2.78)	37.87 (15.75)	47.93 (11.71)	15.49 (26.73)	21.94 (24.58)	27.86 (27.71)	22.91 (26.62)	18.21 (23.69)
GCV	55.42 (1.74)	64.21 (3.23)	85.80 (14.20)	46.68 (35.15)	22.30 (25.60)	30.39 (38.09)	49.05 (38.95)	44.44 (38.91)
PCV	62.93 (3.27)	74.55 (16.08)	98.28 (18.40)	49.18 (44.16)	31.29 (35.50)	41.23 (47.10)	54.13 (47.17)	48.02 (45.55)
%H	77.56 (28.11)	74.19 (4.04)	76.22 (59.51)	90.08 (63.36)	50.81 (52.02)	54.35 (65.39)	82.08 (68.16)	85.62 (72.95)
GA%	100.54 (1.90)	113.94 (1.34)	154.30 (22.57)	57.64 (57.64)	32.74 (38.04)	46.16 (63.44)	91.53 (66.23)	84.70 (68.46)

ECV, environmental coefficient of variation; GCV, genotypic coefficient of variation; PCV, phenotypic coefficient of variation; %H, broad sense heritability, GA%, genetic advance percent of mean.

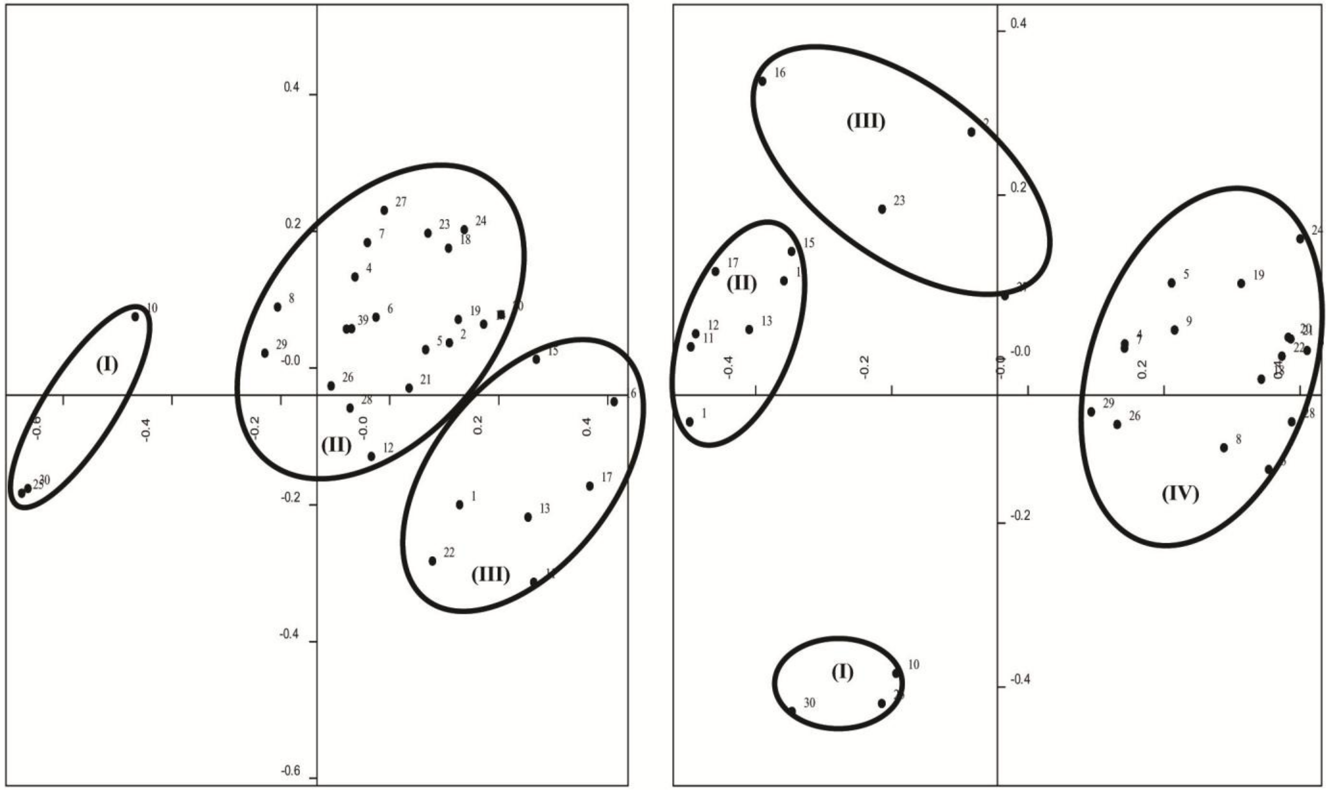
The values outside the parenthesis are for the rainy season and those inside the parenthesis are for the postrainy season.

Kranti, ICSV 93046, RVRT 2, Giddi Maldandi, RVRT 3, and Dagidi Solapur) that were on par with IS 18551, were placed in group II. The genotypes ICSB 433, ICSV 705, ICSV 25019, ICSV 25026, ICSV 25039, PS 35805, and Phule Vasudha showing moderate levels of resistance to shoot fly were placed in group III.

Genotypic diversity based on the morphological traits placed the test genotypes into four groups (Fig. 9b), suggesting that there was considerable morphological diversity in the genotypes used for shoot fly screening. The susceptible genotypes Swarna, 296 B and CSV 15 were placed together in group I; whereas Phule Yasodha, Moulee, Phule Chitra, Phule Anuradha, M 35-1, Parbhani Moti, CSV 18R, IS 2123, IS 2146, IS 2312, Akola Kranti, Phule Vasudha, RVRT 2, RVRT 3, and Dagidi Solapur having morphological traits conferring resistance to shoot fly were placed together along with the resistant check IS 18551 in group IV. ICSB 433, ICSV 700, ICSV 705, ICSV 713, ICSV 25019, ICSV 25022, ICSV 25026, ICSV 25039, PS 35805, ICSV 93046, and Giddi Maldandi possessing a combination of morphological traits conferring resistance/ susceptibility to shoot fly, and exhibiting moderate levels of shoot fly resistance were placed in groups II and III.

4.3.2 Genetic diversity of sorghum genotypes based on simple sequence repeat (SSR) markers

Thirty eight SSR markers were used assessing genetic diversity for this activity. Individual PCR products were pooled based on the product sizes, and separated in capillary electrophoresis using internal size standard. Of these 38 SSRs, one marker was monomorphic and remaining polymorphic (Table 24). A total of 150 alleles were detected with an average of 3.95 alleles per marker, and 2 to 9 alleles per marker. The polymorphic information content (PIC) values for these markers in the reference set of sorghum varied from 0.00 (ISEP0310) to 0.80 (sb5-206) with an average of 0.45. The highest level of polymorphism was shown by sb5-206 (0.80), followed by Xtxp012 (0.79), Xtxp265 (0.77), and Xtxp015 (0.74). Observed heterozygosity varied from 0.00 (sb4-72, gpsb067, mSbCIR306, Xtxp010, mSbCIR223, Xtxp021, mSbCIR329, ISEP0310 and gpsb089) to 0.14 (mSbCIR262) with a mean of 0.05. Gene diversity varied from 0.10 (Xtxp021) to 0.83 (sb5-206) with an average of 0.50. sb5-206 marker was the most informative, with most alleles, high gene diversity and the highest PIC value.



(a)

(b)

Fig. 9: Diversity (Principal co-ordinates) among the sorghum genotypes based on **(a)** shoot fly resistance and **(b)** morphological traits across seasons. (1 = ICSB 433, 2 = ICSV 700, 3 = Phule Yasodha, 4 = Moulee, 5 = Phule Chitra, 6 = Phule Anuradha, 7 = M 35-1, 8 = Parbhani Moti, 9 = CSV 18R, 10 = CSV 15, 11 = ICSV 705, 12 = ICSV 713, 13 = ICSV 25019, 14 = ICSV 25022, 15 = ICSV 25026, 16 = ICSV 25039, 17 = PS 35805, 18 = IS 2123, 19 = IS 2146, 20 = IS 2312, 21 = Akola Kranti, 22 = Phule Vasudha, 23 = ICSV 93046, 24 = IS 18551, 25 = Swarna, 26 = RVRT 2, 27 = Giddi Maldandi, 28 = RVRT 3, 29 = Dagidi Solapur, 30 = 296 B).

Table 24. Information of SSR markers used in the diversity study and their properties.

Marker	Major allele frequency	Allele number	Gene diversity	Heterozygosity	PIC
mSbCIR238	0.36	6.00	0.75	0.07	0.72
sb4-72	0.53	4.00	0.55	0.00	0.46
Xcup53	0.41	3.00	0.64	0.07	0.57
gpsb123	0.59	4.00	0.58	0.11	0.53
Xtxp265	0.28	8.00	0.80	0.10	0.77
gpsb067	0.55	2.00	0.49	0.00	0.37
mSbCIR276	0.86	2.00	0.24	0.12	0.21
mSbCIR306	0.59	3.00	0.57	0.00	0.50
Xtxp010	0.55	3.00	0.59	0.00	0.53
Xtxp057	0.45	7.00	0.71	0.10	0.67
Xcup14	0.67	3.00	0.49	0.10	0.43
mSbCIR240	0.67	3.00	0.48	0.04	0.42
mSbCIR246	0.93	2.00	0.12	0.00	0.12
Xtxp114	0.54	3.00	0.59	0.04	0.52
Xcup63	0.93	2.00	0.13	0.00	0.12
Xtxp012	0.32	8.00	0.81	0.07	0.79
mSbCIR223	0.90	4.00	0.19	0.00	0.18
Xtxp141	0.35	4.00	0.72	0.11	0.67
mSbcir262	0.62	3.00	0.48	0.14	0.38
sb6-84	0.39	6.00	0.75	0.07	0.71
msbcir300	0.40	3.00	0.65	0.07	0.58
Xtxp021	0.79	4.00	0.35	0.00	0.33
Xtxp136	0.95	3.00	0.10	0.10	0.09
txp273	0.60	4.00	0.56	0.07	0.50
Xcup61	0.88	2.00	0.21	0.03	0.18
Xtxp278	0.62	2.00	0.47	0.03	0.36
Xtxp015	0.38	8.00	0.77	0.10	0.74
SbAG-B02	0.48	6.00	0.69	0.03	0.64
mSbCIR329	0.93	3.00	0.13	0.00	0.12
Xcup11	0.65	2.00	0.46	0.03	0.35
mSbCIR283	0.70	6.00	0.49	0.04	0.47
ISEP0310*	1.00	1.00	0.00	0.00	0.00
sb5-206	0.30	9.00	0.83	0.07	0.80
gpsb089	0.77	2.00	0.36	0.00	0.29
gpsb148	0.50	3.00	0.60	0.07	0.52
Xcup02	0.83	4.00	0.30	0.10	0.28
mSbCIR286	0.63	2.00	0.47	0.04	0.36
Xtxp145	0.33	6.00	0.74	0.13	0.70
Mean	**0.61**	**3.95**	**0.50**	**0.05**	**0.45**
Minimum	**0.28**	**1.00**	**0.00**	**0.00**	**0.00**
Maximum	**1.00**	**9.00**	**0.83**	**0.14**	**0.80**

PIC, polymorphic information component; * Monomorphic marker.

The 38 SSR markers placed the genotypes into 4 groups suggesting that there was considerable genetic diversity among the sorghum genotypes used in this study (Fig. 10). Based on the Unweighted Pair Group Method with Arithmetic mean (UPGMA), the susceptible genotypes Swarna and 296 B were grouped together along with CSV 15, indicating that CSV 15 carries susceptible alleles. The genotypes IS 2123, IS 2312, IS 2146, ICSV 25039 possessing shoot fly resistance genes were grouped together with IS 18551 the shoot fly-resistant check. The other genotypes exhibiting mixture of the resistant and susceptible genes/showing moderate resistance to shoot fly were grouped separately. The SSR marker analysis revealed the genetic diversity of the sorghum genotypes used in the experiment. Based on the phenotypic and genotypic data, genotypes that are genetically diverse and showing resistance to shoot fly were selected, to study the nature of gene action for resistance to shoot fly and the traits associated with shoot fly resistance.

4.4 Biochemical components of resistance to shoot fly, *A. soccata*

4.4.1 Carbohydrates, proteins, tannins and phenols from the sorghum plant sample

The lyophilised plant material of the glass house grown sorghum samples were used to estimate the biochemical components such as total carbohydrates, proteins, tannins and total phenols. The test genotypes differed significantly for all the biochemical components estimated [df (28, 28) and $P \leq 0.01$] (Table 25).

4.4.2 Total carbohydrates

Carbohydrate amounts ranged from 12.29% in Moulee to 17.43% in ICSV 713. The genotypes Swarna (16.43%), IS 2312 (16.29%), ICSV 705 (15.86%) and ICSV 25026 (15.86%) possessed higher amounts of carbohydrates as compared to the resistant check, IS 18551 (Table 25). There was no trend in the amounts of total carbohydrates in relation to shoot fly resistance, but higher amount of carbohydrates were present in shoot fly susceptible genotypes.

4.4.3 Proteins

Protein content ranged from 265.0 to 367.5 mg/g, with a mean of 315.98 mg/g. ICSV 25026 showed high protein content (367.5 mg/g) followed by ICSV 25022 (360.0 mg/g). The resistant check, IS 18551 had 322.5 mg/g of protein, while the susceptible check, Swarna

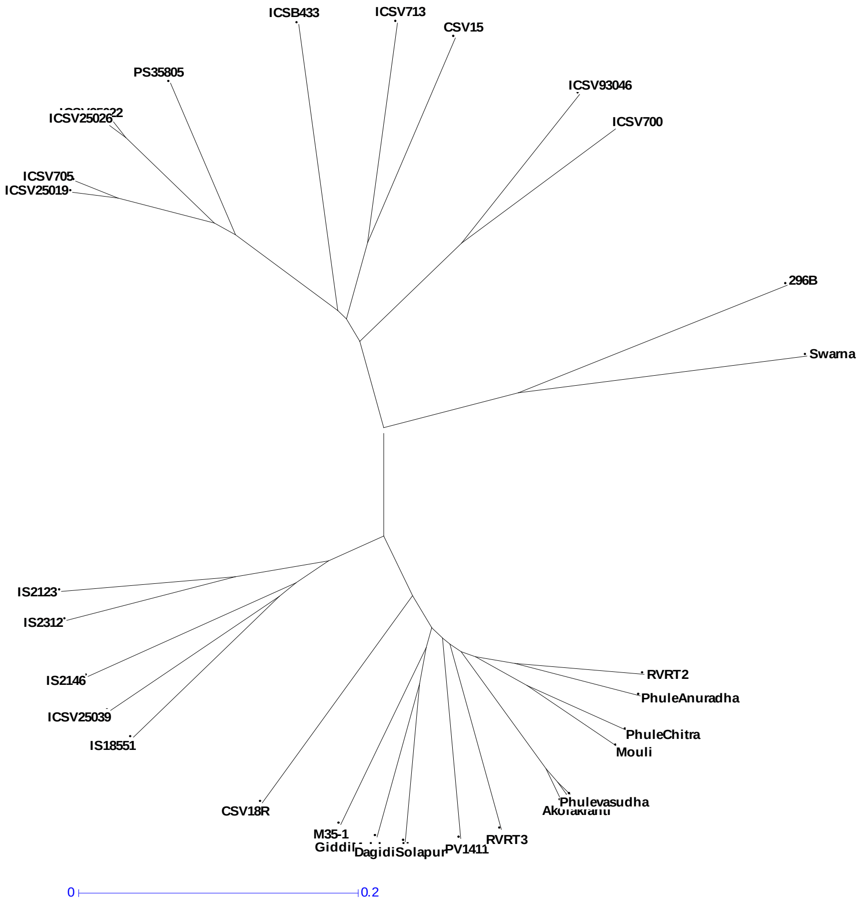


Fig. 10: Dendrogram showing the distance (dissimilarity) between the genotypes: UPGMA (Unweighted Pair Group Method with Arithmetic Mean).

Table 25. Evaluation of biochemical components of sorghum genotypes exhibiting resistance/susceptibility to shoot fly, *A. soccata* (ICRISAT, Patancheru, 2012-13).

Genotype	% of carbohydrate	Protein (mg/g of sample)	Poly phenols mg/g	Tannins (catechin equivalents/100mg tissue)
ICSB 433	13.1	315.0	4.2	960.0
ICSV 700	13.6	291.2	5.3	1085.0
Phule Yasodha	13.5	305.0	6.4	1260.0
Mouli	12.3	317.5	4.8	1320.0
Phule Chitra	12.7	332.5	5.6	1560.0
Phule Anuradha	12.4	287.5	5.1	1440.0
M 35-1	14.4	312.5	6.3	1260.0
Parbhani Moti	13.1	322.5	4.8	1080.0
CSV 18R	14.1	305.0	6.3	1380.0
CSV 15	14.3	325.0	3.6	1500.0
ICSV 705	15.9	342.5	6.1	2105.0
ICSV 713	17.4	332.5	6.3	1440.0
ICSV 25019	15.3	337.5	8.4	1680.0
ICSV 25022	14.2	360.0	6.8	2950.0
ICSV 25026	15.9	367.5	6.9	1500.0
ICSV 25039	13.9	335.0	4.4	1920.0
PS 35805	14.9	280.0	4.7	1500.0
IS 2123	15.6	305.0	6.1	1440.0
IS 2146	14.2	265.0	4.9	1800.0
IS 2312	16.3	307.5	5.7	2050.0
Akola Kranti	14.6	280.5	5.4	2165.0
Phule Vasudha	15.5	335.2	5.0	1440.0
ICSV 93046	15.6	307.5	5.9	1620.0
IS 18551 ***(R)***	15.4	322.5	4.0	1265.0
Swarna ***(S)***	16.4	305.0	4.2	1320.0
RVRT 2	14.4	307.5	5.2	1145.0
Giddi Maldandi	15.3	345.0	5.4	1860.0
RVRT 3	15.6	327.5	5.0	1320.0
Dagidi Solapur	14.4	302.5	4.6	1620.0
296 B	15.3	300.0	5.3	1380.0
Mean	**14.64**	**315.98**	**5.42**	**1545.50**
SE ±	**0.77**	**5.80**	**0.24**	**73.22**
Vr	**2.62****	**16.28****	**17.77****	**30.16****
LSD (P 0.05)	**2.22**	**16.79**	**0.69**	**211.79**
CV %	**7.40**	**2.60**	**6.20**	**6.70**

*, ** F test significant at P 0.05 and 0.01, respectively; ***(R)***, resistant check; ***(S)***, susceptible check.

305.0 mg/g of protein (Table 25). No proper trend in the amounts of protein in relation to shoot fly resistance, but most of the shoot fly-resistant genotypes possessed higher amounts of protein content than the susceptible check Swarna.

4.4.4 Polyphenols

The amounts of polyphenols ranged 3.6 – 8.4 mg/g. Phule Yasodha, Phule Chitra, M 35-1, CSV 18R, ICSV 705, ICSV 713, ICSV 25019, ICSV 25022, ICSV 25026, IS 2123, IS 2312 and ICSV 93046 had higher amounts of polyphenols than the susceptible check, Swarna (4.2 mg/g) (Table 25). Most of these genotypes exhibited resistance to shoot fly. However, the resistant check, IS 18551 had low polyphenol content (4.0 mg/g).

4.4.5 Condensed tannins

The amount of condensed tannins ranged from 960.0 to 2950.0 Catechin equivalents (Cat. equi.), with a mean value of 1545.5 Cat. equi. (Table 25). ICSV 705, ICSV 25019, ICSV 25022, ICSV 25039, IS 2146, IS 2312, Akola Kranti, ICSV 93046, Giddi Maldandi and Dagidi Solapur had higher amounts of tannins than the susceptible check, Swarna; and these genotypes also exhibited resistance to shoot fly, *A. soccata*. The resistant check, IS 18551 had low amounts of tannins content (1265.0 Cat. equi.). M 35-1 had moderate amounts of tannins (1260.0 Cat. equi.). This shows the randomness in the amounts of tannins in the sorghum genotypes.

The genotypes ICSV 25019 and ICSV 25022 possessed all the biochemical components in higher proportion (except carbohydrates), and were resistant to shoot fly, *A. soccata*, suggesting that lower carbohydrate content and higher protein, polyphenol and tannin content together played a key role in shoot fly resistance.

4.4.6 HPLC fingerprints of methanol extracts of different sorghum genotypes expressing resistance to shoot fly, *A. Soccata*

The HPLC finger prints of 30 sorghum genotypes had altogether 55 different peaks, with varying retention times and peak areas. Methanol extract of the susceptible genotype, Swarna had 24 peaks, whereas the resistant check IS 18551 had 32 peaks. Of these, 10 peaks were common for both the genotypes, but with varying peak areas. The remaining peaks were unique to each genotype. The common peaks with varying peak areas were recorded in all the genotypes, including the resistant and susceptible checks within the range of 2.00 to

7.79 minutes retention time, with a few exceptions. The major difference was observed in the retention time of the peaks of the susceptible genotypes, which were not observed in the genotypes exhibiting resistance to shoot fly. Therefore, the compounds in these peaks may be associated with susceptibility to shoot fly.

To identify and quantify the compounds present in the sorghum genotypes 24 standards were run under similar conditions, of which the retention times of 7 compounds matched with the HPLC profiles of the sorghum genotypes, and their amounts were quantified (Table 26). The phenolic compounds kaempferol and salicylic acid were present in IS 18551, but absent in the susceptible check, Swarna. The genotypes showing moderate levels of resistance to shoot fly also possessed these components. 3, 4-dihydroxy benzoic acid was observed in the susceptible check, Swarna (9.6 µg/100mg of plant sample), but was absent in the resistant check, IS 18551. Most of the moderately resistant genotypes had 3, 4-dihydroxy benzoic acid with varying concentrations.

The genotypes ICSB 433, ICSV 700, SPV 1359, Moulee, Phule Chitra, Phule Anuradha, ICSV 705, ICSV 93046 and RVRT 2 had the HPLC peaks at the same retention time as in IS 18551, with few exceptions (Table 27, 28). ICSV 25019, ICSV 25022, ICSV 25026, and ICSV 25039 had similar fingerprints as that of the resistant check, IS 18551. The differences in the peak areas were observed between the resistant and susceptible genotypes, with higher peak areas in the resistant genotypes, suggesting greater amounts of certain chemical in the shoot fly-resistant genotypes. The susceptible genotypes CSV 15, Swarna and 296 B had fewer peaks than IS 18551, indicating the importance of the compounds present in the resistant check, which possibly conferred shoot fly resistance. Though the peaks with similar retention times were seen in both the resistant and susceptible genotypes, greater peak areas were exhibited by the genotypes showing moderate levels of resistance to shoot fly (Table 28). The chromatographic profile of methanol extracts of 30 sorghum genotypes is given in Fig. 11.

Table 26. Amounts of phenolic acids (flavonoids) (µg/100mg of sorghum plant sample) in different sorghum genotypes showing resistance/susceptibility to sorghum shoot fly, *A. soccata* (ICRISAT, Patancheru, 2012-13).

Flavonoid standard	Retention time	ICSB 433	ICSV 700	SPV 1359	Moulee	Phule chitra	Phule Anuradha	M 35-1	SPV 1411	CSV 18 R	CSV 15	ICSV 705	ICSV 713	ICSV 25019	ICSV 25022	ICSV 25026
3,4 Dihydroxy Benzoic acid	3.9	5.9	-	-	-	-	2.5	-	-	-	11.1	-	8.7	5.8	-	7.3
Naringin	5.1	128.4	220.8	202.8	193.0	146.5	-	189.0	-	-	154.0	-	-	-	-	395.0
Vanillic acid	10.6	-	26.0	10.4	-	-	-	-	-	13.1	185.0	-	-	-	63.1	-
Ferulic acid	17.5	-	-	-	-	31.8	-	28.2	99.2	-	-	-	-	87.9	-	-
Kaempferol	20.9	103.9	153.2	85.7	78.5	133.1	107.3	106.8	21.1	108.3	-	43.8	-	-	112.6	-
Syringic acid	22.2	8.9	7.4	15.6	14.9	10.3	-	38.2	-	-	22.3	483.2	-	-	-	-
Salicylic acid	39.8	-	-	-	-	78.1	171.0	35.4	-	155.1	110.5	72.0	-	-	-	129.2

Flavonoid standard	Retention time	ICSV 25039	PS 35805	IS 2123	IS 2146	IS 2312	Akola Kranti	Phule Vasudha	ICSV 93046	IS 18551	Swarna	RVRT 2	Gidda Maldandi	RVRT 3	Dagidi Solapur	296 B
3,4 Dihydroxy Benzoic acid	3.9	-	47.0	10.6	42.6	60.3	6.5	86.3	4.4	-	9.6	-	5.9	38.3	49.9	3.7
Naringin	5.1	-	227.5	-	258.9	91.8	94.5	-	-	-	-	-	-	650.4	162.8	-
Vanillic acid	10.6	-	-	51.2	99.3	-	32.9	-	-	-	38.4	-	-	-	-	-
Ferulic acid	17.5	361.6	-	13.6	-	-	278.8	-	-	-	332.1	-	-	-	96.8	-
Kaempferol	20.9	-	74.3	26.7	157.7	134.8	15.2	-	52.4	66.2	-	67.5	-	-	-	-
Syringic acid	22.2	-	18.8	-	-	-	-	-	394.8	-	-	-	-	-	24.9	-
Salicylic acid	39.8	-	-	-	-	-	-	-	35.0	65.1	-	118.7	-	25.9	-	-

Table 27. Retention times and peak areas of unknown components of phenolic acids (flavonoids) in sorghum genotypes exhibiting resistance to shoot fly, *A. soccata* (ICRISAT, Patancheru, 2012-13).

Retention time	ICSB 433	ICSV 700	SPV 1359	Moulee	Phule chitra	Phule Anuradha	M 35-1	SPV 1411	CSV 18 R	CSV 15	ICSV 705	ICSV 713	ICSV 25019	ICSV 25022	ICSV 25026
2.46	65236	93359	73782	81088	80032	37266	78461	202695	173479	36904	63432	-	1627906	1389735	1083982
3.73	-	107502	111203	138709	116232	58599	122109	59410	107933	280072	279404	199518	366445	483489	405650
4.76	78268	55079	84867	79561	59482	64281	38461	553030	476020	551058	30290	494719	586807	145382	206212
7.45	136585	-	-	-	-	-	-	484386	204742	1031598	-	-	-	-	748486
8.53	-	-	-	-	-	-	-	565193	-	454172	-	2294727	-	-	262052
15.97	-	-	-	-	-	-	-	-	-	90807	-	-	-	116216	2145555
17.97	-	-	-	-	-	264026	-	-	-	-	-	-	3391973	-	-
19.17	-	355800	71394	51384	1039615	795799	1204543	-	41599	-	941998	-	3603653	-	-
22.85	-	-	214795	193502	213551	128919	358734	-	311097	-	-	-	-	-	-
35.98	-	-	-	-	-	3257410	294949	-	-	-	63135	-	-	-	-
38.14	69716	127729	238644	241392	215842	201611	151445	-	-	-	37090	-	-	-	-
38.28	60754	98710	229218	208159	275485	225703	-	-	-	-	73581	-	-	-	-
38.48	-	-	-	-	218453	247981	-	-	-	-	294568	-	-	-	-
38.60	-	-	-	-	-	-	-	-	-	-	309712	-	-	-	-
39.27	40736	24870	20607	20698	54375	54813	-	-	-	-	161154	48551	-	-	255726
39.54	-	46217	130774	97104	15727	14567	-	-	-	-	94233	-	-	-	-
41.65	24045	16449	234793	590176	334069	543457	-	35254	-	-	-	-	55191	-	46050
41.87	-	93920	39973	-	-	-	106694	36316	97360	-	1092896	-	58001	-	-
43.60	-	61536	52847	73667	106516	124934	31241	-	-	-	113634	32652	-	-	-
44.31	-	47569	-	-	38246	39712	-	-	-	-	36389	-	-	50483	-

Table 27. (Cont..)

Retention time	ICSV 25039	PS 35805	IS 2123	IS 2146	IS 2312	Akola Kranti	Phule Vasudha	ICSV 93046	IS 18551	Swarna	RVRT 2	Gidda Maldandi	RVRT 3	Dagidi Solapur	296 B
2.46	1680963	1198673	41543	1168045	1198593	72494	2440244	30803	148360	-	196884	148279	1308864	967779	-
3.73	1611803	474937	199509	467666	432610	309339	4786741	332641	117077	-	97295	112715	694758	407211	115551
4.76	-	40168	520558	97220	517519	523332	801171	-	828816	-	714960	665339	362857	206516	489518
7.45	-	-	239717	241224	649372	1296795	-	-	331237	-	52013	798493	306498	544152	725056
8.53	428938	1017715	-	-	-	-	-	68253	164180	-	-	-	-	-	-
15.97	-	-	-	-	-	-	-	221603	171723	-	-	1292880	-	-	-
17.97	-	-	95289	-	-	-	-	-	1098431	-	-	454191	-	-	-
19.17	154308	53618	-	-	-	381750	-	1183005	545417	-	68922	-	-	-	-
22.85	-	-	-	26578	-	-	-	-	143092	-	375126	-	-	-	-
35.98	-	-	-	50873	-	760277	-	82208	3474032	-	-	-	276221	133922	185303
38.14	-	-	-	30887	-	-	-	60318	93906	-	243938	-	115623	-	-
38.28	-	-	-	-	-	-	-	-	131910	-	246270	-	-	-	-
38.48	-	-	20231	-	-	-	-	-	123279	-	154936	-	-	16715	-
38.60	-	-	-	-	-	-	-	-	278289	-	-	-	-	-	-
39.27	-	-	676165	-	-	-	-	104950	73586	-	60134	-	-	-	31764
39.54	-	-	-	-	-	-	345583	75822	27459	-	27977	-	-	-	-
41.65	-	-	118145	-	-	-	112795	-	14682	-	207142	-	-	-	-
41.87	-	-	38236	-	-	-	34350	287210	175152	-	-	-	-	-	-
43.60	-	-	-	-	-	-	-	65095	49748	-	63703	56656	22061	27406	23613
44.31	-	-	-	-	-	-	-	41211	39186	-	48427	-	-	-	-

Table 28. Retention times and peak areas of unknown components of phenolic acids (flavonoids) in the sorghum genotypes exhibiting resistance/susceptibility to shoot fly, *A. soccata* (ICRISAT, Patancheru, 2012-13).

Retention time	ICSB 433	ICSV 700	SPV 1359	Moulee	Phule chitra	Phule Anuradha	M 35-1	SPV 1411	CSV 18 R	CSV 15	ICSV 705	ICSV 713	ICSV 25019	ICSV 25022	ICSV 25026
2.08	28613	-	-	-	-	-	-	-	164304	-	-	246134	509264	222893	195671
2.30	14122	-	23716	24298	32364	24536	30046	59289	49803	33219	216334	264679	82543	98502	75826
2.68	658401	952376	872799	1071356	933238	919261	1041073	861850	759432	951253	968792	1178830	-	-	-
3.47	204281	214381	226088	249183	242138	264799	254431	235737	220112	325719	17736	362443	509211	290321	277111
10.25	-	-	-	-	-	-	-	205558	-	-	-	2811933	-	-	-
24.57	-	-	-	-	337596		-	-	64761	-	-	-	-	-	879334
37.88	43696	196784	245997	194620	34666	29616	-	-	-	-	19106	-	-	-	-
38.88	-	44254	60888	50240	176964	174627	-	-	-	-	287992	28897	-	-	-
40.79	-	42027	31187	53050	22138	39987	287908	100156	-	-	34357	565779	134281	206911	42844
43.81	34632	38659	46124	48677	64801	76962	36514	-	-	-	43354	33005	-	-	-

Retention time	ICSV 25039	PS 35805	IS 2123	IS 2146	IS 2312	Akola Kranti	Phule Vasudha	ICSV 93046	IS 18551	Swarna	RVRT 2	Gidda Maldandi	RVRT 3	Dagidi Solapur	296 B
2.08	-	243882	344758	287273	222208	330402	448919	-	171941	40084	180096	-	248743	165067	266386
2.30	-	72011	175899	63895	98315	-	-	153827	46413	9208	50634	65828	102819	78289	201062
2.68	-	-	1040795	-	-	1051728	-	1121489	710040	906271	847159	906242	-	-	1001597
3.47	155352	273694	358635	131231	263578	328160	4502860	-	294504	321583	333553	360226	431187	264313	304720
10.25	-	-	1523058	-	-	76903	-	-	158426	65020	-	-	-	-	-
24.57	-	665378	-	115171	131538	-	-	-	428214	28306	-	-	-	-	-
37.88	-	-	54370	-	-	-	-	37557	41674	41608	238810	-	-	-	40901
38.88	-	-	-	-	-	-	-	540194	273101	20862	-	-	-	44391	-
40.79	221344	-	-	-	-	-	214408	23773	38861	79648	25385	194021	434379	93636	212630
43.81	-	-	-	-	-	-	-	33087	21341	34210	34016	-	39645	32605	25617

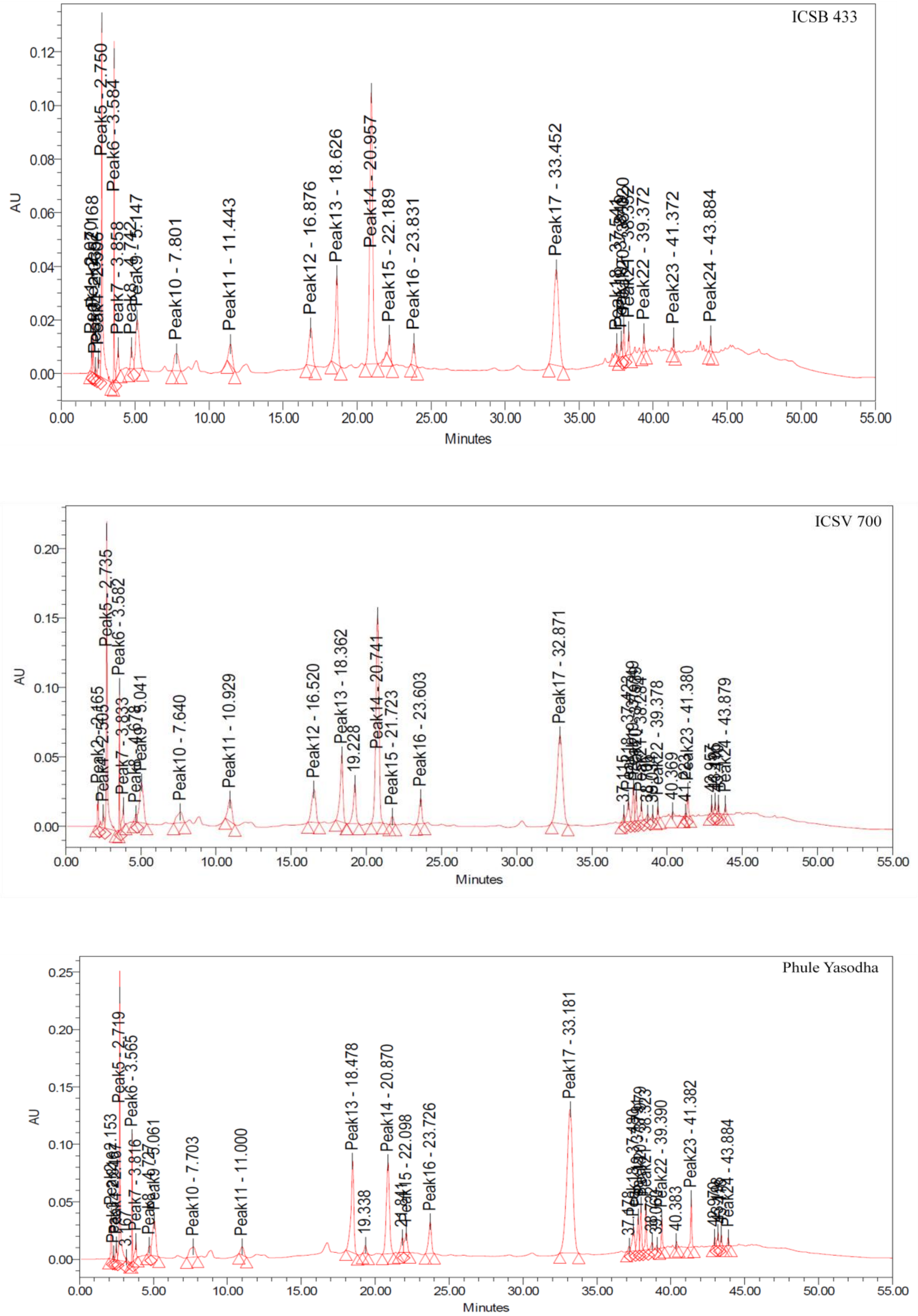


Fig. 11: HPLC chromatographic profile of phenolic compounds of 30 sorghum genotypes

Fig. 11(Cont..)

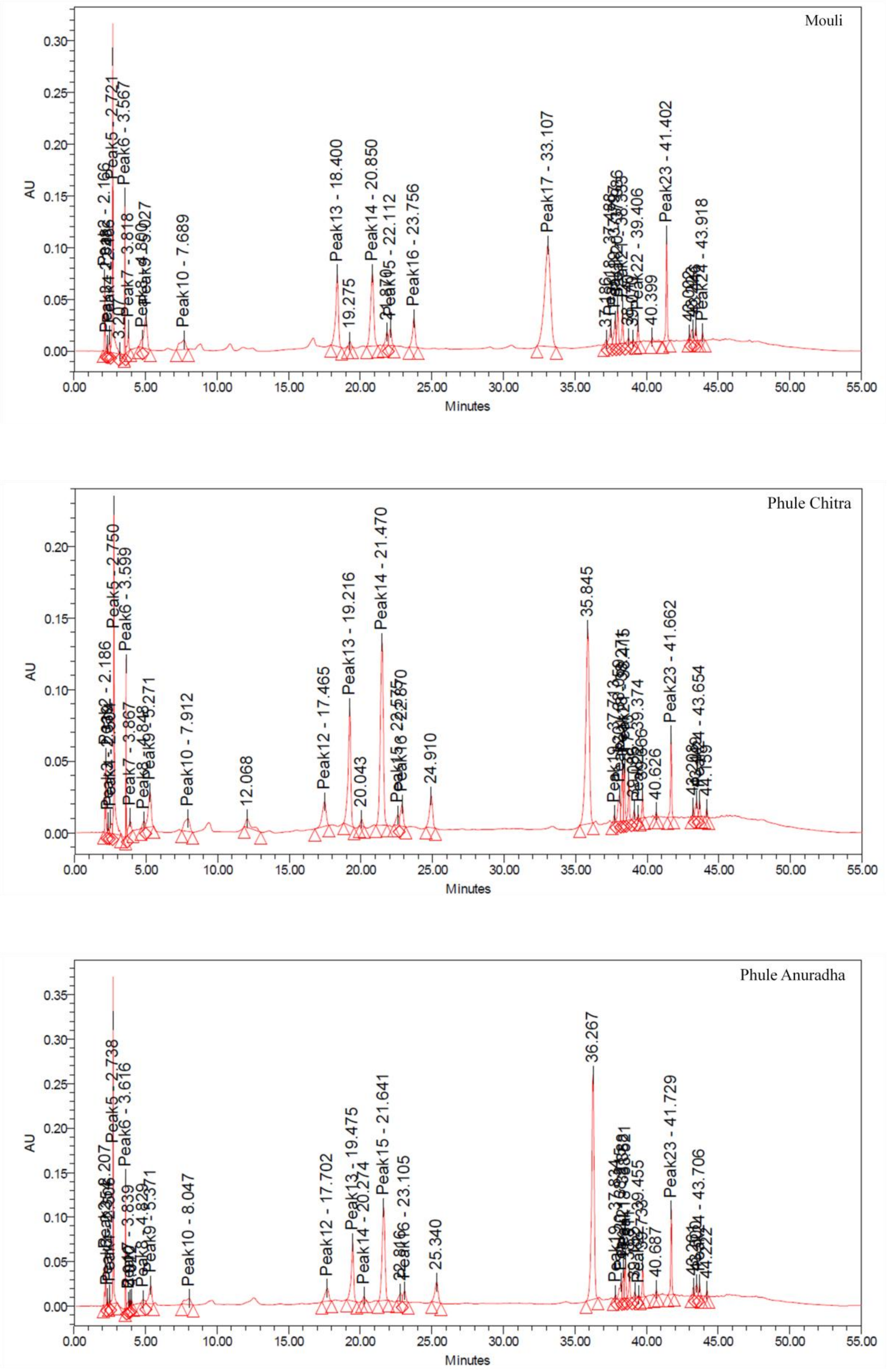

Mouli
AU
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Peak5 - 2.721
Peak6 - 3.567
Peak2 - 2.166
3.297
Peak7 - 3.818
Peak9 - 5.027
Peak10 - 7.689
Peak13 - 18.400
19.275
Peak14 - 20.850
Peak15 - 22.112
21.870
Peak16 - 23.756
Peak17 - 33.107
37.186
38.593
39.406
Peak22
40.399
Peak23 - 41.402
Peak24 - 43.918
Minutes
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Phule Chitra
AU
0.20
0.15
0.10
0.05
0.00
Peak5 - 2.750
Peak6 - 3.559
Peak2 - 2.186
Peak7 - 3.867
Peak8 - 4.848
Peak9 - 5.271
Peak10 - 7.912
12.068
Peak12 - 17.465
Peak13 - 19.216
20.043
Peak14 - 21.470
22.870
24.910
35.845
39.374
40.626
Peak23 - 41.662
43.654
44.159
Minutes
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Phule Anuradha
AU
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Peak5 - 2.738
Peak6 - 3.616
2.207
Peak7 - 3.839
Peak8 - 4.829
Peak9 - 5.371
Peak10 - 8.047
Peak12 - 17.702
Peak13 - 19.475
Peak14 - 20.274
Peak15 - 21.641
Peak16 - 23.105
22.816
25.340
36.267
39.455
40.687
Peak23 - 41.729
43.706
44.222
Minutes
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00

Fig. 11(Cont..)

