SEASONAL VARIATION IN SORGHUM RESISTANCE TO SHOOT FLY

(Atherigona soccata Rondani)

by

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CERTIFICATE

This is to certify that the thesis entitled "**SEASONAL VARIATION IN SORGHUM RESISTANCE TO SHOOT FLY (*Atherigona soccata* Rondani)**" submitted in partial fulfillment of the requirements for the degree of "Master of Science in Agriculture" of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bonafide research work carried out by **MR. MAHAD ABDI FARAH** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

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

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DECLARATION

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

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ABSTRACT

The studies on seasonal variation in sorghum (Somalia germplasm) resistance to shoot fly *Atherigona varia soccata* Rondani were conducted in four experimental sowings in three seasons viz. late postrainy season 1990-91, early rainy 1991, and early postrainy 1991-92 at ICRISAT Center. Investigations included evaluation for resistance of the entries to the shoot fly over seasons for less oviposition, less damage resulting in fewer deadhearts and tolerance/recovery resistance.

In view of seasonal variation, entries were assessed in relation to various environmental parameters namely temperature, humidity and rainfall and their influence on varietal resistance was monitored.

INTRODUCTION

CHAPTER I

INTRODUCTION

Sorghum, *Sorghum bicolor* (L.) Moench Graminae is one of the major staple food crops in the semi-arid tropics, and ranks fifth in average production among the world's cereal crops following wheat, rice, corn, and barley (Young and Teetes, 1977). World production of sorghum grain is currently 52 million tonnes which is produced on some 42 million ha (FAO, 1985). It is believed that sorghum originated in eastern Africa (de Wet et al. 1970). But it is presently grown on all six continents. In the technologically advanced countries it is used mainly for animal fodder (Leuschner, 1985), but in the semi-arid tropics where it is a major food source of the population, it is also used as fodder, fuel, and building material. Three-quarters of the world's acreage devoted to sorghum production is located in Africa and India which however, together produce only one third of the world's produce (Swarna, 1991). In Somalia, sorghum is an important food crop and is currently grown on 500,000 ha with very low yields (Mao, 1988). In India, sorghum is the third important cereal after rice and wheat, and is currently grown on 15.3 million hectares (FAO, 1986). Generally, grain yields of sorghum on peasant farms are low, ranging from 500-800 kg ha^{-1} (Sheshu Reddy, 1982).

One of The most important factors that are responsible for low yeilds is losses resulting from insect pest attack. Of the several the thousand accessions of sorghum cultivars available, most are susceptible to at least a hundred species of insects, known to cause various levels of damage (Young and Teetes, 1977). However, the sorghum shoot fly, *Atherigona soccata* Rondani,*Chilo partellus* Swinhoe, and *Busseola fusca* Fuller; head bug, *Calocoris angustatus* Lethiery; and sorghum midge, *Contrania sorghicola* Coquillet are the major species which cause extensive damage to sorghum at different growth stages.

The shoot fly is widely distributed in Asia and Africa. It has been reported in almost all sorghum growing areas of the world. It attacks sorghum from 1 to 4 weeks after seedling emergence and damage is caused by the larvae which after hatching, crawl along the leaf sheath then upwards into the plant whorl from where it migrates dawnwards until it reaches the growing point. Feeding at this point results in death of the central whorl leaf and the typical symptom which is referred to as "deadheart". Fly population varies across seasons and years, depending upon environmental factors and cropping systems. Shoot fly population monitoring with fish meal traps established in Bonka Dryland Agricultural Research Station (BDARS), Somalia, in 1987 showed that the peak emergence of flies occurred between 1-16 July during long rains season. During short rains of

1987-88, peak emergence occured from 19 December to 3 January (Lavigne, 1988). However the identification of the species of *Atherigona* is still unknown and the biology and economic importance of shoot fly in Somalia are yet to be thoroughly studeid.

The majority of the sorghum grown in Somalia belongs to the race durra. It matures early (around 100 days) and has good forage value (Prasada Rao, 1987). It is well adapted to the region for both grain and fodder yield even under biotic (shoot fly and stem borers) and abiotic (terminal drought) stress (Prasada Rao, 1987).