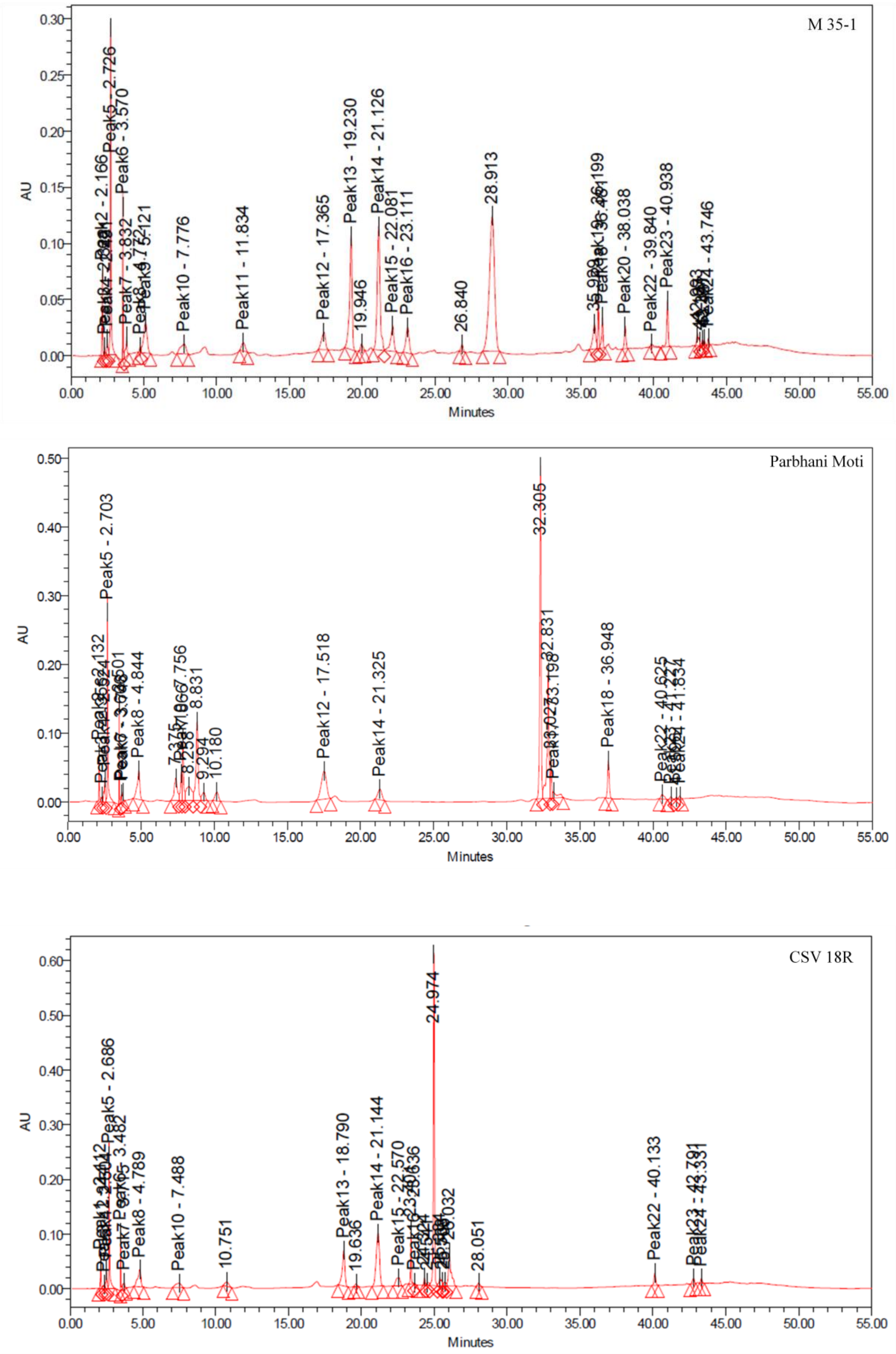
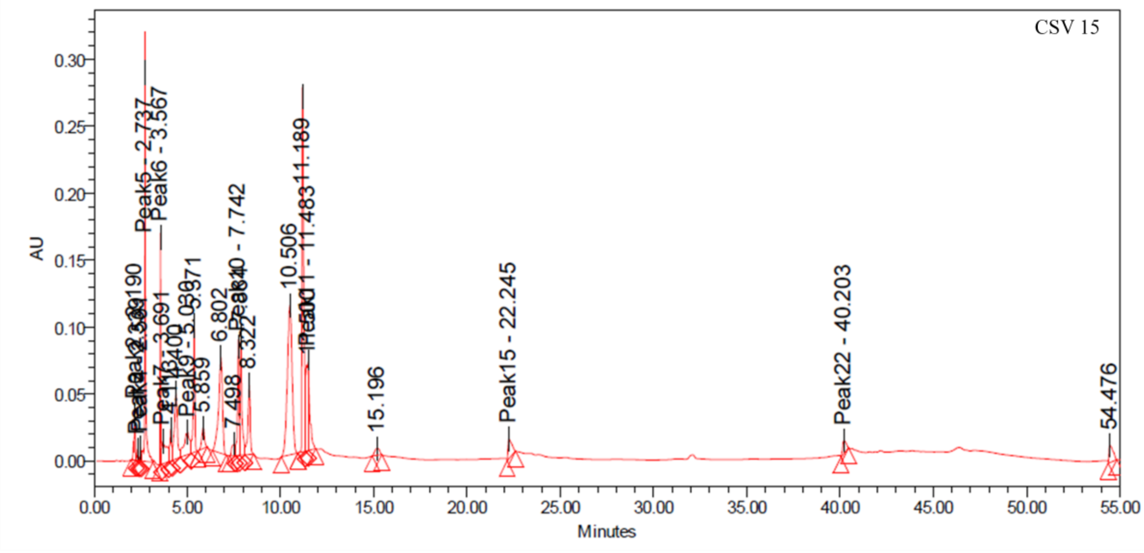
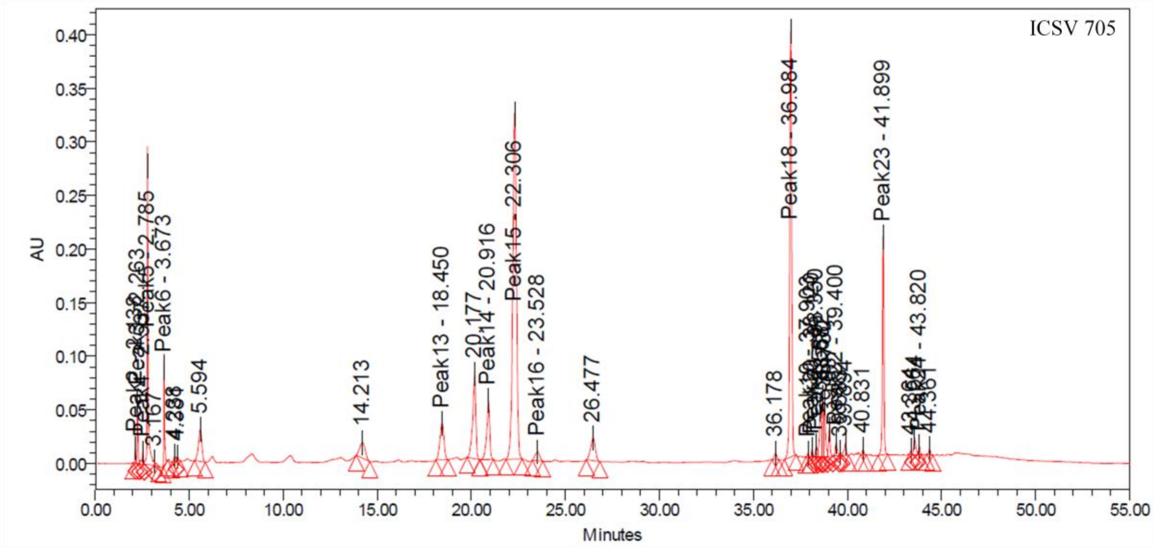

M 35-1
AU
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Peak2 - 2.166
Peak5 - 2.726
Peak6 - 3.570
Peak7 - 3.832
Peak9 - 5.121
Peak10 - 7.776
Peak11 - 11.834
Peak12 - 17.365
Peak13 - 19.230
19.946
Peak14 - 21.126
Peak15 - 22.081
Peak16 - 23.111
26.840
28.913
35.929
36.199
Peak20 - 38.038
Peak22 - 39.840
Peak23 - 40.938
Peak24 - 43.746
Minutes
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Parbhani Moti
AU
0.50
0.40
0.30
0.20
0.10
0.00
Peak5 - 2.703
2.132
Peak8 - 4.844
7.375
7.756
8.258
8.831
9.294
10.180
Peak12 - 17.518
Peak14 - 21.325
32.305
32.831
33.198
Peak18 - 36.948
Peak22 - 40.625
41.834
Minutes
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
CSV 18R
AU
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Peak5 - 2.686
3.482
Peak7
Peak8 - 4.789
Peak10 - 7.488
10.751
Peak13 - 18.790
19.636
Peak14 - 21.144
Peak15 - 22.570
24.974
26.032
28.051
Peak22 - 40.133
Peak23 - 42.791
Peak24 - 43.331
Minutes
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00

Fig. 11(Cont..)


CSV 15
AU
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Peak5 - 2.737
Peak6 - 3.567
Peak7 - 3.691
Peak9 - 5.030
5.859
6.802
Peak10 - 7.742
7.498
8.322
10.506
Peak11 - 11.483
11.189
15.196
Peak15 - 22.245
Peak22 - 40.203
54.476
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Minutes


ICSV 705
AU
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
2.785
Peak6 - 3.673
3.167
4.398
5.594
14.213
Peak13 - 18.450
20.177
Peak14 - 20.916
Peak15 - 22.306
Peak16 - 23.528
26.477
36.178
Peak18 - 36.984
39.400
40.831
Peak23 - 41.899
43.820
44.361
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Minutes

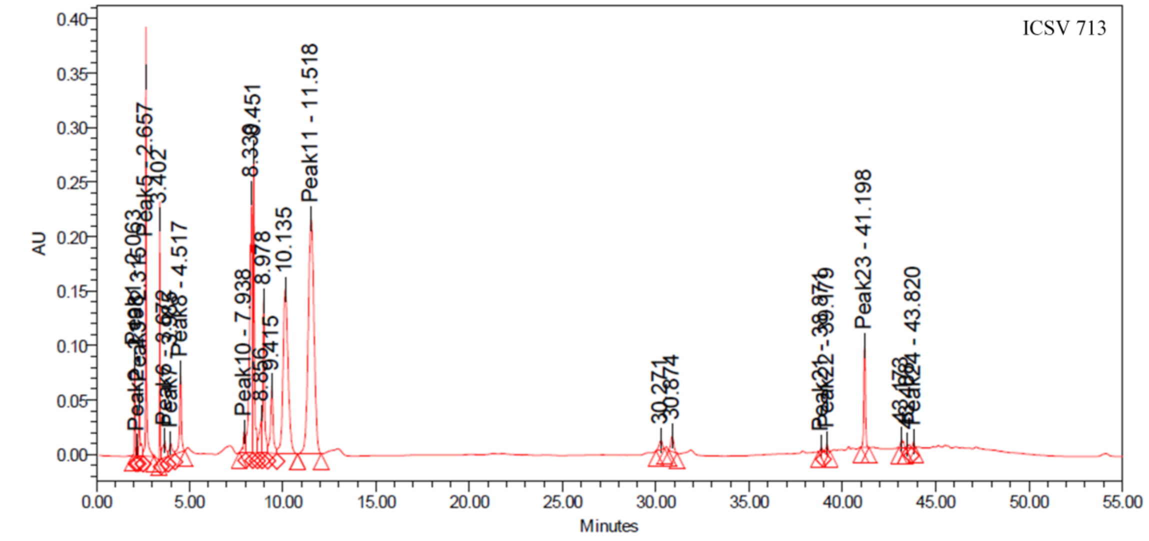

ICSV 713
AU
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Peak5 - 2.657
3.402
Peak8 - 4.517
Peak10 - 7.938
8.339
9.451
8.856
8.978
9.415
10.135
Peak11 - 11.518
30.271
30.874
Peak23 - 41.198
43.820
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Minutes

Fig. 11(Cont..)

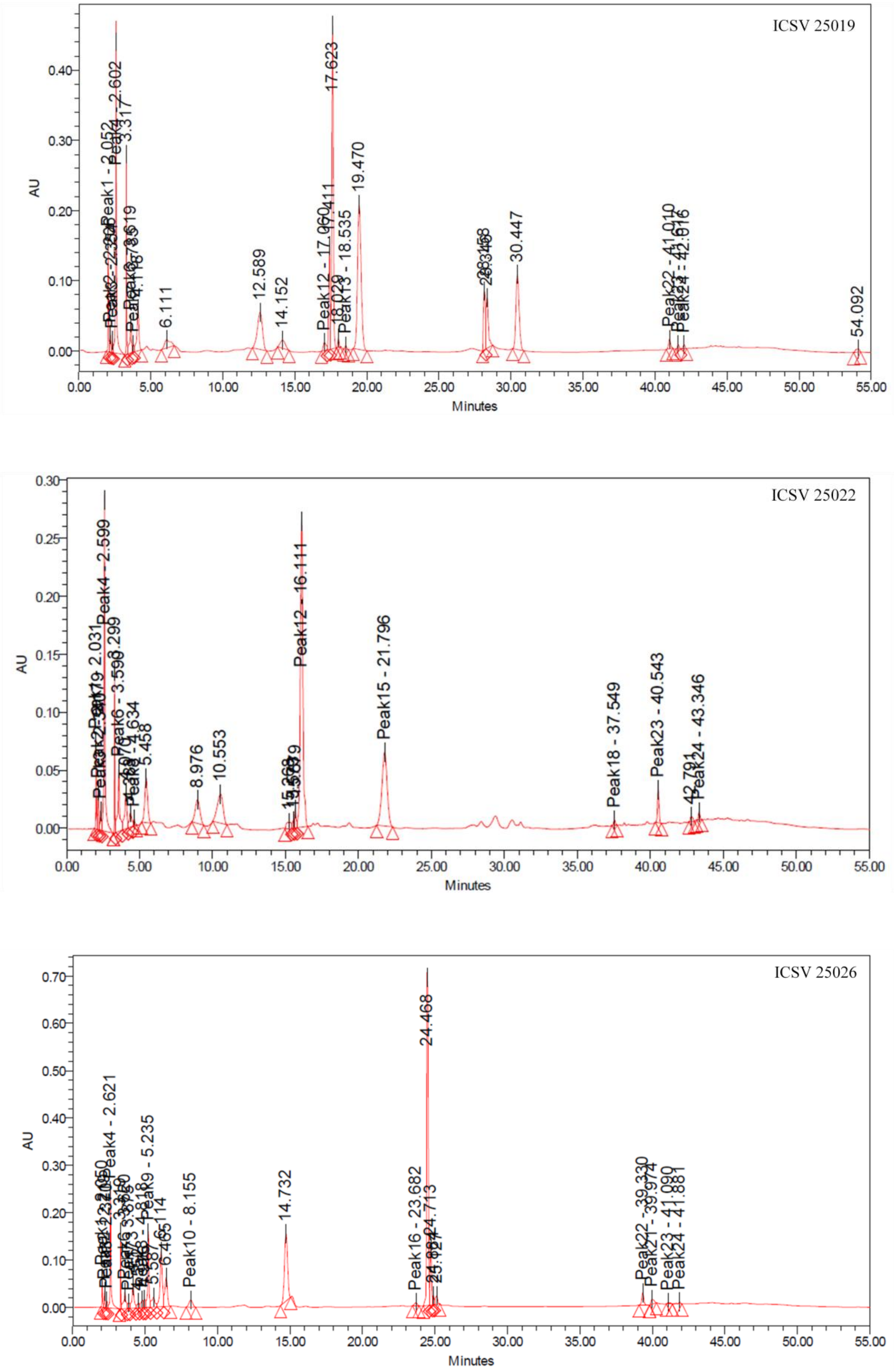
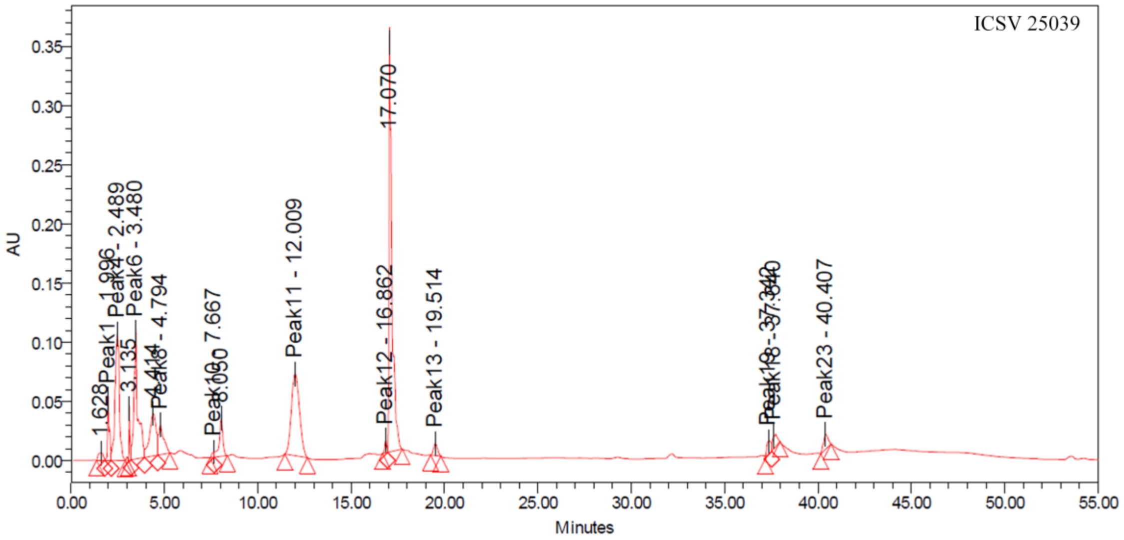

ICSV 25019
AU
Minutes
Peak1 - 2.052
2.602
3.317
12.589
14.152
6.111
17.623
Peak12 - 17.060
Peak13 - 18.535
19.470
30.447
Peak22 - 41.010
54.092
ICSV 25022
AU
Minutes
Peak4 - 2.599
3.299
Peak6 - 3.590
4.634
5.458
8.976
10.553
Peak12 - 16.111
Peak15 - 21.796
Peak18 - 37.549
Peak23 - 40.543
Peak24 - 43.346
42.791
ICSV 25026
AU
Minutes
Peak4 - 2.621
Peak9 - 5.235
6.465
6.114
5.587
Peak10 - 8.155
14.732
24.468
Peak16 - 23.682
24.713
25.127
Peak22 - 39.330
Peak21 - 39.974
Peak23 - 41.090
Peak24 - 41.881
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00

Fig. 11(Cont..)


ICSV 25039
AU
Minutes
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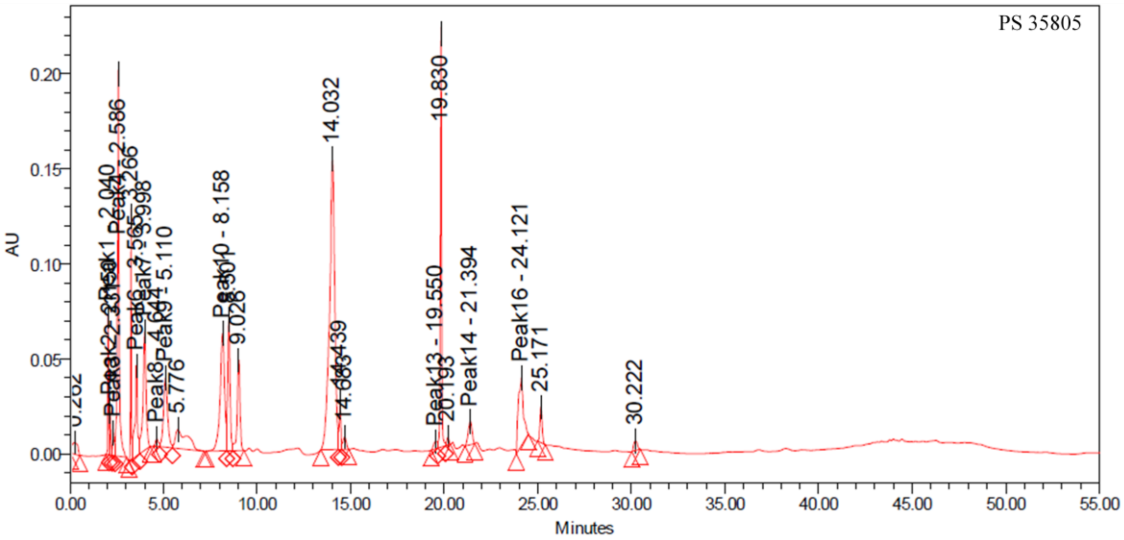
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
1.628
Peak1 - 1.996
Peak4 - 2.489
3.135
Peak6 - 3.480
4.414
Peak8 - 4.794
Peak10
7.667
8.050
Peak11 - 12.009
Peak12 - 16.862
17.070
Peak13 - 19.514
Peak18 - 37.340
Peak23 - 40.407


PS 35805
AU
Minutes
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0.05
0.10
0.15
0.20
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
0.262
Peak1 - 2.040
Peak4 - 2.586
3.266
3.998
Peak7
Peak9 - 5.110
Peak8
5.776
Peak10 - 8.158
9.028
14.032
14.439
14.683
Peak13 - 19.550
19.830
20.193
Peak14 - 21.394
Peak16 - 24.121
25.171
30.222

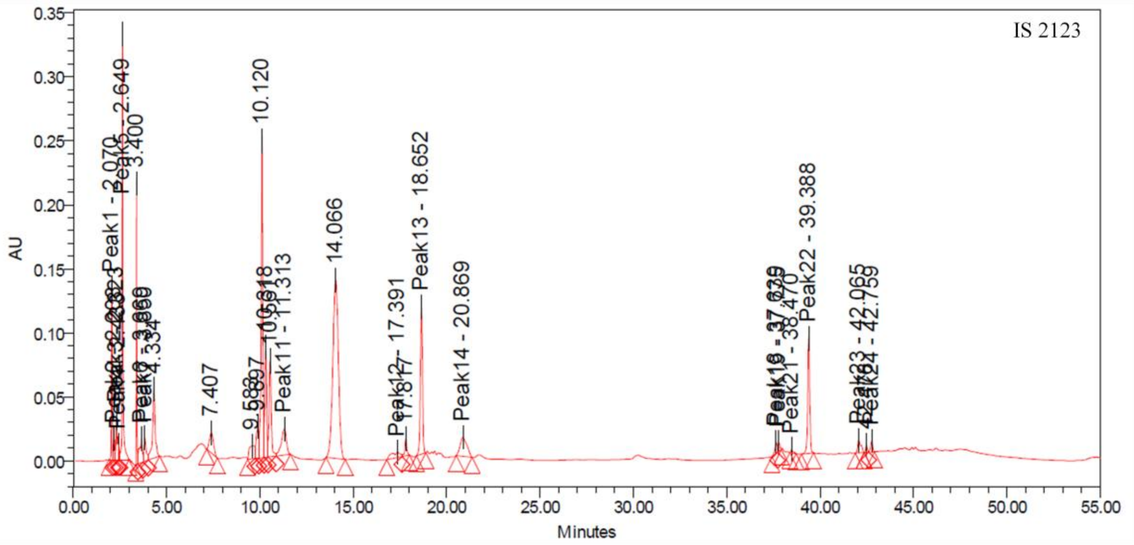
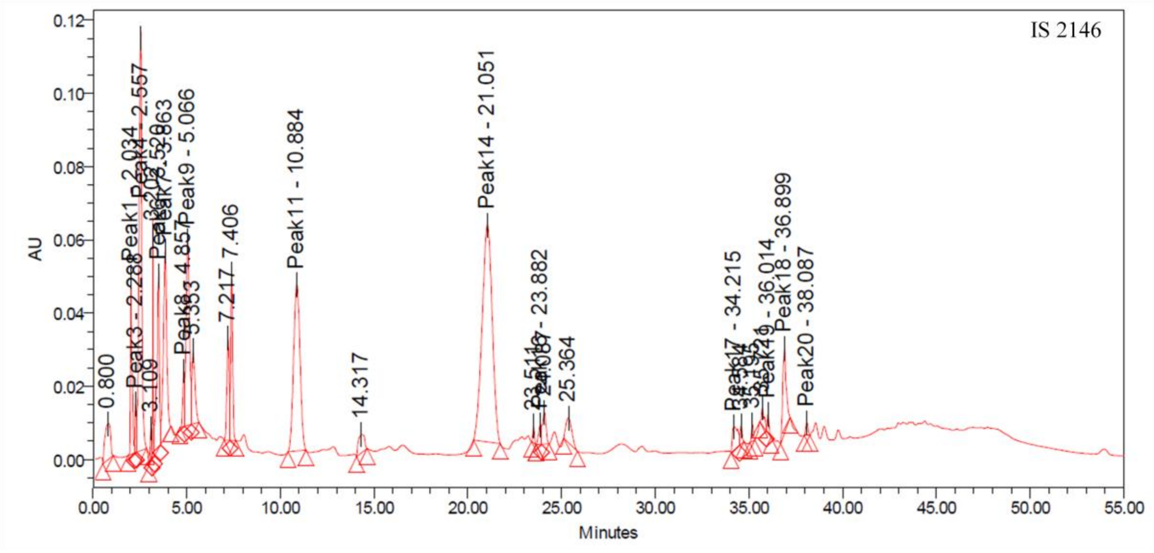

IS 2123
AU
Minutes
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Peak1 - 2.070
Peak5 - 2.649
3.400
3.869
4.334
7.407
9.583
10.120
10.618
Peak11 - 11.313
14.066
Peak12 - 17.391
17.817
Peak13 - 18.652
Peak14 - 20.869
Peak19 - 37.639
Peak21 - 38.470
Peak22 - 39.388
Peak23 - 42.065
Peak24 - 42.759

Fig. 11(Cont..)


IS 2146
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Minutes
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Peak1 - 2.034
Peak3 - 2.288
Peak4 - 2.557
3.109
Peak7 - 3.863
Peak8 - 4.857
5.353
Peak9 - 5.066
7.217
7.406
Peak11 - 10.884
14.317
Peak14 - 21.051
23.511
23.882
25.364
Peak17 - 34.215
Peak18 - 36.899
36.014
Peak20 - 38.087
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
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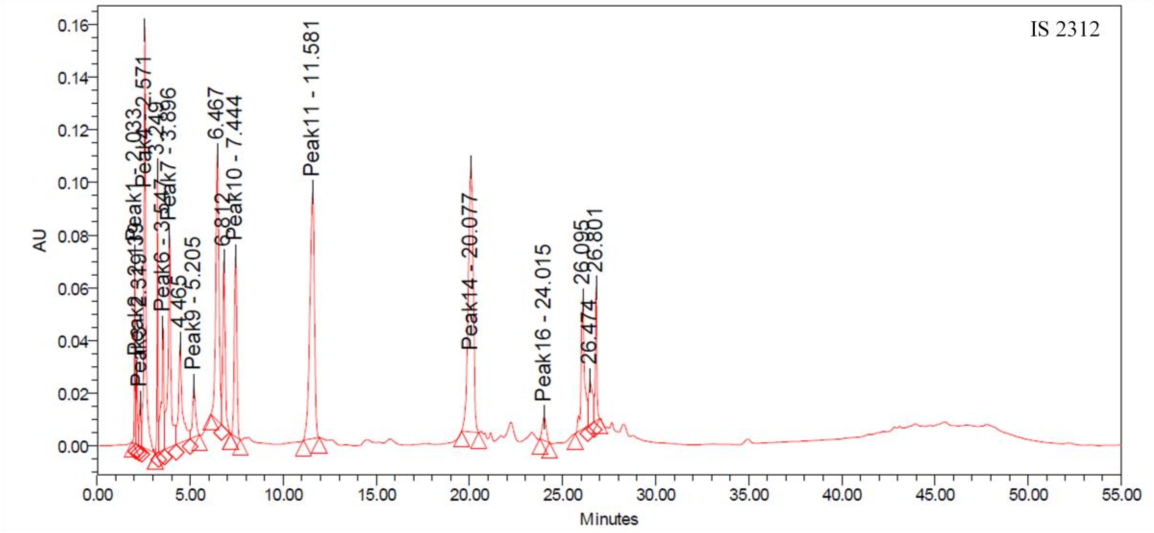
45.00
50.00
55.00


IS 2312
AU
Minutes
Peak1 - 2.033
Peak2
Peak3
Peak4 - 2.571
Peak6 - 3.547
3.249
Peak7 - 3.896
4.465
Peak9 - 5.205
6.467
6.812
Peak10 - 7.444
Peak11 - 11.581
Peak14 - 20.077
Peak16 - 24.015
26.095
26.474
26.801
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00

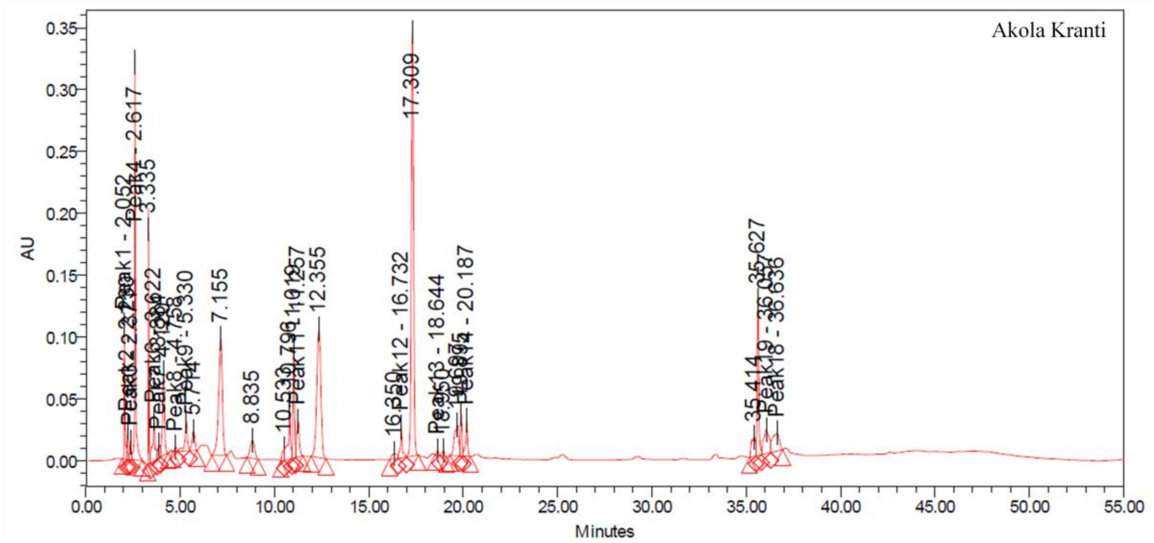
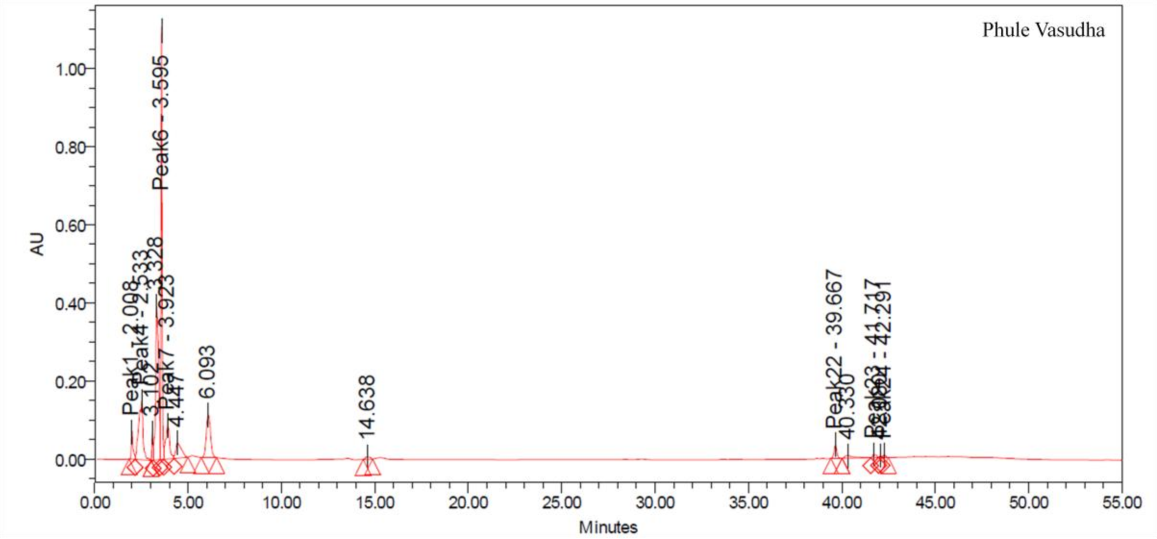

Akola Kranti
AU
Minutes
Peak1 - 2.052
Peak4 - 2.617
3.335
3.622
Peak8 - 4.758
Peak9 - 5.330
5.714
7.155
8.835
10.530
10.796
Peak11
11.257
12.355
16.250
Peak12 - 16.732
17.309
Peak13 - 18.644
Peak14 - 20.187
35.414
35.627
Peak19
Peak18 - 36.636
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00

Fig. 11(Cont..)


Phule Vasudha
AU
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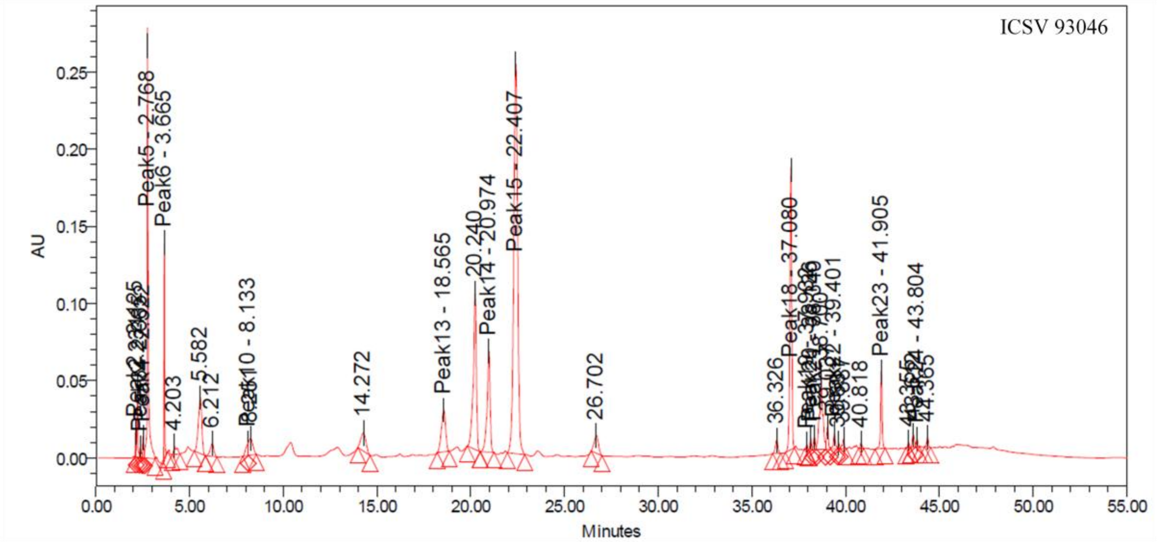
0.80
0.60
0.40
0.20
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Peak1 - 2.098
Peak4 - 2.833
3.107
3.328
Peak6 - 3.595
Peak7 - 3.923
4.447
6.093
14.638
Peak22 - 39.667
40.330
Peak23 - 41.717
Peak24 - 42.291


ICSV 93046
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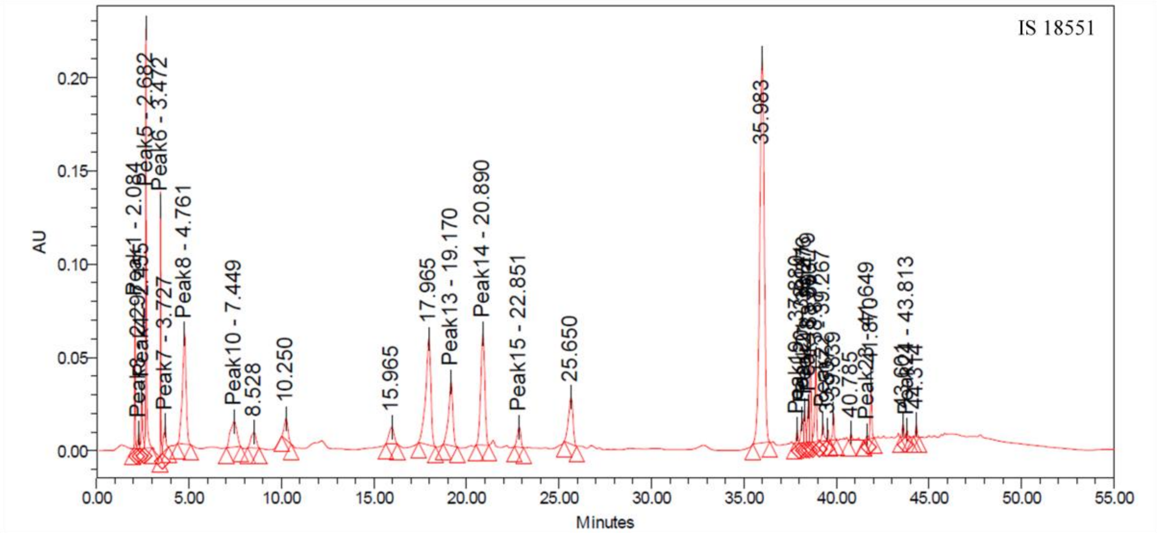
0.10
0.05
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Peak5 - 2.768
Peak6 - 3.665
4.203
5.582
6.212
Peak10 - 8.133
14.272
Peak13 - 18.565
20.240
Peak14 - 20.974
Peak15 - 22.407
26.702
36.326
Peak18 - 37.080
39.401
40.818
Peak23 - 41.905
43.804
44.365


IS 18551
AU
Minutes
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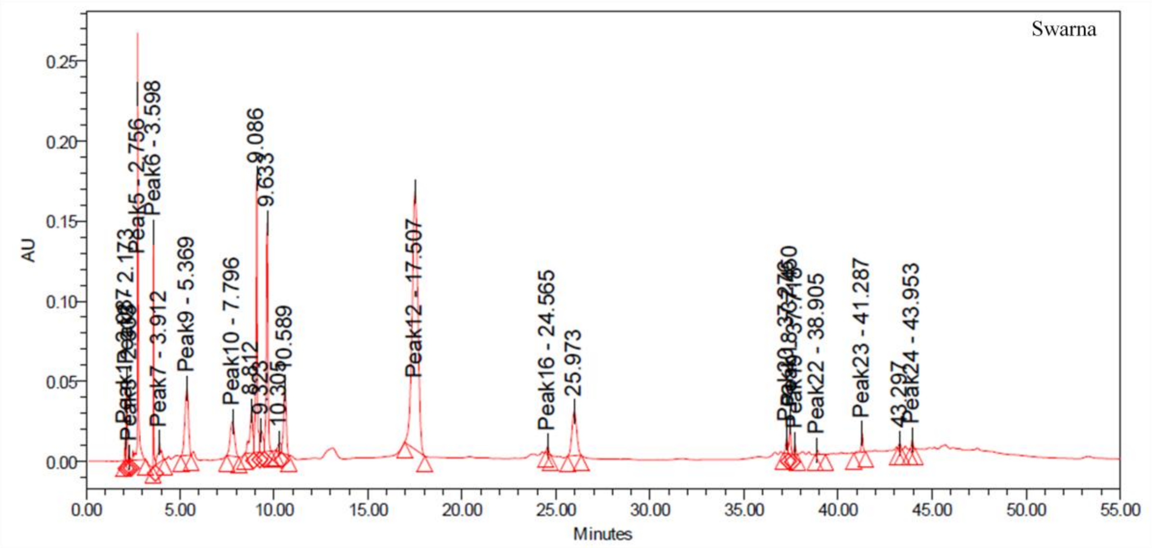
0.15
0.10
0.05
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Peak1 - 2.084
Peak5 - 2.682
Peak6 - 3.472
Peak7 - 3.727
Peak8 - 4.761
Peak10 - 7.449
8.528
10.250
15.965
17.965
Peak13 - 19.170
Peak14 - 20.890
Peak15 - 22.851
25.650
35.983
39.267
40.785
41.649
43.813
44.314

Fig. 11(Cont..)


Swarna
AU
Minutes
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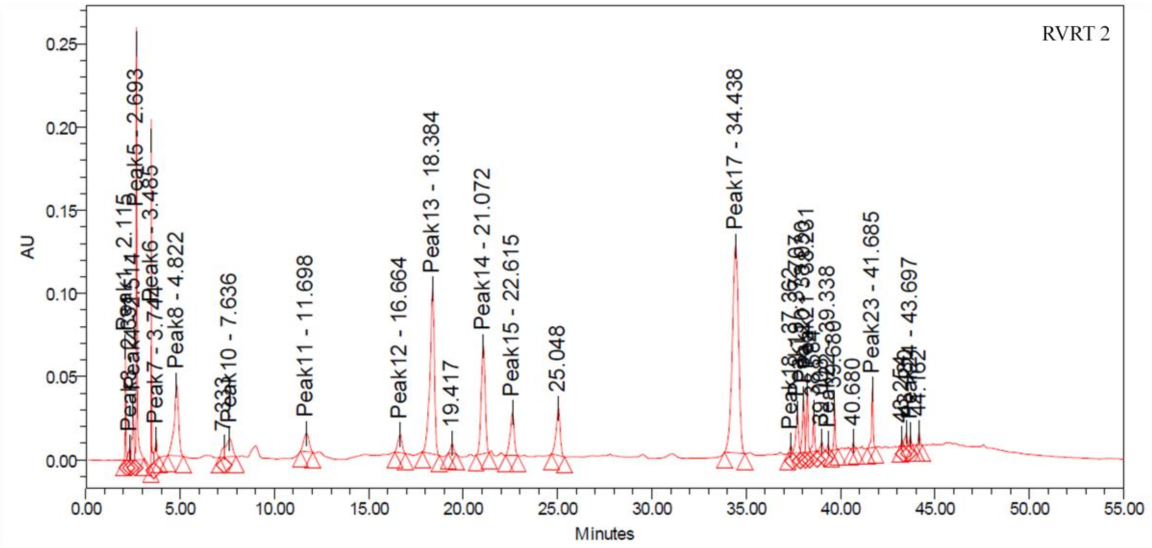
0.05
0.10
0.15
0.20
0.25
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Peak5 - 2.756
Peak6 - 3.598
Peak7 - 3.912
Peak9 - 5.369
Peak10 - 7.796
9.086
9.633
9.325
10.305
10.589
Peak12 - 17.507
Peak16 - 24.565
25.973
Peak22 - 38.905
Peak23 - 41.287
43.297
Peak24 - 43.953


RVRT 2
AU
Minutes
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0.05
0.10
0.15
0.20
0.25
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Peak1 - 2.115
Peak5 - 2.693
Peak6 - 3.485
Peak7 - 3.744
Peak8 - 4.822
7.333
Peak10 - 7.636
Peak11 - 11.698
Peak12 - 16.664
Peak13 - 18.384
19.417
Peak14 - 21.072
Peak15 - 22.615
25.048
Peak17 - 34.438
Peak18 - 37.362
39.338
40.680
Peak23 - 41.685
43.697
44.162

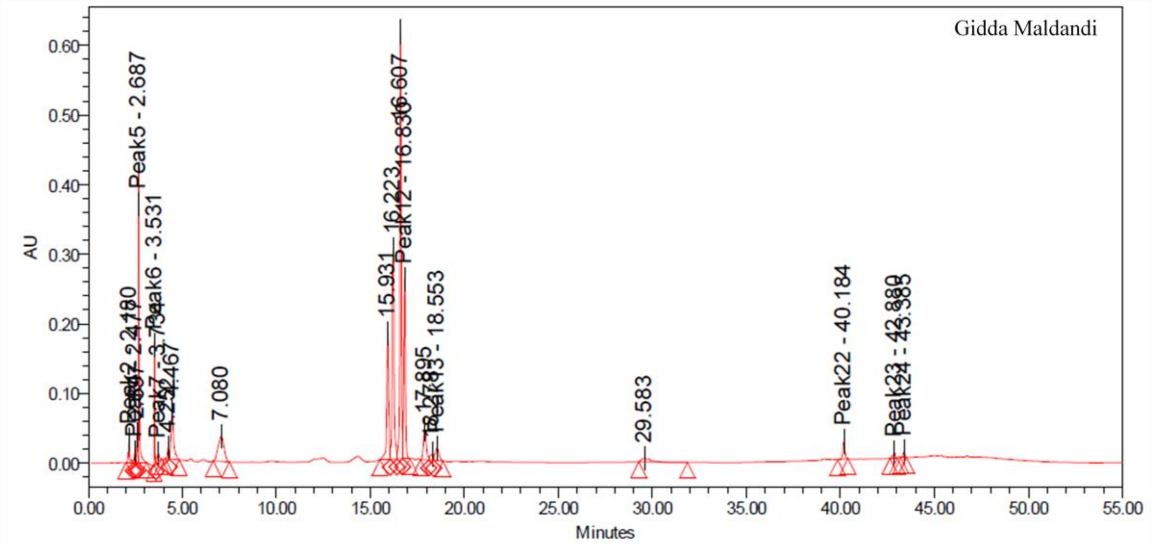
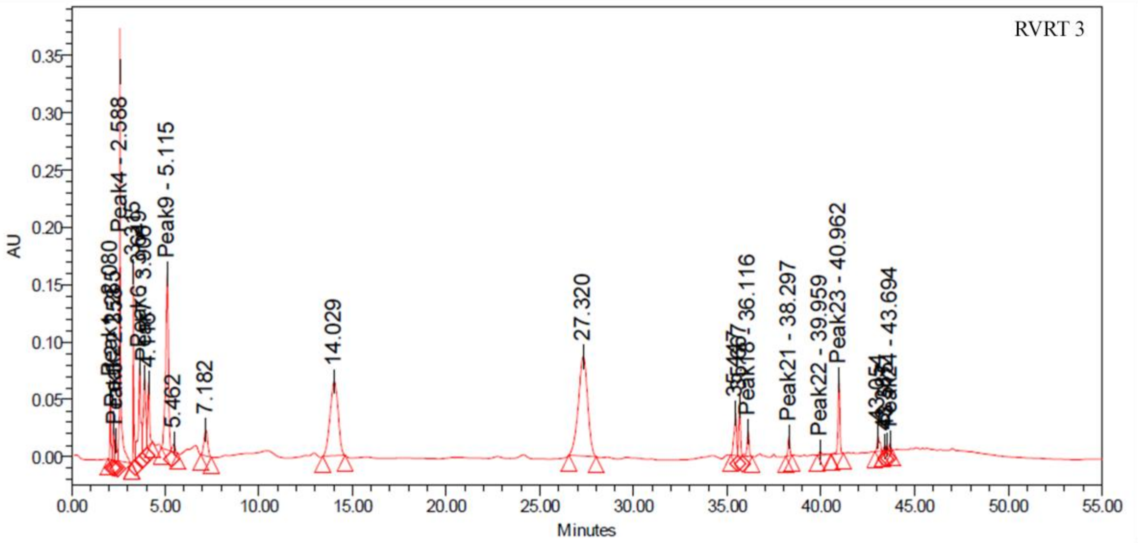
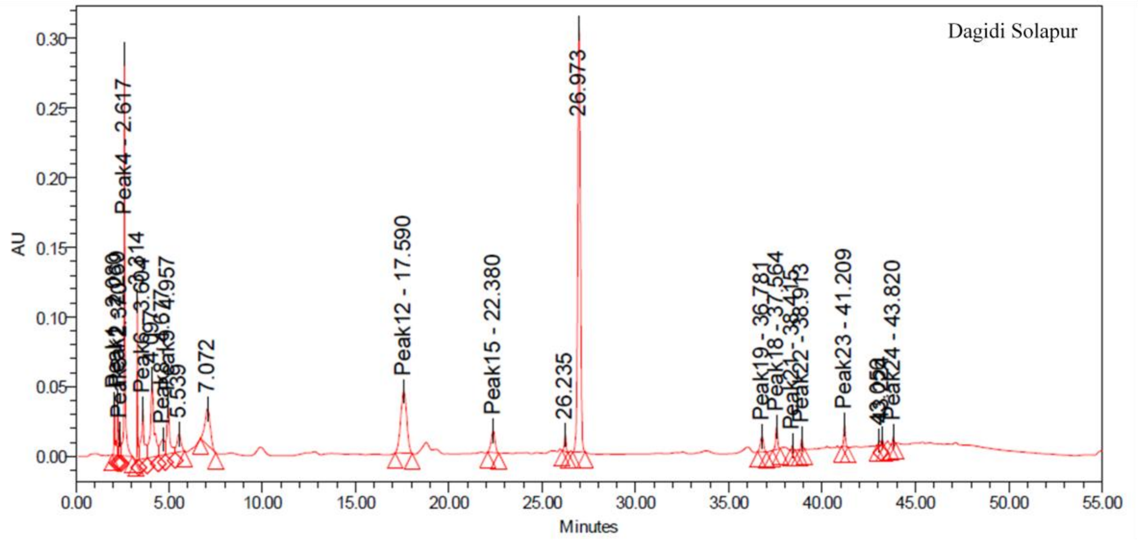
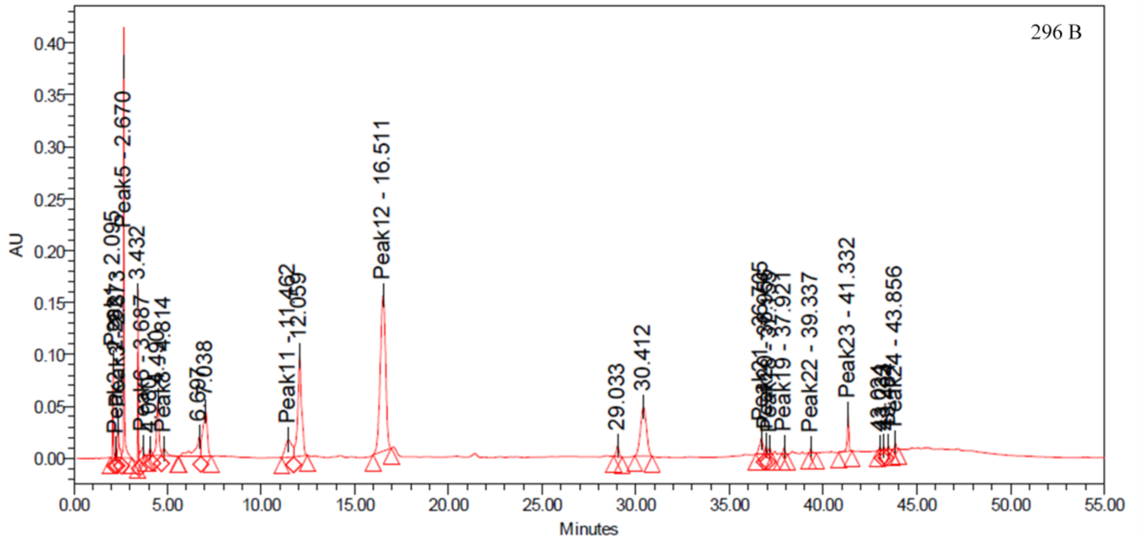

Gidda Maldandi
AU
Minutes
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
Peak5 - 2.687
Peak6 - 3.531
Peak7 - 3.734
4.467
7.080
15.931
16.223
Peak12 - 16.830
16.607
17.895
Peak13 - 18.553
29.583
Peak22 - 40.184
Peak23 - 42.880
Peak24 - 43.383

Fig. 11(Cont..)


RVRT 3
AU
Minutes
Peak4 - 2.588
Peak9 - 5.115
Peak6
5.462
7.182
14.029
27.320
36.116
Peak18
Peak21 - 38.297
Peak22 - 39.959
Peak23 - 40.962
Peak24 - 43.694
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00


Dagidi Solapur
AU
Minutes
Peak4 - 2.617
Peak6 - 3.604
4.957
5.539
7.072
Peak12 - 17.590
Peak15 - 22.380
26.235
26.973
Peak19 - 36.781
Peak22 - 38.913
Peak23 - 41.209
Peak24 - 43.820
0.00
0.05
0.10
0.15
0.20
0.25
0.30
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00


296 B
AU
Minutes
Peak5 - 2.670
2.095
3.432
Peak6 - 3.687
4.814
6.697
7.038
Peak11 - 11.462
12.059
Peak12 - 16.511
29.033
30.412
Peak19 - 37.921
Peak22 - 39.337
Peak23 - 41.332
Peak24 - 43.856
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00

4.5 Inheritance of resistance to sorghum shoot fly, *Atherigona soccata* in sorghum, *Sorghum bicolor*

4.5.1 Expression of resistance to shoot fly, *A. soccata* by the F_1 hybrids (10 X 10 diallel) in comparison with the parents

The variance ratio for 10 parents, 45 F_1's along with 45 reciprocal crosses for all the traits studied were significant at $P \leq 0.01$, with few exceptions. Variance ratio of plants with shoot fly eggs (%), number of shoot fly eggs/plant, and leafsheath pigmentation were significant only in the postrainy season (Table 29).

Very high levels of oviposition (2-4 eggs per plant) were recorded during the rainy season as compared to the postrainy season (1-2 eggs/plant). During rainy season, the genotypes ICSV 25019 (69.73%) and IS 2123 (81.33%), the direct crosses IS 2123 X IS 2146 (66.67%), and IS 18551 X Swarna (74.81%), and the reciprocal cross IS 18551 X M 35-1 (75.76%) exhibited lower oviposition as compared to that of susceptible check Swarna with 93.60% of plants with eggs. In the postrainy season, almost all the crosses exhibited lower percentage of plants with shoot fly eggs than the susceptible check Swarna, with few exceptions. Higher ovipostion was observed in the susceptible genotypes CSV 15 and Swarna and in crosses where these were involved as either of the parents, with 2-3 eggs/plant across the seasons, but there were a few exceptions.

The percentage plants with shoot fly deadhearts in the parents varied from 21.45-83.72% during rainy season, and 3.96-53.05% in the postrainy season; and for crosses, the deadheart percentage ranged from 44.44-100% in the rainy season, and 0.00-68.48% during the postrainy season. The genotypes ICSV 700, Phule Anuradha, ICSV 25019, PS 35805, IS 2123, and IS 2146 exhibited lower deadheart percentage and were on par with the resistant check, IS 18551 across seasons than CSV 15 (83.33% and 40.40%deadhearts respectively, in the rainy and postrainy seasons) and Swarna (76.45% and 53.05%). The genotype M 35-1 showed a susceptible reaction in the rainy season and exhibited resistant nature in the postrainy season. Thirty-three crosses exhibited resistance to shoot fly across seasons, and PS 35805 and IS 18551 were involved as one of the parents in most of these crosses. Most of the genotypes and crosses showed higher number of deadhearts in the rainy season than in the postrainy season.

Table 29. Expression of resistance to sorghum shoot fly, *A. soccata* in sorghum (ICRISAT, Patancheru, 2013-14).

Pedigree	Plants with shoot fly eggs (%)		Number of shoot fly eggs/plant		Shoot fly deadhearts (%)		ORS	
	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR
Parents								
ICSV 700	92.24	16.55	2.33	1.13	66.44	7.48	6.33	6.67
Phule Anuradha	96.29	10.02	2.15	1.00	75.92	8.06	5.00	6.33
M 35-1	91.41	18.25	1.70	1.06	83.72	17.77	8.33	4.00
CSV 15	100.00	44.49	3.57	1.22	83.33	40.40	8.00	6.33
ICSV 25019	69.73	16.53	1.31	1.05	21.45	6.39	5.00	4.33
PS 35805	96.19	10.21	1.81	1.06	44.62	2.17	4.33	4.00
IS 2123	81.33	10.44	2.27	1.00	60.07	4.30	6.00	4.00
IS 2146	94.80	17.72	2.24	1.13	54.59	5.32	6.00	5.33
IS 18551	89.78	6.30	2.12	1.33	60.21	3.96	6.00	4.00
Swarna	93.60	84.57	1.72	1.38	76.45	53.05	8.67	8.33
Direct crosses								
ICSV 700 X Phule Anuradha	100.00	9.39	1.71	0.67	88.64	6.67	5.00	7.00
ICSV 700 X M 35-1	100.00	36.57	1.94	1.00	89.56	32.87	5.67	6.00
ICSV 700 X CSV 15	93.94	30.81	1.92	1.08	80.68	26.64	7.00	7.67
ICSV 700 X ICSV 25019	86.90	22.62	2.17	0.89	73.81	7.54	5.67	5.33
ICSV 700 X PS 35805	80.91	27.78	2.15	1.33	70.91	37.04	4.67	5.67
ICSV 700 X IS 2123	87.88	35.91	3.09	1.00	85.61	15.28	6.00	6.33
ICSV 700 X IS 2146	93.94	33.43	1.65	1.39	74.68	10.17	6.67	5.00
ICSV 700 X IS 18551	100.00	35.81	2.10	1.00	83.33	17.22	6.00	7.00
ICSV 700 X Swarna	93.33	56.78	2.10	1.29	93.33	34.30	7.67	7.00
Phule Anuradha X M 35-1	90.48	3.03	1.56	0.33	90.48	3.03	6.67	6.33
Phule Anuradha X CSV 15	88.89	53.70	2.17	1.00	92.59	35.19	6.00	6.00
Phule Anuradha X ICSV 25019	100.00	47.13	1.26	1.00	96.97	25.05	6.00	6.00
Phule Anuradha X PS 35805	100.00	30.71	1.42	1.00	94.44	19.20	6.33	5.00
Phule Anuradha X IS 2123	100.00	28.69	2.15	1.17	85.86	20.36	5.67	4.67
Phule Anuradha X IS 2146	88.33	54.98	1.93	1.00	92.46	41.29	5.33	6.00
Phule Anuradha X IS 18551	100.00	15.58	2.24	1.00	77.78	14.29	5.67	6.33
Phule Anuradha X Swarna	100.00	65.02	2.21	1.47	94.44	51.86	7.00	6.00
M 35-1 X CSV 15	100.00	48.68	2.30	1.17	91.67	52.38	6.67	5.67
M 35-1 X ICSV 25019	91.67	4.17	2.24	0.33	91.38	12.50	4.67	6.00
M 35-1 X PS 35805	100.00	10.37	1.87	0.67	76.67	6.67	6.33	4.00
M 35-1 X IS 2123	86.77	14.54	2.15	1.00	66.27	17.50	6.00	5.67
M 35-1 X IS 2146	95.83	24.44	2.29	0.83	82.37	24.44	6.00	5.67
M 35-1 X IS 18551	96.08	30.00	3.26	1.83	72.16	28.89	6.00	5.00
M 35-1 X Swarna	91.53	29.44	2.04	1.33	72.75	6.67	5.33	6.67
CSV 15 X ICSV 25019	94.44	70.91	1.80	2.03	94.44	55.45	7.00	6.67
CSV 15 X PS 35805	100.00	83.82	1.54	1.07	93.89	37.88	6.00	7.33
CSV 15 X IS 2123	100.00	21.09	1.76	1.42	85.19	14.42	5.00	5.00
CSV 15 X IS 2146	100.00	72.89	2.16	1.29	89.56	63.36	6.00	5.67
CSV 15 X IS 18551	96.30	60.15	2.14	1.23	97.44	42.12	6.00	7.00
CSV 15 X Swarna	93.33	58.18	1.71	1.56	86.67	68.48	7.67	7.00
ICSV 25019 X PS 35805	85.19	16.98	1.84	1.00	44.44	8.89	5.67	6.33
ICSV 25019 X IS 2123	90.48	2.08	2.47	0.33	61.69	20.83	5.00	5.67
ICSV 25019 X IS 2146	100.00	21.59	2.56	1.00	83.33	11.36	4.67	4.33
ICSV 25019 X IS 18551	95.83	7.54	2.19	0.67	95.83	20.71	5.00	5.00
ICSV 25019 X Swarna	86.77	53.52	1.89	1.27	79.37	46.48	7.33	7.67
PS 35805 X IS 2123	90.48	15.76	1.83	0.67	69.05	12.73	4.33	5.67
PS 35805 X IS 2146	90.11	18.52	2.08	0.83	68.42	14.81	5.00	7.00
PS 35805 X IS 18551	87.83	8.10	2.49	0.67	67.20	5.90	4.33	5.67
PS 35805 X Swarna	97.44	49.66	2.06	1.28	66.80	28.28	6.67	7.00
IS 2123 X IS 2146	66.67	12.63	1.33	1.00	66.67	7.87	6.33	6.67
IS 2123 X IS 18551	91.67	15.74	2.18	0.67	77.22	11.57	5.67	6.00
IS 2123 X Swarna	100.00	51.67	1.85	1.41	92.59	24.17	4.33	5.67
IS 2146 X IS 18551	100.00	6.49	2.09	0.67	87.88	2.56	6.33	4.67
IS 2146 X Swarna	93.64	66.32	1.89	1.22	87.58	51.91	5.67	5.33
IS 18551 X Swarna	74.81	61.34	3.44	1.32	85.93	46.41	6.00	5.33

Table 29. (Cont..)

Pedigree	Plants with shoot fly eggs (%)		Number of shoot fly eggs/plant		Shoot fly deadhearts (%)		ORS	
	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR
Reciprocal crosses								
Phule Anuradha X ICSV 700	100.00	26.85	2.21	1.17	78.33	9.72	5.00	5.33
M 35-1 X ICSV 700	100.00	23.65	1.42	1.08	89.26	12.22	5.33	7.00
M 35-1 X Phule Anuradha	100.00	11.11	1.92	0.44	76.07	0.00	6.33	5.67
CSV 15 X ICSV 700	100.00	91.67	2.27	1.19	91.90	45.83	5.33	6.00
CSV 15 X Phule Anuradha	100.00	37.04	1.39	0.88	93.33	39.15	6.00	6.33
CSV 15 X M 35-1	96.97	55.39	2.05	1.15	96.97	61.45	5.67	6.00
ICSV 25019 X ICSV 700	93.33	13.69	2.33	0.67	76.67	8.93	5.00	6.33
ICSV 25019 X Phule Anuradha	84.85	20.00	1.56	1.11	49.90	13.33	5.67	6.00
ICSV 25019 X M 35-1	100.00	27.36	2.14	1.07	91.53	9.26	5.67	5.33
ICSV 25019 X CSV 15	100.00	99.29	2.97	1.56	85.79	46.19	6.33	7.67
PS 35805 X ICSV 700	100.00	16.30	1.88	1.17	56.88	5.56	5.33	6.00
PS 35805 X Phule Anuradha	83.33	4.17	3.08	0.33	53.17	0.00	5.67	6.00
PS 35805 X M 35-1	100.00	33.86	2.23	1.00	89.74	17.99	6.00	6.00
PS 35805 X CSV 15	88.89	20.63	2.14	0.83	77.78	30.16	7.00	7.67
PS 35805 X ICSV 25019	100.00	25.71	1.89	1.00	75.79	0.00	6.33	6.00
IS 2123 X ICSV 700	96.97	23.93	1.82	1.17	63.54	12.26	6.67	6.33
IS 2123 X Phule Anuradha	100.00	28.10	2.29	1.33	80.16	28.69	7.00	4.67
IS 2123 X M 35-1	97.62	42.06	2.33	1.00	84.92	12.96	5.33	6.33
IS 2123 X CSV 15	100.00	62.64	2.80	1.14	95.24	47.19	6.67	6.00
IS 2123 X ICSV 25019	95.83	25.16	2.19	1.00	64.96	16.23	3.67	5.33
IS 2123 X PS 35805	100.00	15.15	1.67	0.67	82.15	15.15	5.00	6.00
IS 2146 X ICSV 700	100.00	16.50	3.47	1.00	93.33	0.00	6.33	5.00
IS 2146 X Phule Anuradha	93.94	12.96	1.87	0.67	90.91	6.48	5.67	5.67
IS 2146 X M 35-1	87.04	16.62	1.25	1.00	57.83	18.22	6.33	5.67
IS 2146 X CSV 15	100.00	59.43	2.27	1.13	84.26	49.20	5.00	4.67
IS 2146 X ICSV 25019	100.00	13.22	1.38	1.17	86.61	12.96	3.50	5.00
IS 2146 X PS 35805	96.97	24.36	2.29	1.00	90.24	11.79	5.33	4.67
IS 2146 X IS 2123	100.00	9.71	2.27	1.33	73.61	16.85	6.00	4.33
IS 18551 X ICSV 700	100.00	24.16	1.64	1.25	69.44	10.94	6.67	6.67
IS 18551 X Phule Anuradha	90.28	15.00	1.73	0.67	60.00	6.67	6.33	5.33
IS 18551 X M 35-1	75.76	30.28	2.00	1.33	63.64	3.33	6.67	6.67
IS 18551 X CSV 15	100.00	33.27	1.72	1.23	91.67	26.88	6.67	4.67
IS 18551 X ICSV 25019	91.67	9.09	1.59	0.44	83.06	24.58	5.00	5.33
IS 18551 X PS 35805	100.00	25.57	2.35	1.07	78.70	13.26	5.00	5.67
IS 18551 X IS 2123	82.22	10.36	2.22	1.17	72.22	5.59	6.00	4.67
IS 18551 X IS 2146	96.97	23.61	2.19	1.53	74.46	13.06	5.33	6.00
Swarna X ICSV 700	100.00	89.17	2.23	1.31	98.04	58.33	4.67	6.33
Swarna X Phule Anuradha	100.00	60.71	1.78	1.12	90.00	44.05	6.33	6.00
Swarna X M 35-1	100.00	65.29	1.49	0.94	96.97	32.42	6.00	6.00
Swarna X CSV 15	100.00	81.96	1.95	1.26	100.00	65.75	8.00	6.67
Swarna X ICSV 25019	100.00	57.41	2.01	1.54	96.97	52.78	7.33	7.33
Swarna X PS 35805	100.00	63.64	2.25	1.29	91.56	25.76	6.00	7.33
Swarna X IS 2123	100.00	63.26	2.37	1.63	74.44	37.88	7.00	6.00
Swarna X IS 2146	100.00	43.59	2.17	1.29	100.00	48.29	6.33	6.33
Swarna X IS 18551	100.00	67.33	2.43	1.47	100.00	47.48	6.00	6.33
Mean	**94.59**	**33.80**	**2.08**	**1.08**	**79.99**	**23.57**	**5.92**	**5.88**
SE ±	**6.35**	**10.76**	**0.43**	**0.26**	**10.09**	**10.38**	**0.54**	**0.61**
Vr (99, 198)	**1.25^{NS}**	**4.79****	**1.14^{NS}**	**1.45****	**2.06****	**3.05****	**3.06****	**2.31****
LSD (P 0.05)	**17.72**	**30.00**	**1.19**	**0.72**	**28.14**	**28.93**	**1.51**	**1.71**

*, ** F test significant at P 0.05 and 0.01, respectively; R, rainy season; PR, postrainy season; NS, non-significant; ORS, overall resistance score.

M 35-1 X Swarna, PS 35805 X Swarna, IS 18551 X ICSV 700, IS 18551 X Phule Anuradha, and ICSV 700 X IS 2146 exhibited antibiosis resistance mechanism across seasons. Twenty-four crosses showed antibiosis as a mechanism of resistance to shoot fly in the rainy season. The direct crosses ICSV 700 X IS 2123, ICSV 700 X IS 18551, CSV 15 X PS 35805, CSV 15 X IS 18551, PS 35805 X Swarna, IS 2123 X Swarna, and reciprocal crosses CSV 15 X ICSV 700, ICSV 25019 X CSV 15, IS 2123 X M 35-1, IS 18551 X M 35-1, Swarna X M 35-1, Swarna X PS 35805 and Swarna X IS 2123 exhibited lower shoot fly deadhearts than the plants with shoot fly eggs, indicating antibiosis as mechanism of resistance to shoot fly during the postrainy season.

4.5.2 Morphological traits

ICSV 700, Phule Anuradha, IS 2123, IS 2146 and IS 18551, and the 29 crosses were glossy with high plant vigor, and had leafsheath pigmentation and high trichome density on the abaxial and adaxial leaf surfaces (Table 30). Phule Anuradha, ICSV 25019, PS 35805, IS 2123, IS 2146 and IS 18551 the resistant parents were common in most of these crosses. The hybrids ICSV 700 X M 35-1, ICSV 700 X PS 35805, ICSV 700 X IS 2146, Phule Anuradha X M 35-1, M 35-1 X Phule Anuradha, M 35-1 X IS 2146, M 35-1 X IS 18551, IS 2146 X Phule Anuradha and IS 18551 X Swarna expressed the leaf glossiness, leafsheath pigmentation, high vigor and high trichome density only in the rainy season; whereas the crosses ICSV 700 X CSV 15, M 35-1 X PS 35805, PS 35805 X IS 2123, PS 35805 X IS 18551, IS 2123 X M 35-1, IS 2123 X IS 2146 expressed these traits only in the postrainy season. The cross between the parents with high and low waxy bloom resulted in progenies with high waxy bloom. Few of the hybrids in the rainy season, and most of the hybrids in the postrainy season exhibited high waxy bloom. The cross between the tan (colorless plant) and non-tan (red colored plant) plants resulted in non-tan hybrids, with either of the non-tan parent acting as a male or female.

4.5.3 Combining ability analysis of shoot fly resistance and morphological traits

4.5.3.1 Analysis of variance for combining ability

The estimation of mean sum of squares (ANOVA) for GCA of parents and SCA of hybrids (Table 31) revealed that the mean sum of squares for general combining ability of all the traits studied in the rainy season and postrainy seasons were significant at P 0.01. Since, the mean sum of squares in the rainy season for plants with shoot fly eggs, number

Table 30. Morphological characteristics of sorghum (Parents & F_1 crosses) evaluated for resistance to sorghum shoot fly, *A. soccata* (ICRISAT, Patancheru, 2013-14).

Pedigree	Leaf glossy score		Plant vigor score		Leafsheath pigmentation		Trichome density on abaxial leaf surface		Trichome density on adaxial leaf surface		Waxy bloom		Plant color	
	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR
Parents														
ICSV 700	2.67	1.00	1.33	1.00	1.67	1.00	139.00	89.56	162.67	109.22	1.33	2.00	2.00	2.00
Phule Anuradha	1.50	2.67	1.00	1.33	1.50	2.00	73.33	62.56	98.22	64.00	1.67	2.00	1.00	1.00
M 35-1	3.67	3.00	2.67	1.33	1.67	2.00	83.78	70.67	85.44	57.67	2.00	2.00	1.00	1.00
CSV 15	3.33	5.00	2.00	3.00	1.67	3.00	0.00	0.00	0.00	0.00	3.00	2.67	2.00	2.00
ICSV 25019	2.33	3.33	1.00	2.33	1.00	2.00	45.56	47.56	64.78	45.33	3.00	3.00	2.00	2.00
PS 35805	4.00	3.33	2.33	2.33	1.67	2.00	64.78	61.22	74.11	72.89	3.00	3.00	2.00	2.00
IS 2123	3.67	1.00	2.33	1.00	2.33	2.00	58.78	51.44	60.11	59.28	1.00	2.00	1.00	1.00
IS 2146	2.00	1.33	1.33	1.00	1.67	1.67	106.89	84.28	120.67	97.61	1.00	2.00	1.00	1.00
IS 18551	3.33	1.00	2.00	1.00	1.67	1.33	84.11	84.56	97.56	101.56	1.00	1.00	1.00	1.00
Swarna	3.67	5.00	2.00	2.33	2.00	2.00	33.89	7.11	32.22	13.33	3.00	3.00	1.00	1.00
Direct crosses														
ICSV 700 X Phule Anuradha	3.67	2.33	2.00	1.67	1.67	1.67	59.67	59.06	92.33	72.11	1.00	2.00	1.00	1.00
ICSV 700 X M 35-1	3.00	3.33	1.33	2.33	2.00	2.00	66.44	83.11	108.67	104.78	1.00	2.00	1.00	1.00
ICSV 700 X CSV 15	3.67	3.33	2.33	2.00	1.33	2.00	51.67	54.78	89.00	101.28	1.67	3.00	2.00	2.00
ICSV 700 X ICSV 25019	2.67	2.67	1.67	1.33	1.00	2.00	68.33	75.89	112.22	102.67	1.33	2.00	2.00	2.00
ICSV 700 X PS 35805	2.67	4.00	1.33	2.33	1.00	2.33	49.56	52.33	74.78	63.56	1.33	2.33	2.00	2.00
ICSV 700 X IS 2123	3.33	3.00	1.67	2.00	1.67	2.00	49.22	64.11	78.89	87.78	1.00	2.00	1.00	1.00
ICSV 700 X IS 2146	2.67	3.00	1.00	2.33	1.33	2.00	54.11	71.44	93.00	74.00	1.33	1.67	1.00	1.00
ICSV 700 X IS 18551	2.33	2.33	1.33	1.33	1.33	1.67	65.11	90.78	102.67	96.44	1.00	1.33	1.00	1.00
ICSV 700 X Swarna	3.00	4.67	1.50	2.33	2.00	2.00	67.11	58.11	104.78	74.78	1.67	2.33	1.00	1.00
Phule Anuradha X M 35-1	2.67	3.33	1.33	2.33	1.67	2.67	51.33	58.56	68.11	72.22	1.00	2.33	1.00	1.00
Phule Anuradha X CSV 15	4.00	4.00	2.00	1.67	1.67	2.67	34.22	36.50	48.00	38.94	1.67	2.67	1.00	1.00
Phule Anuradha X ICSV 25019	3.33	3.33	1.33	2.00	1.33	2.33	52.11	56.00	69.56	56.67	1.33	2.33	1.00	1.00
Phule Anuradha X PS 35805	3.00	3.67	1.67	2.00	2.00	2.33	56.00	53.11	68.22	64.56	1.33	2.00	1.00	1.00
Phule Anuradha X IS 2123	3.00	3.00	2.00	2.00	1.33	2.00	45.00	67.11	61.56	66.22	1.00	1.67	1.00	1.00
Phule Anuradha X IS 2146	3.33	3.67	2.00	1.67	1.67	2.33	81.22	69.56	98.22	88.22	1.67	1.67	1.00	1.00

Table 30. (Cont..)

Pedigree	Leaf glossy score		Plant vigor score		Leafsheath pigmentation		Trichome density on abaxial leaf surface		Trichome density on adaxial leaf surface		Waxy bloom		Plant color	
	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR
Phule Anuradha X IS 18551	2.00	3.33	1.00	1.33	1.33	2.00	75.00	81.44	95.22	98.00	1.67	1.00	1.00	1.00
Phule Anuradha X Swarna	4.67	4.67	2.33	2.00	2.00	2.67	27.28	9.17	35.22	18.17	2.33	2.67	1.00	1.00
M 35-1 X CSV 15	3.67	4.33	2.00	2.67	1.33	2.33	2.00	26.56	6.11	32.44	2.00	2.33	1.00	1.00
M 35-1 X ICSV 25019	4.00	3.33	2.67	2.33	1.33	2.00	44.00	40.33	55.33	49.78	1.67	2.33	1.00	1.00
M 35-1 X PS 35805	2.67	3.33	1.67	2.00	1.33	2.33	42.22	55.61	54.22	73.78	1.33	3.00	1.00	1.00
M 35-1 X IS 2123	2.33	3.33	1.33	1.67	1.33	2.00	47.56	36.89	58.11	51.67	1.00	2.00	1.00	1.00
M 35-1 X IS 2146	2.67	3.67	1.67	1.67	1.33	2.33	64.56	71.78	94.56	88.00	1.00	2.00	1.00	1.00
M 35-1 X IS 18551	2.67	3.00	1.33	2.67	1.67	2.00	60.67	94.83	85.78	103.06	1.00	1.33	1.00	1.00
M 35-1 X Swarna	1.67	3.33	1.33	2.33	1.33	2.00	47.67	58.17	72.44	80.89	1.67	2.00	1.00	1.33
CSV 15 X ICSV 25019	4.33	5.00	2.00	2.00	2.00	2.33	0.00	0.00	0.78	0.00	3.00	2.67	2.00	2.00
CSV 15 X PS 35805	4.33	4.00	2.33	2.33	2.67	2.33	0.00	0.00	0.00	0.00	2.67	3.00	2.00	2.00
CSV 15 X IS 2123	4.33	4.67	2.00	2.00	1.67	2.67	6.44	3.89	12.22	7.78	2.33	2.33	1.00	1.00
CSV 15 X IS 2146	4.00	4.00	2.33	2.00	1.67	3.00	34.89	25.00	49.67	44.22	2.33	2.00	1.00	1.00
CSV 15 X IS 18551	4.67	4.00	2.67	2.33	1.33	2.00	36.44	21.00	54.44	28.83	1.67	2.00	1.00	1.00
CSV 15 X Swarna	4.33	4.67	2.67	2.67	1.33	3.00	3.78	0.00	6.22	0.00	2.67	3.00	1.00	1.00
ICSV 25019 X PS 35805	3.00	3.33	1.00	2.67	1.33	2.33	37.89	68.56	57.00	59.61	3.00	3.00	2.00	2.00
ICSV 25019 X IS 2123	3.33	3.67	2.00	2.67	1.00	2.67	44.89	47.22	58.33	61.39	1.33	2.33	1.00	1.00
ICSV 25019 X IS 2146	3.67	4.00	1.67	2.00	1.33	2.00	75.67	80.78	100.44	96.78	1.33	2.00	1.00	1.00
ICSV 25019 X IS 18551	2.33	3.67	1.00	2.00	1.33	2.00	67.00	92.44	94.11	110.11	1.00	2.00	1.00	1.00
ICSV 25019 X Swarna	4.33	5.00	2.67	2.67	2.00	2.00	17.89	8.44	29.22	13.89	3.00	3.00	1.00	1.00
PS 35805 X IS 2123	2.33	2.67	1.33	2.00	1.33	2.00	44.78	52.67	58.56	64.44	1.00	2.00	1.00	1.00
PS 35805 X IS 2146	2.33	2.67	1.67	1.67	1.33	2.33	69.33	43.78	87.67	70.33	1.00	2.33	1.00	1.00
PS 35805 X IS 18551	3.33	3.00	2.00	1.33	2.00	2.00	62.22	55.00	89.22	83.67	1.00	2.00	1.00	1.00
PS 35805 X Swarna	3.33	4.67	2.00	2.67	2.33	2.33	28.67	11.67	44.67	9.89	3.00	3.00	1.00	1.00
IS 2123 X IS 2146	3.33	3.33	1.33	2.33	1.67	2.00	46.44	77.33	70.67	81.67	1.00	2.00	1.00	1.00
IS 2123 X IS 18551	2.00	2.33	1.00	1.33	1.00	2.00	55.22	69.39	85.11	79.78	1.00	1.00	1.00	1.00
IS 2123 X Swarna	3.33	3.67	2.33	2.00	1.33	2.00	24.11	30.33	43.00	32.44	1.67	2.33	1.00	1.00
IS 2146 X IS 18551	1.67	2.00	1.00	1.00	1.33	2.00	88.33	104.33	124.67	115.00	1.33	1.00	1.00	1.00

Table 30. (Cont..)

Pedigree	Leaf glossy score		Plant vigor score		Leafsheath pigmentation		Trichome density on abaxial leaf surface		Trichome density on adaxial leaf surface		Waxy bloom		Plant color	
	2013 R	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**
IS 2146 X Swarna	3.67	4.33	1.67	2.33	1.33	2.00	83.11	46.06	112.11	56.00	2.00	2.67	1.00	1.00
IS 18551 X Swarna	3.33	4.67	2.00	2.33	1.33	2.33	59.56	56.89	87.00	84.11	1.67	2.00	1.00	1.00
Reciprocal crosses														
Phule Anuradha X ICSV 700	3.00	2.67	1.33	2.00	1.33	2.00	72.78	74.22	105.00	93.00	1.33	2.00	1.00	1.00
M 35-1 X ICSV 700	3.67	3.33	2.33	2.33	1.67	2.00	48.78	64.78	77.78	82.44	1.33	2.00	1.00	1.00
M 35-1 X Phule Anuradha	2.33	4.00	1.33	2.00	1.00	2.33	53.89	41.78	69.22	46.67	1.00	2.00	1.00	1.00
CSV 15 X ICSV 700	4.00	5.00	2.33	2.00	1.67	2.33	20.56	4.33	39.67	13.17	1.67	2.33	2.00	2.00
CSV 15 X Phule Anuradha	3.67	4.33	1.67	2.00	2.67	2.33	3.22	0.00	4.11	0.00	1.67	2.33	1.00	1.00
CSV 15 X M 35-1	3.67	5.00	2.00	2.33	1.33	2.67	5.89	0.00	8.33	0.00	1.67	2.33	1.00	1.00
ICSV 25019 X ICSV 700	2.67	2.67	1.33	1.33	1.67	2.00	58.56	70.22	79.89	76.00	1.67	2.33	2.00	2.00
ICSV 25019 X Phule Anuradha	3.00	3.67	2.00	1.67	1.67	2.33	40.67	72.39	51.89	68.06	1.33	2.33	1.00	1.00
ICSV 25019 X M 35-1	3.67	3.33	2.00	2.33	1.00	2.00	48.78	52.17	57.89	53.61	2.00	2.00	1.00	1.00
ICSV 25019 X CSV 15	3.33	4.67	1.67	2.33	1.67	2.67	4.33	0.00	3.67	0.00	3.00	3.00	2.00	2.00
PS 35805 X ICSV 700	3.00	3.67	1.67	2.00	2.00	2.00	45.22	62.39	79.44	71.94	1.67	2.33	2.00	2.00
PS 35805 X Phule Anuradha	1.67	3.00	1.00	1.67	1.67	2.00	48.00	58.67	65.78	60.11	1.67	2.00	1.00	1.00
PS 35805 X M 35-1	2.33	4.00	1.33	2.33	1.33	2.33	41.00	42.89	60.78	54.61	1.67	2.33	1.00	1.00
PS 35805 X CSV 15	2.67	4.33	1.00	2.00	1.83	2.67	5.78	29.94	12.22	36.39	2.67	3.00	1.67	1.67
PS 35805 X ICSV 25019	2.33	3.67	1.67	2.00	1.67	2.00	42.22	68.61	59.00	64.00	3.00	3.00	2.00	2.00
IS 2123 X ICSV 700	1.67	2.33	1.33	1.33	1.33	1.67	45.78	68.89	71.00	70.33	1.00	2.00	1.00	1.00
IS 2123 X Phule Anuradha	3.67	4.00	1.67	2.33	1.33	2.33	46.83	45.17	59.22	47.78	1.00	2.00	1.00	1.00
IS 2123 X M 35-1	3.67	3.33	1.67	1.67	1.33	2.00	40.11	50.33	60.33	59.00	1.00	2.00	1.00	1.00
IS 2123 X CSV 15	4.67	5.00	2.67	2.33	2.00	2.33	1.00	6.72	7.78	5.44	2.00	2.33	1.00	1.00
IS 2123 X ICSV 25019	2.67	3.33	1.33	1.33	1.00	2.00	31.89	41.39	47.67	51.83	1.00	2.33	1.00	1.00
IS 2123 X PS 35805	3.00	3.00	1.33	1.67	1.33	1.67	63.56	63.44	79.44	60.44	1.33	2.00	1.00	1.00
IS 2146 X ICSV 700	3.33	2.67	1.33	1.33	1.33	2.00	79.33	60.22	110.78	70.89	1.00	2.00	1.00	1.00
IS 2146 X Phule Anuradha	2.33	3.67	1.67	2.00	2.00	2.33	76.00	87.33	109.56	86.78	1.67	2.00	1.00	1.00
IS 2146 X M 35-1	2.33	3.00	1.00	1.33	1.67	2.00	81.39	88.56	85.50	99.44	1.00	2.00	1.00	1.00
IS 2146 X CSV 15	4.00	4.33	2.33	2.33	1.67	2.33	35.89	4.33	53.78	11.33	2.00	2.33	1.00	1.00

Table 30. (Cont..)

Pedigree	Leaf glossy score		Plant vigor score		Leafsheath pigmentation		Trichome density on abaxial leaf surface		Trichome density on adaxial leaf surface		Waxy bloom		Plant color	
	2013 R	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**
IS 2146 X ICSV 25019	2.50	3.33	1.00	2.00	1.00	1.67	95.78	78.11	113.00	94.22	1.00	2.00	1.00	1.00
IS 2146 X PS 35805	2.67	2.67	1.67	1.33	1.33	2.00	91.78	63.56	118.67	66.67	1.33	2.00	1.00	1.00
IS 2146 X IS 2123	2.00	2.00	1.00	1.00	1.67	1.67	90.00	91.33	106.00	110.78	1.00	1.67	1.00	1.00
IS 18551 X ICSV 700	2.67	2.00	1.00	1.00	1.00	1.33	77.89	60.44	101.56	78.78	1.00	1.67	1.00	1.00
IS 18551 X Phule Anuradha	3.00	3.00	1.67	2.00	1.33	2.00	61.78	58.33	95.00	76.89	1.00	1.67	1.00	1.00
IS 18551 X M 35-1	2.67	3.33	1.00	1.67	1.00	2.00	57.33	69.33	83.22	94.22	1.00	1.33	1.00	1.00
IS 18551 X CSV 15	3.67	4.33	2.33	2.33	1.67	2.00	39.00	38.11	67.33	59.39	1.67	1.67	1.00	1.00
IS 18551 X ICSV 25019	3.33	3.00	1.67	1.67	1.67	2.00	81.78	73.00	107.33	77.56	1.00	1.67	1.00	1.00
IS 18551 X PS 35805	2.00	2.33	1.33	2.00	1.00	2.00	64.56	86.22	99.00	96.78	1.00	1.67	1.00	1.00
IS 18551 X IS 2123	2.33	2.00	1.33	1.33	1.00	2.00	70.11	75.00	99.11	93.78	1.00	1.67	1.00	1.00
IS 18551 X IS 2146	2.33	1.67	1.33	1.00	1.67	2.00	89.33	94.44	112.11	107.11	1.00	1.67	1.00	1.00
Swarna X ICSV 700	4.33	4.67	2.33	2.00	1.67	2.00	66.89	58.94	108.89	74.67	2.33	2.00	1.00	1.00
Swarna X Phule Anuradha	3.67	4.33	2.33	2.00	1.67	2.00	16.11	20.89	26.67	32.89	2.33	2.33	1.00	1.00
Swarna X M 35-1	4.33	5.00	2.00	2.67	2.33	2.33	21.89	22.33	26.89	17.89	2.33	2.00	1.00	1.00
Swarna X CSV 15	4.33	5.00	2.67	2.67	2.33	2.33	4.78	0.00	9.78	0.00	2.67	3.00	1.00	1.00
Swarna X ICSV 25019	3.67	4.67	2.67	3.00	1.67	2.00	13.22	2.11	15.89	3.22	3.00	3.00	1.00	1.00
Swarna X PS 35805	4.33	4.67	2.67	2.00	1.33	2.67	16.00	5.44	19.33	5.39	3.00	3.00	1.00	1.00
Swarna X IS 2123	4.67	4.67	2.67	3.00	1.67	2.00	16.89	21.56	29.56	19.44	2.00	2.67	1.00	1.00
Swarna X IS 2146	4.67	4.33	1.67	2.33	1.33	2.00	67.22	55.28	92.78	73.67	2.67	3.00	1.00	1.00
Swarna X IS 18551	3.67	4.67	2.33	2.33	2.00	2.00	50.22	78.22	89.78	97.44	2.33	2.33	1.00	1.00
Mean	**3.17**	**3.52**	**1.74**	**1.96**	**1.55**	**2.12**	**49.70**	**50.90**	**68.70**	**60.45**	**1.70**	**2.19**	**1.20**	**1.16**
SE ±	**0.57**	**0.35**	**0.40**	**0.34**	**0.36**	**0.24**	**7.69**	**10.22**	**9.06**	**9.92**	**0.24**	**0.23**	**0.03**	**0.05**
Vr (99, 198)	**2.04****	**8.03****	**1.70****	**2.18****	**1.08**^{NS}	**1.84****	**12.46****	**7.75****	**14.81****	**11.12****	**8.07****	**4.74****	**118.09****	**58.48****
LSD (P 0.05)	**1.58**	**0.97**	**1.12**	**0.96**	**0.99**	**0.68**	**21.45**	**28.50**	**25.26**	**27.65**	**0.68**	**0.65**	**0.09**	**0.13**

** F probability significant at P 0.05; NS, non-significant; R, rainy season; PR, postrainy season.

Table 31. Analysis of variance (ANOVA) showing mean sum of squares of general, specific and reciprocal combining abilities of F_1 (10 X 10) diallel (ICRISAT, Patancheru, 2013-14).