Generally, with the introduction of newly developed high yielding hybrids that are highly susceptible to insect pests, the problem has become more serious (Jotwani, 1981). Recent studeis have also shown that introduced exotic cultivars were not superior to the local sorghum when tested for yield, insect, and disease resistance at BDARS. This was attributed mainly to their lateness in maturity compared to locals (Moa, 1988). Control of shoot fly on sorghum has proven difficult. Cultural practices such as early sowing and the eradication of alternate wild hosts reduce damage but are not always practical. Some of the conventional methods have only been successful when chemicals with high mamalian toxicity and which are not cost effective for subsistence farmers are used.

Plant resistance is important in pest manegement of dry land crops and is of particular relevance in sorghum. The potential of plant breeding for pest resistance is primarily limited by the genetic variation in the host species. The first reported attempt to screen a collection of 214 sorghum lines for shoot fly resistance was by Ponnaiya (1951a). Blum (1976) reported non-preference for oviposition as a primary resistance mechanism for shoot fly in sorghum. At ICRISAT, susceptible cultivars are preferred for egg laying in terms of higher number of eggs per plant and plants with eggs. Doggett (1972) and Blum (1972) have also established the existence of recovery resistance as a secondary mechanism of resistance.Some sorghum cultivars possess high levels of antibiosis in which mortality of first instar larvae was very high, growth of the surviving larvae was significantly lower, and female longevity was also reduced (Raina *et al.* 1981). Maiti *et al.* (1980) suggested that resistant sorghum lines possessed trichomes on the abaxial surface of the leaf and was related to a lesser frequency both of oviposition by the shoot fly and of subsequent larval damage. Agarwal and House (1982) found that the level of resistance was greater when both the glossy (pale green smooth and shining leaves) expression and trichome traits occur together. The movement of freshly hatched larvae to the base of the central shoot is facilitated by the accumulation of dew on the sorghum leaves which may remain wet longer (Raina *et al.* 1981). Leaf surface wetness (LSW) was shown to be higher in 10 days old seedlings of susceptible sorghum genotyptes than in seedlings of other ages and genotypes (Nwanze *et al.* 1990). Many shoot fly breeding lines with moderate levels of resistance and reasonable yield potential have been developed Ghode 1971, Kundu and Sharma 1975; Sharma *et al.* 1983. Under traditional farming system, where farmers use little or no agricultural inputs, host plant resistance is thus one of the most important components for sound pest management.

The cultivated sorghum of the semi-arid regions of East Africa occur in almost all the sorghum ecological zones of the world (Guiragossian and Peacock, 1986). Indeed environmental conditions that cause plant stresses are all too common and severely effect food production in eastern Africa.Environmental factors can reduce the performance of sorghum thereby altering the suitability of the plant as host to shoot flies.

Ecological resistance results from some temporary shifts in the environmental conditions. Plant development is dependent on temperature suitable for metabolic activity (Threshow, 1970). Water is directly or indirectly required for all life processes and every chemical reaction, mainly photosynthesis and respiration (Threshow, 1970).Moreover, water is a medium in which essential nutrients are carried from the soil solution to the cell. Light is a basic form of energy that directly or indirectly propels the life processes of most living organisms. Plant response (growth development, differentiation, and reproduction) are determined by the quality, intensity and duration (photoperiod) of light (DiCosmo and Towers, 1984). These ecological factors may influence shoot fly by altering its microenvironment and the chemical and physiological characteristics of its host and therefore, nutritional value of their food. These alterations can lead to changes in the levels of resistance of sorghum to the shoot fly between seasons.

Therefore, a program was developed to screen the collection of Somali sorghum germplasm under sorghumshoot fly infestation at different seasons representing changing environmental conditions. The main objectives of these program were :

OBJECTIVES

1. To evaluate Somali sorghum germplasm at ICRISAT for resistance to the sorghum shoot fly *Atherigona soccata* Rondani across seasons.

2. To study the influence of environmental factors on the resistance of sorghum to shoot fly *A. soccata* Rondani damage.