Source	GCA		SCA		Reciprocal		Error	
	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR
Plants with shoot fly eggs (%)	62.20	2707.91**	42.10	524.18**	56.02	256.12**	40.36	110.81
Number of shoot fly eggs/plant	0.20	0.33**	0.19	0.09	0.23	0.06	0.18	0.07
Shoot fly deadhearts (%)	673.87**	2410.48**	190.33**	146.67	136.37	93.05	101.81	107.64
Overall resistance score	3.14**	3.23**	0.89**	0.77**	0.448 *	0.51	0.29	0.38
Leaf glossy score	2.89**	7.34**	0.43	0.49**	0.42	0.17*	0.32	0.12
Plant vigor score	1.13**	1.33**	0.24*	0.17*	0.13	0.13	0.16	0.12
Leafsheath pigmentation	0.34	0.65**	0.11	0.06	0.12	0.05	0.13	0.06
Trichome density on abaxial leaf surface	6126.24 **	6846.39**	292.89 **	236.67**	104.26 **	173.84**	59.16	104.42
Trichome density on adaxial leaf surface	10789.18 **	9028.91**	346.52 **	314.57**	166.63 **	285.76**	81.99	98.31
Plant color	0.82 **	0.80 **	0.12 **	0.13 **	0.00	0.00	0.00	0.00
Waxy bloom	3.91 **	2.22 **	0.22 **	0.07	0.05	0.05	0.06	0.05

*, ** F probability significant at P 0.05 and P 0.01, respectively; GCA, general combining ability; SCA, specific combining ability; R, rainy season; PR, postrainy season.

of shoot fly eggs/plant and leafsheath pigmentation were non-significant, the combining ability estimates were not computed for these traits. The mean sum of squares due to SCA weresignificant for all the traits during the rainy and postrainy seasons, except leaf glossy score during the rainy season and number of shoot fly eggs/plant, shoot fly deadhearts (%), and leafsheath pigmentation in the postrainy season. This indicated substantial genetic variability for the characters studied, and also the predominance of both the additive and non-additive nature of gene action. The mean sum of squares for the reciprocal crosses were significant for trichome density on abaxial and adaxial leaf surfaces across seasons; overall resistance score during the rainy season, and plants with shoot fly eggs, and leaf glossy score during the postrainy season, suggesting influence of cytoplasmic factors in expression of the traits associated with shoot fly resistance in sorghum.

4.5.4 Estimates of *gca, sca* and reciprocal effects of shoot fly resistance and morphological traits of parents and hybrids

4.5.4.1 *gca* effects of shoot fly resistance traits

The general combining ability (*gca*) effects for shoot fly deadhearts ranged from -8.13 (PS 35805) to 9.80 (CSV 15) in the rainy season, and from -8.80 (PS 35805) to 20.86 (CSV 15) in the postrainy season (Table 32). The genotypes Phule Anuradha (1.88 and -4.51* respectively, in the rainy and postrainy seasons), ICSV 25019 (-6.22** and -3.28), PS 35805 (-8.13** and -8.80**), IS 2123 (-4.91* and -6.26**), and IS 18551 (-2.07 and -6.10**) exhibited negative and significant *gca* effects, although there were a few exceptions. M 35-1 and Phule Anuradha exhibited positive but non-significant *gca* effects in the rainy season but showed negative effects in the postrainy season. CSV 15 (9.80** and 20.86**) and Swarna (8.03** and 20.30**) exhibited significant positive *gca* effects across seasons. Similar pattern was observed in case of overall resistance score across seasons.

The genotypes CSV 15 (20.65**) and Swarna (22.83**) showed significant and positive *gca* effects for percentage plants with shoot fly eggs and number of shoot fly eggs/plant in the postrainy season. Phule Anuradha (-5.25**), M 35-1 (-6.11**), ICSV 25019 (-4.58*), PS 35805 (-6.91**), IS 2123 (-7.54**), IS 2146 (-4.89**), and IS 18551 (-7.50**) exhibited significant negative *gca* effects for plants with shoot fly eggs (%),

Table 32. Estimates of general combining ability effects of shoot fly resistance and morphological traits of parents (10 X 10 diallel) across seasons (ICRISAT, Patancheru, 2013).

Traits	ICSV 700	Phule Anuradha	M 35-1	CSV 15	ICSV 25019	PS 35805	IS 2123	IS 2146	IS 18551	Swarna
Plants with shoot fly eggs (%)	(-0.71)	(-5.25*)	(-6.11**)	(20.65**)	(-4.58*)	(-6.91**)	(-7.54**)	(-4.89*)	(-7.50**)	(22.83**)
Number of shoot fly eggs/plant	(0.02)	(-0.16**)	(-0.09)	(0.16**)	(-0.07)	(-0.13*)	(-0.02)	(0.01)	(0.02)	(0.26**)
Shoot fly deadhearts (%)	-0.45 (-5.25*)	1.88 (-4.51*)	2.4 (-4.15)	9.80** (20.86**)	-6.22** (-3.28)	-8.13** (-8.80**)	-4.91* (-6.26**)	-0.32 (-2.81)	-2.07 (-6.10**)	8.03** (20.30**)
ORS	-0.06 (0.38**)	-0.04 (-0.03)	0.25* (-0.2)	0.58** (0.43**)	-0.45** (-0.08)	-0.44** (-0.03)	-0.24* (-0.43**)	-0.23* (-0.47**)	-0.09 (-0.32*)	0.71** (0.75**)
Leaf glossy score	-0.14 (-0.53**)	-0.22 (-0.05)	-0.11 (0.05)	0.73** (0.98**)	-0.03 (0.13)	-0.22 (-0.05)	-0.02 (-0.45**)	-0.30* (-0.47**)	-0.34** (-0.68**)	0.66** (1.07**)
Plant vigor score	-0.15 (-0.21**)	-0.13 (-0.11)	-0.01 (0.1)	0.41** (0.34**)	-0.08 (0.14)	-0.08 (0.07)	-0.01 (-0.16*)	-0.24** (-0.28**)	-0.17* (-0.31**)	0.45** (0.44**)
Leafsheath pigmentation	(-0.27**)	(0.09)	(0.04)	(0.38**)	(-0.01)	(0.06)	(-0.07)	(-0.06)	(-0.22**)	(0.06)
Trichome density on abaxial leaf surface	16.52** (14.75**)	2.66 (2.82)	-0.07 (4.06)	-35.24** (-38.35**)	-3.93* (0.24)	-2.81 (-1.09)	-5.36** (-0.12)	26.18** (18.19**)	16.76** (22.51**)	-14.72** (-23.01**)
Trichome density on adaxial leaf surface	29.09** (20.90**)	2.27 (0.32)	-3.48 (3.54)	-45.04** (-41.49**)	-6.56** (-3.95)	-4.88* (-2.85)	-8.36** (-1.92)	30.03** (21.07**)	24.69** (28.75**)	-17.76** (-24.38**)
Waxy bloom	-0.32** (-0.12*)	-0.20** (-0.14**)	-0.24** (-0.12*)	0.58** (0.35**)	0.33** (0.28**)	0.28** (0.31**)	-0.44** (-0.17**)	-0.29** (-0.19**)	-0.45** (-0.64**)	0.75** (0.43**)
Plant color	0.24** (0.24**)	-0.16** (-0.16**)	-0.16** (-0.14**)	0.23** (0.22**)	0.24** (0.24**)	0.23** (0.22**)	-0.16** (-0.16**)	-0.16** (-0.16**)	-0.16** (-0.16**)	-0.16** (-0.14**)

*, ** t test significant at P 0.05 and P 0.01 probability levels; ORS, overall resistance score. The values inside the parentheses are for postrainy season and outside the parentheses for rainy season.

whereas Phule Anuradha (-0.16**) and PS 35805 (-0.13*) exhibited significant negative *gca* effects for number of shoot fly eggs/plant in the postrainy season.

4.5.4.2 *gca* effects of morphological traits

The *gca* effects of leaf glossy score ranged from -0.34 (IS 18551) to 0.73 (CSV 15), and for plant vigor score from -0.24 (IS 2146) to 0.45 (Swarna) in the rainy season. In the postrainy season the *gca* effects for leaf glossy score ranged from -0.68 (IS 18551) to 1.07 (Swarna), for plant vigor score from -0.31 (IS 18551) to 0.44 (Swarna) and for leafsheath pigmentation from -0.27 (ICSV 700) to 0.38 (CSV 15) in the postrainy season (Table 32). IS 2146 and IS 18551 exhibited significant negative *gca* effects, and CSV 15 and Swarna exhibited significant positive *gca* effects for leaf glossy score and for plant vigor score across seasons. ICSV 700 and IS 2123 exhibited significant negative *gca* effects in the postrainy season, both for leaf glossy score and plant vigor score. ICSV 700 (-0.27**) and IS 18551 (-0.22**) exhibited significant negative and CSV 15 (0.38**) significant positive *gca* effects for leafsheath pigmentation in the postrainy season.

The general combining ability effects for trichome density on the abaxial leaf surface ranged from -35.24 (CSV 15) to 16.52 (ICSV 700) in the rainy season; and from -38.35 (CSV 15) to 22.51 (IS 18551) in the postrainy season. CSV 15 (-35.24**), ICSV 25019 (-3.93**), IS 2123 (-5.36**) and Swarna (-14.72**) exhibited significant negative *gca* effects, while ICSV 700 (16.52**), IS 2146 (26.18**) and IS 18551 (16.76**) exhibited significant positive *gca* effects in the rainy season. CSV 15 (-38.35**) and Swarna (-23.01**) showed significant negative, and ICSV 700 (14.75**), IS 2146 (18.19**) and IS 18551 (22.51**) significant positive *gca* effects for trichome density on abaxial leaf surface in the postrainy season.

The *gca* effects of trichome density on the adaxial leaf surface ranged from -45.04 (CSV 15) to 30.03 (IS 2146) in the rainy season, and from -41.49 (CSV 15) to 28.75 (IS 18551) in the postrainy season. CSV 15 (-45.04**), ICSV 25019 (-6.56**), PS 35805 (-4.88*), IS 2123 (-8.36**) and Swarna (-17.76**) exhibited significant negative *gca* effects, while ICSV 700 (29.09**), IS 2146 (30.03**), and IS 18551 (24.69**) exhibited significant positive *gca* effects for trichome density in the rainy season. CSV 15 (-41.49**) and Swarna (-24.38**) exhibited significant negative *gca* effects, and ICSV 700 (20.90**), IS 2146 (21.07**) and IS 18551 (28.75**) significant positive *gca* effects for trichome density on adaxial leaf surface in the postrainy season.

The *gca* effects of waxy bloom ranged from -0.45 (IS 18551) to 0.75 (Swarna) in the rainy season, and from -0.64 (IS 18551) to 0.43 (Swarna) in the postrainy season ICSV 700 (-0.32** and -0.12* respectively, in the rainy and postrainy season), Phule Anuradha (-0.20** and -0.14**), M 35-1 (-0.24** and -0.12*), IS 2123 (-0.44** and -0.17**), IS 2146 (-0.29** and -0.19**) and IS 18551 (-0.45** and -0.64**) exhibited significant negative *gca* effects; while CSV 15 (0.58** and 0.35**), ICSV 25019 (0.33** and 0.28**), PS 35805 (0.28** and 0.31**) and Swarna (0.75** and 0.43**) exhibited significant positive *gca* effects across seasons. The general combining ability effect of plant color ranged from -0.16 to 0.24 in the rainy season, and -0.14 to 0.24 in the postrainy season. ICSV 700, CSV 15, ICSV 25019, and PS 35805 exhibited significant positive *gca* effects across seasons, while the other genotypes showed significant negative *gca* effects.

4.5.5 Specific combining ability effects of shoot fly resistance and morphological traits

4.5.5.1 *sca* effects of shoot fly resistance traits

The *sca* effects of plants with shoot fly eggs (%) ranged from -13.04 to 37.56 in the postrainy season. The range of *sca* effects for shoot fly deadheart (%) varied from -12.42 to 17.74 in the rainy season, and the overall resistance score from -1.16 to 1.15 in the rainy season, and from -0.80 to 1.22 in the postrainy season (Table 33). ICSV 700 X Swarna, Phule Anuradha X Swarna, CSV 15 X ICSV 25019, CSV 15 X IS 2146 and IS 18551 X Swarna exhibited significant positive *sca* effects for percentage plants with shoot fly eggs in the postrainy season. M 35-1 X ICSV 25019 and ICSV 25019 X IS 18551 exhibited significant positive *sca* effects for shoot fly deadheart (%) in the rainy season. ICSV 700 X IS 2123, ICSV 700 X IS 2146, ICSV 25019 X PS 35805, ICSV 25019 X Swarna and IS 2123 X IS 2146 in the rainy season; and ICSV 700 X IS 18551, CSV 15 X ICSV 25019, CSV 15 X PS 35805, and ICSV 25019 X Swarna in the postrainy season exhibited significant positive *sca* effects for overall resistance score. ICSV 700 X Phule Anuradha, M 35-1 X Swarna, CSV 15 X IS 2146, ICSV 25019 X IS 2123, ICSV 25019 X IS 2146, PS 35805 XIS 18551, and IS 2123 X Swarna in the rainy season; and ICSV 700 X IS 2146 in the postrainy season exhibited significant negative *sca* effects for overall resistance score.

Table 33. Estimates of specific combining ability effects of shoot fly resistance traits of F_1 crosses (10 X 10 diallel) of sorghum, across seasons (ICRISAT, Patancheru, 2013-14).

Pedigree	Plants with shoot fly eggs (%)	Shoot fly deadhearts (%)	ORS	
	2013 PR	2013 R	2013 R	2013 PR
ICSV 700 X Phule Anuradha	-7.39	2.06	-0.83*	-0.07
ICSV 700 X M 35-1	5.46	7.48	-0.61	0.43
ICSV 700 X CSV 15	9.82	-3.05	-0.28	0.13
ICSV 700 X ICSV 25019	-8.03	1.91	-0.09	-0.35
ICSV 700 X PS 35805	-1.82	-7.51	-0.43	-0.40
ICSV 700 X IS 2123	6.69	-0.05	0.71*	0.50
ICSV 700 X IS 2146	-0.92	4.78	0.86*	-0.80*
ICSV 700 X IS 18551	6.71	-1.08	0.56	0.88*
ICSV 700 X Swarna	19.38**	8.12	-0.41	-0.35
Phule Anuradha X M 35-1	-13.04	-0.99	0.37	0.35
Phule Anuradha X CSV 15	-1.50	1.30	-0.46	-0.12
Phule Anuradha X ICSV 25019	11.93	-2.22	0.40	0.23
Phule Anuradha X PS 35805	-1.87	0.07	0.56	-0.32
Phule Anuradha X IS 2123	9.71	6.05	0.69	-0.75
Phule Anuradha X IS 2146	12.64	10.14	-0.15	0.45
Phule Anuradha X IS 18551	-3.43	-10.91	0.21	0.30
Phule Anuradha X Swarna	13.82*	2.33	0.07	-0.60
M 35-1 X CSV 15	6.02	2.14	-0.58	-0.28
M 35-1 X ICSV 25019	-5.02	15.29*	-0.55	0.07
M 35-1 X PS 35805	3.66	8.96	0.44	-0.65
M 35-1 X IS 2123	10.48	-1.88	-0.26	0.75
M 35-1 X IS 2146	0.06	-11.96	0.23	0.45
M 35-1 X IS 18551	12.27	-12.42	0.26	0.47
M 35-1 X Swarna	-0.83	-5.55	-1.21**	-0.10
CSV 15 X ICSV 25019	37.56**	6.55	0.61	0.93*
CSV 15 X PS 35805	7.01	4.18	0.44	1.22**
CSV 15 X IS 2123	-2.72	5.34	-0.43	-0.38
CSV 15 X IS 2146	18.93**	-2.56	-0.77*	-0.68
CSV 15 X IS 18551	2.09	6.84	-0.08	-0.17
CSV 15 X Swarna	-4.88	-4.48	0.62	-0.23
ICSV 25019 X PS 35805	1.37	-5.52	0.96**	0.40
ICSV 25019 X IS 2123	-5.73	-5.53	-0.90*	0.13
ICSV 25019 X IS 2146	-4.60	11.52	-1.16**	-0.67
ICSV 25019 X IS 18551	-11.08	17.74**	-0.39	-0.32
ICSV 25019 X Swarna	5.75	6.37	1.15**	0.95*
PS 35805 X IS 2123	-1.57	8.66	-0.58	0.42
PS 35805 X IS 2146	1.76	7.80	-0.09	0.45
PS 35805 X IS 18551	-0.24	3.17	-0.73*	0.13
PS 35805 X Swarna	9.26	-0.70	0.14	0.57
IS 2123 X IS 2146	-7.87	-4.62	0.71*	0.52
IS 2123 X IS 18551	-3.39	1.72	0.24	0.20
IS 2123 X Swarna	10.70	0.41	-0.73*	-0.37
IS 2146 X IS 18551	-4.04	3.57	0.23	0.23
IS 2146 X Swarna	5.55	6.09	-0.40	-0.33
IS 18551 X Swarna	17.53*	7.02	-0.55	-0.48

*, ** t test significant at P 0.05 and P 0.01 probability levels; ORS, overall resistance score; R, rainy season; PR, postrainy season.

4.5.5.2 *sca* effects of morphological traits

The *sca* effects of leaf glossy score ranged from -0.73 to 0.90 (in the postrainy season), for plant vigor score from -0.52 to 0.68 and -0.55 to 0.48, for trichome density on the abaxial leaf surface -25.68 to 15.47 and -22.85 to 18.53, for trichome density on the adaxial leaf surface from -25.92 to 26.80 and -29.98 to 25.95, and for waxy bloom from -0.55 to 0.72 (in the rainy season only) respectively, in the rainy and postrainy seasons (Table 34).

ICSV 700 X PS 35805, ICSV 700 X Swarna, Phule Anuradha X IS 2123, Phule Anurdha X IS 2146, CSV 15 X IS 2123, ICSV 25019 X IS 2146, and IS 18551 X Swarna exhibited significant positive *sca* effects for leaf glossy score in the postrainy season. ICSV 700 X ICSV 25019, M 35-1 X Swarna, CSV 15 X Swarna, and IS 2146 X IS 18551 exhibited significant negative *sca* effects for leaf glossy score in the postrainy season. M 35-1 X ICSV 25019, CSV 15 X IS 18551, and ICSV 25019 X Swarna in the rainy season; and ICSV 700 X M 35-1, Phule Anuradha X IS 2123 in the postrainy season exhibited significant positive *sca* effects for plant vigor score. M 35-1 X Swarna in the rainy season, and ICSV 700 X ICSV 25019 in the postrainy season exhibited negative *sca* effects for plant vigor score.

ICSV 700 X PS 35805, ICSV 700 X IS 2123, ICSV 700 X IS 2146, ICSV 700 X IS 18551, Phule Anuradha X Swarna, M 35-1 X CSV 15, ICSV 25019 X Swarna in the rainy season; and ICSV 700 X IS 2146, Phule Anuradha X Swarna, CSV 15 X IS 2146, ICSV 25019 X Swarna, PS 35805 X IS 2146, and PS 35805 X Swarna in the postrainy season showed significant negative *sca* effects for trichome density on the abaxial leaf surface. ICSV 700 X Swarna across seasons, and ICSV 25019 X IS 2146, ICSV 25019 X IS 18551, PS 35805 X IS 2123 and IS 2146 X Swarna in the rainy season, and ICSV 25019 X PS 35805, IS 2123 X IS 2146 and IS 18551 X Swarna in the postrainy season exhibited significant positive *sca* effects for trichome density on the abaxial leaf surface.

The crosses ICSV 700 X PS 35805, ICSV 700 X IS 2123, ICSV 700 X IS 2146, ICSV 700 X IS 18551, Phule Anuradha X Swarna, M 35-1 X CSV 15, CSV 15 X ICSV 25019, CSV 15 X PS 35805, ICSV 25019 X Swarna, and PS 35805 X Swarna in the rainy season; and ICSV 700 X IS 2146, ICSV 700 X IS 18551, CSV 15 X ICSV 25019, ICSV 25019 X Swarna, and PS 35805 X Swarna in the postrainy season showed significant negative *sca* effects for trichome density on the adaxial leaf surface. ICSV 700

X Swarna, CSV 15 X IS 18551, ICSV 25019 XIS 2146, ICSV 25019 X IS 18551, PS 35805 X IS 2123, IS 2146 X Swarna and IS 18551 X Swarna in the rainy season; and ICSV 700 X CSV 15, ICSV 700 X Swarna, ICSV 25019 X IS 2146, IS 2123 X IS 2146 and IS 18551 X Swarna in the postrainy season exhibited significant positive *sca* effects for trichome density on the adaxial leaf surface.

The *sca* effects of Phule Anuradha X CSV 15, Phule Anuradha X ICSV 25019, CSV 15 X Swarna, ICSV 25019 X IS 2123, ICSV 25019 X IS 2146, ICSV 25019 X IS 18551, PS 35805 X IS 2123, PS 35805 X IS 2146, and PS 35805 X IS 18551 in the rainy season exhibited significant negative *sca* effects for waxy bloom trait. Phule Anuradha X IS 2146, Phule Anuradha X IS 18551, CSV 15 X ICSV 25019, CSV 15 X IS 2123, ICSV 25019 X PS 35805 in the rainy season exhibited significant positive *sca* effects for waxy bloom.

4.5.6 Reciprocal combining ability effects of shoot fly resistance and morphological traits

The traits that had shown significant mean sum of squares for reciprocal mean squares were involved in the reciprocal combining ability studies. The reciprocal effects of the crosses CSV 15 X ICSV 700, ICSV 25019 X CSV 15, IS 2123 X M 35-1, IS 2123 X CSV 15, Swarna X ICSV 700, Swarna X M 35-1 exhibited significant negative reciprocal effects; while the crosses PS 35805 X CSV 15, IS 2146 X Phule Anuradha showed significant positive reciprocal effects for plants with shoot fly eggs (%) in the postrainy season (Table 35). IS 2123 X CSV 15 and Swarna X IS 2123 exhibited significant negative reciprocal effects; and CSV 15 X ICSV 700 and Swarna X ICSV 700 exhibited significant positive reciprocal effects for overall resistance score during the rainy season. CSV 15 X ICSV 700, IS 2123 X Phule Anuradha, Swarna X M 35-1, and Swarna XIS 2123 exhibited significant negative effects, and IS 2146 X IS 2123 exhibited positive reciprocal effects for leaf glossy score in the postrainy season.

IS 2146 X ICSV 700, IS 2146 X ICSV 25019, IS 2146 X PS 35805, IS 2146 X IS 2123 in the rainy season, and PS 35805 X CSV 15, IS 18551 X ICSV 25019 in the postrainy season exhibited significant negative reciprocal effects for trichome density on the abaxial leaf surface. CSV 15 X ICSV 700, CSV 15 X Phule Anuradha and Swarna X M 35-1 across seasons, and CSV 15 X M 35-1, and IS 18551 X IS 2123 in the postrainy season exhibited significant positive reciprocal effects for trichome density on the abaxial

Table 34. Estimates of specific combining ability effects of morphological traits of F_1 crosses (10 X 10 diallel) of sorghum across seasons (ICRISAT, Patancheru, 2013-14).

Pedigree	Leaf glossy score	Plant vigor score		Trichome density on abaxial leaf surface		Trichome density on adaxial leaf surface		Waxy bloom
	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R
ICSV 700 X Phule Anuradha	-0.43	0.20	0.20	-2.70	-1.84	-1.38	0.89	0.02
ICSV 700 X M 35-1	0.30	0.25	0.48*	-8.57	4.22	-1.09	8.72	0.05
ICSV 700 X CSV 15	0.20	0.33	-0.09	5.10	2.24	11.59	17.36**	-0.26
ICSV 700 X ICSV 25019	-0.45*	-0.02	-0.55*	1.11	7.16	4.85	11.93	-0.18
ICSV 700 X PS 35805	0.90**	-0.02	0.35	-16.06**	-7.21	-15.78**	-10.75	-0.13
ICSV 700 X IS 2123	0.13	-0.08	0.08	-13.41**	0.96	-14.49*	-0.38	0.09
ICSV 700 X IS 2146	0.32	-0.18	0.36	-25.68**	-18.01**	-25.92**	-29.98**	0.10
ICSV 700 X IS 18551	-0.13	-0.25	-0.27	-11.53*	-12.56	-20.37**	-22.50**	0.10
ICSV 700 X Swarna	0.62**	-0.13	-0.02	15.47**	15.88*	26.80**	17.75**	-0.10
Phule Anuradha X M 35-1	0.15	-0.28	0.21	0.29	-7.61	1.19	-4.86	-0.23
Phule Anuradha X CSV 15	-0.28	-0.19	-0.35	1.58	2.88	0.14	0.20	-0.38*
Phule Anuradha X ICSV 25019	-0.10	0.13	-0.15	-2.08	10.24	-3.69	5.54	-0.46**
Phule Anuradha X PS 35805	-0.08	-0.21	-0.09	2.43	3.26	0.93	4.42	-0.25
Phule Anuradha X IS 2123	0.48*	0.23	0.48*	-1.13	2.54	-2.22	-1.84	-0.03
Phule Anuradha X IS 2146	0.67**	0.46	0.26	0.04	6.54	2.87	5.67	0.49**
Phule Anuradha X IS 18551	0.38	-0.11	0.13	-0.77	-6.34	-0.55	-2.07	0.32*
Phule Anuradha X Swarna	-0.03	0.27	-0.29	-15.98**	-15.68*	-22.27**	-10.86	0.12
M 35-1 X CSV 15	0.12	-0.14	0.10	-10.49*	-3.34	-12.94*	-6.28	-0.18
M 35-1 X ICSV 25019	-0.37	0.68*	0.13	0.67	-8.95	-2.05	-8.35	0.07
M 35-1 X PS 35805	0.15	-0.16	0.03	-5.22	-4.63	-2.83	3.05	-0.21
M 35-1 X IS 2123	0.22	-0.23	-0.24	-0.45	-11.24	2.40	-6.74	0.00
M 35-1 X IS 2146	0.23	-0.16	-0.29	-2.86	7.02	-5.20	8.66	-0.15
M 35-1 X IS 18551	0.28	-0.39	0.41	-7.39	4.60	-5.41	5.89	0.02

Table 34. (Cont..)

Pedigree	Leaf glossy score	Plant vigor score		Trichome density on abaxial leaf surface		Trichome density on adaxial leaf surface		Waxy bloom
	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R
M 35-1 X Swarna	-0.47*	-0.52*	0.00	-0.16	8.30	2.24	9.77	-0.18
CSV 15 X ICSV 25019	0.20	-0.24	-0.27	-8.40	-12.79	-14.88*	-15.02*	0.42**
CSV 15 X PS 35805	-0.28	-0.41	-0.20	-8.80	3.50	-12.68*	2.09	0.14
CSV 15 X IS 2123	0.78**	0.19	0.03	-5.41	-7.13	-5.31	-10.43	0.35*
CSV 15 X IS 2146	0.13	0.43	0.15	-5.29	-16.08*	-1.97	-12.25	0.20
CSV 15 X IS 18551	0.35	0.53*	0.35	6.46	-5.52	12.54*	-3.61	-0.13
CSV 15 X Swarna	-0.73**	0.07	-0.07	4.51	10.45	2.12	5.42	-0.33*
ICSV 25019 X PS 35805	-0.10	-0.26	0.16	-2.93	18.53**	0.73	8.15	0.72**
ICSV 25019 X IS 2123	0.30	0.01	0.06	-2.06	-6.71	-0.78	2.03	-0.40*
ICSV 25019 X IS 2146	0.48*	-0.09	0.18	13.72**	10.12	14.57*	17.93**	-0.55**
ICSV 25019 X IS 18551	0.37	-0.16	0.05	11.83*	9.07	13.89*	8.58	-0.55**
ICSV 25019 X Swarna	0.12	0.55*	0.30	-15.52**	-22.85**	-21.82**	-23.58**	0.25
PS 35805 X IS 2123	-0.18	-0.33	-0.04	12.61*	8.36	13.54*	6.77	-0.35*
PS 35805 X IS 2146	-0.33	0.24	-0.25	7.46	-14.33*	9.32	-10.17	-0.49**
PS 35805 X IS 18551	-0.12	0.18	-0.05	-0.29	-1.72	5.63	3.87	-0.49**
PS 35805 X Swarna	0.13	0.22	-0.14	-9.86	-18.25**	-14.07*	-25.58**	0.30
IS 2123 X IS 2146	0.07	-0.33	0.15	-2.33	15.36*	-2.03	16.63*	0.05
IS 2123 X IS 18551	-0.22	-0.39	-0.15	1.54	-1.10	7.08	-0.51	0.22
IS 2123 X Swarna	0.03	0.32	0.26	-9.15	-1.83	-6.31	-8.21	-0.15
IS 2146 X IS 18551	-0.53*	-0.16	-0.37	-3.84	7.79	-5.03	0.79	0.24
IS 2146 X Swarna	0.22	-0.28	0.21	13.97**	4.59	21.47**	7.69	0.20
IS 18551 X Swarna	0.77**	0.15	0.25	3.12	17.15*	12.76*	25.95**	0.04

*, ** t test significant at P 0.05 and P 0.01 probability levels; R, rainy season; PR, postrainy season.

Table 35. Estimates of reciprocal combining ability effects of reciprocal crosses (10 X 10 diallel) of sorghum across seasons (ICRISAT, Patancheru, 2013-14).

Pedigree	Plants with shoot fly eggs (%)	ORS	Leaf glossy score	Trichome density on lower leaf surface		Trichome density on upper leaf surface	
	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR
Phule Anuradha X ICSV 700	-8.73	-	-0.17	-6.55	-7.58	-6.33	-10.44
M 35-1 X ICSV 700	6.46	0.17	0.00	8.85	9.17	15.40*	11.17
M 35-1 X Phule Anuradha	-4.04	0.17	-0.33	-1.28	8.39	-0.57	12.78
CSV 15 X ICSV 700	-30.43**	0.80*	-0.83**	15.6**	25.22**	24.70**	44.05**
CSV 15 X Phule Anuradha	8.33	-	-0.17	15.5**	18.25**	21.90**	19.47**
CSV 15 X M 35-1	-3.36	0.50	-0.33	-1.93	13.28*	-1.10	16.22*
ICSV 25019 X ICSV 700	4.47	0.33	0.00	4.90	2.84	16.20**	13.33*
ICSV 25019 X Phule Anuradha	13.57	0.17	-0.17	5.72	-8.20	8.85	-5.70
ICSV 25019 X M 35-1	-11.60	-0.50	0.00	-2.37	-5.92	-1.27	-1.92
ICSV 25019 X CSV 15	-14.18*	0.33	0.17	-2.17	0.00	-1.45	0.00
PS 35805 X ICSV 700	5.74	-0.33	0.17	2.15	-5.03	-2.35	-4.19
PS 35805 X Phule Anuradha	13.27	0.33	0.33	4.02	-2.78	1.22	2.22
PS 35805 X M 35-1	-11.75	0.17	-0.33	0.60	6.36	-3.27	9.58
PS 35805 X CSV 15	31.59**	-0.50	-0.17	-2.88	-14.97*	-6.10	-18.19**
PS 35805 X ICSV 25019	-4.37	-0.33	-0.17	-2.17	-0.03	-0.98	-2.20
IS 2123 X ICSV 700	5.99	-0.33	0.33	1.72	-2.39	3.97	8.72
IS 2123 X Phule Anuradha	0.30	-0.67	-0.50*	-0.93	10.97	1.15	9.22
IS 2123 X M 35-1	-13.77*	0.33	0.00	3.72	-6.72	-1.12	-3.67
IS 2123 X CSV 15	-20.77**	-0.80*	-0.17	2.72	-1.42	2.22	1.17
IS 2123 X ICSV 25019	-11.54	0.67	0.17	6.52	2.92	5.33	4.78
IS 2123 X PS 35805	0.30	-0.33	-0.17	-9.40	-5.39	-10.43	2.00
IS 2146 X ICSV 700	8.47	0.17	0.17	-12.60*	5.61	-8.88	1.56
IS 2146 X Phule Anuradha	21.01**	-0.17	0.00	2.62	-8.89	-5.67	0.72
IS 2146 X M 35-1	3.91	-0.17	0.33	-8.42	-8.39	4.53	-5.72
IS 2146 X CSV 15	6.73	0.50	-0.17	-0.52	10.33	-2.05	16.45*
IS 2146 X ICSV 25019	4.19	0.58	0.33	-10.10*	1.33	-6.30	1.28
IS 2146 X PS 35805	-2.92	-0.17	0.00	-11.20*	-9.89	-15.50*	1.83
IS 2146 X IS 2123	1.46	0.17	0.67**	-21.80**	-7.00	-17.70**	-14.56*
IS 18551 X ICSV 700	5.83	-0.33	0.17	-6.38	15.17*	0.57	8.83
IS 18551 X Phule Anuradha	0.29	-0.33	0.17	6.62	11.56	0.13	10.56
IS 18551 X M 35-1	-0.14	-0.33	-0.17	1.67	12.75	1.28	4.42
IS 18551 X CSV 15	13.44	-0.33	-0.17	-1.28	-8.56	-6.45	-15.28*
IS 18551 X ICSV 25019	-0.78	-	0.33	-7.40	9.72	-6.62	16.28*
IS 18551 X PS 35805	-8.74	-0.33	0.33	-1.17	-15.61*	-4.90	-6.56
IS 18551 X IS 2123	2.69	-0.17	0.17	-7.43	-2.81	-7.00	-7.00
IS 18551 X IS 2146	-8.57	0.50	0.17	-0.50	4.94	6.28	3.95
Swarna X ICSV 700	-16.19*	1.5**	0.00	0.10	-0.42	-2.05	0.06
Swarna X Phule Anuradha	2.16	0.33	0.17	5.57	-5.86	4.30	-7.36
Swarna X M 35-1	-17.92*	-0.33	-0.83**	12.90*	17.92**	22.8**	31.50**
Swarna X CSV 15	-11.89	-0.17	-0.17	-0.52	0.00	-1.78	0.00
Swarna X ICSV 25019	-1.95	-	0.17	2.33	3.17	6.65	5.33
Swarna X PS 35805	-6.99	0.33	0.00	6.32	3.11	12.70*	2.25
Swarna X IS 2123	-5.80	-1.30**	-0.50*	3.63	4.39	6.73	6.50
Swarna X IS 2146	11.37	-0.33	0.00	7.93	-4.61	9.67	-8.83
Swarna X IS 18551	-3.00	-	0.00	4.67	-10.67	-1.42	-6.67

*, ** t test significant at P 0.05 and P 0.01 probability levels; ORS, overall resistance score.

leaf surface. IS 2146 X PS 35805 in the rainy season, IS 2146 X IS 2123 across seasons, and IS 18551 X CSV 15 in the postrainy season exhibited significant negative reciprocal effects for trichome density on the adaxial leaf surface. M 35-1 X ICSV 700 and Swarna X PS 35805 in the rainy season, and CSV 15 X ICSV 700, CSV 15 X Phule Anuradha, ICSV 25019 X ICSV 700, Swarna X M 35-1 across seasons, and CSV 15 X M 35-1, IS 2146 X CSV 15 and IS 18551 XICSV 25019 in the postrainy season exhibited significant positive reciprocal effects for trichome density on the adaxial leaf surface.

4.5.7 Combining ability estimates and genetic parameters of shoot fly resistance and morphological traits

Shoot fly deadhearts (%) in the rainy season, and plants with shoot fly eggs (%) in the postrainy season showed high σ^2s than the variance due to general combining ability (σ^2g), indicating the predominance of dominance gene action in controlling the expression of resistance to sorghum shoot fly, *A. soccata* (Table 36).This was confirmed by high dominance variance than the additive variance for these traits. The other traits that had σ^2g and σ^2s on par with each other exhibited both additive and non-additive type of gene action.

Variance due to GCA (σ^2g) was higher than the variance due to SCA (σ^2s) for trichome density on abaxial and adaxial leaf surfaces across seasons; indicating the predominance of additive gene action in controlling the expression of these traits. Trichome density on abaxial and adaxial leaf surfaces showed high additive variance (σ^2a) than the dominance variance (σ^2d) across seasons. Leaf glossy score and plant vigor score in the postrainy season exhibited high additive variance than the dominance variance. Overall resistance score exhibited high dominance variance to the additive variance across seasons. Plant vigor score and trichome density on the abaxial and adaxial leaf surfaces across seasons, and leaf glossy score in the postrainy season exhibited high GCA/SCA ratio, indicating the additive type of gene action controlling the expression of these traits. These traits also had high predictability ratios.

Heritability estimates for narrowsense heritability of all the traits ranged from 0.22 to 0.73; while the broadsense heritability estimates ranged from 0.50 to 0.99in the rainy season, and 0.23 to 0.77 and 0.46 to 0.99 respectively, in the postrainy season. Most of the traits exhibited moderate to high heritability values. Plants with shoot fly deadhearts and overall resistance score in the rainy season, and plants with shoot fly eggs,

Table 36. Estimates of various genetic parameters for different shoot fly resistance and morphological traits of sorghum across seasons (ICRISAT, Patancheru, 2013-14).

Traits	Plants with shoot fly eggs (%)	Number of shoot fly eggs/plant	Shoot fly deadhearts (%)	ORS	Leaf glossy score	Plant vigor score	Leafsheath pigmentation	Trichome density on abaxial leaf surface	Trichome density on adaxial leaf surface	Waxy bloom	Plant color
σ^2 g	(129.86)	(0.01)	28.60 (115.14)	0.14 (0.14)	0.13 (0.36)	0.05 (0.06)	(0.03)	303.35 (337.10)	535.36 (446.53)	0.19 (0.11)	0.04 (0.04)
σ^2 s	(413.37)	(0.03)	88.51	0.59 (0.39)	(0.37)	0.08 (0.05)	-	233.73 (132.26)	264.53 (216.25)	0.16	0.12 (0.13)
σ^2 r	(72.66)	-	-	0.08	(0.03)	-	-	22.55 (34.71)	42.32 (93.72)	-	-
σ^2 e	(110.81)	(0.07)	101.81 (107.64)	0.29 (0.38)	0.32 (0.12)	0.16 (0.12)	(0.06)	59.16 (104.42)	81.99 (98.31)	0.06 (0.05)	-
σ^2 a	(259.71)	(0.03)	57.21 (230.28)	0.29 (0.29)	0.26 (0.72)	0.10 (0.12)	(0.06)	606.71 (674.2)	1070.72 (893.06)	0.39 (0.22)	0.08 (0.08)
σ^2d	(413.37)	(0.03)	88.51	0.59 (0.39)	(0.37)	0.08 (0.05)	-	233.73 (132.26)	264.53 (216.25)	0.16	0.12 (0.13)
σ^2 p	(856.54)	(0.11)	264.81 (369.66)	1.25 (1.12)	0.74 (1.24)	0.32 (0.30)	(0.12)	922.15 (945.58)	1459.56 (1301.35)	0.60 (0.28)	0.21 (0.21)
h_{ns}^2	(0.30)	(0.23)	0.22 (0.62)	0.23 (0.26)	0.35 (0.58)	0.30 (0.41)	(0.51)	0.66 (0.71)	0.73 (0.69)	0.65 (0.77)	0.40 (0.39)
h_b^2	(0.79)	(0.46)	0.55 (0.73)	0.70 (0.61)	0.50 (0.88)	0.55 (0.59)	(0.54)	0.91 (0.85)	0.92 (0.85)	0.91 (0.82)	0.99 (0.99)
GCA/SCA ratio	(0.31)	(0.51)	0.32	0.24 (0.37)	(0.97)	0.59 (1.13)	-	1.30 (2.55)	2.02 (2.07)	1.22	0.33 (0.32)
Predictability ratio	(0.39)	(0.51)	0.39	0.32 (0.42)	(0.66)	0.54 (0.69)	-	0.72 (0.84)	0.80 (0.81)	0.71	0.40 (0.39)

σ^2g, gca variance; σ^2s, sca variance; σ^2r, reciprocal variance; σ^2e, environmental/error variance; σ^2a, additive variance; σ^2d, dominance variance; σ^2p, phenotypic variance; h_{ns}^2, narrow sense heritability; h_b^2, broad sense heritability; GCA, general combining ability; SCA, specific combining ability. The values outside the parentheses are for rainy season, whereas inside the parentheses are for postrainy season.

number of shoot fly eggs/plant, and overall resistance score in the postrainy season exhibited low (≤ 0.30) narrowsense heritability. The other traits exhibited moderate to high narrowsense heritability. All the shoot fly resistance and morphological traits across seasons exhibited high broadsense heritability values.

4.6 Inheritance of agronomic and panicle traits in the postrainy season sorghum, *Sorghum bicolor*

4.6.1 Agronomic traits

Evaluation of 10 parents and 90 F_1s, including the reciprocals, showed significant differences for all the traits studied across seasons at $P \leq 0.01$. Days to 50% flowering was ranged from 60.67 to 81.33 days in the rainy season, 56.33 to 78.00 days in the postrainy season (Table 37). Almost all the crosses flowered early, with few exceptions. The crosses between the parents with early and late flowering were early flowering, indicating dominance of earliness for anthesis. The mean plant height was 285.50 cm in the rainy season and 190.91 cm in the postrainy season. The crosses CSV 15 X ICSV 25019, CSV 15 X PS 35805, ICSV 25019 X CSV 15, ICSV 25019 X PS 35805, ICSV 25019 X IS 2123, ICSV 25019 X Swarna, PS 35805 X CSV 15, PS 3505 X ICSV 25019, PS 35805 X IS 2146, PS 35805 X Swarna, Swarna X ICSV 25019, Swarna X PS 35805 exhibited moderate plant height across seasons. The parents and the crosses with the moderate plant height can be exploited in developing the commercial hybrids with shoot fly resistance.

The crosses ICSV 700 X ICSV 25019, Phule Anuradha X PS 35805, Phule Anuradha X Swarna, M 35-1 X ICSV 700, ICSV 25019 X M 35-1, ICSV 25019 X IS 2123, IS 18551 X Swarna, Swarna X ICSV 700, Swarna X CSV 15, and Swarna X IS 18551 exhibited high 100 seed weight and grain yield with good agronomic desirability. The grain yield of the crosses CSV 15 X IS 2123, ICSV 25019 X Swarna, PS 35805 X Swarna, IS 2123 X CV 15, IS 2123 X ICSV 25019, IS 2123 X Swarna, Swarna X ICSV 25019 and Swarna X IS 2123 was high in the rainy season. Twenty five crosses exhibited high 100 seed weight and grain yield in the postrainy season.

4.6.2 Panicle and grain characteristics

The panicle and grain characteristics were also evaluated to understand the nature of gene action for panicle traits to develop an effective selection criterion for the postrainy season

Table 37. Agronomic characteristics of sorghum (Parents and F_1's) evaluated for resistance to sorghum shoot fly, *A. soccata* across seasons (ICRISAT, Patancheru, 2013-14).

Pedigree	Days to 50% flowering		Plant height (cm)		100 seed weight (g)		Grain yield (t/ha)		Agronomic score	
	2013 R	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**
Parents										
ICSV 700	81.33	76.67	308.90	188.90	2.30	2.37	0.79	5.02	5.00	3.67
Phule Anuradha	62.33	63.33	258.90	178.90	2.90	4.23	1.22	6.51	4.67	4.33
M 35-1	75.33	71.67	306.10	186.70	2.40	3.50	0.66	6.87	5.00	3.67
CSV 15	71.00	61.33	254.40	180.00	2.50	3.03	1.54	5.23	3.00	3.00
ICSV 25019	64.67	64.00	131.10	108.90	2.30	2.10	1.90	3.01	2.00	3.00
PS 35805	68.67	65.33	120.60	102.20	2.20	2.37	1.70	3.12	2.00	3.00
IS 2123	73.33	71.67	283.30	175.60	2.13	2.50	0.77	5.64	5.00	4.33
IS 2146	68.00	72.67	278.90	181.10	1.80	2.33	0.88	5.56	5.00	4.67
IS 18551	78.33	78.00	313.30	203.30	1.70	2.23	0.51	4.23	5.00	3.33
Swarna	67.33	63.00	166.10	137.80	3.30	3.77	1.89	5.17	2.00	2.00
Direct crosses										
ICSV 700 X Phule Anuradha	65.33	74.67	314.40	235.60	2.73	3.77	3.58	15.18	4.33	2.67
ICSV 700 X M 35-1	64.67	69.67	321.10	217.80	2.63	4.00	3.73	12.51	3.67	3.33
ICSV 700 X CSV 15	75.33	70.67	326.70	208.90	2.37	3.30	4.73	14.18	2.33	4.00
ICSV 700 X ICSV 25019	66.67	67.67	307.80	198.90	2.80	3.63	4.80	12.72	3.00	3.00
ICSV 700 X PS 35805	67.00	67.00	308.90	204.40	2.47	3.07	6.25	12.13	3.33	3.67
ICSV 700 X IS 2123	68.00	68.67	303.30	218.90	2.50	3.40	4.12	13.73	4.67	4.33
ICSV 700 X IS 2146	69.00	71.33	317.80	207.80	2.53	3.53	2.57	5.49	4.00	3.67
ICSV 700 X IS 18551	67.33	70.33	338.90	231.10	2.40	3.30	5.31	11.87	3.67	3.33
ICSV 700 X Swarna	67.33	67.67	318.90	213.30	3.07	4.03	4.10	10.46	5.00	3.00
Phule Anuradha X M 35-1	64.00	66.00	273.30	202.20	2.60	4.37	2.93	11.99	4.00	3.33
Phule Anuradha X CSV 15	62.00	59.33	302.20	202.20	3.00	4.07	1.97	8.94	4.00	3.33
Phule Anuradha X ICSV 25019	60.67	59.67	280.00	183.30	2.87	3.97	2.58	10.69	3.67	2.67
Phule Anuradha X PS 35805	62.00	61.00	280.00	176.70	2.97	3.53	5.89	14.08	3.33	3.33
Phule Anuradha X IS 2123	63.33	64.33	280.00	187.80	2.60	3.83	3.40	12.40	4.33	4.00
Phule Anuradha X IS 2146	64.00	66.00	292.20	186.70	2.20	4.00	2.89	7.17	4.00	3.67
Phule Anuradha X IS 18551	64.67	65.00	310.00	207.80	2.27	3.47	4.68	12.70	3.33	4.00
Phule Anuradha X Swarna	62.67	61.67	296.70	198.90	3.43	4.33	4.76	9.44	3.33	3.33
M 35-1 X CSV 15	64.00	69.67	316.70	211.10	2.97	3.37	4.47	11.58	3.67	3.00
M 35-1 X ICSV 25019	62.67	62.67	304.40	203.30	2.77	3.83	3.34	13.94	3.33	3.33
M 35-1 X PS 35805	63.33	63.67	296.10	171.10	2.73	3.43	4.00	11.51	2.67	3.00
M 35-1 X IS 2123	66.00	70.00	295.60	197.80	2.57	3.50	3.84	14.34	4.67	4.33
M 35-1 X IS 2146	64.00	69.33	293.30	197.80	2.20	3.93	1.96	7.17	4.67	4.00
M 35-1 X IS 18551	67.33	70.33	322.20	211.10	2.37	3.17	4.69	14.47	3.67	3.00
M 35-1 X Swarna	68.67	67.00	314.40	207.80	2.37	3.13	4.49	11.56	3.33	3.33

Table 37. (Cont..)

Pedigree	Days to 50% flowering		Plant height (cm)		100 seed weight (g)		Grain yield (t/ha)		Agronomic score	
	2013 R	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**
CSV 15 X ICSV 25019	62.67	56.33	228.90	148.90	2.47	3.50	6.94	13.28	1.67	2.33
CSV 15 X PS 35805	65.33	57.33	250.00	157.80	2.50	3.33	7.16	12.62	2.00	2.67
CSV 15 X IS 2123	66.00	61.33	297.80	184.40	2.67	3.23	7.95	14.49	4.33	3.67
CSV 15 X IS 2146	64.00	63.33	290.00	196.70	2.77	3.30	2.88	7.34	3.33	3.67
CSV 15 X IS 18551	65.33	63.33	340.00	214.40	2.47	2.97	5.72	13.77	3.00	3.00
CSV 15 X Swarna	64.67	59.00	307.80	197.80	3.10	3.67	4.38	11.11	3.67	2.33
ICSV 25019 X PS 35805	66.00	60.33	126.70	104.40	1.97	2.43	4.33	7.57	2.00	3.00
ICSV 25019 X IS 2123	64.33	63.00	258.30	166.70	2.87	3.50	4.95	13.61	4.67	3.33
ICSV 25019 X IS 2146	63.33	63.67	273.30	173.30	2.80	3.70	2.41	6.99	4.33	3.67
ICSV 25019 X IS 18551	65.33	65.00	302.20	208.90	2.37	2.90	4.18	12.91	3.33	2.67
ICSV 25019 X Swarna	60.67	61.67	186.70	140.00	3.27	3.00	7.65	10.16	1.67	2.67
PS 35805 X IS 2123	66.67	63.00	275.60	161.10	2.73	2.90	3.88	12.48	4.33	3.67
PS 35805 X IS 2146	62.67	61.00	261.10	180.00	2.53	3.20	2.14	7.20	3.67	3.33
PS 35805 X IS 18551	65.33	63.33	317.80	202.20	2.43	2.60	4.11	11.42	3.00	3.00
PS 35805 X Swarna	64.00	61.00	183.90	138.90	2.73	2.80	5.36	10.40	2.00	2.67
IS 2123 X IS 2146	68.00	71.00	292.20	195.60	1.97	3.10	2.01	6.51	4.67	4.33
IS 2123 X IS 18551	68.67	73.33	297.80	206.70	2.00	2.50	2.49	10.32	5.00	4.33
IS 2123 X Swarna	67.33	67.00	290.00	197.80	3.20	3.60	5.07	10.86	4.33	4.33
IS 2146 X IS 18551	67.33	72.00	290.00	211.10	2.10	3.03	2.23	8.33	4.67	4.67
IS 2146 X Swarna	63.33	62.00	296.70	210.00	2.63	3.87	3.13	5.40	4.33	3.67
IS 18551 X Swarna	68.33	65.00	326.70	222.20	2.90	3.50	5.06	12.10	3.67	3.00
Reciprocal crosses										
Phule Anuradha X ICSV 700	66.33	64.00	315.60	213.30	2.67	4.17	3.93	10.04	3.67	3.67
M 35-1 X ICSV 700	68.00	69.00	316.70	218.90	2.67	4.30	6.54	11.72	4.00	3.67
M 35-1 X Phule Anuradha	64.67	64.33	283.30	212.20	2.57	4.10	3.25	10.90	3.33	4.33
CSV 15 X ICSV 700	69.33	67.67	333.30	205.60	2.47	3.27	5.82	15.09	2.33	3.00
CSV 15 X Phule Anuradha	64.00	58.67	310.00	217.80	3.10	4.10	4.68	11.48	3.33	3.67
CSV 15 X M 35-1	62.67	63.67	302.20	212.20	2.90	4.13	4.14	14.25	3.67	3.67
ICSV 25019 X ICSV 700	68.33	66.67	311.10	197.80	2.57	3.47	5.02	12.99	3.00	3.00
ICSV 25019 X Phule Anuradha	61.33	59.00	282.20	186.70	3.30	4.13	5.97	11.13	3.00	2.67
ICSV 25019 X M 35-1	66.00	68.67	307.80	185.60	2.90	3.50	5.47	15.24	3.67	3.33
ICSV 25019 X CSV 15	64.00	59.33	230.00	157.80	2.47	3.00	7.46	11.77	2.00	2.67
PS 35805 X ICSV 700	71.00	65.67	308.90	203.30	2.53	3.07	6.29	12.33	2.67	3.33
PS 35805 X Phule Anuradha	63.33	68.33	287.80	211.10	2.93	3.27	4.20	17.28	3.33	3.33
PS 35805 X M 35-1	64.67	64.33	297.80	196.70	2.77	3.53	4.52	14.00	4.67	2.67
PS 35805 X CSV 15	64.67	57.33	237.80	152.20	2.40	2.90	6.74	10.79	2.83	3.00
PS 35805 X ICSV 25019	66.67	61.33	127.20	104.40	2.00	2.07	3.10	7.02	2.00	3.00

Table 37. (Cont..)

Pedigree	**Days to 50% flowering**		**Plant height (cm)**		**100 seed weight (g)**		**Grain yield (t/ha)**		**Agronomic score**	
	2013 R	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**	**2013 R**	**2013 PR**
IS 2123 X ICSV 700	68.00	70.00	312.20	207.80	2.57	3.47	4.76	12.21	5.00	4.33
IS 2123 X Phule Anuradha	64.67	66.67	287.80	192.20	2.57	3.63	3.89	11.64	5.00	3.33
IS 2123 X M 35-1	68.67	68.33	312.20	196.70	2.37	3.50	2.90	13.93	4.33	4.33
IS 2123 X CSV 15	65.00	64.00	290.00	195.60	2.83	3.20	7.04	13.29	5.00	3.67
IS 2123 X ICSV 25019	66.67	64.33	268.90	161.10	2.77	3.20	5.09	13.91	4.33	3.67
IS 2123 X PS 35805	66.67	59.33	271.10	171.10	2.90	3.13	4.60	12.58	4.33	3.67
IS 2146 X ICSV 700	66.67	71.33	320.00	208.90	2.57	3.17	2.21	5.45	4.33	4.33
IS 2146 X Phule Anuradha	62.00	64.33	287.80	191.10	2.43	3.73	2.40	6.72	4.67	4.33
IS 2146 X M 35-1	66.33	68.33	293.30	198.90	2.20	3.70	2.76	7.08	5.00	4.67
IS 2146 X CSV 15	64.00	57.33	306.70	187.80	2.73	3.37	3.21	6.90	4.33	3.67
IS 2146 X ICSV 25019	63.67	63.67	270.00	165.60	2.37	3.43	1.96	6.93	4.50	4.67
IS 2146 X PS 35805	64.00	63.33	280.00	168.90	2.40	3.33	2.10	7.38	4.00	4.33
IS 2146 X IS 2123	68.00	69.33	300.00	198.90	1.90	3.30	2.32	6.62	4.67	4.67
IS 18551 X ICSV 700	71.00	71.33	343.30	211.10	2.13	3.20	4.82	10.72	4.00	3.33
IS 18551 X Phule Anuradha	64.67	65.00	307.80	208.90	2.30	3.43	4.84	14.73	3.67	3.67
IS 18551 X M 35-1	72.33	70.33	320.00	221.10	2.30	3.23	5.95	13.67	3.33	3.67
IS 18551 X CSV 15	67.33	63.67	335.60	227.80	2.47	2.97	6.16	12.98	3.33	3.00
IS 18551 X ICSV 25019	66.00	63.00	305.60	197.80	2.37	2.97	3.12	13.75	3.00	3.00
IS 18551 X PS 35805	68.67	63.67	307.80	206.70	2.23	2.77	4.28	13.02	3.00	3.00
IS 18551 X IS 2123	72.67	69.33	293.30	207.80	2.23	2.83	4.00	11.36	5.00	4.33
IS 18551 X IS 2146	68.33	71.00	320.00	196.70	1.87	2.93	2.35	5.85	5.00	4.33
Swarna X ICSV 700	68.00	66.33	317.80	225.60	2.90	4.20	5.82	8.62	3.33	3.00
Swarna X Phule Anuradha	61.00	58.00	312.80	204.40	3.30	4.60	4.73	9.44	3.67	3.33
Swarna X M 35-1	64.00	62.33	315.60	193.30	3.13	4.47	4.36	10.39	3.33	3.00
Swarna X CSV 15	63.33	57.33	298.90	216.70	2.77	4.10	4.92	11.58	3.67	2.67
Swarna X ICSV 25019	61.33	59.33	186.70	142.20	2.83	2.90	7.38	9.46	2.00	2.67
Swarna X PS 35805	64.67	61.67	191.10	148.90	2.57	3.03	8.70	9.10	1.67	2.33
Swarna X IS 2123	64.00	62.67	294.40	176.70	2.90	3.73	4.94	10.79	4.33	4.00
Swarna X IS 2146	62.67	60.00	286.70	211.10	2.60	3.50	2.36	5.92	3.33	3.33
Swarna X IS 18551	64.67	67.33	330.00	230.00	2.83	3.40	5.27	11.69	3.67	3.00
Mean	**66.10**	**65.25**	**285.50**	**190.91**	**2.60**	**3.38**	**4.10**	**10.43**	**3.69**	**3.46**
SE ±	**1.13**	**1.40**	**6.21**	**5.83**	**0.12**	**0.15**	**0.71**	**1.04**	**0.35**	**0.40**
Vr (99, 198)	**10.09****	**10.90****	**56.80****	**22.91****	**8.66****	**12.87****	**6.37****	**9.65****	**7.48****	**2.41****
LSD (P 0.05)	**3.14**	**3.90**	**17.33**	**16.26**	**0.34**	**0.42**	**1.97**	**2.90**	**0.97**	**1.12**

** F probability significant at P 0.01; R, rainy season; PR, postrainy season.

sorghums. All the panicle traits showed significant variability among the genotypes for all the characteristics studied, in both the rainy and postrainy seasons with significant variance ratio (P 0.01) (Table 38). The mean scores for inflorescence exsertion were 1.90 and 2.41; for panicle compactness 2.30 and 2.63; for glume color 2.80 and 2.87; and for glume coverage 2.00 and 1.71 respectively, in the rainy and postrainy seasons.

4.6.3 Association of the agronomic and panicle traits with shoot fly resistance

Days to 50% flowering, inflorescence exsertion, panicle compactness, glume coverage and presence of awns were significantly and negatively correlated with shoot fly damage parameters across seasons, with few exceptions (Table 39). Plant height, 100 seed weight, grain yield and glume color showed positive correlation with shoot fly damage across seasons.

4.6.4 Association inbetween the agronomic traits

Agronomic score was positively correlated with days to 50% flowering and plant height, but negatively correlated with grain yield (Table 40). Days to 50% flowering were significantly and positively correlated with plant height, and negatively correlated with 100 seed weight and grain yield. Grain yield was positively correlated with plant height in the postrainy season, and 100 seed weight across seasons. Significant positive correlation was observed between plant height and 100 seed weight in the postrainy season.

4.6.5 Association between the panicle traits

Significant positive correlation was observed between inflorescence exsertion and panicle compactness, and between awns and the panicle traits across seasons (Table 41). Panicle shape was positively correlated with inflorescence exsertion, and panicle compactness in the postrainy season. Glume color exhibited negative correlation with inflorescence exsertion in the rainy season, and with panicle shape in the postrainy season. Glume cover exhibited positive correlation with glume color in the rainy season, and negative correlation in the postrainy season.

Table 38. Panicle and grain characteristics of sorghum (Parents and F$_1$'s) evaluated for resistance to sorghum shoot fly, *A. soccata* across seasons (ICRISAT, Patancheru, 2013-14).

Pedigree	Inflorescence exsertion		Panicle compactness		Panicle shape	Glume color		Glume coverage		Awns		Grain lustre
	2013 R	2013 PR	2013 R	2013 PR	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 PR
Parents												
ICSV 700	2.00	2.00	2.00	3.00	4.00	2.00	2.00	5.00	5.00	2.00	2.00	2.00
Phule Anuradha	2.33	3.00	2.00	3.00	4.00	3.00	3.00	3.00	1.00	2.00	2.00	2.00
M 35-1	2.00	2.00	2.00	3.00	4.00	3.00	3.00	3.00	1.00	2.00	2.00	2.00
CSV 15	2.00	1.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00	1.00	2.00
ICSV 25019	2.67	2.00	3.00	3.00	4.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00
PS 35805	3.00	2.00	3.00	3.00	4.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00
IS 2123	2.33	4.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	2.00	2.00	2.00
IS 2146	2.00	4.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	2.00	2.00	2.00
IS 18551	2.00	2.00	2.00	3.00	4.00	3.00	3.00	9.00	9.00	2.00	2.00	1.00
Swarna	1.00	1.00	2.00	2.00	1.00	6.00	4.00	1.00	1.00	1.00	1.00	2.00
Direct crosses												
ICSV 700 X Phule Anuradha	2.00	2.67	2.00	3.00	4.00	3.00	2.67	1.67	1.00	2.00	2.00	2.00
ICSV 700 X M 35-1	2.00	2.33	2.00	3.00	4.00	3.00	2.67	1.67	1.00	2.00	2.00	2.00
ICSV 700 X CSV 15	1.67	1.33	2.00	2.00	1.33	2.00	2.00	1.00	1.00	1.00	1.00	2.00
ICSV 700 X ICSV 25019	2.00	1.67	2.00	2.33	2.00	2.00	2.00	1.00	1.00	1.00	1.00	2.00
ICSV 700 X PS 35805	2.00	1.00	2.00	3.00	4.00	2.00	2.00	1.67	1.00	1.00	1.00	2.00
ICSV 700 X IS 2123	2.00	4.00	3.00	3.00	3.00	3.00	3.33	1.67	1.00	2.00	2.00	2.00
ICSV 700 X IS 2146	2.00	3.00	2.67	3.00	3.33	3.00	2.67	2.33	1.00	2.00	2.00	2.00
ICSV 700 X IS 18551	1.33	2.33	2.00	3.00	4.00	3.00	3.33	5.67	4.33	2.00	2.00	1.67
ICSV 700 X Swarna	2.00	1.00	2.00	2.00	1.00	3.67	4.00	1.67	1.67	1.00	1.00	2.00
Phule Anuradha X M 35-1	2.00	3.00	2.00	2.67	3.00	3.00	3.00	1.00	1.00	2.00	2.00	2.00
Phule Anuradha X CSV 15	1.67	1.67	2.00	2.00	1.33	2.00	3.33	1.00	1.00	1.00	1.00	2.00
Phule Anuradha X ICSV 25019	2.00	2.33	2.00	2.00	1.00	3.00	3.00	1.00	1.00	1.00	1.00	2.00
Phule Anuradha X PS 35805	2.00	3.00	2.33	2.33	2.00	3.00	3.00	1.00	1.00	1.00	1.00	2.00
Phule Anuradha X IS 2123	2.67	4.00	3.00	3.00	3.00	3.00	3.00	1.67	1.00	2.00	2.00	2.00
Phule Anuradha X IS 2146	2.67	4.00	2.67	3.00	3.00	3.00	3.00	1.67	1.00	2.00	2.00	2.00
Phule Anuradha X IS 18551	2.00	2.33	2.00	3.00	4.00	3.00	3.00	3.00	5.00	2.00	2.00	2.00
Phule Anuradha X Swarna	1.67	1.33	2.00	2.00	1.00	3.00	4.00	1.00	1.00	1.00	1.00	2.00
M 35-1 X CSV 15	1.00	1.00	2.00	2.33	2.67	2.00	2.33	1.00	1.67	1.00	1.00	2.00
M 35-1 X ICSV 25019	1.00	1.00	2.00	2.00	1.00	3.00	3.00	1.00	1.00	1.00	1.00	2.00
M 35-1 X PS 35805	1.00	1.67	2.33	3.00	4.00	3.00	3.00	2.33	1.00	1.00	1.00	2.00
M 35-1 X IS 2123	2.00	4.00	2.67	3.00	3.00	3.00	3.00	1.67	1.00	2.00	2.00	2.00
M 35-1 X IS 2146	2.33	4.00	2.67	3.00	3.00	3.00	3.00	1.00	1.00	2.00	2.00	2.00
M 35-1 X IS 18551	1.67	2.33	2.00	3.00	4.00	3.00	3.00	5.00	4.33	2.00	2.00	2.00
M 35-1 X Swarna	2.00	1.33	2.00	3.00	4.00	2.00	2.00	3.00	1.00	1.00	1.00	2.00
CSV 15 X ICSV 25019	2.33	3.00	2.00	2.00	1.33	1.00	1.67	1.00	1.00	1.00	1.00	2.00

Table 38. (Cont..)

Pedigree	Inflorescence exsertion		Panicle compactness		Panicle shape	Glume color		Glume coverage		Awns		Grain lustre
	2013 R	2013 PR	2013 R	2013 PR	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 PR
CSV 15 X PS 35805	2.33	1.67	2.00	2.00	1.33	1.00	2.00	1.00	1.00	1.00	1.00	2.00
CSV 15 X IS 2123	2.00	4.00	3.00	3.00	3.33	2.67	2.33	1.67	1.00	1.00	1.00	2.00
CSV 15 X IS 2146	2.00	2.33	2.67	3.00	3.67	2.33	2.67	1.00	1.00	1.00	1.00	2.00
CSV 15 X IS 18551	1.33	1.33	2.00	2.00	1.00	3.00	2.33	4.33	3.67	1.33	1.00	2.00
CSV 15 X Swarna	1.00	1.00	2.00	1.00	2.00	3.33	3.33	1.67	1.00	1.00	1.00	2.00
ICSV 25019 X PS 35805	3.00	3.00	2.33	3.00	4.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00
ICSV 25019 X IS 2123	3.00	4.00	3.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00	1.00	2.00
ICSV 25019 X IS 2146	2.33	4.00	2.67	3.00	3.67	3.00	3.00	1.00	1.00	1.00	1.00	2.00
ICSV 25019 X IS 18551	1.00	1.00	2.00	2.67	3.00	3.00	2.33	3.00	3.00	1.00	1.00	2.00
ICSV 25019 X Swarna	1.00	1.33	2.00	2.00	1.00	3.00	3.33	1.00	1.00	1.00	1.00	2.00
PS 35805 X IS 2123	2.33	4.00	3.00	3.00	3.00	3.00	2.67	2.33	1.00	1.00	1.00	2.00
PS 35805 X IS 2146	2.33	3.33	3.00	3.00	3.67	3.00	3.00	1.00	1.00	1.00	1.00	2.00
PS 35805 X IS 18551	1.33	1.67	2.00	2.00	1.00	3.00	3.00	3.67	3.67	1.00	1.00	1.67
PS 35805 X Swarna	1.00	1.00	2.00	2.00	1.00	3.00	3.00	1.00	1.00	1.00	1.00	2.00
IS 2123 X IS 2146	3.00	4.00	3.00	3.00	3.00	3.00	3.00	1.67	1.00	2.00	2.00	2.00
IS 2123 X IS 18551	2.67	4.00	3.00	3.00	3.00	3.00	3.00	4.33	4.33	2.00	2.00	2.00
IS 2123 X Swarna	2.00	4.00	2.67	3.00	3.67	3.00	4.00	1.00	1.00	1.00	1.00	2.00
IS 2146 X IS 18551	2.33	3.00	3.00	3.00	3.00	3.00	3.33	2.33	3.67	2.00	2.00	2.00
IS 2146 X Swarna	1.00	2.00	2.00	3.00	4.00	4.00	4.00	1.67	1.00	1.00	1.00	2.00
IS 18551 X Swarna	1.00	1.00	2.00	2.00	1.00	4.00	4.00	4.33	4.33	1.00	1.00	2.00
Reciprocal crosses												
Phule Anuradha X ICSV 700	2.00	3.00	2.00	3.00	4.00	3.00	3.00	1.67	1.00	2.00	2.00	2.00
M 35-1 X ICSV 700	1.67	2.67	2.00	3.00	4.00	3.00	2.33	1.67	1.00	2.00	2.00	2.00
M 35-1 X Phule Anuradha	2.33	2.00	2.00	2.33	2.00	3.00	3.00	1.00	1.00	2.00	1.67	1.67
CSV 15 X ICSV 700	1.67	1.33	2.00	2.33	2.33	2.00	2.00	1.67	1.00	1.00	1.00	2.00
CSV 15 X Phule Anuradha	1.33	1.33	2.00	2.00	1.67	2.00	2.33	1.00	1.00	1.00	1.00	2.00
CSV 15 X M 35-1	1.33	1.33	2.00	2.00	1.33	2.00	2.33	1.00	1.67	1.00	1.00	2.00
ICSV 25019 X ICSV 700	1.00	1.67	2.00	2.67	3.00	2.00	2.00	1.67	1.00	1.00	1.00	2.00
ICSV 25019 X Phule Anuradha	1.33	1.33	2.00	2.33	2.00	3.00	3.00	1.67	1.00	1.00	1.00	2.00
ICSV 25019 X M 35-1	1.33	1.67	2.00	2.67	3.00	3.00	3.00	1.67	1.00	1.00	1.00	2.00
ICSV 25019 X CSV 15	2.00	2.67	2.00	2.00	1.67	1.00	2.00	1.00	1.00	1.00	1.00	2.00
PS 35805 X ICSV 700	1.67	1.33	2.00	3.00	4.00	2.00	2.00	1.00	1.00	1.00	1.00	2.00
PS 35805 X Phule Anuradha	1.67	2.00	2.00	3.00	4.00	3.00	2.67	1.00	1.00	1.00	1.00	2.00
PS 35805 X M 35-1	1.00	1.33	2.00	3.00	4.00	3.00	2.67	1.67	1.00	1.00	1.00	2.00
PS 35805 X CSV 15	2.33	2.33	2.00	2.00	1.67	1.00	2.33	1.00	1.00	1.00	1.00	2.00
PS 35805 X ICSV 25019	3.00	3.00	2.00	3.00	4.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00
IS 2123 X ICSV 700	2.67	4.00	3.00	3.00	3.00	3.00	2.67	2.33	1.00	2.00	2.00	2.00
IS 2123 X Phule Anuradha	2.67	4.00	3.00	3.00	3.00	3.00	2.67	1.67	1.00	2.00	2.00	2.00

Table 38. (Cont..)

Pedigree	Inflorescence exsertion		Panicle compactness		Panicle shape	Glume color		Glume coverage		Awns		Grain lustre
	2013 R	2013 PR	2013 R	2013 PR	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 PR
IS 2123 X M 35-1	3.00	4.00	3.00	3.00	3.00	3.00	3.00	1.67	1.00	2.00	2.00	2.00
IS 2123 X CSV 15	2.67	4.00	2.67	3.00	3.00	2.33	2.33	1.67	1.00	1.00	1.00	2.00
IS 2123 X ICSV 25019	2.00	3.67	3.00	3.00	3.00	3.00	3.00	1.67	1.00	1.00	1.00	2.00
IS 2123 X PS 35805	2.67	3.67	3.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00	1.00	2.00
IS 2146 X ICSV 700	2.33	3.67	2.67	3.00	3.33	3.00	2.67	1.67	1.00	2.00	2.00	2.00
IS 2146 X Phule Anuradha	2.67	4.00	3.00	3.00	3.00	3.00	3.00	1.67	1.00	2.00	1.67	2.00
IS 2146 X M 35-1	2.67	4.00	3.00	3.00	3.00	3.00	3.00	1.00	1.00	2.00	2.00	2.00
IS 2146 X CSV 15	1.00	3.33	2.33	3.00	4.00	2.33	3.33	1.00	1.67	1.00	1.00	2.00
IS 2146 X ICSV 25019	2.33	3.67	3.00	3.00	3.67	3.00	3.00	1.00	1.00	1.00	1.00	2.00
IS 2146 X PS 35805	2.67	3.67	3.00	3.00	3.33	3.00	3.00	1.00	1.00	1.00	1.00	2.00
IS 2146 X IS 2123	3.00	4.00	3.00	3.00	3.00	3.00	3.00	1.67	1.00	2.00	2.00	2.00
IS 18551 X ICSV 700	2.00	2.67	2.00	3.00	4.00	3.00	3.67	5.67	3.67	2.00	2.00	2.00
IS 18551 X Phule Anuradha	2.33	2.67	2.00	3.00	4.00	3.00	3.33	4.33	5.00	2.00	2.00	2.00
IS 18551 X M 35-1	2.00	2.33	2.00	3.00	4.00	3.00	3.00	5.00	5.00	2.00	2.00	2.00
IS 18551 X CSV 15	1.00	1.00	2.00	2.00	1.33	3.00	2.67	2.33	4.33	1.00	1.00	1.67
IS 18551 X ICSV 25019	1.33	1.00	2.00	2.00	1.00	3.00	3.00	3.67	3.00	1.00	1.00	2.00
IS 18551 X PS 35805	1.67	1.33	2.00	2.33	2.00	3.00	3.00	3.67	3.67	1.00	1.00	2.00
IS 18551 X IS 2123	3.00	4.00	3.00	3.00	3.00	3.00	3.00	4.33	4.33	2.00	2.00	2.00
IS 18551 X IS 2146	3.00	2.33	3.00	3.00	3.00	3.00	3.67	3.67	3.67	2.00	2.00	2.00
Swarna X ICSV 700	1.33	1.00	2.00	2.00	1.00	3.00	3.67	1.67	1.00	1.00	1.00	2.00
Swarna X Phule Anuradha	1.00	1.00	2.00	2.00	1.33	2.67	4.00	1.67	1.00	1.00	1.00	2.00
Swarna X M 35-1	1.33	1.00	2.00	2.33	1.00	2.00	4.00	1.00	1.00	1.00	1.00	2.00
Swarna X CSV 15	1.00	1.00	2.00	1.00	2.00	3.33	4.00	1.00	1.00	1.00	1.00	2.00
Swarna X ICSV 25019	1.00	1.00	2.00	2.00	1.00	3.00	2.67	1.00	1.00	1.00	1.00	2.00
Swarna X PS 35805	1.00	1.00	2.00	2.00	1.00	3.00	3.33	1.00	1.00	1.00	1.00	2.00
Swarna X IS 2123	1.67	3.00	3.00	3.00	3.33	3.00	4.00	1.00	1.00	1.00	1.00	2.00
Swarna X IS 2146	1.67	1.00	2.00	3.00	4.00	4.00	4.00	1.67	1.00	1.00	1.00	2.00
Swarna X IS 18551	1.00	1.00	2.00	2.00	1.00	5.00	4.00	4.33	5.00	1.00	1.00	2.00
Mean	**1.90**	**2.41**	**2.30**	**2.63**	**2.75**	**2.80**	**2.87**	**2.00**	**1.71**	**1.40**	**1.35**	**1.98**
SE ±	**0.25**	**0.29**	**0.12**	**0.12**	**0.35**	**0.31**	**0.20**	**0.43**	**0.33**	**0.03**	**0.05**	**0.07**
Vr	**6.49****	**15.17****	**13.65****	**18.62****	**9.81****	**6.20****	**11.35****	**10.81****	**19.91****	**208.27****	**102.88****	**3.18****
LSD (P 0.05)	**0.69**	**0.81**	**0.33**	**0.32**	**0.99**	**0.86**	**0.57**	**1.20**	**0.92**	**0.09**	**0.13**	**0.19**

** F probability significant at P 0.05; R, rainy seaason; PR, postrainy season.

Table 39. Association of agronomic and panicle traits with expression of resistance to sorghum shoot fly, *Atherigona soccata*.

Traits	**Plants with shoot fly eggs (%)**	**Number of shoot fly eggs/plant**	**Shoot fly deadhearts (%)**	**ORS**
Days to 50% flowering	-0.20* (-0.41**)	0.13 (-0.07)	-0.31** (-0.47**)	0.09 (-0.24**)
Plant height	0.13 (-0.01)	0.15 (-0.06)	0.35** (0.07)	-0.07 (-0.02)
100 seed weight	0.21* (0.28**)	-0.03 (-0.04)	0.39** (0.32**)	0.13 (0.15)
Grain yield	0.16* (0.03)	-0.01 (-0.17*)	0.24** (0.05)	0.05 (0.22*)
Agronomic score	-0.03 (-0.43**)	0.09 (-0.17*)	0.02 (-0.41**)	-0.10 (-0.38**)
Inflorescence exsertion	-0.19* (-0.37**)	-0.06 (-0.14)	-0.37** (-0.41**)	-0.18* (-0.31**)
Panicle compactness	-0.13 (-0.55**)	-0.01 (-0.18*)	-0.30** (-0.60**)	-0.28** (-0.45**)
Panicle shape	(-0.48**)	(-0.10)	(-0.49**)	(-0.38**)
Glume color	0.04 (0.24**)	0.06 (0.09)	0.21* (0.26**)	0.15 (0.04)
Glume coverage	-0.17* (-0.16*)	0.15 (0.08)	-0.18* (-0.44**)	-0.01 (-0.13)
Awns	-0.12 (-0.41**)	0.01 (-0.07)	-0.18* (-0.44**)	0.10 (-0.17*)

*, ** Correlation coefficients significant at P 0.05 and P 0.01, respectively; ORS, overall resistance score; The values inside the parentheses are for postrainy season, whereas the values outside the parentheses are for rainy season.

Table 40. Association between the agronomic traits in the postrainy season adapted sorghums.

Traits	Agronomic score	Days to 50% flowering	Plant height	100 seed weight
Days to 50% flowering	0.24** (0.45**)	1.00		
Plant height	0.52** (0.24**)	0.22* (0.41**)	1.00	
100 seed weight	-0.17 (0.01)	-0.51** (-0.23**)	0.04 (0.43**)	1.00
Grain yield	-0.47** (-0.21*)	-0.26** (-0.08)	0.00 (0.36**)	0.36** (0.21*)

*, ** correlation coefficients significant at P 0.05 and P 0.01, respectively. The values inside the parentheses are for postrainy season, whereas the values outside the parentheses are for rainy season.

Table 41. Association between the panicle traits in the postrainy season sorghums.

Traits	Inflorescence exsertion	Panicle compactness	Panicle shape	Glume color	Glume coverage	Awns
Panicle compactness	0.66** (0.66**)	1.00				
Panicle shape	(0.46**)	(0.86**)	1.00			
Glume color	-0.28** (-0.04)	0.05 (-0.14)	(-0.22*)	1.00		
Glume coverage	-0.03 (-0.14)	-0.12 (0.05)	(0.07)	0.25** (0.15)	1.00	
Awns	0.45** (0.53**)	0.30** (0.52**)	(0.44**)	0.20* (0.11)	0.44** (0.29**)	1.00
Grain lustre	(0.10)	(0.01)	(-0.03)	(-0.04)	(-0.55**)	(-0.13)

*, ** Correlation coefficient significant at P 0.05 and P 0.01, respectively. The values inside the parentheses are for postrainy season, whereas the values outside the parentheses are for rainy season.

4.6.6 Combining ability analysis

4.6.6.1 Analysis of variance of combining ability studies

Mean sum of squares for general combining ability of all the traits studied in the rainy season and postrainy seasons were significant at P 0.01 (Table 42). The mean sum of squares due to SCA was significant for all the traits studied, during the rainy and postrainy seasons, except grain lustre during rainy season and agronomic score and waxy bloom in the postrainy season. Both additive and non-additive nature of gene action was observed for most of the agronomic and panicle traits. The mean sum of squares due to reciprocal crosses was significant for days to 50% flowering and 100 seed weight across seasons, inflorescence exsertion during the rainy season; and plant height, panicle compactness, panicle shape, and glume color during the postrainy season, suggesting the influence of cytoplasmic factors in the expression of these traits.

4.6.7 Estimates of *gca, sca* and reciprocal effects of parents and hybrids

4.6.7.1 *gca* effects of agronomic traits

The *gca* effects of days to 50% flowering ranged from -2.87 (Phule Anuradha) to 3.36 (ICSV 700) in the rainy season, and from -3.65 (CSV 15) to 4.40 (ICSV 700) in the postrainy season (Table 43). Phule Anuradha (-2.87**), ICSV 25019 (-1.85**), IS 2146 (-0.77**) and Swarna (-1.37**) exhibited significant negative *gca* effects in the rainy season, and Phule Anuradha (-1.61**), CSV 15 (-3.65**), ICSV 25019 (-2.58**), PS 35805 (-2.58**) and Swarna (-2.60**) exhibited significant negative *gca* effects for days to 50% flowering in the postrainy season. ICSV 700 (3.36**, 4.40** respectively, in the rainy and postrainy season), M 35-1 (0.50*, 2.30**), IS 2123 (1.33**, 1.70**) and IS 18551 (2.46**, 3.17**) across seasons and IS 2146 (1.44**) in the postrainy season showed significant positive *gca* effects for days to 50% flowering.

The *gca* effects for plant height ranged from -44.49 (ICSV 25019) to 32.23 (ICSV 700) in the rainy season, -28.69 (ICSV 25019) to 20.59 (IS 18551) in the postrainy season. ICSV 25019 (-44.49** and -28.69** respectively, in the rainy and postrainy season), PS 35805 (-42.96** and -27.69**) and Swarna (-16.10** and -3.36**) exhibited significant negative *gca* effects for plant height across seasons. The genotypes ICSV 700, Phule Anuradha, M 35-1, CSV 15, IS 2123, IS 2146, and IS 18551 in the rainy season,

Table 42. Analysis of variance (ANOVA) showing mean sum of squares of general, specific and reciprocal combining abilities of F_1 (10 X 10) diallel across seasons (ICRISAT, Patancheru, 2013-14).

Source	GCA		SCA		Reciprocal		Error	
	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR
Days to 50% flowering	75.23 **	168.15 **	10.31 **	8.40 **	2.74 **	4.92 **	1.27	1.96
Plant height (cm)	14639.30 **	5747.19 **	1856.50 **	494.31 **	40.27	69.04 **	38.62	33.99
100 seed weight (g)	0.81 **	2.07 **	0.10 **	0.18 **	0.02 *	0.05 **	0.02	0.02
Grain yield (t/ha)	11.80 **	44.52 **	3.94 **	12.95 **	0.70	1.08	0.50	1.08
Agronomic score	6.83**	3.06**	0.44**	0.15	0.17	0.11	0.12	0.16
Inflorescence exsertion	2.14 **	10.80 **	0.34 **	0.58 **	0.11 **	0.11	0.06	0.09
Panicle compactness	1.68 **	1.74 **	0.08 **	0.17 **	0.01	0.03 **	0.01	0.01
Panicle shape	-	4.88 **	-	1.40 **	-	0.32 **	-	0.13
Glume color	3.73 **	3.42 **	0.54 **	0.26 **	0.02	0.10 **	0.10	0.04
Glume coverage	17.63 **	21.08 **	0.70 **	0.49 **	0.21	0.03	0.19	0.11
Awns	1.91 **	1.85**	0.13 **	0.13**	0.00	0.00	0.00	0.00
Grain lustre	0.02 **	0.04**	0.02	0.02**	0.00	0.01	0.00	0.00

*, ** F probability significant at P 0.05 and P 0.01, respectively; GCA, general combining ability; SCA, specific combining ability; R, rainy season; PR, postrainy season.

and ICSV 700, Phule Anuradha, M 35-1, and IS 18551 in the postrainy season exhibited significant positive *gca* effects for plant height.

The *gca* effects for 100 seed weight ranged from -0.31 (IS 18551) to 0.38 (Swarna) in the rainy and -0.43 (PS 35805) to 0.56 (Phule Anuradha) in the postrainy seasons. PS 35805 (-0.07**), IS 2123 (-0.06**), IS 2146 (-0.26**) and IS 18551 (-0.31**) in the rainy season, and ICSV 25019 (-0.22**), PS 35805 (-0.43**), IS 2123 (-0.16**), and IS 18551 (-0.40**) in the postrainy season exhibited significant negative *gca* effects for 100 seed weight. Whereas, the genotypes Phule Anuradha (0.20**), CSV 15 (0.09**) and Swarna (0.38**) in the rainy season, and ICSV 700 (0.07*), Phule Anuradha (0.56**), M 35-1 (0.33**), and Swarna (0.29**) in the postrainy season showed positive *gca* effects for 100 seed weight.

The *gca* effects of sorghum grain yield ranged from -1.79 (IS 2146) to 0.90 (CSV 15) in the rainy season, and -3.86 (IS 2146) to 1.27 (M 35-1) in the postrainy season. The *gca* effects of Phule Anuradha (-0.43**), M 35-1 (-0.34*) and IS 2146 (-1.79**) in the rainy season, and IS 2146 (-3.86**) and Swarna (-0.99**) in the postrainy season exhibited significant negative *gca* effects for grain yield. The genotypes CSV 15 (0.90**), ICSV 25019 (0.40**), PS 35805 (0.48**) and Swarna (0.74**) in the rainy season and ICSV 700 (0.44*), Phule Anuradha (0.52*), M 35-1 (1.27**), CSV 15 (0.86**) IS 2123 (0.89**) and IS 18551 (0.77**) in the postrainy season showed significant positive *gca* effects for grain yield.