3. To evaluate the performance and yeild potential of these sorghums under natural shoot fly infestation and no infestation (protected) situations.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Extensive reviews of various aspects of sorghum host plant resistance to shoot fly and the progress made in various areas namely, screening techniques (natural and artificial methods), mechanisms and stability of resistance, biophysical and biochemical factors of resistance, larval establishment in the plant whorl and factors associated with resistance (volatiles, seedling vigor, glossiness, leaf surface wetness, etc.) are well documented (Ponnaiya, 1951a and 1951b; Blum, 1967 and 1972; Doggett *et al.* 1972; Sharma *et al.* 1977; Singh *et al.* 1978; Sukhani and Jotwani, 1979; Jotwani and Davies 1980; Maiti *et al.* 1980; Raina *et al.* 1981; Agarwal and House, 1982; Khurana and Verma, 1982; Raina, 1985; Nwanze *et al.* 1990). Several resistant varieties have been identified and sources of resistance utilized in breeding programs to transfer resistance into high yielding background (Singh *et al.* 1986).

2.1 SORGHUM SEEDLING PEST - THE SHOOT FLY

Sorghum, *Sorghum bicolor* L. is an important food and feed crop in the semi-arid tropics and especially for millions of people in the eastern Africa region. It is known to be one of the oldest crops cultivated in Africa, India, China, Thailand, Central and South America, Egypt, and Mediterranean Europe. Sorghum is believed to have originated primarily from West and East Africa although it is difficult to certify when and where it was domesticated (de Wet *et al.* 1970). Of the total 47 million hectares of sorghum grown in the world, east Africa cultivates nearly 13% (Reddy and Omolo 1984). The genus *Atherigona* belongs to the order Diptera and family Muscidae. Unfortunately several of the species in this genus are difficult to determine. Pont (1972) use the shape of the trifoliate process and the hypogial process to determine males. Female identification is based on the large tergite of the ovipositor which is a valueable character.

The adult female is gray in color, about 5 mm in length, is diurnal and most active in the morning and evening. The female *A. soccata* is a fairly robust insect with triangular or circular spots on two or three abdominal tergites. Two regular cones dominate the center of the eighth tergite which is often uniformly black, though the posterior portion in some insects are lighter. The free sclerite is narrow and long. A fine dark line characterizes the seventh tergite with a higher brown area surrounding the posterior half "cricket bats". The sixth tergite is small, square, and without sharp edges.

2.1.1 Distribution

The shoot fly *A. soccata* is a serious pest in practically all sorghum growing countries in Asia, Africa, and Mediterranean Europe. The pest distribution is clearly related to the sorghum crop distribution (Reyes 1984). Its occurrence has not been reported in America and Australia. In East Africa, it is one of the most destructive and important seedling pests of sorghum (Reddy, 1984). Recently, it was clearly and definitely established that shoot fly infestations occur at Bonka Dryland Agricultural Research Station (BDARS), Somalia, (Lavign 1988).

2.1.2 Pest Status and Host Range

The shoot fly was reported and named by Rondani (1871), but the damage caused to sorghum seedlings was first recognized much later by Fletcher (1914) and Ballard and Ramachandra Rao (1924). In addition to sorghum, it also attacks several wild graminaceous plants in various parts of Africa (Deeming, 1971). *Sorghum verticilliflorum* was reported as a common wild host of *A. soccata* in East Africa (Nye, 1960; Starks, 1970). Ogwaro (1978b) reported that *Sorghum bicolor* was markedly preferred in Kenya to other graminaceous plant species. Davies and Sheshu Reddy (1980a) reared shoot flies on 21 species of graminae and noticed that *Sorghum halepense* was by far the most important alternate host with *S. verticilliflorum* and to much lesser extent, *S. sudanese*, being significant hosts. Two wild hosts, *Digitaria sanguinalis* and *S. propingum*, have been reported from China (Shiang-Lin *et al.* (1981). Delabel and Unnithan (1981) observed that shoot fly populations are usually higher on wild sorghum, *Sorghum arundinaceum*, which was also acting as a reservoir than the local cultivated varieties of *Sorghum bicolor* especially during the dry season. But Granados (1972) reported the recovery of adults from *Biachiara reptans* inspite of less preferential oviposition. On the other hand, *Eleusine indica* was preferred over sorghum, but the larvae required more than one plant to complete their development. This indicates that the wild host maintains a small population which does not build up until sorghum is available. There is evidence of a higher reproductive potential for the off-season shoot fly, which can account for the rapid build up of the population in the beginning of the sorghum growing season (Unnithan *et al.* 1985).