The *gca* effects of agronomic score ranged from -0.75 (PS 35805) to 0.96 (IS 2123) in the rainy season, and -0.48 (Swarna) to 0.66 (IS 2146) in the postrainy season. CSV 15 (-0.46** and -0.31** respectively, in the rainy and postrainy season), ICSV 25019 (-0.73** and -0.39**), PS 35805 (-0.75** and -0.31**) and Swarna (-0.47** and -0.48**) exhibited significant negative *gca* effects for agronomic score across seasons. IS 2123 (0.96** and 0.59** respectively, in the rainy and postrainy season), IS 2146 (0.69** and 0.66**) and the genotype IS 18551 (0.18* in the rainy season) exhibited significant positive *gca* effects for the agronomic score.

4.6.7.2 *gca* effects of panicle traits

The *gca* effects of inflorescence exsertion ranged from -0.63 (Swarna) to 0.57 (IS 2123) in the rainy season, and -1.06 (Swarna) to 1.51 (IS 2123) in the postrainy season (Table

43). M 35-1 (-0.13* and 0.16* respectively, in the rainy and postrainy season), CSV 15 (-0.23** and -0.53**), IS 18551 (-0.12** and -0.34**), and Swarna (-0.63** and -1.06**) showed significant negative *gca* effects across seasons, while Phule Anuradha (0.12* and 0.17**), IS 2123 (0.57** and 1.51**), and IS 2146 (0.35** and 0.96**) exhibited positive and significant *gca* effects for inflorescence exsertion across seasons.

The *gca* effects of panicle compactness ranged from -0.25 (Swarna) to 0.62 (IS 2123) in the rainy season, and -0.50 (CSV 15) to 0.37 (IS 2123 and IS 22146) in the postrainy season. The genotypes ICSV 700, Phule Anuradha, M 35-1, CSV 15, IS 18551 and Swarna exhibited significant and negative *gca* effects and the genotypes IS 2123 and IS 2146 exhibited positive and significant *gca* effects for panicle compactness in the rainy season. The genotypes CSV 15, ICSV 25019, and Swarna exhibited significant negative *gca* effects, while ICSV 700, M 35-1, PS 35805, IS 2123 and IS 2146 exhibited significant positive *gca* effects for panicle compactness in the postrainy season.

The *gca* effects of the panicle shape ranged from -0.94 (Swarna) to 0.58 (IS 2146) in the postrainy season. The genotypes CSV 15, ICSV 25019 and Swarna exhibited significant negative *gca* effects and the genotypes ICSV 700, M 35-1, PS 35805, IS 2123 and IS 2146 exhibited significant positive *gca* effects for panicle shape in the postrainy season.

The *gca* effects of glume color ranged from -0.65 (CSV 15) to 0.73 (Swarna) in the rainy season, and -0.52 (ICSV 25019) to 0.80 (Swarna) in the postrainy season. The genotypes ICSV 700 (-0.13* and -0.23** respectively, in the rainy and postrainy season), CSV 15 (-0.65** and -0.40**), ICSV 25019 (-0.47** and -0.52**), and PS 35805 (-0.47** and -0.48**) exhibited significant negative *gca* effects, while IS 2123 (0.18** and 0.13**), IS 2146 (0.27** and 0.25**), IS 18551 (0.38** and 0.27**) and Swarna (0.73** and 0.80**) exhibited significant positive *gca* effects for glume color across seasons.

The general combining ability of glume cover ranged from -0.65 to 2.52 in the rainy season, and -0.51 to 2.89 in the postrainy season. All the genotypes exhibited significant negative *gca* effects except IS 18551 (2.52** and 2.89**) with significant positive *gca* effects for glume coverage across seasons.

The *gca* effects of awns ranged from -0.36 to 0.25 in the rainy season, and -0.35 to 0.25 in the postrainy season. CSV 15, ICSV 25019, PS 35805 and Swarna exhibited

Table 43. Estimates of general combining ability of agronomical and panicle traits of parents (10 X 10 diallel) across seasons (ICRISAT, Patancheru, 2013-14).

Traits	ICSV 700	Phule Anuradha	M 35-1	CSV 15	ICSV 25019	PS 35805	IS 2123	IS 2146	IS 18551	Swarna
Days to 50% flowering	3.36** (4.40**)	-2.87** (-1.61**)	0.50* (2.30**)	-0.35 (-3.65**)	-1.85** (-2.58**)	-0.44 (-2.58**)	1.33** (1.70**)	-0.77** (1.44**)	2.46** (3.17**)	-1.37** (-2.60**)
Plant height (cm)	32.23** (19.42**)	5.59** (7.92**)	19.43** (10.53**)	5.19** (1.87)	-44.49** (-28.69**)	-42.96** (-27.69**)	3.87** (-2.13)	5.96** (1.53)	31.29** (20.59**)	-16.10** (-3.36**)
100 seed weight (g)	-0.02 (0.07*)	0.20** (0.56**)	0.01 (0.33**)	0.09** (0.01)	0.04 (-0.22**)	-0.07** (-0.43**)	-0.06* (-0.16**)	-0.26** (-0.05)	-0.31** (-0.40**)	0.38** (0.29**)
Grain yield (t/ha)	0.23 (0.44*)	-0.43** (0.52*)	-0.34* (1.27**)	0.90** (0.86**)	0.40** (0.07)	0.48** (0.03)	-0.14 (0.89**)	-1.79** (-3.86**)	-0.06 (0.77**)	0.74** (-0.99**)
Agronomic score	0.13 (0.04)	0.18* (0.11)	0.26** (0.11)	-0.46** (-0.31**)	-0.73** (-0.39**)	-0.75** (-0.31**)	0.96** (0.59**)	0.69** (0.66**)	0.18* (-0.01)	-0.47** (-0.48**)
Inflorescence exsertion	-0.05 (-0.18**)	0.12* (0.17**)	-0.13* (-0.16*)	-0.23** (-0.53**)	0.00 (-0.16*)	0.13* (-0.21**)	0.57** (1.51**)	0.35** (0.96**)	-0.12* (-0.34**)	-0.63** (-1.06**)
Panicle compactness	-0.17** (0.13**)	-0.13** (0.00)	-0.15** (0.13**)	-0.20** (-0.50**)	-0.03 (-0.10**)	0.02 (0.05*)	0.62** (0.37**)	0.43** (0.37**)	-0.13** (0.02)	-0.25** (-0.47**)
Panicle shape	(0.41**)	(0.01)	(0.35**)	(-0.70**)	(-0.24**)	(0.20**)	(0.31**)	(0.58**)	(0.01)	(-0.94**)
Glume color	-0.13* (-0.23**)	0.12 (0.18**)	0.03 (0.00)	-0.65** (-0.40**)	-0.47** (-0.52**)	-0.47** (-0.48**)	0.18** (0.13**)	0.27** (0.25**)	0.38** (0.27**)	0.73** (0.80**)
Glume coverage	0.35** (0.03)	-0.28** (-0.31**)	-0.05 (-0.27**)	-0.65** (-0.31**)	-0.65** (-0.51**)	-0.55** (-0.44**)	-0.01 (-0.37**)	-0.31** (-0.41**)	2.52** (2.89**)	-0.38** (-0.31**)
Awns	0.24** (0.25**)	0.24** (0.21**)	0.24** (0.23**)	-0.35** (-0.35**)	-0.36** (-0.35**)	-0.36** (-0.35**)	0.24** (0.25**)	0.24** (0.23**)	0.25** (0.25**)	-0.36** (-0.35**)
Grain lustre	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(-0.13**)	(0.02)

*, ** t test significant at P 0.05 and P 0.01 probability levels. The values outside the parentheses are for rainy season and inside the parentheses are for postrainy season.

significant negative *gca* effects, while ICSV 700, Phule Anuradha, M 35-1, IS 2123, IS 2146 and IS 18551 exhibited significant positive *gca* effects for presence of awns across seasons.

4.6.8 Specific combining ability effects

4.6.8.1 *sca* effects of agronomic traits

The *sca* effects for days to 50% flowering ranged from -3.66 to 3.19 and -3.20 to 3.61 during the rainy and postrainy season, respectively. For plant height the *sca* effects ranged from -71.09 to 45.68 and -30.09 to 22.75, for 100 seed weight - from 0.56 to 0.37 and -0.50 to 0.38, for grain yield from -1.24 to 2.65 and -3.24 to 4.70 respectively, for the rainy and postrainy seasons. For agronomic score from -1.02 to 0.91 in the rainy season (Table 44). Ten hybrids in the rainy season and nine hybrids in the postrainy season exhibited significant negative *sca* effects for days to 50% flowering. ICSV 700 X CSV 15 across seasons, and Phule Anuradha X PS 35805 and M 35-1 X CSV 15 in the postrainy season showed significant positive *sca* effects for days to 50% flowering.

Significant negative *sca* effects for plant height were observed for fourteen hybrids in the rainy season, and 10 hybrids in the postrainy season. Fifteen hybrids across seasons, Phule Anuradha X Swarna, ICSV 25019 X IS 2123, ICSV 25019 X IS 2146, PS 35805 X IS 2123, IS 2123 X Swarna in the rainy season, and M 35-1 X CSV 15 in the postrainy season exhibited significant positive *sca* effects for plant height.

Nine hybrids in the rainy season, and four hybrids in the postrainy season exhibited significant negative *sca* effects for 100 seed weight.

Significant negative *sca* effects for grain yield were observed in Phule Anuradha X CSV 15, ICSV 25019 X PS 35805 across seasons, CSV 15 X Swarna in the rainy season, and ICSV 700 X IS 2146 in the postrainy season. Phule Anuradha X PS 35805, Phule Anuradha X IS 18551, M 35-1 X IS 18551, CSV 15 X IS 2123 across seasons, ICSV 700 X Phule Anuradha, ICSV 700 X PS 35805, CSV 15 X ICSV 25019, CSV 15 X PS 35805, CSV 15 X IS 18551, ICSV 25019 X Swarna, PS 35805 X Swarna in the rainy season and ICSV 700 X CSV 15, ICSV 700 X ICSV 25019, M 35-1 X ICSV 25019, M 35-1 X IS 2123, CSV 15 X PS 35805, ICSV 25019 X IS 2123, ICSV 25019 X IS 18551, IS 18551 X Swarna in the postrainy season, exhibited significant and positive *sca* effects for grain yield.

Table 44. Estimates of specific combining ability effects of agronomic traits of F_1 crosses (10 X 10 diallel) of sorghum across seasons (ICRISAT, Patancheru, 2013-14).

Pedigree	Days to 50% flowering		Plant height (cm)		100 seed weight (g)		Grain yield (t/ha)		Agronomic score
	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R
ICSV 700 X Phule Anuradha	-0.80	1.30	-8.32*	6.19	-0.06	-0.05	-0.11	1.22	0.00
ICSV 700 X M 35-1	-3.66**	-2.62**	-18.26**	-2.53	0.08	0.37**	1.16*	-0.03	-0.25
ICSV 700 X CSV 15	3.19**	3.16**	7.10	-4.98	-0.23**	-0.18	0.05	2.90**	-1.02**
ICSV 700 X ICSV 25019	-0.15	0.10	36.21**	16.69**	0.09	0.32**	0.21	1.91**	-0.09
ICSV 700 X PS 35805	-0.06	-0.74	34.11**	21.24**	0.01	0.04	1.51**	1.33	-0.07
ICSV 700 X IS 2123	-2.83**	-2.02*	-13.80**	5.13	0.04	0.14	0.29	1.21	0.05
ICSV 700 X IS 2146	-0.90	0.25	-4.79	-3.53	0.25**	-0.06	-0.13	-1.55*	-0.34
ICSV 700 X IS 18551	-2.80**	-1.99*	-7.89	-9.81*	0.02	0.20*	0.83	-0.36	-0.16
ICSV 700 X Swarna	-0.46	-0.05	16.72**	12.47**	0.05	0.38**	-0.07	-0.34	0.82**
Phule Anuradha X M 35-1	0.57	-0.77	-32.19**	-2.14	-0.21**	-0.04	-0.24	-0.77	-0.46*
Phule Anuradha X CSV 15	0.09	-0.99	9.85*	9.30*	0.18*	0.13	-1.21*	-1.60*	0.26
Phule Anuradha X ICSV 25019	-0.41	-1.72	34.53**	14.86**	0.27**	0.32**	0.22	-0.11	0.20
Phule Anuradha X PS 35805	-0.16	3.61**	35.76**	22.75**	0.24**	-0.12	0.92*	4.70**	0.21
Phule Anuradha X IS 2123	-0.60	0.16	-11.09**	-6.70	-0.14	-0.06	0.12	0.19	-0.16
Phule Anuradha X IS 2146	0.50	0.10	-7.02	-11.48**	-0.21*	-0.04	0.79	-0.15	-0.22
Phule Anuradha X IS 18551	-1.06	-1.80	-13.49**	-11.09**	-0.19*	-0.10	1.18*	1.99**	-0.55*
Phule Anuradha X Swarna	-0.06	-1.20	29.75**	6.19	0.21*	0.23*	0.36	-0.52	0.10
M 35-1 X CSV 15	-2.95**	2.76**	-0.64	8.35*	0.25**	0.03	-0.31	0.35	0.18
M 35-1 X ICSV 25019	-0.45	0.70	45.68**	21.69**	0.21*	0.18	0.28	2.82**	0.28
M 35-1 X PS 35805	-2.20**	-0.97	35.01**	10.13**	0.23**	0.20*	0.04	1.03	0.46*
M 35-1 X IS 2123	-0.63	-0.09	-4.89	-2.09	-0.06	-0.05	-0.23	1.55*	-0.41
M 35-1 X IS 2146	-0.70	-0.15	-17.54**	-4.65	-0.13	0.15	0.41	-0.72	0.20
M 35-1 X IS 18551	0.74	-0.39	-15.10**	-5.92	0.05	-0.11	1.64**	1.60*	-0.63**
M 35-1 X Swarna	1.07	-0.29	26.18**	2.47	-0.22**	-0.20*	-0.04	0.27	-0.15
CSV 15 X ICSV 25019	-0.60	-1.19	-16.73**	-10.76**	-0.24**	0.08	1.83**	1.16	-0.66**
CSV 15 X PS 35805	-0.35	-1.69	-3.80	-10.09**	-0.15	0.15	1.50**	0.38	-0.06

Table 44. (Cont..)

Pedigree	Days to 50% flowering		Plant height (cm)		100 seed weight (g)		Grain yield (t/ha)		Agronomic score
	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R
CSV 15 X IS 2123	-1.61*	-0.64	-0.65	-0.64	0.14	-0.02	2.65**	1.71*	0.48*
CSV 15 X IS 2146	-1.01	-2.70**	1.70	-2.09	0.34**	-0.01	-0.13	-0.32	-0.08
CSV 15 X IS 18551	-1.91*	-1.27	15.80**	7.75*	0.10	-0.02	1.02*	1.31	-0.24
CSV 15 X Swarna	-0.41	-0.84	28.76**	17.80**	-0.12	0.21*	-1.06*	1.04	0.91**
ICSV 25019 X PS 35805	2.49**	0.75	-71.09**	-30.09**	-0.56**	-0.49**	-1.24**	-3.24**	-0.21
ICSV 25019 X IS 2123	-0.11	-0.70	18.73**	3.80	0.26**	0.34**	0.69	2.37**	0.58*
ICSV 25019 X IS 2146	-0.01	-0.44	24.70**	5.69	0.23**	0.45**	-0.51	0.31	0.77**
ICSV 25019 X IS 18551	-1.08	-1.84*	31.60**	20.52**	0.06	0.17	-0.75	2.05**	0.03
ICSV 25019 X Swarna	-1.91*	0.43	-38.22**	-17.76**	0.06	-0.50**	2.29**	0.29	-0.66**
PS 35805 X IS 2123	-0.36	-3.20**	26.92**	5.02	0.37**	0.22*	-0.17	1.19	0.43
PS 35805 X IS 2146	-1.60*	-1.94*	22.06**	9.69*	0.22**	0.36**	-0.65	0.69	0.20
PS 35805 X IS 18551	-1.16	-2.34*	38.97**	20.63**	0.13	0.13	-0.31	0.99	-0.12
PS 35805 X Swarna	0.00	1.26	-38.93**	-15.98**	-0.24**	-0.33**	1.73**	0.29	-0.64**
IS 2123 X IS 2146	1.30	1.78	0.80	6.91	-0.33**	0.02	0.02	-0.90	-0.67**
IS 2123 X IS 18551	0.74	1.21	-25.08**	-2.15	-0.10	-0.16	-0.65	-1.25	0.17
IS 2123 X Swarna	-0.43	0.48	18.95**	1.80	0.15	0.15	0.32	0.50	0.15
IS 2146 X IS 18551	0.00	1.65	-17.72**	-9.14*	-0.03	0.05	0.07	-0.26	0.28
IS 2146 X Swarna	-1.00	-3.09**	16.32**	21.47**	-0.08	0.06	-0.27	0.07	-0.07
IS 18551 X Swarna	-0.73	0.35	27.64**	17.97**	0.22**	0.18	0.40	1.68*	0.27

*, ** t test significant at P 0.05 and P 0.01 respectively; R, rainy season; PR, postrainy season.

ICSV 700 X CSV 15, Phule Anuradha X M 35-1, Phule Anuradha X IS 18551, M 35-1 X IS 18551, CSV 15 X ICSV 25019, ICSV 25019 X Swarna, PS 35805 X Swarna, IS 2123 X IS 2146 exhibited significant negative *sca* effects while ICSV 700 X Swarna, M 35-1 X PS 35805, CSV 15 X IS 2123, CSV 15 X Swarna, ICSV 25019 X IS 2123, ICSV 25019 X IS 2146 exhibited significant positive *sca* effects for agronomic score in the rainy season.

4.6.8.2 *sca* effects of panicle traits

The *sca* effects of the inflorescence exsertion ranged from -0.92 to 0.95 and -0.91 to 1.11, for panicle compactness from -0.52 to 0.37 and -0.67 to 0.50, for glume color from -1.53 to 0.67 and -0.67 to 0.65, for glume coverage -1.22 to 0.78 and -1.09 to 0.71, for awns from -0.25 to 0.36 and 0.25 to 0.35 respectively, in the rainy and postrainy seasons. For panicle shape it ranged from -1.46 to 1.60 and grain lustre from -0.16 to -0.01 in the postrainy season (Table 45).

Six hybrids across seasons, five hybrids in the rainy season, and four hybrids in the postrainy season exhibited significant negative *sca* effects for inflorescence exsertion. Eight hybrids in the rainy season and twelve hybrids in the postrainy season exhibited significant positive *sca* effects for inflorescence exsertion.

Six hybrids in the rainy season, fourteen hybrids in the postrainy season exhibited significant negative *sca* effects and seven hybrids in the rainy season and twelve hybrids in the postrainy season exhibited significant positive *sca* effects for panicle compactness.

Seventeen hybrids showed significant negative *sca* effects and fourteen hybrids exhibited positive and significant *sca* effects for panicle shape in the postrainy season.

Five hybrids in the rainy season, four hybrids in the postrainy season, and 35-1 X Swarna and ICSV 25019 X PS 35805 across seasons exhibited significant negative *sca* effects for glume color. Nine hybrids across seasons and CSV 15 X IS 18551, IS 18551 X Swarna in the rainy season and ICSV 700 X IS 18551, ICSV 700 X Swarna, CSV 15 X IS 2146, PS 35805 X IS 18551 in the postrainy season exhibited significant positive *sca* effects for glume color.

Four hybrids in the rainy season, five hybrids in the postrainy season, and ICSV 700 X M 35-1 and IS 2146 XIS 18551 across seasons, exhibited significant negative *sca*

Table 45. Estimates of specific combining ability effects of panicle traits of F_1 crosses (10 X 10 diallel) of sorghum, across seasons (ICRISAT, Patancheru, 2013-14).

Pedigree	Inflorescence exsertion		Panicle compactness		Panicle shape	Glume color		Glume coverage		Awns		Grain lustre
	2013 R	2013 PR	2013 R	2013 PR	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 PR
ICSV 700 X Phule Anuradha	0.02	0.43*	-0.03	0.23**	0.82**	0.25	0.02	-0.42	-0.43*	0.16**	0.19**	0.01
ICSV 700 X M 35-1	0.10	0.43*	-0.02	0.10	0.49*	0.33	-0.13	-0.65*	-0.46*	0.16**	0.17**	0.01
ICSV 700 X CSV 15	0.03	-0.37	0.03	-0.10	-0.63**	0.02	-0.23	-0.39	-0.43*	-0.25**	-0.25**	0.01
ICSV 700 X ICSV 25019	-0.37*	-0.41*	-0.13	-0.17*	-0.43	-0.17	-0.12	-0.39	-0.23	-0.24**	-0.25**	-0.01
ICSV 700 X PS 35805	-0.17	-0.86**	-0.18*	0.18*	0.64**	-0.17	-0.15	-0.49	-0.29	-0.24**	-0.25**	0.01
ICSV 700 X IS 2123	-0.10	0.26	0.22**	-0.13	-0.48*	0.18	0.23	-0.35	-0.36	0.16**	0.15**	-0.01
ICSV 700 X IS 2146	-0.05	0.14	0.07	-0.13	-0.41	0.10	-0.22	-0.05	-0.33	0.16**	0.17**	-0.01
ICSV 700 X IS 18551	-0.08	0.61**	-0.03	0.22**	0.82**	-0.02	0.60**	0.78**	-0.63**	0.15**	0.15**	-0.02
ICSV 700 X Swarna	0.43**	-0.17	0.08	-0.30**	-1.23**	-0.03	0.40**	-0.32	-0.09	-0.24**	-0.25**	-0.01
Phule Anuradha X M 35-1	0.27	0.08	-0.05	-0.27**	-0.61**	0.08	-0.05	-0.69 *	-0.13	0.16**	0.04	-0.16**
Phule Anuradha X CSV 15	-0.30	-0.56**	0.00	-0.13	-0.56*	-0.23	0.18	-0.09	-0.09	-0.25**	-0.21**	0.01
Phule Anuradha X ICSV 25019	-0.37*	-0.59**	-0.17*	-0.37**	-1.03**	0.58**	0.47**	0.25	0.11	-0.24**	-0.21**	-0.01
Phule Anuradha X PS 35805	-0.33*	0.13	-0.05	-0.02	0.04	0.58**	0.27*	-0.19	0.04	-0.24**	-0.21**	0.01
Phule Anuradha X IS 2123	0.07	-0.09	0.18*	0.00	-0.08	-0.07	-0.35*	-0.05	-0.03	0.16**	0.19**	-0.01
Phule Anuradha X IS 2146	0.28	0.46*	0.20*	0.00	-0.35	-0.15	-0.30*	0.25	0.01	0.16**	0.04	-0.01
Phule Anuradha X IS 18551	0.25	0.26	-0.07	0.35**	1.22**	-0.27	-0.15	-0.59*	0.71**	0.15**	0.19**	0.14**
Phule Anuradha X Swarna	-0.07	-0.36	0.05	-0.17*	-0.66**	-0.78**	0.15	-0.02	-0.09	-0.24**	-0.21**	-0.01
M 35-1 X CSV 15	-0.38*	-0.56**	0.02	-0.10	-0.40	-0.15	-0.13	-0.32	0.54*	-0.25**	-0.23**	0.01
M 35-1 X ICSV 25019	-0.62**	-0.76**	-0.15	-0.33**	-0.86**	0.67**	0.65**	0.01	0.07	-0.24**	-0.23**	-0.01
M 35-1 X PS 35805	-0.92**	-0.54**	-0.03	0.18*	0.70**	0.67**	0.45**	0.58*	0.01	-0.24**	-0.23**	0.01
M 35-1 X IS 2123	0.15	0.24	0.03	-0.13	-0.41	0.02	0.00	-0.29	-0.06	0.16**	0.17**	-0.01
M 35-1 X IS 2146	0.37*	0.79**	0.22**	-0.13	-0.68**	-0.07	-0.12	-0.65*	-0.03	0.16**	0.19**	-0.01
M 35-1 X IS 18551	0.17	0.43*	-0.05	0.22**	0.89**	-0.18	-0.13	0.51	0.34	0.15**	0.17**	0.14**
M 35-1 X Swarna	0.52**	-0.02	0.07	0.37**	0.34	-1.53**	-0.67**	0.41	-0.13	-0.24**	-0.23**	-0.01
CSV 15 X ICSV 25019	0.48**	1.11**	-0.10	-0.03	-0.31	-0.65**	-0.12	0.28	0.11	0.35**	0.35**	-0.01

Table 45. (Cont..)

Pedigree	Inflorescence exsertion		Panicle compactness		Panicle shape	Glume color		Glume coverage		Awns		Grain lustre
	2013 R	2013 PR	2013 R	2013 PR	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 PR
CSV 15 X PS 35805	0.52**	0.33	-0.15	-0.18*	-0.75**	-0.65**	0.18	0.18	0.04	0.35**	0.35**	0.01
CSV 15 X IS 2123	0.08	0.61**	0.08	0.50**	0.80**	0.20	-0.27*	0.31	-0.03	-0.25**	-0.25**	-0.01
CSV 15 X IS 2146	-0.53**	-0.01	-0.07	0.50**	1.20**	-0.05	0.28*	-0.05	0.34	-0.25**	-0.23**	-0.01
CSV 15 X IS 18551	-0.40*	-0.37	0.00	-0.15*	-0.89**	0.50*	-0.23	-0.55	-0.29	-0.10**	-0.25**	-0.02
CSV 15 X Swarna	-0.05	0.18	0.12	-0.67**	0.89**	0.48*	0.40**	0.35	-0.09	0.35**	0.35**	-0.01
ICSV 25019 X PS 35805	0.95**	0.96**	-0.15	0.42**	1.29**	-0.83**	-0.87**	0.18	0.24	0.36**	0.35**	-0.01
ICSV 25019 X IS 2123	0.02	0.08	0.08	0.10	0.17	0.52*	0.52**	-0.02	0.17	-0.24**	-0.25**	-0.02
ICSV 25019 X IS 2146	0.07	0.63**	0.10	0.10	0.57*	0.43*	0.40**	-0.05	0.21	-0.24**	-0.23**	-0.02
ICSV 25019 X IS 18551	-0.63**	-0.91**	-0.17*	-0.22**	-0.53*	0.32	0.05	-0.55	-1.09**	-0.25**	-0.25**	0.13**
ICSV 25019 X Swarna	-0.28	-0.02	-0.05	-0.07	-0.58*	-0.03	-0.15	0.01	0.11	0.36**	0.35**	-0.02
PS 35805 X IS 2123	-0.12	0.13	0.03	-0.05	-0.26	0.52*	0.32*	0.21	0.11	-0.24**	-0.25**	-0.01
PS 35805 X IS 2146	0.10	0.34	0.22**	-0.05	-0.03	0.43*	0.37**	-0.15	0.14	-0.24**	-0.23**	-0.01
PS 35805 X IS 18551	-0.43**	-0.36	-0.22**	-0.53**	-1.46**	0.32	0.35*	-0.32	-0.49*	-0.25**	-0.25**	-0.02
PS 35805 X Swarna	-0.47*	-0.14	-0.10	-0.22**	-1.01**	-0.03	-0.02	-0.09	0.04	0.36**	0.35**	-0.01
IS 2123 X IS 2146	0.17	-0.87**	-0.38**	-0.37**	-0.65**	-0.22	-0.25	-0.02	0.07	0.16**	0.17**	-0.02
IS 2123 X IS 18551	0.47**	0.43*	0.18*	-0.02	-0.08	-0.33	-0.27*	-0.19	0.11	0.15**	0.15**	0.13**
IS 2123 X Swarna	-0.02	0.64**	0.13	0.47**	1.37**	-0.68**	0.20	-0.62*	-0.03	-0.24**	-0.25**	-0.02
IS 2146 X IS 18551	0.52**	-0.36	0.37**	-0.02	-0.35	-0.42*	0.12	-1.22**	-0.53*	0.15**	0.17**	0.13**
IS 2146 X Swarna	-0.30	-0.81**	-0.52**	0.47**	1.60**	0.23	0.08	0.35	0.01	-0.24**	-0.23**	-0.02
IS 18551 X Swarna	-0.17	-0.01	0.05	-0.18*	-0.83**	0.62**	0.07	0.18	0.37	-0.25**	-0.25**	0.13**

*, ** Significant at P 0.05 and P 0.01 probability levels; R, rainy season; PR, postrainy season.

effects for glume cover. The crosses ICSV 700 X IS 18551, M 35-1 X PS 35805 in the rainy season and Phule Anuradha X IS 18551, M 35-1 X CSV 15 in the postrainy season exhibited significant positive *sca* effects for glume cover.

Twenty four hybrids exhibited significant negative *sca* effects and nineteen hybrids exhibited significant positive *sca* effects across the seasons for presence of awns. The crosses Phule Anuradha X M 35-1, and Phule Anuradha X IS 2146 in the rainy season exhibited significant positive *sca* effects for awns.

The *sca* effects of grain lustre for rainy season was not calculated because the mean sum of squares for SCA was non-significant. The *sca* effects of Phule Anuradha X M 35-1 were significant and negative in the postrainy season for grain lustre. Phule Anuradha X IS 18551, M 35-1 X IS 18551, ICSV 25019 X IS 18551, IS 2123 X IS 18551, IS 2146 X IS 18551, and IS 18551 X Swarna exhibited significant positive *sca* effects in the postrainy season for grain lustre.

4.6.9 Reciprocal combining ability effects of agronomic and panicle traits

M 35-1 X ICSV 700, ICSV 25019 X M 35-1, IS 18551 X ICSV 700, IS 18551 X M 35-1, IS 18551 X PS 35805, IS 18551 X IS 2123 in the rainy season, PS 35805 X Phule Anuradha in the postrainy season, and PS 35805 X Phule Anuradha across seasons, exhibited significant negative reciprocal effects for days to 50% flowering (Table 46). CSV 15 X ICSV 700 and Swarna X IS 18551 in the rainy season, six hybrids in the postrainy season, and Swarna X M 35-1 and Swarna X IS 2123 across seasons exhibited significant positive reciprocal effects for days to 50% flowering.

The crosses CSV 15 X Phule Anuradha, PS 35805 X Phule Anuradha, PS 35805 X ICSV 700, and Swarna X CSV 15 exhibited significant negative and the crosses Phule Anuradha X ICSV 700, ICSV 25019 X M 35-1, IS 18551 X ICSV 700, and Swarna X IS 2123 showed significant positive reciprocal effects for plant height in the postrainy season.

ICSV 25019 X Phule Anuradha in the rainy season and Phule Anuradha X ICSV 700, CSV 15 X M 35-1, Swarna X CSV 15 in the postrainy season, and Swarna X M 35-1 across seasons, exhibited significant negative reciprocal effects for 100 seed weight. IS 2146 X ICSV 25019, Swarna X CSV 15, Swarna X ICSV 25019 in the rainy season and

Table 46. Estimates of reciprocal combining ability effects of reciprocal crosses (10 X 10 diallel) of sorghum across seasons (ICRISAT, Patancheru, 2013-14).

Pedigree	Days to 50% flowering		Plant height	100 seed weight		Inflorescence exsertion	Panicle compactness	Panicle shape	Glume color
	2013 R	2013 PR	2013 PR	2013 R	2013 PR	2013 R	2013 PR	2013 PR	2013 PR
Phule Anuradha X ICSV 700	-0.50	5.33**	11.11**	0.03	-0.20*	-	-	-	-0.17
M 35-1 X ICSV 700	-1.70*	0.33	-0.56	-0.02	-0.15	0.17	-	-	0.17
M 35-1 X Phule Anuradha	-0.33	0.83	-5.00	0.02	0.13	-0.17	0.17*	0.50*	-
CSV 15 X ICSV 700	3.00**	1.50	1.67	-0.05	0.02	-	-0.17*	-0.50*	-
CSV 15 X Phule Anuradha	-1.00	0.33	-7.78*	-0.05	-0.02	0.17	-	-0.17	0.50**
CSV 15 X M 35-1	0.67	3.00**	-0.56	0.03	-0.38**	-0.17	0.17*	0.67**	-
ICSV 25019 X ICSV 700	-0.83	0.50	0.56	0.12	0.08	0.50**	-0.17*	-0.50*	-
ICSV 25019 X Phule Anuradha	-0.33	0.33	-1.67	-0.20**	-0.08	0.30*	-0.17*	-0.50*	-
ICSV 25019 X M 35-1	-1.70*	-3.00**	8.89*	-0.07	0.17	-0.17	-0.33**	-1.00**	-
ICSV 25019 X CSV 15	-0.67	-1.50	-4.44	-	0.25*	0.17	-	-0.17	-0.17
PS 35805 X ICSV 700	-2.00**	0.67	0.56	-0.03	-	0.17	-	-	-
PS 35805 X Phule Anuradha	-0.67	-3.67**	-17.22**	0.02	0.13	0.17	-0.33**	-1.00**	0.17
PS 35805 X M 35-1	-0.67	-0.33	-12.78**	-0.02	-0.05	-	-	-	0.17
PS 35805 X CSV 15	0.33	-	2.78	0.05	0.22*	-	-	-0.17	-0.17
PS 35805 X ICSV 25019	-0.33	-0.50	-	-0.02	0.18	-	-	-	-
IS 2123 X ICSV 700	-	-0.67	5.56	-0.03	-0.03	-0.30*	-	-	0.33*
IS 2123 X Phule Anuradha	-0.67	-1.17	-2.22	0.02	0.10	-	-	-	0.17
IS 2123 X M 35-1	-1.33	0.83	0.56	0.10	-	-0.50**	-	-	-
IS 2123 X CSV 15	0.50	-1.33	-5.56	-0.08	0.02	-0.30*	-	0.17	-
IS 2123 X ICSV 25019	-1.17	-0.67	2.78	0.05	0.15	0.50**	-	-	-
IS 2123 X PS 35805	-	1.83*	-5.00	-0.08	-0.12	-0.17	-	-	-0.17
IS 2146 X ICSV 700	1.17	-	-0.56	-0.02	0.18	-0.17	-	-	-
IS 2146 X Phule Anuradha	1.00	0.83	-2.22	-0.12	0.13	-	-	-	-
IS 2146 X M 35-1	-1.17	0.50	-0.56	-	0.12	-0.17	-	-	-
IS 2146 X CSV 15	-	3.00**	4.45	0.02	-0.03	0.50**	-	-0.17	-0.33*
IS 2146 X ICSV 25019	-0.17	-	3.89	0.20**	0.13	-	-	-	-
IS 2146 X PS 35805	-0.67	-1.17	5.56	0.07	-0.07	-0.17	-	0.17	-
IS 2146 X IS 2123	-	0.83	-1.67	0.03	-0.10		-	-	-
IS 18551 X ICSV 700	-1.80*	-0.50	10.00*	0.13	0.05	-0.30*	-	-	-0.17
IS 18551 X Phule Anuradha	-	-	-0.56	-0.02	0.02	-0.17	-	-	-0.17
IS 18551 X M 35-1	-2.50**	-	-5.00	0.03	-0.03	-0.17	-	-	-
IS 18551 X CSV 15	-1.00	-0.17	-6.67	-	-	0.17	-	-0.17	-0.17
IS 18551 X ICSV 25019	-0.33	1.00	5.56	-	-0.03	-0.17	0.33**	1.00**	-0.33*
IS 18551 X PS 35805	-1.70*	-0.17	-2.22	0.10	-0.08	-0.17	-0.17*	-0.50*	-
IS 18551 X IS 2123	-2.00**	2.00*	-0.56	-0.12	-0.17	-0.17	-	-	-
IS 18551 X IS 2146	-0.50	0.50	7.22	0.12	0.05	-0.30*	-	-	-0.17
Swarna X ICSV 700	-0.33	0.67	-6.11	0.08	-0.08	0.30*	-	-	0.17
Swarna X Phule Anuradha	0.83	1.83*	-2.78	0.07	-0.13	0.30*	-	-0.17	-
Swarna X M 35-1	2.30**	2.33*	7.22	-0.40**	-0.67**	0.30*	0.33**	1.50**	-1.00**
Swarna X CSV 15	0.67	0.83	-9.45*	0.20*	-0.22*	-	-	-	-0.33*
Swarna X ICSV 25019	-0.33	1.17	-1.11	0.20**	0.05	-	-	-	0.33*
Swarna X PS 35805	-0.33	-0.33	-5.00	0.08	-0.12	-	-	-	-0.17
Swarna X IS 2123	1.70*	2.17*	10.56**	0.15	-0.07	0.17	-	0.17	-
Swarna X IS 2146	0.33	1.00	-0.55	0.02	0.18	-0.30*	-	-	-
Swarna X IS 18551	1.80*	-1.17	-3.89	0.03	0.05	-	-	-	-

*, ** t test significant at 0.05 and 0.01 probability levels; ORS, overall resistance score.

ICSV 25019 X CSV 15, PS 35805 X CSV 15 in the postrainy season exhibited significant positive reciprocal effects for 100 seed weight.

4.6.10 Combining ability estimates and genetic parameters of agronomic and panicle traits

Variance due to GCA (σ^2g) was higher than the variance due to SCA (σ^2s) for glume cover across seasons (Table 47); agronomic score and waxy bloom in the rainy season

and days to 50% flowering and inflorescence exsertion in the postrainy season also showed high *gca* variance, indicating the predominance of additive gene action in controlling the expression of these traits. Plant height and grain yield exhibited higher σ^2s than the σ^2g across seasons; days to 50% flowering, inflorescence exsertion and glume color in the rainy season, and panicle shape in the postrainy season showed high σ^2s than the variance due to *gca*, indicating the predominance of non-additive type of gene action in controlling the expression of these traits. The other traits that had similar σ^2g and σ^2s exhibited both additive and non-additive type of gene action.

Glume cover showed greater additive (σ^2a) than the dominance variance (σ^2d) across seasons. Agronomic score, waxy bloom, and panicle compactness in the rainy season, and days to 50% flowering, plant height, 100 seed weight, inflorescence exertion, and glume color in the postrainy season showed higher additive variance than the dominance variance. Overall resistance score, grain yield, and plant color exhibited higher dominance variance than the additive variance across seasons. Days to 50% flowering, plant height, inflorescence exsertion, and glume color in the rainy season and panicle shape in the postrainy season possessed higher dominance variance than the additive variance.

Glume cover and awns exhibited high GCA/SCA ratios across seasons. Agronomic score, waxy bloom, and panicle compactness in the rainy season, and days to 50% flowering, plant height, 100 seed weight, inflorescence exsertion, and glume color in the postrainy season exhibited high GCA/SCA ratios, indicating the additive type of gene action controlling the expression of these traits.

Panicle compactness, glume cover and awns showed high predictability ratios across seasons. The predictability ratios for agronomic score, and waxy bloom in the

Table 47. Estimates of various genetic parameters for different agronomic and panicle traits of sorghum across seasons (ICRISAT, Patancheru, 2013-14).

Traits	Days to 50% flowering	Plant height (cm)	100 seed weight (g)	Grain yield (t/ha)	Agronomic score	Inflorescence exsertion	Panicle compactness	Panicle shape	Glume color	Glume coverage	Awns	Grain lustre
σ^2 g	3.70 (8.31)	730.03 (285.66)	0.04 (0.10)	0.57 (2.17)	0.34 (0.15)	0.10 (0.54)	0.08 (0.09)	(0.24)	0.18 (0.17)	0.87 (1.05)	0.10 (0.09)	-
σ^2 s	9.05 (6.44)	1817.89 (460.32)	0.08 (0.16)	3.44 (11.87)	0.32	0.27 (0.49)	0.07 (0.16)	(1.27)	0.45 (0.21)	0.51 (0.38)	0.12 (0.12)	0.02 (0.01)
σ^2 r	0.74 (1.48)	(17.53)	(0.02)	-	-	0.03	(0.01)	(0.1)	(0.03)	-	-	-
σ^2 e	1.27 (1.96)	38.62 (33.99)	0.02 (0.02)	0.50 (1.08)	0.12 (0.16)	0.06 (0.09)	0.01 (0.01)	(0.13)	0.10 (0.04)	0.19 (0.11)	-	-
σ^2 a	7.40 (16.62)	1460.07 (571.32)	0.08 (0.20)	1.13 (4.34)	0.67 (0.29)	0.21 (1.07)	0.17 (0.17)	(0.48)	0.36 (0.34)	1.74 (2.10)	0.19 (0.19)	-
σ^2d	9.05 (6.44)	1817.89 (460.32)	0.08 (0.16)	3.44 (11.87)	0.32	0.27 (0.49)	0.07 (0.16)	(1.27)	0.45 (0.21)	0.51 (0.38)	0.12 (0.12)	0.02 (0.01)
σ^2 p	18.45 (26.50)	3317.39 (1083.15)	0.18 (0.40)	5.17 (17.29)	1.14 (0.41)	0.57 (1.66)	0.25 (0.35)	(1.97)	0.87 (0.62)	2.46 (2.55)	0.32 (0.31)	0.02 (0.02)
h_{ns}^2	0.40 (0.63)	0.44 (0.53)	0.45 (0.51)	0.22 (0.25)	0.59 (0.71)	0.37 (0.65)	0.68 (0.50)	(0.24)	0.42 (0.54)	0.71 (0.82)	0.60 (0.60)	0.10 (0.17)
h_b^2	0.89 (0.87)	0.99 (0.95)	0.90 (0.91)	0.88 (0.94)	0.87 (0.67)	0.85 (0.94)	0.95 (0.94)	(0.89)	0.93 (0.89)	0.92 (0.97)	1.00 (0.99)	1.00 (0.78)
GCA/SCA ratio	0.41 (1.29)	0.40 (0.62)	0.49 (0.64)	0.16 (0.18)	1.04	0.38 (1.09)	1.26 (0.55)	(0.19)	0.41 (0.79)	1.70 (2.73)	0.77 (0.75)	0.06 (0.14)
Predictability ratio	0.45 (0.72)	0.45 (0.55)	0.5 (0.56)	0.25 (0.27)	0.68	0.43 (0.69)	0.72 (0.53)	(0.27)	0.45 (0.61)	0.77 (0.85)	0.61 (0.6)	0.10 (0.22)

σ^2g, gca variance; σ^2s, sca variance; σ^2r, reciprocal variance; σ^2e, environmental/error variance; σ^2a, additive variance; σ^2d, dominance variance; σ^2p, phenotypic variance; h_{ns}^2, narrow sense heritability; h_b^2, broad sense heritability; GCA, general combining ability; SCA, specific combining ability; the values in the parentheses are for postrainy season and off the parentheses are for rainy season.

rainy season, and days to 50% flowering, plant height, 100 seed weight, inflorescence exsertion and glume color in the postrainy season were quite high.

Heritability estimates of the traits studied ranged from 0.10 to 0.71 (narrowsense heritability), and 0.85 to 1.00 (broadsense heritability) in the rainy season, and 0.17 to 0.82 (narrowsense heritability) and 0.67 to 0.99 (broadsense heritability) in the postrainy season. Almost all the traits exhibited moderate to high heritability values, except grain yield and grain lustre across the seasons. Panicle shape in the postrainy season exhibited low (≤ 0.30) narrowsense heritability.

DISCUSSION

5.1 Stability and expression of resistance to sorghum shoot fly, *A. soccata* across seasons

The significant F-values for all the traits studied indicated the diverse nature of the genotypes used in this study. Shoot fly resistance is a highly complex character with low heritability and high environmental influence for shoot fly damage (Aruna *et al* 2011a). The experimental results indicated that, the genotypic response differs across seasons. Oviposition non-preference (antixenosis), antibiosis and tolerance are the major components of resistance in sorghum to shoot fly (Doggett *et al* 1970; Raina *et al* 1981; Sharma and Nwanze 1997; Dhillon *et al* 2005, 2006b; Sivakumar *et al* 2008). Leaf surface chemicals influence the host plant resistance by the *A. soccata* females (Chamarthi *et al* 2011), while trichomes probably hinder the movement of newly hatched larvae to the base of the whorl (Sharma and Nwanze 1997). Some of the genotypes used in this study exhibited resistance to shoot fly either in the rainy or in the postrainy season, suggesting that environmental influence on expression of resistance to *A. soccata*. The seasonal variation in expression of resistance to shoot fly damage is influenced by the effect of climatic factors on survival and development of shoot fly, and the indirect effects through plant growth and biochemical composition of the host plants (Sharma 2014).

5.2 Mechanisms of resistance and association of morphological and agronomic traits with resistance to shoot fly, *A. soccata*

In the present studies, several genotypes exhibited non-preference for oviposition, of which some also showed antibiosis component of resistance against survival of shoot fly larvae. Oviposition by sorghum shoot fly is significantly and negatively associated with trichome density and leaf glossiness (Omori *et al* 1983; Dhillon *et al* 2005). Similar associations were confirmed in the present studies. Genotypes with glossy and trichomed leaves are resistant to shoot fly damage, which are inherited independently, and apparently have an additive effect in reducing shoot fly damage (Agrawal and House 1982; Maiti and Gibson 1983; Maiti *et al* 1984; Sharma and Nwanze 1997; Dhillon *et al* 2005, 2006a, c). Light pink-pigmented plants with low chlorophyll content are less susceptible to shoot fly damage (Singh *et al* 1981; Kamatar *et al* 2003; Dhillon 2004; Dhillon *et al* 2005, 2006b; Chamarthi *et al* 2011). Most of the genotypes exhibited leaf glossiness, leafsheath pigmentation, trichomes on abaxial and adaxial leaf surface and expressed resistance to shoot fly with lower oviposition and deadhearts across seasons, indicating the importance of these traits for shoot fly resistance and as well as the resistant nature of the genotypes. In the present study, the leaf glossiness, leafsheath pigmentation, seedling vigor, endosperm texture and trichomes on the abaxial and adaxial leaf surfaces were found to be positively associated with shoot fly resistance as reported earlier (Taneja and Leuschner 1985). However, vigor was earlier reported to be associated negatively with shoot fly resistance (Dhillon *et al* 2005; Chamarthi *et al* 2011). Shoot fly resistant lines have faster seedling growth, shorter peduncle and longer stems and internodes (Sharma and Nwanze 1997). But, in experiment 2, it is negatively associated with shoot fly resistance. Though similar genotypes were used in both the experiments the variation observed in the association of plant vigor trait in experiment 1 and experiment 2 may be due to the influence of the environmental factors.

Recovery or overall resistance is a type of plant response to shoot fly damage, in which the plants have the ability to recover from shoot fly damage through production of secondary tillers with productive panicles once the main plant is damaged by shoot fly. Recovery resistance was highly associated with the level of primary resistance and shoot fly density (Blum 1969; Doggett *et al* 1970; Jotwani and Srivastava 1970; Raina 1985; Sharma and Nwanze 1997). The shoot fly resistant genotypes produce more numbers of uniform productive tillers than the susceptible ones, and at times yield more under shoot fly infestation (Sharma and Nwanze 1997). The overall resistance score was positively associated with 100 seed weight, leafsheath pigmentation, seedling vigor score, leaf glossiness score, waxy bloom, grain color, endosperm texture and endosperm color, suggesting that the genotypes with a combination of these traits can be selected for resistance to *A. soccata*.

The intensity of oviposition was high in the rainy season under moderate and high humidity than in the postrainy season, suggesting that environmental conditions during the rainy season are favourable for shoot fly survival. High G x E interactions for deadheart percentage has been reported earlier by Singh and Rana (1986), and Aruna *et al* (2011a). Therefore, there is a need to adopt different strategies to breed for shoot fly resistance during the rainy and the postrainy seasons, e.g. grain yield was positively correlated with shoot fly resistance traits such as number of shoot fly eggs per 100 plants, percentage of plants with shoot fly eggs, plants with deadhearts, and overall resistance score during the rainy season, but negatively correlated during the postrainy season. Some of the sorghum genotypes exhibit an inherent ability to produce side-tillers after the main shoot is killed by shoot fly. These genotypes can produce reasonable grain yields if the plant is not attacked again (Taneja and Leuschner 1985). Though the shoot fly infestation was high during the rainy season, the genotypes recovered from the damage and produced productive tillers because of availability of moisture, resulting in higher grain yield (Ashok Kumar *et al* 2008). However, during the postrainy season, the grain yield was negatively correlated with shoot fly resistance traits as the grain yield was influenced by shoot fly damage, and there was limited capacity to recover from shoot fly damage as shoot fly population is high during the postrainy season and the tillers generated were also infested by shoot fly.

Grain yield is influenced by many biotic and abiotic factors, and the physicochemical traits of the plant. Correlation coefficients provide information on dependence/association among the traits. However it is difficult to pinpoint the major factors that affect the expression of resistance/grain yield because of the intricate interactions between the traits being examined. Therefore, path coefficient analysis and stepwise regression was used to understand the nature of such interactions. Path coefficients serve as an effective parameter for determining the relative contribution/effect of individual traits, to identify the traits which have direct effects and correlation coefficients (+ve or –ve) in the same direction for use in crop improvement (Sharma *et al* 1990b). Path coefficients of leaf glossiness, plant vigor, plant height, plant color and trichome density exhibited direct effects and correlation in the same direction suggesting the importance of these traits in shoot fly resistance.

The present studies suggested that leaf glossiness, trichomes, leafsheath pigmentation and seedling vigor can be used as morphological markers to select for shoot fly resistance in sorghum, and the genotypes showing resistance to shoot fly damage can be used in the sorghum improvement programs for developing cultivars with shoot fly resistance and adaptation to the postrainy season.

Development of shoot fly resistant parents is critical for producing shoot fly resistant hybrids (Jayanthi *et al* 1996, Reddy *et al* 1997). The grain yield was negatively associated with plant vigor and leaf glossiness and positively associated with trichome density in the postrainy season but the trichome density was negatively associated in the rainy season. As a result of such intricate interactions it is difficult to combine traits conferring resistance to shoot fly damage with high grain yield. The genotypes Phule Chitra, ICSV 707, ICSV 711, IS 5604, and Akola Kranti exhibited moderate levels of resistance to shoot fly with high grain yield, and hence these genotypes can be involved in breeding the shoot fly resistant sorghums with adaptation to the postrainy season. Among them Phule Chitra and Akola Kranti are released cultivars for postrainy season cultivation and are being disseminated to farmers' on-large scale. ICSB 463, ICSB 713, and ICSV 93089 showed resistance to shoot fly in the rainy season, and had high grain yield, whereas ICSV 25010, IS 2146, and IS 2312 exhibited resistance to *A. soccata* with high grain yield potential in the postrainy season, suggesting that there is a need to follow season specific strategies to breed for developing cultivars with high grain yield and resistance to shoot fly.

Trait heritabilities can be determined with greater accuracy if it is studied along with genetic advance, and genetic advance of percent mean (Johnson *et al* 1955). The success of a variety crop improvement program depends largely on the genetic variability present in the population. Genetic coefficients of variation along with heritability estimates provide a better indication of the amount of genetic variation for a trait than the either parameter alone. In the present studies, the environmental factors influenced the expression resistance to sorghums hoot fly, but high heritability and genetic advance suggested the possibility of developing shoot fly-resistant sorghums. High heritability, GCV and genetic advance indicated predominance of additive gene effects in controlling the expression of shoot fly resistance. Trichome density and leaf glossiness have high heritability, and are highly correlated with expression of resistance to shoot fly (Maiti and Gibson 1983; Sharma and Nwanze 1997; Dhillon *et al* 2005, 2006a; Aruna and Padmaja 2009). Season specific expression of shoot fly resistance indicated that there is a need to breed the sorghum genotypes specific for the rainy or postrainy seasons.

5.3 Genetic diversity and biochemical component of resistance to shoot fly, *A. soccata*

Most of the postrainy season adapted sorghums have originated in India and have a narrow diversity for various traits that are important for adaptation in postrainy season. The improved genotypes are not popular with farmers as they do not match M 35-1 for shoot fly resistance and drought tolerance. Many breeding programs, however, deal with the variability generated from crosses within the germplasm originating from India, with narrow genetic variability, and this is the main reason for lack of improvement in grain/fodder yield productivity in the postrainy season sorghums. Genetic diversity studies based on the 38 SSR markers revealed the diverse nature of the genotypes with shoot fly resistance. Hence, by using the genetically diverse genotypes heterotic hybrids can be developed with higher levels of shoot fly resistance. Principal co-ordinate analysis placed the test genotypes into different groups suggesting that there is considerable diversity among the genotypes tested. The shoot fly-resistant genotypes placed in different groups can be used to increase the level and broaden the genetic base of resistance to shoot fly. The shoot fly resistance and the morphological traits that exhibited direct effects and correlations in the same direction can be used to select shoot fly resistant sorghums.

Secondary metabolites, including terpenes, phenolics and nitrogen (N) and sulphur (S) containing compounds, defend plants against a variety of herbivores and pathogenic microorganisms as well as various kinds of abiotic stresses (Mazid *et al* 2011). Among cereals, sorghum has the highest content of phenolic compounds reaching up to 6% (w/w) in some varieties (Deshpande *et al* 1986; Beta *et al* 1999; Awika and Rooney 2004). Estimation of biochemical components revealed that though significant difference does not exist inbetween the resistant and susceptible checks but showed significant differences within the genotypes. The genotypes exhibiting moderate resistance to shoot fly showed lower content of total carbohydrates, with higher protein, polyphenols and tannins. Lower reducing sugars and higher tannins were earlier reported by Singh *et al* 2004 and Chamarthi *et al* 2011. Plant phenolics provide resistance to aphid, *Rhopalosiphum padi* (L.) in wheat (Juan *et al* 2001), and to stem borer, *C. partellus* in maize (Kabre and Ghorpade 1998). Similar results were reported in the present studies.

The HPLC fingerprints of sorghum phenolics revealed that 3, 4-dihydroxy benzoic acid was absent in IS 18551 a resistant check, but seen in other moderately resistant genotypes in low concentrations. Kaempferol is present in all the resistant sources indicating the importance of this compound in shoot fly resistance. Ferulic acid, vanillic acid and 3, 4-dihydroxy benzoic acid was seen in higher concentrations in the susceptible genotypes than the resistant genotypes indicated that these compounds lead to susceptibility. Phule Chitra and M 35-1 showed naringenin, ferulic acid, kaempferol, syringic acid and salicylic acid compounds. Several unknown peaks were reported with high peak areas in most of the resistant genotypes. Though common peaks were seen in the resistant and susceptible genotypes but higher peak areas were reported in the resistant sources indicated the importance of high concentration of these components for shoot fly resistance. Though few of the genotypes showed most of the phenolic components but were poor in resistance to shoot fly indicating the importance of combination of shoot fly resistant and morphological traits along with the biochemical components in the expression of shoot fly resistance.

5.4 Inheritance of shoot fly resistance, morphological, agronomic and panicle traits and combining ability studies of sorghum genotypes

The *per se* performance of the parents and hybrids indicated the existence of genetic potential for improving shoot fly resistance in sorghum. Performance of the parents and their hybrids during the rainy and postrainy seasons indicated variation in expression of shoot fly resistance across seasons; with greater susceptibility in the rainy season. Differences in oviposition preference between CMS and maintainer lines have been observed during the rainy and postrainy seasons (Umakanth *et al* 2012). The performance of hybrids was season specific indicating the influence of environmental factors in expression of shoot fly resistance (Padmaja *et al* 2010; Aruna *et al* 2011a). Most of the crosses involving shoot fly-resistant parents (both direct and reciprocals) showed resistance to shoot fly, suggesting that shoot fly resistance can be transferred into the progenies. F_1 hybrids based on shoot fly-resistant parents exhibited leaf glossiness, high plant vigor, leafsheath pigmentation, and high trichome density across seasons, suggesting that these traits can be used in selecting the shoot fly resistant sorghums. The genotypes ICSV 700, M 35-1, ICSV 25019, PS 35805, IS 2123, IS 2146 and IS 18551 showed resistance to shoot fly across seasons, and hence, these can be effectively utilised in developing the shoot fly-resistant sorghums.

Estimates of combining ability studies will be useful in selecting desirable parents for developing the shoot fly-resistant hybrids. Significant mean sum of squares due to GCA for all characters, and SCA for some of the traits indicated that both additive and non-additive types of gene action contributed for shoot fly resistance (Borikar and Chopde 1982). Significant reciprocal mean sum of squares for plants with shoot fly eggs, overall resistance score and trichome density indicated that factors in the cytoplasm also influenced the inheritance of these traits. Therefore, care should be taken while selecting the parents with these traits for use in sorghum improvement. Significant GCA effects were mainly due to the additive genetic variance, and higher order additive interactions, while the differences in SCA are due to non-additive, dominance and epitasis (Falconer 1989). Leaf glossy score, plant vigor and trichome density had greater GCA variance, with high GCA/SCA and predictability ratios, suggesting predominance of additive type of gene action. Plants with shoot fly eggs and deadhearts, and overall resistance score exhibited higher SCA variance, but lower GCA/SCA and predictability ratios, suggesting the predominance of non-additive (dominance) type of gene action for these traits. Predominance of different types of gene action, and their heritability differs with the shoot fly population (Rana *et al* 1981; Borikar and Chopde 1982). Almost all the traits across seasons exhibited high broadsense heritabilities, indicating high environmental influence on the inheritance of shoot fly resistance. High narrowsense heritability indicated predominance of additive gene action. CSV 15 and Swarna exhibited significant positive *gca* effects for all the shoot fly resistance traits studied. Genotypes with significant negative *gca* effects were good combiners for shoot fly resistance. Genotypes with negative *gca* effects for plants with shoot fly eggs, number of shoot fly eggs/plant, shoot fly deadhearts, leaf glossy score, plant vigor score and leafsheath pigmentation, significant positive *gca* effects for trichome density can be selected and effectively utilised in the breeding program (Sharma *et al* 1977; Hallali *et al* 1982; Dhillon *et al* 2006c). The crosses with negative *sca* effects for leaf glossy and plant vigor scores can be utilised in the hybrid breeding process. Significant reciprocal combining ability effects of some of the genotypes indicted that maternal effects also influenced the inheritance of resistance to shoot fly. This information should be taken into consideration to select genotypes for use as a male or female parent.

Plant height, 100 seed weight and grain yield were associated with susceptibility to shoot fly. Days to 50% flowering, agronomic score, inflorescence exsertion, panicle compactness, panicle shape, glume coverage and awns were associated with shoot fly resistance. The association inbetween the shoot fly resistance, morphological and agronomic traits suggested complex interactions between shoot fly and plant traits. Significance of the GCA and SCA mean sum of squares for all the traits across seasons suggested that both the additive and non-additive nature of gene action for agronomic and panicle characteristics. The significance of reciprocal combining ability effects for days to 50% flowering, plant height and 100 seed weight, suggesting maternal effects for inheritance of these traits. These interactions should be taken into consideration while developing strategies for improving sorghums for shoot fly resistance and high grain yield. Genotypes with negative GCA effects for days to 50% flowering can be utilised to develop the hybrids with early flowering. To develop hybrids with moderate height, care should be taken to select the parents with moderate plant height. Additive gene action in the rainy season and dominance in the postrainy season for days to 50% flowering and plant height suggested G X E interactions for these traits. This contrasting gene expression in the rainy and postrainy seasons for days to 50% flowering and plant height suggested the season specific breeding of these traits. Meng *et al* (1998), Rafiq *et al* (2002), and Mohammed Maarouf (2009) reported additive gene action for days to 50% flowering, while Erenso (1998) reported additive gene action for plant height. Higher magnitude of SCA variance was reported by Manickam and Vijender Das (1994) and Umakanth *et al* (2002) for both the plant traits. High GCA/SCA and predictability ratios for 100 seed weight in the postrainy season indicated the predominance of additive gene action, whereas both additive and non-additive gene action was observed in the rainy season. Grain yield exhibited higher SCA variance suggesting the predominance of dominance (non-additive) type of gene action (Wilson *et al* 1978; Singhania 1980; Amsalu 1987; Hovny *et al* 2000; Umakanth *et al* 2002; Girma *et al* 2010). However, the importance of both the additive and non-additive gene action was observed for 100 seed weight by Toure *et al* (1996).

The knowledge of the genetic architecture of grain yield, and morphological and agronomic traits will be useful for formulating a meaningful breeding strategy for developing improved genotypes. Most of the hybrids exhibited higher grain yield than the parents even if one of the parent was high yielding, suggesting that one of the parent should possess high grain yield for developing high yielding hybrids. The panicle traits such as inflorescence exsertion and glume color exhibited predominance of additive gene action in the postrainy season, and dominance gene action in the rainy season, while glume cover and presence of awns showed predominance of additive gene action. The genotypes CSV 15, ICSV 25019, PS 35805 and Swarna exhibited negative GCA effects for almost all the traits, but positive GCA effects for grain yield. Hence, these genotypes can be effectively used in the breeding high yielding sorghums. The crosses involving the genotype IS 2146 either as male or female parent showed a decrease in grain yield. Phule Anuradha and M 35-1 showed positive GCA effects for 100 seed weight but negative GCA effects for grain yield in the rainy season, and positive effects in the postrainy season, suggesting that these genotypes can be effectively utilised for breeding high yielding shoot fly resistant sorghums for the postrainy season. ICSV 25019, PS 35805, IS 2123 and IS 18551 exhibited negative GCA effects for 100 seed weight, but showed positive GCA effects for grain yield. Hence, these genotypes can be utilised for breeding high yielding sorghums with shoot fly resistance. Though the genotypes CSV 15 and Swarna showed positive GCA effects for 100 seed weight and grain yield, but these may not be good parents in a shoot fly resistance breeding program. ICSV 700, IS 2123, and IS 18551 showed positive GCA effects for most of the traits and these can be utilised for improving shoot fly resistance. Higher narrow and broadsense heritability estimates suggested high heritability of these traits across environments.

SUMMARY AND CONCLUSION

The sorghum genotypes exhibiting resistance to shoot fly, *A. soccata* in the rainy and postrainy season can be utilised in breeding shoot fly-resistant sorghums with adaptation to postrainy season. Leaf glossiness, leafsheath pigmentation, and trichome density can be used as morphological marker traits for selecting the shoot fly-resistant sorghums. Genotypes with a diverse combination of shoot fly resistance and morphological traits can be used to increase the levels of shoot fly resistance in the high yielding cultivars for the postrainy season. Shoot fly resistance, and morphological and agronomic traits exhibiting significant correlations, and direct/indirect effects (path coefficients) in the same direction (+ve or –ve) should be used as the selection criteria to develop shoot fly-resistant cultivars. High magnitude of broadsense heritability along with higher genetic advance for shoot fly resistance and morphological traits suggested that these traits were under the control of additive gene action, and can be used for developing genotypes with resistance to shoot fly damage.

Molecular, morphological, and agronomic diversity in shoot fly-resistant sorghums can be exploited to breed shoot fly-resistant hybrids. Variation in the biochemical components of the sorghum seedlings indicated that these compounds influenced insect feeding and development. Hence, selection based on biochemical markers will also be useful for developing the shoot fly-resistant hybrids.

The present studies indicated that the parents involved in the crossing program should be diverse, and possess the shoot fly resistance genes. Both the additive and non-additive type of gene action controlled expression of resistance to shoot fly, *A. soccata*. The variance components revealed the presence of both additive and non-additive type of gene action for morphological and agronomic traits. The significance of reciprocal effects suggested that some of the traits not only had direct genetic effects, but were influenced by cytoplasmic factors in the female parent. Most of the traits exhibited high narrow- and broadsense heritability, indicating the predominance of additive type of gene action, as well as influence of the environmental factors on expression of resistance to shoot fly. Expression of resistance to sorghum shoot fly exhibited season specificity, and utmost care should be taken while selecting the parental lines. The predominance of dominance type of gene action for shoot fly resistance traits indicated that heterosis breeding is ideal for improving shoot fly resistance in sorghum. The predominance of additive gene action for leaf glossy score, plant vigor, leafsheath pigmentation and trichome density suggested that recombination breeding with pedigree method can be used for incorporating these traits in sorghum cultivars. Variation in expression of shoot fly resistance across seasons was due to non-additive genetic components of the traits conferring shoot fly resistance. Crosses with significant positive or negative *sca* effects for shoot fly resistance suggested that hybridization is necessary to increase the levels of shoot fly resistance. Parents involved in crosses with significant specific combining abilities can be utilised in hybrid breeding process. The genotypes with good general combining ability for shoot fly resistance and high grain yield will be more useful for developing the shoot fly-resistant cultivars for increasing the productivity of sorghum in the postrainy season. An understanding of the association between shoot fly resistance, and morphological and agronomic traits will be useful to improve the strategies to develop shoot fly-resistant cultivars with desirable plant type, and adaptation to the postrainy season.

Phule Yasodha, Moulee, Phule Anuradha, IS 2312, Phule Vasudha, and RVRT 2 exhibited resistance to shoot fly damage, and had high grain yield during the postrainy season; while ICSB 433, ICSV 700, M 35-1, ICSV 25019 and ICSV 25022 showed high grain yield during the rainy season, and also suffered low shoot fly damage. ICSV 700, Phule Anuradha, M 35-1, ICSV 25019, PS 35805, IS 2123, and IS 18551 exhibiting moderate to high levels of shoot fly resistance can be exploited for developing high-yielding sorghums with resistance to shoot fly.

Future work

- Based on the present work, parents with different combinations of shoot fly resistance, morphological and agronomic traits and use in multigenic crosses for developing the shoot fly resistant hybrids with adaptation to postrainy season.
- Sorghum genotypes showing resistance to shoot fly should be characterized for the resistance/ tolerance to other biotic/abiotic constraints in the postrainy season.
- Quantification of the unknown compounds obtained in HPLC fingerprints of sorghum methanol extracts, should be undertaken for better understanding of the biochemical mechanisms of resistance to shoot fly.
- There is a need to study inheritance of biochemical components associated with resistance to shoot fly, *A. soccata*.

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Mechanisms and diversity of resistance to sorghum shoot fly, *Atherigona soccata*

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Abstract

Sorghum shoot fly, *Atherigona soccata*, is one of the important pests of postrainy season sorghums. Of the 90 sorghum genotypes evaluated for resistance to this pest, RHRB 12, ICSV 713, 25026, 93046 and 25027, IS 33844-5, Giddi Maldandi and RVRT 3 exhibited resistance in postrainy season, while ICSB 463, Phule Anuradha, RHRB 19, Parbhani Moti, ICSV 705, PS 35805, IS 5480, 5622, 17726, 18368 and 34722, RVRT 1, ICSR 93031 and Dagidi Solapur showed resistance in rainy season, suggesting season-specific expression of resistance to *A. soccata*. ICSB 461, ICSB 463, Phule Yasodha, M 35-1, ICSV 700, 711, 25010, 25019 and 93089, IS 18662, Phule Vasudha, IS 18551 and 33844-5 and Barsizoot had fewer deadhearts than plants with eggs across seasons, suggesting antibiosis as one of the resistance mechanism. Five genotypes exhibited resistance with high grain yield across seasons. Correlation, path and stepwise regression analyses indicated that leaf glossiness, seedling vigour, trichome density, oviposition and leaf sheath pigmentation were associated with the expression of resistance/susceptibility to shoot fly, and these can be used as marker traits to select and develop shoot fly-resistant sorghums.

Key words: *Sorghum bicolor* — postrainy — deadheart — resistance — antibiosis — *Atherigona soccata*

Sorghum, *Sorghum bicolor* (L.) Moench, is the fifth most important grain crop after maize, rice, wheat and barley. It is a staple food for over 750 million people in Africa, Asia and Latin America (CAC 2011). India is the largest sorghum grower in the world with an area of 6.18 million hectares, production of 5.28 million tons and an average productivity of 854.4 kg/ha (FAO 2014). Sorghum is a multipurpose crop for food, feed and fodder, and of late, it is emerging as a fuel crop for bioethanol production. Several biotic and abiotic constraints influence the production and productivity of sorghum. Among the biotic constraints, insect pests are one of the major factors influencing the grain yield in sorghum and result in losses of over $1000 million in grain and forage yield (ICRISAT 1992, 2007). Nearly 32% of the actual production of sorghum is lost because of insect pests in India (Borad and Mittal 1983).

More than 150 insect pests damage sorghum, of these, sorghum shoot fly, *Atherigona soccata* (Rondani), is one of the major insect pests of sorghum (Sharma 1993). Sorghum shoot fly, infests the sorghum plant from the first to the fourth week after seedling emergence. Under humid conditions, female fly lays elongated cigar-shaped eggs on the abaxial surface of the leaf, parallel to the leaf midrib. After egg hatching, the maggot crawls to the central whorl of the leaves, reaches the growing point, cuts the central leaf and feeds on it. As a result, the central whorl dries off and gives a typical deadheart symptom (Fig. 1). Usually, shoot fly population begins to increase in July, peaks in August-September and declines thereafter. The shoot fly infestations are high when sorghum plantings are staggered due to erratic rainfall (Sharma 1985). Shoot fly infestations are normally high in the postrainy season crops planted from September to October. Temperatures above 35°C and below 18°C, and continuous rainfall or very dry weather reduce shoot fly survival (Jotwani 1978).

Shoot fly infestation leads to heavy crop loss due to decrease in grain and fodder yields. Losses due to shoot fly damage can be reduced by using resistant varieties, following good cultural practices, timely planting and timely application of proper insecticides (Sharma 1985). However, planting times in the semi-arid tropics (SAT) are dependent on the onset of rains, while the cost of insecticides restricts the poor farmers from applying them (Sharma 1993). Therefore, host plant resistance (HPR) is one of the most effective means of keeping shoot fly populations below economic threshold levels. Plant resistance to sorghum shoot fly appears to be a complex character and depends on the interplay of number of componential characters, which finally sum up in the expression of resistance to shoot fly (Dhillon 2004). A number of genotypes with resistance to shoot fly have been identified, but the levels of resistance are low to moderate (Jotwani 1978, Taneja and Leuschner 1985, Sharma et al. 2003). In India, shoot fly has attained the status of a principal pest mainly because of the introduction of improved sorghum varieties and hybrids susceptible to this insect, continuous cropping, ratooning and narrow genetic variability (Singh and Rana 1986). The sorghum cultivars to be grown during the postrainy season must have moderate to high levels of primary or recovery resistance to shoot fly (Sharma 1993). Efforts have been made to transfer shoot fly resistance into cytoplasmic male-sterile and restorer lines to produce shoot fly-resistant hybrids (Dhillon et al. 2005, Sharma et al. 2005, Belum VS Reddy et al. 2006). None of the newly developed varieties or hybrids has been able to replace the landrace cultivar, ‘Maldandi’ (M 35-1), as they have limited shoot fly resistance. Phule Yasodha, Phule Chitra and Parbhani-Moti, which have moderate levels of resistance to shoot fly, have been adopted by the farmers in certain areas. However, the level of resistance to shoot fly in the identified sources varies with insect density and across environments (Sharma and Nwanze 1997, Dhillon et al. 2005). Therefore, it is crucial to identify the sorghum genotypes with different resistance mechanisms to increase the levels and diversify the basis of resistance to this insect. Hence, the present studies were undertaken to identify the lines with diverse mechanisms of resistance to shoot fly, with adaptation to the postrainy season, which can be used in breeding to diversify the basis of resistance to shoot fly, *A. soccata*.

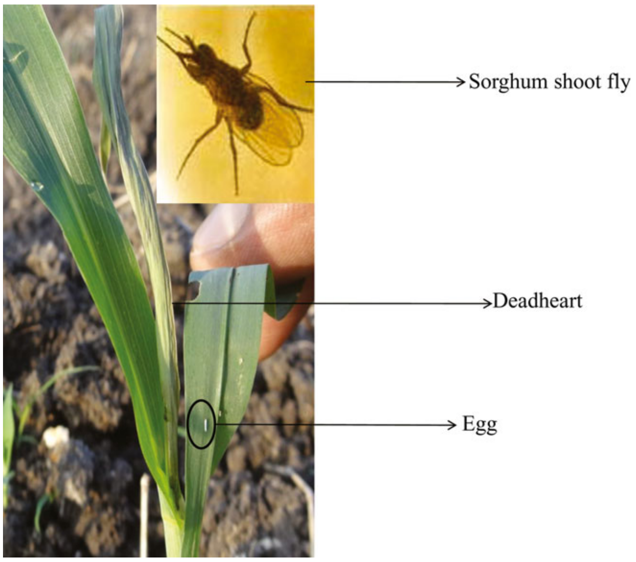

Fig. 1: Shoot fly deadheart bearing an egg under the surface of the leaf Inset: sorghum shoot fly, *Atherigona soccata*

Materials and Methods

Experimental material: The experiments were conducted during the 2010 postrainy and 2011 rainy seasons, at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Telangana, India (latitude 17.53°N, longitude 78.27°E and altitude of 545 m).

The test material consisted of a diverse array of 90 sorghum genotypes comprising of germplasm accessions, landraces, breeding lines and commercial cultivars with adaptation to postrainy season in India. Postrainy season sorghums are typically grown under receding moisture on deep to shallow black soils (Vertisols) between September and February. A basal dose of fertiliser (Ammonium phosphate @ 100 kg/ha) was applied for raising the crop. The test genotypes were sown in two rows of 2.0 m length, with a row-to-row spacing of 75 cm and a spacing of 10 cm between the plants within a row. There were two replications in a randomized complete block design (RCBD). The seeds were sown with a two-cone planter at a depth of 5.0 cm below the soil surface. Thinning was carried out for 7 days after seedling emergence (DAE) and before the onset of shoot fly incidence, and 35–40 plants were retained in each plot. Interlard fish-meal technique was used to increase the shoot fly incidence in the test material (Soto 1974, Sharma et al. 1992). Interculture was carried out at 15 and 30 DAE; earthing up and application of urea at 100 kg/ha were carried out at 30 DAE and the field was irrigated after every 20 days of interval in postrainy season; and hand weeding was carried out whenever necessary, but there was no insecticide application in the experimental block. One set of the test material was also grown under protected conditions to record data on agronomic and morphological traits.

Observations

Shoot fly damage parameters: Data were recorded on plants with shoot fly eggs and number of shoot fly eggs at 14 DAE and shoot fly deadhearts at 21 DAE and expressed as the percentage of plants with shoot fly eggs and deadhearts and number of eggs per 100 plants. Overall resistance score was recorded on 1–9 scale before harvesting (1 = plants with <10% deadhearts and uniform tillers and harvestable panicles; 9 = plants with >80% deadhearts, and a few or no productive tillers) (Sharma et al. 1992).

Morphological characteristics: Data were recorded on leaf glossiness, leafsheath pigmentation and seedling vigour at 7-10 DAE and trichome density on the abaxial and adaxial leaf surfaces at 14 DAE. Data were also recorded on waxy bloom, plant colour, inflorescence exsertion, inflorescence compactness, inflorescence shape, glume colour, grain lustre, grain colour, total soluble sugars (TSS), endosperm texture, grain subcoat, glume coverage and endosperm colour (IBPGR and ICRISAT 1993). Leaf glossiness was evaluated visually on a 1–5 scale at 10-12 DAE (fifth leaf stage), when the expression of this trait is most apparent, in the early morning hours, when there was maximum reflection of light from the leaf surface (1 = highly glossy and 5 = non-glossy) (Sharma and Nwanze 1997). The leafsheath pigmentation was visually scored on a 1–3 rating scale at 7 DAE (Dhillon et al. 2006c). Seedling vigour was recorded at 10 DAE on 1–3 scale (1 = highly vigorous and 3 = poor plant vigour) (Sharma and Nwanze 1997). The density of trichomes on both the surfaces of leaf was recorded at 12 DAE by taking a 2.5-cm^2 portion from the centre of the fifth leaf (Maiti and Bidinger 1979). The leaf samples were taken from three plants at random and placed in acetic acid and alcohol (2 : 1) in stoppered glass vials (10 ml capacity) for 24 h to clear the chlorophyll, and subsequently transferred into lactic acid (90%) as a preservative. The leaf sections were mounted on a glass slide in a drop of lactic acid and observed at 10× magnification under a stereomicroscope. The trichomes on the abaxial and adaxial leaf surfaces were counted and expressed as numbers of trichomes in a 10× microscopic field.

Waxy bloom was visually scored on a 1–3 scale (1 = slightly waxy and 3 = completely waxy) at the flag leaf stage of the crop. Plant colour was evaluated visually on a 1–2 scale (1 = pigmented – non-tan, and 2 = non-pigmented – tan); inflorescence exsertion was scored on a 1–3 scale (1 = panicle fully exserted and 3 = poor panicle exsertion); inflorescence compactness on a 1–3 scale (1 = loose inflorescence and 3 = compact inflorescence); inflorescence shape on a 1–4 scale (1 = erect inflorescence and 4 = elliptic inflorescence); glume colour on 1–6 scale (1 = white glume and 6 = purple glume); glume coverage on a 1–9 scale (1 = 25% grain covered with glumes and 9 = glumes longer than the grain); leaf midrib colour on a 1–4 scale (1 = white coloured midrib and 4 = brown coloured midrib); awns as 1 = absence of awns and 2 = presence of awns; grain lustre as 1 = non-lustrous grain and 2 = lustrous grain; and grain colour on a 1–5 scale (1 = white coloured grain and 5 = buff coloured grain). Data on endosperm texture were recorded on a 1–5 scale (1 = completely corneous endosperm and 5 = completely starchy endosperm); grain subcoat was evaluated on a 1–2 scale (1 = absence of subcoat, and 2 = presence of subcoat); and endosperm colour was evaluated on a 1–3 scale (1 = white coloured endosperm and 3 = red coloured endosperm) (IBPGR and ICRISAT 1993). Total soluble sugars (TSS) was recorded with the help of hand refractometer (ATAGO® Master – α, Cat. no. 2311,

Table 1: Mean sum of squares of analysis of variance and of sorghum genotypes evaluated for resistance to shoot fly, *Atherigona soccata* (ICRISAT, Patancheru, 2010 postrainy and 2011 rainy seasons)

Source of variation	df	Plants with shoot fly eggs (%)	Total number of shoot fly eggs/100 plants	Shoot fly deadhearts (%)	ORS
Replication	1	48.40	351.00	659.40	1.59
Genotype	89	1442.80**	14921.00**	1655.90**	7.37**
Season	1	7316.60**	101144.00**	6324.50**	8.08**
Genotype*Season	89	285.20**	4771.00**	308.80**	1.82**
Error	178	186.50	1832.00	172.80	0.88
Total	358				

**Mean sum of squares significant at P = 0.01; ORS, overall resistance score.

Table 2: Evaluation of sorghum genotypes for resistance to sorghum shoot fly, *Atherigona soccata*, in the postrainy season sorghums (ICRISAT, Patancheru, 2010–2011)

	Number of shoot fly eggs/100 plants		Plants with shoot fly eggs (%)		Plants with shoot fly deadhearts (%)		ORS	
Genotype	2010PR	2011R	2010PR	2011R	2010PR	2011R	2010PR	2011R
ICSB 433	114.0	64.0	30.3	57.5	37.5	50.0	6.5	5.5
ICSB 461	100.0	94.0	60.2	77.2	52.3	74.2	7.5	5.0
ICSB 463	65.0	66.0	47.1	58.3	40.7	51.0	5.5	4.0
ICSV 700	139.0	67.0	44.6	58.3	37.6	55.6	5.5	4.5
Phule Yasodha	82.0	61.0	53.7	56.1	34.3	38.6	5.0	4.0
Macia	189.0	117.0	57.1	78.0	61.7	77.3	7.0	6.5
ICSV 745	146.0	97.0	81.5	81.6	83.3	76.6	7.0	6.5
Mouli	109.0	79.0	61.8	62.1	58.3	62.7	5.5	6.0
Phule Chitra	66.0	48.0	48.2	45.2	50.8	49.5	4.5	4.5
NTJ 2	270.0	137.0	82.5	89.2	73.3	87.5	7.5	6.0
Phule Anuradha	54.0	32.0	46.1	32.3	59.5	27.3	5.5	3.5
RHRB 12	61.0	93.0	36.4	70.7	39.8	73.6	5.5	5.0
RHRB 19	114.0	36.0	65.1	36.0	58.5	41.0	4.5	4.0
M 35-1	86.0	51.0	51.6	46.1	36.6	41.1	4.5	5.0
Parbhani Moti	109.0	51.0	53.3	41.3	56.9	39.8	4.0	5.0
CSV 18R	73.0	73.0	54.0	57.9	63.6	60.6	5.0	4.5
CSV 15	213.0	131.0	82.5	89.5	73.2	91.6	6.0	6.0
ICSV 702	70.0	44.0	38.2	38.8	37.7	46.1	5.0	3.5
ICSV 705	98.0	56.0	53.0	51.9	48.5	42.7	6.0	3.5
ICSV 707	68.0	77.0	20.0	64.2	20.1	50.7	4.5	4.5
ICSV 711	87.0	60.0	45.8	55.0	36.3	43.7	5.0	4.0
ICSV 713	92.0	66.0	41.6	62.3	41.6	59.9	5.0	4.5
ICSV 714	137.0	102.0	64.7	78.7	51.0	75.6	5.5	3.5
ICSV 25006	36.0	43.0	48.5	23.7	43.4	45.4	4.5	5.0
ICSV 25010	83.0	69.0	40.0	69.2	31.1	46.5	5.5	3.0
ICSV 25019	41.0	80.0	38.1	67.7	19.4	59.3	6.5	4.0
ICSV 25022	40.0	37.0	39.9	33.9	34.4	41.8	4.5	3.5
ICSV 25026	55.0	63.0	36.2	54.4	48.7	50.0	4.5	3.0
ICSV 25027	129.0	60.0	45.6	49.0	35.9	58.5	5.0	5.5
ICSV 25039	82.0	39.0	18.5	34.1	31.5	43.4	5.5	3.5
ICSV 93089	62.0	55.0	47.2	55.1	31.4	39.2	6.0	6.5
IS 5480	90.0	35.0	54.4	33.4	43.3	37.2	5.5	4.0
PS 35805	55.0	36.0	18.4	38.9	15.4	24.3	7.0	3.0
IS 1044	139.0	100.0	60.7	81.8	59.3	70.3	6.5	4.0
IS 1104	79.0	44.0	28.3	38.5	38.1	38.8	3.5	4.0
IS 2123	79.0	30.0	27.0	25.6	24.7	20.3	3.5	4.0
IS 2146	52.0	56.0	44.6	45.8	39.1	40.4	4.0	4.5
IS 2312	49.0	36.0	34.1	35.5	35.9	27.2	4.5	4.0
IS 4646	56.0	43.0	25.3	44.3	28.3	25.5	5.0	3.0
IS 5470	46.0	54.0	27.1	54.2	21.6	19.2	4.0	3.0
IS 5604	84.0	36.0	33.8	36.2	33.9	15.0	4.0	4.0
IS 5622	69.0	37.0	51.7	37.0	62.5	33.9	4.5	5.0
IS 17726	88.0	35.0	60.6	33.6	56.2	32.3	5.0	5.0
IS 18368	75.0	63.0	63.9	51.9	65.4	41.3	6.5	5.0
IS 18662	87.0	76.0	65.4	62.6	47.4	33.5	4.5	5.0
Akola Kranti	66.0	38.0	35.6	37.6	28.2	32.7	4.5	4.5
Phule Vasudha	96.0	66.0	53.6	60.6	44.7	50.4	4.5	4.5
ICSV 93046	93.0	83.0	42.5	67.5	37.5	58.3	5.5	4.0
IS 10023	231.0	109.0	70.0	90.7	45.8	89.3	8.0	6.0
IS 11189	293.0	248.0	77.0	96.0	75.5	96.0	7.0	6.5
IS 11200	325.0	143.0	88.6	92.7	80.5	92.9	5.5	6.0
IS 11469	133.0	144.0	62.0	91.4	81.4	91.4	6.0	7.5
IS 11510	534.0	123.0	59.2	92.5	86.3	96.7	6.0	7.5
IS 12195	178.0	106.0	83.3	93.1	71.8	89.1	6.0	7.0
RVRT 1	70.0	84.0	81.6	64.2	70.2	57.1	6.5	6.0
IS 38162	148.0	177.0	80.9	97.3	84.5	95.7	8.0	7.0
IS 23891	118.0	167.0	60.4	90.2	77.4	89.6	6.1	8.5
IS 23930	178.0	139.0	90.8	93.2	80.9	94.7	7.5	8.0
IS 23999	94.0	84.0	92.8	68.0	87.8	66.7	8.0	7.0
IS 27954	136.0	116.0	72.9	82.5	92.3	87.0	8.5	8.0
IS 28102	53.0	123.0	81.2	89.5	69.9	100.0	5.7	8.5
IS 28792	177.0	143.0	68.5	89.5	72.4	88.1	7.5	7.0
IS 31705	191.0	153.0	83.3	91.4	92.8	93.1	5.7	9.0
IS 41204	95.0	169.0	47.6	96.8	75.4	95.3	7.1	8.0
IS 41207	150.0	139.0	100.0	93.9	83.3	90.4	5.7	9.0
IS 34722	276.0	100.0	81.5	67.6	69.6	66.1	6.0	5.0

(continued)

Table 2. (continued)

Genotype	Number of shoot fly eggs/100 plants		Plants with shoot fly eggs (%)		Plants with shoot fly deadhearts (%)		ORS	
	2010PR	2011R	2010PR	2011R	2010PR	2011R	2010PR	2011R
IS 34723	225.0	156.0	83.3	95.6	87.5	89.9	6.0	7.5
IS 34724	109.0	165.0	68.5	90.4	78.8	88.9	6.0	7.0
IS 34725	140.0	150.0	69.0	93.3	62.0	89.1	8.1	6.5
IS 34726	194.0	174.0	94.2	94.0	78.1	91.0	6.0	6.0
IS 34727	454.0	175.0	71.5	92.3	78.6	89.6	5.5	5.5
IS 34728	258.0	140.0	67.5	84.1	62.5	82.6	7.0	7.5
RVRT 2	114.0	71.0	42.9	58.3	39.6	65.5	4.5	5.0
IS 34730	128.0	132.0	65.1	87.7	63.8	86.2	4.5	6.0
IS 34731	252.0	197.0	73.8	89.5	47.9	88.1	4.5	6.5
IS 33844-5	50.0	103.0	53.8	63.4	43.5	55.9	5.5	5.5
Giddi Maldandi	158.0	104.0	50.8	74.7	53.4	68.3	4.5	6.5
Barsizoot	100.0	82.0	67.2	70.8	44.8	62.5	5.5	5.0
M 35-1-19	118.0	149.0	59.7	93.4	37.5	93.4	4.5	8.0
ICSR 93031	135.0	42.0	77.8	38.6	74.4	38.6	7.0	5.0
ICSB 52	157.0	180.0	77.5	94.7	67.6	94.7	8.0	9.0
RVRT 3	85.0	85.0	53.6	68.4	48.6	58.9	5.0	4.0
ICSB 24002	301.0	182.0	71.4	96.5	62.3	96.8	6.0	9.0
ICSB 38	93.0	130.0	59.5	89.8	48.6	87.3	8.0	9.0
Dagidi Solapur	161.0	76.0	51.0	59.6	68.5	53.4	4.5	5.5
296 B	125.0	113.0	72.2	81.6	79.1	83.2	7.0	6.0
ICSR 92003	123.0	133.0	80.3	92.8	85.2	87.4	7.5	6.0
DJ 6514	76.0	196.0	77.7	98.7	66.7	100.0	5.0	6.5
IS 18551 (*R*)	76.0	25.0	51.0	25.0	42.2	24.7	4.5	4.5
Swarna (*S*)	223.0	146.0	71.2	89.7	58.7	86.7	8.0	6.5
Mean	128.92	95.43	58.4	67.42	55.5	63.85	5.73	5.54
SE ±	37.83	19.81	10.34	8.87	10.98	7.32	0.74	0.59
Vr	5.16[1]	6.27[1]	3.37[1]	6.41[1]	3.20[1]	11.14[1]	2.83[1]	7.70[1]
LSD (P = 0.05)	106.34	55.66	29.04	24.93	30.86	20.57	2.08	1.66

[1] *F*-test significant at P = 0.01; R, rainy season; PR, postrainy season; (*R*), resistant check; (*S*), susceptible check; SE, standard error Vr, variance ratio; and ORS, overall resistance score (1 plant with uniform tillers and harvestable panicles, and 9 plants with a few or no productive tillers).