2.1.3 Population Dynamics

The incidence of shoot fly is highly seasonal. The population are extremely low during the dry period and the beginning of the following season and thus early planted sorghum escape or are less severely injured than late sown crops (Ponnaiya, 1951a; Rivnay, 1960; Davies and Jewett, 1966; Deeming, 1971; Clearwater and Othieno, 1977). However, in China, the first generation of shoot fly causes heavy damage and early sown sorghum are reported to suffer serious losses (Shiang-Lin *et al.* 1981). In Somalia, a period of at least one month after the beginning of the long rains for the population of *A. soccata* to build up to noticeable levels. Shoot fly incidence is effected by seasonal conditions and meteorological factors such as humidity and temperature (Usman, 1968; Jotwani and Srivastava 1970). Damage sever ity varies considerably from season to season and year to year. The population dynamics of shoot fly has been studied, usually by growing regular planting of sorghum throughout the year (Kundu *et al.* 1971). This results in cross infestation and often gives erraneous impression of insect number and periods of peak incidence. Population dynamics can be studied through the actual damage to the sorghum seedling i.e. "deadhearts" and presence of adult flies by egg count on seedling and fly catches in trap baited with an attractant. Fish meal has been reported to attract flies (Starks, 1970) and was used in traps for pest monitoring in ICRISAT (Sheshu Reddy *et al.* 1981) and several other locations. The need for a simple trapping method to overcome these problems resulted in the use of fish meal as a bait to attract shoot fly into sorghum plots for increasing the efficiency of screening for resistance to this pest (Starks, 1970).

2.1.4 Biology

Shoot fly attacks sorghum from 1 to 4 weeks after seed ling emergence. The white, elongate, cigar-shaped eggs are laid singly on the under surface of the leaves parallel to the midrib. The larva after hatching crawls along the leaf sheath then upwards into the plant whorl, from there it moves down wards between the fifth and sixth leaves until it reaches the growing point which it cuts, causing drying of the central whorl leaf and the typical "deadheart" symptom. Larval development is completed in 8 to 10 days and pupation takes place mostly in the soil. Pupal period is about 8 days. The shoot fly completes its life cycle (from egg to adult) within 17 to 21 days (Kundu and Kishore, 1970). As a result of shoot fly attack, plant stand and number of harvested heads are greatly reduced. The death of the main central shoot leaf often results in the production of side tillers which are also attacked in situations of high shoot fly pressure, but quite often serve as a mechanism of recovery resistance.

2.1.5 Shoot fly management

Although a few parasites have been reported on *Atherigona soccata*, detailed information is lacking on them and their effect seems to be minimal. A relatively small number of hymenopterous parasites have been reported from eggs, larvae, and pupae of the shoot fly in Africa

(Deeming, 1971) and Asia (Pont, 1972). Sheshu Reddy and Davies (1979) have reported an *Erythraeid* predator on the eggs and early larvae at ICRISAT, Hyderabad, India.

The efficacy of cultural control practices is now an established fact and is being applied in Israel and other countries (Young, 1981) either deliberately or as a result of already established cropping patterns as in Thailand. The other most common cultural practice is the removal of affected plants and high seed rate (Ponnaiya, 1951a,b). However, experimental results from Davies and Sheshu Reddy (1981) show that higher plant density increases shoot fly numbers, eggs laid and plants attacked. Destruction of alternate hosts of *A. soccata* which appear to be a potential source of carry-over in the summer seasons has been recommended (Davies and Sheshu Reddy, 1981).

Chemical control of shoot fly has been successfully achieved with systemic insecticides (Jotwani and Sukhani, 1968; Barry, 1972a) but success with contact insecticides has been only partial (Swaine and Wyat, 1954; Wheatley, 1961), and in some cases, complete failure was reported (Igram, 1959). Insecticide treatment has also been known to result in increased shoot fly infestation (Davies and Jewett, 1966). Conventional methods for the chemical control of shoot fly are not practical for subsistence farmers. Resistant cultivars are a realistic alternative to chemical control but such cultivars should be comparable in yield with commonly used hybrids and varieties. There is therefore the need to develop shoot fly resistant sorghum varieties as a major component in an integrated management scheme for the control of this pest.