Brix 0.0 ~ 33.0%). For this purpose, the plant at physiological maturity stage was cut with secateurs at the centre of the 4th internode and squeezed to extract the juice. A drop of this juice was placed on to the hand refractometer, and the value of TSS was recorded.

Agronomic characteristics: The data on agronomic traits (days to 50% flowering, plant height, agronomic score, 100-seed weight and grain yield) were also recorded. The data on days to 50% flowering were recorded when half the panicle and nearly 50% of plants in the plot had attained the anthesis stage. Plant height of three plants was taken at maturity, which were selected at random within a plot. Agronomic desirability was recorded at crop maturity on a 1–5 scale (1 = good productive potential and ability to withstand insect damage; 5 = poor productive potential and prone to insect damage). Data on 100-seed weight and grain yield were recorded after harvesting.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) using GenStat® 13th version (GenStat 2010). Significance of the differences between the genotypes was judged by *F*-test, while the genotypic means were compared by least significant difference (LSD) at P ≤ 0.05. Simple correlations, stepwise regression and path coefficient analyses were performed using GenStat, SAS 9.2 (SAS Institute Inc. 2004) and GENRES statistical software package (GENRES 1994), respectively, to identify morphological traits associated with the shoot fly resistance and grain yield.

Results

Expression of resistance to sorghum shoot fly, *Atherigona soccata*, across seasons

The genotypic and environmental interactions were significant (P < 0.001) for percentage of plants with shoot fly eggs and eggs per 100 plants, plants with shoot fly deadhearts and overall resistance score (Table 1). However, the mean sum of squares for environmental effects was relatively higher than the genotypic effects, suggesting that environment has a considerable bearing on the expression of resistance to *A. soccata*.

There were significant differences between the genotypes for number of shoot fly eggs per 100 plants, percentage of plants with shoot fly eggs and deadhearts, and overall resistance score in both the seasons (Table 2). The genotypes Phule Yasodha, Phule Chitra, M 35-1, ICSV 702, ICSV 707, ICSV 711, ICSV 25006, ICSV 25010, ICSV 25022, ICSV 25039, IS 1104, IS 2123, IS 2146, IS 2312, IS 4646, IS 5470, IS 5604, Akola Kranti and IS 18551 were not preferred for egg laying and suffered lower deadheart incidence (15–51% deadhearts) as compared to the susceptible check, Swarna (86% plants with deadhearts). These genotypes also exhibited better tolerance (recovery resistance) to shoot fly damage (overall resistance score < 4.5). RHRB 12, ICSV 713, ICSV 25026, ICSV 25027, ICSV 93046, IS 33844-5, Giddi Maldandi and RVRT 3 exhibited resistance to shoot fly in the postrainy season, while ICSB 463, Phule Anuradha, RHRB 19, Parbhani Moti, ICSV 705, IS 5480, PS 35805, IS 5622, IS 17726, IS 18368, RVRT 1, IS 34722, ICSR 93031 and Dagidi Solapur showed resistance to shoot fly damage in the rainy season. The genotypes ICSB 461, ICSB 463, ICSV 700, Phule Yasodha, M 35-1, ICSV 711, ICSV 25010, ICSV 25019, ICSV 93089, IS 18662, Phule Vasudha, IS 18551, IS 33844-5 and Barsizoot had less number of plants with shoot fly deadhearts than the number of plants with eggs, suggesting that these genotypes have antibiosis mechanism of resistance to *A. soccata*.

The genotypes ICSB 463, ICSV 700, Phule Yasodha, Phule Chitra, CSV 18R, ICSV 707, ICSV 711, ICSV 713, ICSV 25019, ICSV 25039, ICSV 93089, IS 5480, IS 2146, IS 2312, IS 4646, IS 5604, IS 5622, IS 18662, Akola Kranti, Phule Vasudha, RVRT 2, Giddi Maldandi, M 35-1-19, RVRT 3, Dagidi Solapur, IS 33844-5 and IS 18551 were glossy with pigmented leafsheath and high trichome density with plant vigour (Annexure S1). Some of these genotypes exhibited resistance to shoot fly damage across seasons, with a few exceptions.

Association between the parameters measuring the expression of resistance to shoot fly, *Atherigona soccata*

Number of shoot fly eggs per 100 plants and percentage of plants with shoot fly eggs (*r* = 0.94** and 0.59**, respectively, for rainy and postrainy seasons) and deadhearts (*r* = 0.92** and 0.52**) [*, ** correlation coefficients significant at P = 0.05 and P = 0.01, respectively] were correlated significantly and positively (data not shown). The overall resistance/susceptibility score was significantly and positively correlated with eggs per 100 plants (*r* = 0.73** and 0.36**, for rainy and postrainy seasons, respectively), plants with eggs (*r* = 0.67** and 0.51**) and deadheart incidence (*r* = 0.73** and 0.52**). Plants with shoot fly eggs were also positively correlated with deadheart incidence (*r* = 0.93** and 0.84**).

Association of morphological traits with the expression of resistance to sorghum shoot fly, *Atherigona soccata*

The correlation coefficients between the agronomic and morphological traits with the expression of resistance to shoot fly, *A. soccata*, revealed that 100-seed weight, leafsheath pigmentation, seedling vigour score, leaf glossiness score, waxy bloom, plant colour, grain colour, endosperm texture and endosperm colour were significantly and positively correlated with resistance/susceptibility to shoot fly damage in both the seasons (Table 3). Trichomes on the abaxial and adaxial leaf surfaces, inflorescence exsertion, grain coverage by the glume, grain lustre and awns were negatively and significantly correlated with resistance to shoot fly damage in both the seasons. Agronomic score and plant height showed significant and negative associations with shoot fly-resistant traits during the rainy season, while grain

Table 3: Association of agronomic and morphological traits with the expression of resistance to sorghum shoot fly, *Atherigona soccata*, in the postrainy season sorghums

Plant traits	Number of shoot fly eggs/100 plants	Plants with shoot fly eggs (%)	Plants with shoot fly deadhearts (%)	ORS
Agronomic traits				
Days to 50% flowering	0.31** (−0.08)	0.22* (−0.05)	0.23* (0.09)	0.09 (−0.09)
Agronomic score	−0.30** (0.04)	−0.33** (0.12)	−0.37** (0.12)	−0.20* (−0.27**)
Plant height	−0.13 (0.03)	−0.17 (0.06)	−0.16 (0.11)	−0.03 (−0.34**)
100-seed weight	0.40** (0.25*)	0.39** (0.52**)	0.40** (0.45**)	0.41** (0.16)
Grain yield	0.23* (−0.42**)	0.24* (−0.63**)	0.21* (−0.60**)	0.12 (−0.71**)
Morphological traits				
Leafsheath pigmentation	0.21* (0.08)	0.27** (0.16)	0.33** (0.13)	0.14 (0.43**)
Plant vigour score	0.35**	0.33**	0.37**	0.23*
Leaf glossy score	0.82** (0.59**)	0.84** (0.75**)	0.87** (0.76**)	0.63** (0.69**)
Leaf midrib colour	−0.09 (−0.01)	−0.04 (−0.15)	0.02 (−0.17)	0.04 (0.07)
Waxy bloom	0.48**	0.53**	0.54**	0.30**
Plant colour	0.21*	0.24*	0.29**	0.05
Number of trichomes on the abaxial surface	−0.72** (−0.52**)	−0.71** (−0.62**)	−0.72** (−0.66**)	−0.62** (−0.53**)
Number of trichomes on the adaxial surface	−0.72** (−0.59**)	−0.70** (−0.61**)	−0.72** (−0.68**)	−0.63** (−0.57**)
Seed/panicle traits				
Inflorescence exsertion	−0.05 (−0.28**)	−0.11 (−0.25*)	−0.14 (−0.27**)	−0.15 (−0.33**)
Inflorescence compactness	−0.36** (0.06)	−0.38** (−0.13)	−0.44** (−0.08)	−0.30** (−0.22*)
Inflorescence shape	−0.22* (0.26**)	−0.26** (0.10)	−0.32** (0.18)	−0.24* (−0.02)
Glume colour	0.02 (0.37**)	0.01 (0.28**)	−0.04 (0.34**)	0.08 (0.11)
Glume coverage	−0.14 (−0.26**)	−0.13 (−0.27**)	−0.17 (−0.21*)	−0.08 (−0.27**)
Awns	−0.35** (−0.36**)	−0.42** (−0.27**)	−0.38** (−0.14)	−0.16 (−0.44**)
Grain colour	0.37** (0.32**)	0.34** (0.35**)	0.35** (0.47**)	0.30** (0.27**)
Grain lustre	−0.23* (−0.15)	−0.29** (−0.31**)	−0.32** (−0.40**)	−0.24* (−0.20*)
Grain subcoat	−0.05 (0.10)	−0.06 (0.20*)	−0.05 (0.25*)	−0.11 (0.15)
Endosperm texture	0.40** (0.36**)	0.31** (0.44**)	0.33** (0.53**)	0.47** (0.14)
Endosperm colour	0.34** (0.36**)	0.37** (0.36**)	0.39** (0.40**)	0.36** (0.08)

The values outside the parenthesis are the correlation coefficients of rainy season, and those inside the parenthesis are for the postrainy season.
*,**Correlation coefficient significant at P = 0.05 and P = 0.01, respectively.

Table 4: Association between agronomic and morphological traits in the postrainy season-adapted sorghums

Plant traits	Leafsheath pigmentation	Plant vigour score	Leaf glossy score	Leaf midrib colour	Waxy bloom	Plant colour	Number of trichomes on the abaxial surface	Number of trichomes on the adaxial surface	Total soluble sugars (TSS)
Days to 50% flowering	−0.26** (−0.07)	−0.05	0.21* (0.02)	−0.36** (0.11)	−0.06	−0.18	−0.06 (0.05)	−0.06 (0.05)	0.08
Agronomic score	−0.44** (−0.29**)	−0.66**	−0.34** (−0.09)	−0.42** (0.38**)	−0.72**	−0.83**	0.21* (0.05)	0.19 (0.10)	0.08
Plant height	−0.46** (−0.41**)	−0.54**	−0.16 (−0.08)	−0.45** (−0.30**)	−0.76**	−0.81**	0.05 (0.07)	0.03 (0.08)	0.28**
100-seed weight	−0.07 (−0.16)	−0.13	0.42** (0.45**)	−0.04 (−0.35**)	−0.03	−0.19	−0.34** (0.33**)	−0.36** (−0.31**)	0.41**
Grain yield	0.10 (−0.18)	0.34**	0.21* (−0.70**)	0.07 (0.06)	0.30**	0.36**	−0.09 (0.45**)	−0.08 (0.51**)	−0.01

The values outside the parenthesis are the correlation coefficients of rainy season, and those inside the parenthesis are for the postrainy season.
*,**Correlation coefficients significant at P = 0.05 and P = 0.01, respectively.

Table 5: Association between panicle and seed traits with agronomic traits in the postrainy season-adapted sorghums

Plant traits	Days to 50% flowering	Agronomic score	Plant height	100-seed weight	Grain yield
Inflorescence exsertion	−0.01 (0.01)	0.04 (0.29**)	−0.04 (−0.15)	−0.11 (−0.08)	−0.11 (0.30**)
Inflorescence compactness	−0.12 (0.29**)	0.14 (0.33**)	0.01 (0.03)	−0.26** (0.15)	−0.16 (0.05)
Inflorescence shape	0.06 (0.20*)	0.22* (0.37**)	0.13 (0.15)	−0.19 (0.12)	−0.17 (−0.08)
Glume colour	0.23* (−0.07)	0.54** (0.32**)	0.48** (0.15)	0.24* (0.38**)	−0.34**(−0.37**)
Glume coverage	0.33** (0.03)	0.50** (0.24*)	0.53** (0.35**)	0.15 (−0.19)	−0.32** (0.23*)
Awns	−0.02 (0.24*)	0.46** (0.42**)	0.51** (0.49**)	0.15 (0.07)	−0.37** (0.35**)
Grain colour	0.35** (−0.07)	0.23* (0.17)	0.23* (0.29**)	0.62** (0.20*)	−0.28** (−0.38**)
Grain lustre	−0.11 (−0.02)	0.06 (−0.14)	0.06 (0.07)	−0.12 (−0.20*)	−0.02 (0.33**)
Grain subcoat	−0.17 (−0.09)	−0.07 (0.07)	−0.01 (−0.08)	0.05 (0.06)	0.21* (−0.23*)
Endosperm texture	0.19 (0.19)	0.15 (0.27**)	0.32** (0.23*)	0.21* (0.41**)	−0.07 (−0.35**)
Endosperm colour	0.36** (−0.17)	0.16 (0.18)	0.26** (0.21*)	0.45** (0.11)	−0.31** (−0.30**)

The values outside the parenthesis are the correlation coefficients of rainy season, and those inside the parenthesis are for the postrainy season.
*,**Correlation coefficient significant at P = 0.05 and 0.01, respectively.

yield exhibited a significant and positive correlation in the rainy season and a significant and negative correlation with shoot fly resistance in the postrainy season.

Association of agronomic and morphological traits with resistance to shoot fly, *Atherigona soccata*

Agronomic score and plant height were significantly and negatively correlated with leafsheath pigmentation, seedling vigour score, leaf midrib colour, waxy bloom and plant colour in both the seasons (Table 4). Agronomic score was positively associated with trichome density, while plant height was positively associated with TSS during the rainy season. The 100-seed weight was positively associated with leaf glossiness in both the seasons and with TSS in the rainy season, but negatively associated with trichome density in both the seasons and with leaf midrib colour during the postrainy season. Grain yield was positively associated with seedling vigour, leaf glossiness, waxy bloom and plant colour during the rainy season, and trichome density during the postrainy season contributes to high grain yield; however, leaf glossiness in the postrainy season and trichome density during the rainy season were negatively associated with grain yield.

Glume colour, glume coverage, presence of awns, grain colour, endosperm texture and endosperm colour were positively associated with agronomic score, plant height and 100-seed weight in both the seasons, whereas glume colour and endosperm colour showed a negative association with grain yield in both the seasons (Table 5). Grain coverage by the glumes and the presence of awns exhibited a positive association with grain yield in the postrainy season, but a negative association in the rainy season, suggesting that different combinations of traits contribute to high grain yield in the rainy and postrainy seasons.

Correlations between panicle traits with morphological traits indicated that inflorescence exsertion, glume coverage, presence of awns and grain lustre were positively associated with trichome density, but negatively with the leaf glossiness (Table 6). Grain colour, grain subcoat, endosperm texture and endosperm colour showed a positive association with leaf glossiness score, but a negative association with trichome density.

Association of agronomic and morphological characteristics of sorghum

Agronomic score was positively associated with days to 50% flowering, plant height and 100-seed weight, but negatively associated with grain yield in the rainy season (Table 7). Plant height showed a positive association with 100-seed weight and days to 50% flowering, but a negative association with grain yield during the rainy season. The 100-seed weight was negatively associated with grain yield in the postrainy season.

Overall resistance score, leafsheath pigmentation, seedling vigour score, leaf glossiness score, leaf midrib colour and waxy bloom were positively and significantly associated with each other in both the seasons (Table 8). Trichome density showed a negative association with overall resistance score, leafsheath pigmentation, seedling vigour score, leaf glossiness score and waxy bloom in both the seasons. Trichome density on the adaxial and abaxial surfaces of the leaf was significantly correlated in both the seasons (r = 0.99** and 0.96**).

Glume colour was positively associated with grain and endosperm colour in both the seasons; glume coverage and presence of awns in the rainy season; and endosperm texture in the postrainy season, but negatively associated with grain lustre in the postrainy season (Table 9). The grain covererage by the glumes was positively associated with awns in both the seasons and with grain colour, endosperm texture and endosperm colour in the rainy season. Grain colour was negatively associated with grain lustre in both the seasons and positively associated with endosperm texture and endosperm colour in both the seasons. Grain lustre was negatively associated with endosperm texture in the postrainy season and with endosperm colour in both the seasons, while endosperm texture was positively associated with endosperm colour in both the seasons.

Grain yield potential of different sorghum genotypes during the rainy and postrainy seasons

The mean performance of the genotypes for grain yield, and agronomic and panicle traits is given in Annexures S2, S3a and S3b. The genotype IS 2123 performed well in postrainy season and yielded 3.87 t/ha, whereas CSV 15 yielded 7.10 t/ha during the rainy season. The genotypes ICSV 700, Phule Chitra, RHRB 12, RHRB 19, ICSV 707, ICSV 711, ICSV 714, ICSV 25022, ICSV 25026, ICSV 25027, IS 1044, IS 5604, IS 18662, Akola Kranti, ICSB 24002 and DJ 6514 yielded high across seasons, whereas ICSB 433, ICSB 463, Macia, ICSV 745, CSV 15, ICSV 713, ICSV 93089, IS 34726, IS 33844-5, Barsizoot, ICSB 52, ICSB 38, 296 B, ICSR 92003 and Swarna yielded high in the rainy season; Phule Yasodha, Phule Anuradha, Parbhani Moti, CSV 18R, ICSV 702, ICSV 25010, IS 1104, IS 2123, IS 2146, IS 2312, IS 5470, IS 5622 and ICSV 93046 exhibited high grain yield in the postrainy season.

Table 6: Association between panicle and seed characteristics with morphological characteristics in the postrainy season-adapted sorghums

Plant traits	Leafsheath pigmentation	Plant vigour score	Leaf glossy score	Leaf midrib colour	Waxy bloom	Plant colour	Number of trichomes on the abaxial surface	Number of trichomes on the adaxial surface	Total soluble sugars (TSS)
Inflorescence exsertion	0.01 (0.08)	−0.13	−0.15 (0.36**)	0.04 (0.16)	−0.06	−0.07	0.10 (0.30**)	0.09 (0.36**)	0.05
Inflorescence compactness	−0.01 (−0.18)	−0.17	−0.44** (−0.11)	−0.11 (−0.10)	−0.22*	−0.06	0.33** (0.06)	0.35** (0.05)	−0.12
Inflorescence shape	−0.11 (−0.17)	−0.21*	−0.34** (0.11)	−0.21* (−0.16)	−0.27**	−0.1	0.24* (−0.10)	0.27** (−0.11)	−0.09
Glume colour	−0.17 (−0.12)	−0.51**	0.08 (0.30**)	−0.49** (−0.38**)	−0.39**	−0.56**	−0.22* (−0.30**)	−0.22* (−0.32**)	0.20*
Glume coverage	−0.29** (−0.20*)	−0.44**	−0.12 (−0.35**)	−0.52** (−0.31**)	−0.44**	−0.37**	0.13 (0.37**)	0.10 (0.36**)	0.22*
Awns	−0.19 (−0.46**)	−0.34**	−0.37** (−0.41**)	−0.07 (−0.03)	−0.65**	−0.47**	0.34** (0.27**)	0.30** (0.35**)	0.22*
Grain colour	−0.07 (−0.15)	−0.26**	0.37** (0.43**)	−0.23* (−0.30**)	0.04	−0.21*	−0.31** (−0.34**)	−0.32** (−0.38**)	0.1
Grain lustre	−0.03 (−0.03)	0.06	−0.39** (−0.24*)	0.16 (0.28**)	−0.26**	−0.11	0.34** (0.17)	0.34** (0.19)	−0.23*
Grain subcoat	0.01 (0.17)	−0.06	0.07 (0.21*)	−0.07 (−0.19)	0.01	0.11	−0.03 (−0.13)	−0.04 (−0.14)	0.15
Endosperm texture	−0.11 (−0.03)	0.06	0.29** (0.41**)	0.01 (−0.14)	−0.04	−0.28**	−0.28** (−0.25*)	−0.29** (−0.28**)	0.12
Endosperm colour	0.08 (−0.31**)	−0.18	0.40** (0.27**)	−0.16 (−0.15)	−0.03	−0.13	−0.34** (−0.25*)	−0.35** (−0.28**)	0.16

The values outside the parenthesis are the correlation coefficients of rainy season, and those inside the parenthesis are for the postrainy season.

*,**Correlation coefficient significant at P = 0.05 and 0.01, respectively.

Table 7: Association between agronomic characteristics in the postrainy season-adapted sorghums

Plant traits	Days to 50% flowering	Agronomic score	Plant height	100-seed weight
Agronomic score	0.27** (0.03)	1		
Plant height	0.35** (0.13)	0.76** (0.50**)	1	
100-seed weight	0.20* (0.15)	0.14 (0.41**)	0.30** (0.31**)	1
Grain yield	0.20* (−0.14)	−0.54** (0.04)	−0.27** (0.14)	−0.04 (−0.49**)

The values outside the parenthesis are the correlation coefficients of rainy season, and those inside the parenthesis are for the postrainy season.
*,**Correlation coefficient significant at P = 0.05 and 0.01, respectively.

Table 8: Association between the morphological characteristics in the postrainy season-adapted sorghums

Plant traits	ORS	Leafsheath pigmentation	Plant vigour score	Leaf glossy score	Leaf midrib colour	Waxy bloom	Plant colour	Number of trichomes on the abaxial surface
Leafsheath pigmentation	0.14 (0.43**)	1.00						
Plant vigour score	0.23*	0.46**	1.00					
Leaf glossy score	0.63** (0.69**)	0.32** (0.29**)	0.31**	1.00				
Leaf midrib colour	0.04 (0.07)	0.35** (0.21*)	0.36**	−0.02 (−0.15)	1.00			
Waxy bloom	0.30**	0.50**	0.60**	0.52**	0.31**	1.00		
Plant colour	0.05	0.53**	0.70**	0.33**	0.45**	0.76**	1.00	
Number of trichomes on the abaxial surface	−0.62** (−0.53**)	−0.18 (−0.26**)	−0.17	−0.73** (0.72**)	0.11 (0.13)	−0.30**	−0.05	1.00
Number of trichomes on the adaxial surface	−0.63** (−0.57**)	−0.19 (−0.26**)	−0.15	−0.73** (0.77**)	0.13 (0.16)	−0.27**	−0.02	0.99** (0.96**)

The values outside the parenthesis are the correlation coefficients of rainy season, and those inside the parenthesis are for the postrainy season.
*,**Correlation coefficient significant at P = 0.05 and 0.01, respectively.

Based on the relationship between grain yield of the test genotypes across seasons (Fig. 2), the genotypes ICSV 25026, ICSV 707 and ICSB 24002 (quadrant IV) exhibited high grain yield in both the seasons. The genotypes CSV 15, RHRB 12, Macia, 296B, ICSR 92006, ICSV 745, Swarna, ICSB 433, IS 34726 and ICSV 714 (quadrant II) performed well in the rainy season, while IS 2123, IS 5622, IS 2312, IS 5470, IS 2146, ICSV 25027, CSV 18R and IS 5604 (quadrant III) exhibited high grain yield potential in the postrainy season.

Direct and indirect effects of morphological traits on grain yield

Path coefficient analysis for grain yield as a dependent factor during the postrainy season revealed that trichomes on adaxial surface of the leaf exhibited positive and significant correlation with grain yield ($r = 0.55^{**}$) and had the maximum direct effects (0.46), with positive indirect effects through leaf glossiness score (0.37) and negative indirect effect through trichomes on the abaxial surface of the leaf (−0.52) (Table 10). Similarly, trichomes on the abaxial surface of leaves showed negative direct effects (−0.54), but the indirect effects were positive through leaf glossiness score (0.35), and trichomes on adaxial leaf surface (0.45), but had a significant and positive correlation with grain yield ($r = 0.48^{**}$). Leaf glossiness score showed negative direct effects (−0.47) on grain yield, and its indirect effects through other traits were also negative, except the trichomes on the abaxial leaf surface (0.40). Leaf glossiness showed a negative and significant correlation with grain yield (−0.72**).

Maximum direct effects (0.53) were shown by the trichomes on the adaxial leaf surface, with a significant and positive correlation with grain yield in the rainy season ($r = 0.21^{*}$). The 100-seed weight showed positive direct effect (0.41) and was significantly correlated with grain yield ($r = 0.56^{**}$) (Table 11). The parameters with correlation and path coefficients in the same direction could be used to select for shoot fly resistance in the postrainy season.

Stepwise regression analysis indicated that factors contributing to grain yield and shoot fly resistance differ in both the seasons. Leaf glossiness score, 100-seed weight (test weight) and plant height explained 56.31% of the variation for grain yield [grain yield (Y) = 2.66 + 0.01 plant height (X_1) − 0.31 test weight (X_2) − 0.35 leaf glossiness score (X_3)], whereas plants with shoot fly eggs and trichomes on the adaxial leaf surface explained 75.55% of the total variation in deadhearts during the postrainy season [shoot fly deadhearts (Y) = 20.51 + 0.69 percentage of plants with shoot fly eggs (X_1) − 0.11 trichomes on adaxial surface (X_2)]. During the rainy season, none of the factors accounted for a significant variation in grain yield, but the number of shoot fly eggs per 100 plants, plants with shoot fly eggs and leaf glossiness score explained 92.03% of the variation for percentage of plants with shoot fly deadhearts [Shoot fly deadhearts (Y) = 0.44 + 10.09 total number of shoot fly eggs per 100 plants (X_1) + 0.56 percentage of plants with shoot fly eggs (X_2) + 5.34 leaf glossiness score (X_3)].

Discussion

Shoot fly resistance is a highly complex character with low heritability and high environmental influence for shoot fly damage (Aruna et al. 2011). The experimental results indicated that the genotypic response differs across seasons. Oviposition non-pref-

Table 9: Association between panicle and seed characteristics in the postrainy season-adapted sorghums

Plant traits	Inflorescence exsertion	Inflorescence compactness	Inflorescence shape	Glume colour	Glume coverage	Awns	Grain colour	Grain lustre	Endosperm texture
Inflorescence compactness	0.12 (0.23*)	1.00							
Inflorescence shape	0.18 (0.06)	0.87** (0.75**)	1.00						
Glume colour	0.06 (−0.23)	0.23* (0.09)	0.27** (0.17)	1.00					
Glume coverage	−0.01 (−0.01)	0.20* (0.00)	0.27** (0.07)	0.49** (0.05)	1.00				
Awns	0.12 (0.39**)	0.11 (0.18)	0.07 (0.18)	0.35** (−0.12)	0.47** (0.26**)	1.00			
Grain colour	−0.07 (−0.25*)	−0.09 (−0.10)	0.05 (0.20*)	0.44** (0.40**)	0.31** (0.14)	0.10 (0.09)	1.00		
Grain lustre	−0.04 (0.16)	0.16 (−0.08)	0.00 (−0.19)	−0.15 (0.37**)	−0.19 (−0.07)	0.24* (0.13)	−0.24* (0.35**)	1.00	
Endosperm texture	0.01 (0.01)	−0.28** (0.10)	−0.19 (0.24*)	0.17 (0.30**)	0.22* (−0.11)	0.14 (0.17)	0.28** (0.28**)	−0.17 (0.29**)	1.00
Endosperm colour	−0.16 (−0.18)	−0.11 (−0.08)	0.02 (0.16)	0.31** (0.40**)	0.32** (−0.12)	0.05 (0.05)	0.88** (0.59**)	−0.20* (0.31**)	0.28** (0.37**)

The values outside the parenthesis are the correlation coefficients of rainy season, and those inside the parenthesis are for the postrainy season.
*,**Correlation coefficient significant at P = 0.05 and 0.01, respectively.

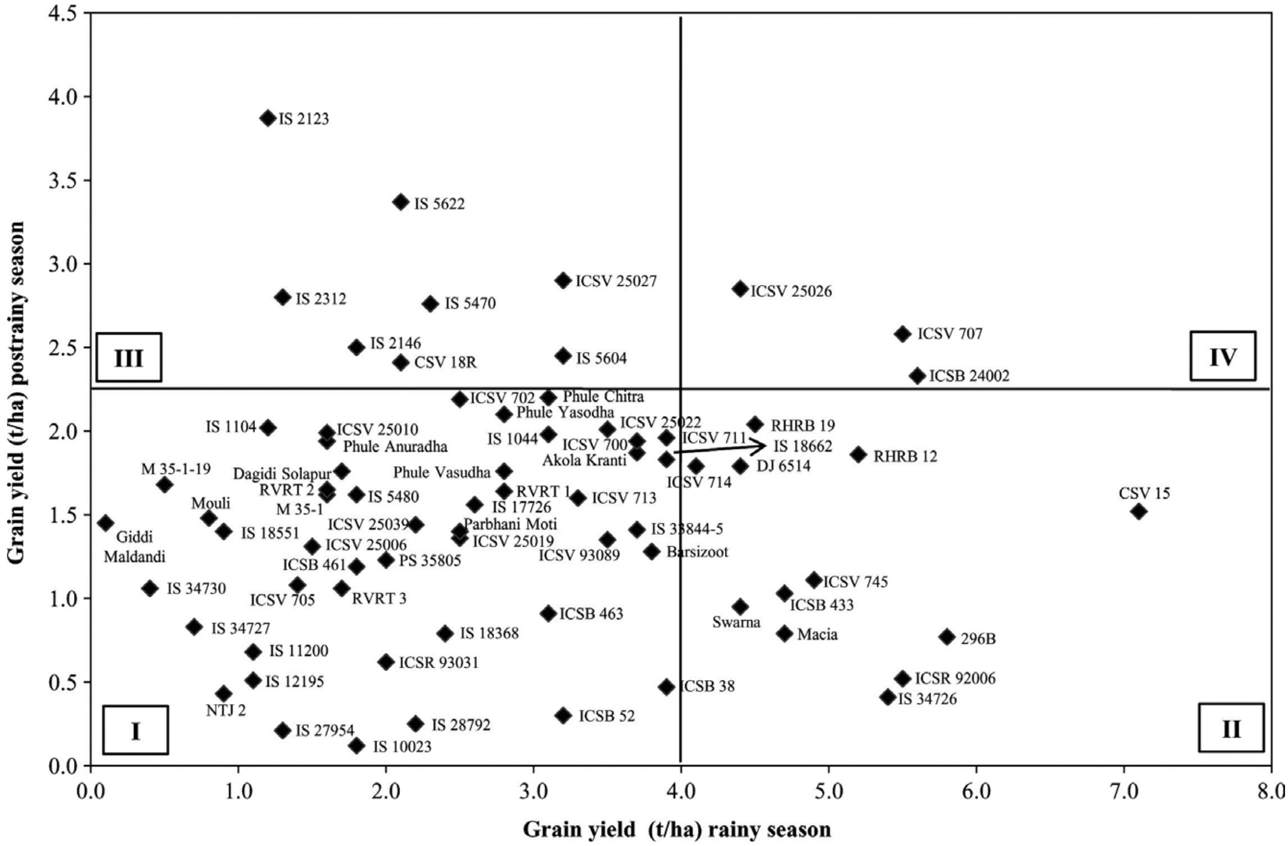

Fig. 2: Relationship between the grain yield in rainy and postrainy seasons and response of the genotypes across the seasons

Table 10: Direct and indirect effects of shoot fly resistance, morphological and seed/panicle characteristics on grain yield during the postrainy season

Plant traits	Number of shoot fly eggs/100 plants	Plants with shoot fly eggs (%)	Plants with shoot fly deadhearts (%)	Leaf glossy score	Number of trichomes on the abaxial surface	Number of trichomes on the adaxial surface	100-seed weight	Inflorescence exsertion	Glume colour	Glume coverage	Awns	Grain yield
Number of shoot fly eggs/100 plants	**0.11**	−0.10	−0.02	−0.27	0.28	−0.27	−0.05	−0.01	−0.04	0.00	−0.05	−0.40**
Plants with shoot fly eggs (%)	0.05	**−0.19**	−0.03	−0.35	0.35	−0.30	−0.11	−0.00	−0.03	0.00	−0.03	−0.64**
Plants with shoot fly deadhearts (%)	0.06	−0.16	**−0.04**	−0.36	0.37	−0.33	−0.09	−0.01	−0.04	0.00	−0.02	−0.61**
Leaf glossy score	0.06	−0.14	−0.03	**−0.47**	0.40	−0.36	−0.09	−0.01	−0.04	0.00	−0.05	−0.72**
Number of trichomes on the abaxial surface	−0.05	0.12	0.02	0.35	**−0.54**	0.45	0.07	0.01	0.04	−0.00	0.03	0.48**
Number of trichomes on the adaxial surface	−0.06	0.12	0.03	0.37	−0.52	**0.46**	0.07	0.01	0.04	−0.00	0.04	0.55**
100-seed weight	0.02	−0.10	−0.02	−0.21	0.19	−0.16	**−0.20**	−0.00	−0.04	0.00	0.01	−0.51**
Inflorescence exsertion	−0.03	0.05	0.01	0.17	−0.16	0.17	0.02	**0.01**	0.03	0.00	0.05	0.30**
Glume colour	0.04	−0.05	−0.01	−0.14	0.17	−0.16	−0.07	−0.01	**−0.12**	0.00	−0.02	−0.36**
Glume coverage	−0.03	0.04	0.01	0.15	−0.19	0.15	0.03	0.00	−0.00	**−0.01**	0.04	0.20
Awns	−0.04	0.05	0.01	0.19	−0.15	0.16	−0.01	0.01	0.02	−0.00	**0.12**	0.34**

[1] Correlation coefficient significant at P = 0.01; highlighted diagonal values are direct effects; Residual effect = 0.62.

erence (antixenosis), antibiosis and tolerance are the major components of resistance in sorghum to shoot fly (Doggett et al. 1970, Raina et al. 1981, Sharma and Nwanze 1997, Dhillon et al. 2005, 2006a, Sivakumar et al. 2008). Leaf surface chemicals influence the host plant resistance by the *A. soccata* females (Chamarthi et al. 2011), while trichomes hinder the movement of shoot fly maggot to reach the growing point (Sharma and Nwanze 1997). In the present studies, several genotypes

Table 11: Direct and indirect effects of shoot fly resistance, morphological and seed/panicle characteristics on grain yield during the rainy season

Plant traits	Plant vigour score	Leaf glossy score	Waxy bloom	Plant colour	Number of trichomes on the abaxial surface	Number of trichomes on the adaxial surface	Days to 50% flowering	Plant height	100-seed weight	Grain yield
Plant vigour score	**0.16**	0.00	−0.03	0.06	0.02	−0.03	0.03	−0.02	0.02	0.30**
Leaf glossy score	0.03	**0.00**	−0.03	0.01	0.31	−0.42	−0.15	0.00	−0.11	−0.18
Waxy bloom	0.08	0.00	**−0.05**	0.06	0.13	−0.15	−0.02	−0.02	−0.03	0.17
Plant colour	0.10	0.00	−0.03	**0.10**	−0.05	0.09	0.10	−0.03	0.04	0.39**
Number of trichomes on the abaxial surface	−0.01	−0.00	0.02	0.01	**−0.40**	0.52	0.11	−0.01	0.08	0.19
Number of trichomes on the adaxial surface	−0.01	−0.00	0.02	0.02	−0.39	**0.53**	0.12	−0.01	0.09	0.21*
Days to 50% flowering	−0.01	0.00	−0.01	−0.03	0.14	−0.19	**−0.32**	0.02	−0.23	−0.55**
Plant height	−0.08	0.00	0.03	−0.07	0.03	−0.05	−0.14	**0.04**	−0.07	−0.40**
100-seed weight	0.01	0.00	0.01	0.01	−0.08	0.11	0.18	−0.01	**0.41**	0.56**

*,**Correlation coefficient significant at P = 0.05 and 0.01 respectively; highlighted diagonal values are direct effects; Residual effect = 0.70.

exhibited non-preference for oviposition, of which some also showed antibiosis component of resistance against the survival of shoot fly larvae. Oviposition by sorghum shoot fly is significantly and negatively associated with trichome density and leaf glossiness (Omori et al. 1983, Dhillon et al. 2005). Similar associations were confirmed in the present studies. Genotypes with glossy and trichomed leaves are resistant to shoot fly damage, which are inherited independently, and apparently have an additive effect in reducing shoot fly damage (Maiti and Gibson 1983, Maiti et al. 1984, Sharma and Nwanze 1997, Dhillon et al. 2005, 2006a,b). Light pink-pigmented plants with low chlorophyll content are less susceptible to shoot fly damage (Singh et al. 1981, Kamatar et al. 2003, Dhillon 2004, Dhillon et al. 2005, 2006c, Chamarthi et al. 2011). In the present study, the leaf glossiness, leafsheath pigmentation, seedling vigour and trichomes on the abaxial and adaxial surface were found to be positively associated with shoot fly resistance as reported earlier (Taneja and Leuschner 1985) However, vigour was earlier reported to be associated negatively with shoot fly resistance (Dhillon et al. 2005, Chamarthi et al. 2011). Shoot fly-resistant lines have faster seedling growth, shorter peduncle and longer stems and internodes (Sharma and Nwanze 1997). Recovery or overall resistance is a type of plant response to shoot fly damage, in which the plants have the ability to recover from shoot fly damage through the production of secondary tillers with productive panicles once the main plant is damaged by shoot fly. Recovery resistance was highly associated with the level of primary resistance and shoot fly density (Blum 1969, Doggett et al. 1970, Jotwani and Srivastava 1970, Raina 1985, Sharma and Nwanze 1997). The shoot fly-resistant genotypes produce more numbers of uniform productive tillers than the susceptible ones and, at times, yield more under shoot fly infestation (Sharma and Nwanze 1997). The overall resistance score was positively associated with 100-seed weight, leafsheath pigmentation, seedling vigour score, leaf glossiness score, waxy bloom, grain colour, endosperm texture and endosperm colour, suggesting that the genotypes with a combination of these traits can be selected for resistance to *A. soccata*.

The seasonal variation in the expression of resistance to shoot fly damage is influenced by the effect of climatic factors on the survival and development of shoot fly, and the indirect effects through plant growth and biochemical composition of the host plants (Sharma 2014). High G × E interactions for deadheart percentage has been reported earlier by Singh and Rana (1986) and Aruna et al. (2011). Therefore, there is a need to adopt different strategies to breed for shoot fly resistance during the rainy and the postrainy seasons, for example grain yield was positively correlated with shoot fly-resistant traits such as number of shoot fly eggs per 100 plants, percentage of plants with shoot fly eggs, plants with deadhearts and overall resistance score during the rainy season, but negatively correlated during the postrainy season. Some of the sorghum genotypes exhibit an inherent ability to produce side tillers after the main shoot is killed by shoot fly. These genotypes can produce reasonable grain yields if the plant is not attacked again (Taneja and Leuschner 1985). Although the shoot fly infestation was high during the rainy season, the genotypes recovered from the damage and produced productive tillers because of the availability of moisture, resulting in higher grain yield (Ashok Kumar et al. 2008). However, during the postrainy season, the grain yield was negatively correlated with shoot fly resistance traits as the grain yield was influenced by shoot fly damage, and there was limited capacity to recover from shoot fly damage as shoot fly population is high during the postrainy season and the tillers generated were also infested by shoot fly.

Grain yield is influenced by many biotic and abiotic factors and the physicochemical traits of the plant. Correlation coefficients provide information on dependence/association among the traits. However, it is difficult to pinpoint the major factors that affect the expression of resistance/grain yield because of the intricate interactions between the traits being examined. Therefore, path coefficient analysis and stepwise regression were used to understand the nature of such interactions. Path coefficients serve as an effective parameter for determining the relative contribution/effect of individual traits, to identify the traits which have direct effects and correlation coefficients (+ve or –ve) in the same direction for use in crop improvement (Sharma et al. 1990).

The present studies suggested that leaf glossiness, trichomes, leafsheath pigmentation and seedling vigour can be used as morphological markers to select for shoot fly resistance in sorghum, and the genotypes showing resistance to shoot fly damage can be used in the sorghum improvement programmes for developing cultivars with shoot fly resistance and adaptation to the postrainy season.

Development of shoot fly-resistant parents is critical for producing shoot fly-resistant hybrids (Jayanthi et al. 1996, Reddy Belum et al. 1997). The grain yield was negatively associated with plant vigour and leaf glossiness and positively associated with trichome density in the postrainy season, but the trichome density was negatively associated in the rainy season. As a result of such intricate interactions, it is difficult to combine traits conferring resistance to shoot fly damage with high grain yield. The genotypes Phule Chitra, ICSV 707, ICSV 711, IS 5604 and Akola Kranti exhibited moderate levels of resistance to shoot fly with high grain yield, and hence, these genotypes can be involved in breeding the shoot fly-resistant sorghums with adaptation to the postrainy season. Among them, Phule Chitra and Akola Kranti are the released cultivars for postrainy season cultivation and are being disseminated to farmers on-large scale. ICSB 463, ICSB 713 and ICSV 93089 showed resistance to shoot fly in the rainy season and had high grain yield, whereas ICSV 25010, IS 2146 and IS 2312 exhibited resistance to *A. soccata* with high grain yield potential in the postrainy season, suggesting that there is a need to follow season-specific strategies to breed for developing cultivars with high grain yield and resistance to shoot fly.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Annexure S1. Morphological characteristics of sorghum genotypes evaluated for resistance to sorghum shoot fly, *Atherigona soccata* (ICRISAT, Patancheru, 2010–2011).

Annexure S2. Agronomic characteristics of sorghum genotypes evaluated for resistance to sorghum shoot fly, *Atherigona soccata* (ICRISAT, Patancheru, 2010–2011).

Annexure S3a. Panicle and grain characteristics of sorghum genotypes evaluated for resistance to sorghum shoot fly, *Atherigona soccata* during the rainy season (ICRISAT, Patancheru, 2010–2011).

Annexure S3b. Panicle and grain characteristics of sorghum genotypes evaluated for resistance to sorghum shoot fly, *Atherigona soccata* during the postrainy season (ICRISAT, Patancheru, 2010–2011).