2.2 VARIETAL RESISTANCE

Resistance to the shoot fly in sorghum was first demonstrated by Ponnaiya (1951a,b). He screened 214 varieties and selected 15 of them which were relatively less damaged by the fly. At ICRISAT, screening for shoot fly resistance has been carried out in the field using the interlard fishmeal technique. Of nearly 14,000 germplasm lines screened so far, 42 lines have been found less susceptible over five seasons (Taneja and Lucshner 1984) Systematic work on screening for identifying sources of resistance was initiated in the sixties under the All India Coordinated Sorghum Improvement Project (AICSIP). More than 10,000 varieties from the world germplasm collection were screened at different locations. Large screening programs were undertaken in other countries, Nigeria, Uganda, Israel and Thailand. Singh *et al.* (1968), Pradhan (1971), Young (1972), Rao *et al.* (1978), Jotwani and Davies (1980) have continued the search for sources of resistance to shoot fly through field evaluation of thousands of varieties of the world sorghum collection.

However, none of the cultivars selected as resistant was found to be satisfactory since the level of the resistance was low to moderate. Singh *et al.* (1981) reported that a greater level of shoot fly resistance is available in purple pigmented plant types. Several cultivars were listed for resistance to both shoot fly and stem borer. Some of the highly promising lines selected which provided the most stable source of shoot fly resistance were IS Nos. 1054, 1151, 3541, 5469, and 5490. However, the resistant varieties were in general poor agronomic types, susceptible to lodging, photosensitive, late maturing and low yielding (Singh *et al* 1986).

2.2.1 Field and Cage-screening Technique

Knowledge of the peak activity period of shoot fly during the season enables planting test entries at the appropriate time so as to provide optimum insect pressure. However, for effective screening, it is very important to ensure high and uniform shoot fly pressure under field conditions. This is achieved by the Fishmeal technique as reported by Reddy *et al* (1981). The interlards of susceptible cultivars (CSH 1) are planted 20 days prior to the test material in four rows, leaving 24 rows for the test material. One week after seedling emergence, fishmeal is spread uniformly in the interlards. The young seedling and fishmeal smell attract the shoot flies which lay their eggs on the interlard seedling. Thus one life cycle (17-21 days) of shoot fly is completed on the interlards before the test material reaches the stage susceptible to attack. Fishmeal is again spread one week after seedling emergence of the test material.

For cage screening, shoot flies are collected from a trap baited with fishmeal. No insecticide is used in this trap. The flies after entering the trap move up into the collection jar due to their positive phototactic behavior and the jar can be easily removed and emptied. All shoot flies are collected every morning and evening and *A. soccata* are separated from other species. The trap-collected flies, most of which are mated females, are kept in holding cages for one day, with sorghum seedlings. They start laying eggs as soon as they are put inside the test cage.

2.3 MECHANISM OF RESISTANCE

2.3.1 Non-preference

Almost all ovipositional non-preference studies with the shoot fly were based on choice tests conducted either in the field or greenhouse conditions. Under field condition, resistance is primarily due to non-preference for oviposition (Jain and Bahatnagar, 1962; Blum, 1967; Rangdhang *et al*, 1970). Jotwani *et al* (1971) reported less than one egg per seedling in resistant varieties, compared with a maximum of 5.73 eggs per seedling on the susceptible variety. Blum (1967) and Jotwani *et al.* (1971) suggested that resistance in shoot fly in sorghum as observed in the field was primarily due to non-preference for oviposition. Singh and Jotwani (1980a) indicated that the efficacy of this mechanism was reduced under heavy shoot fly population pressure. On the other hand, under cage conditions, in the absence of the preferred host, oviposition was equal on resistant and susceptible varieties (Jotwani and Srivastava, 1970; Singh and Narayana, 1978). Sometimes, ovipositional non-preference was also operative in the absence of preferred host(s) (Jotwani *et al.* 1974; Wangtong and Patanakamjom, 1975; Raina *et al.* 1984). Blum (1969b) concluded that ovipositional non-preference was apparent in the progenies of susceptible and resistant sorghum, and was most influenced by shoot fly density (Singh and Jotwani, 1980a). Singh *et al.* (1981) estimated the degree of shoot fly preference to be 55 and 37% in temperate and Indian varieties, respectively.

Ogwaro (1978b) reported high ovipositional preference for the second leaf followed by third, first and fourth leaves in the laboratory, while the third leaf was highly preferred for oviposition followed by second, fourth, fifth, sixth, first and seventh leaves in the field. But Davies and Sheshu Reddy (1980b) found fifth and fourth leaves were preferred in this order for oviposition in the field. On the contrary, Sukhani and Jotwani (1979c) reported that *oviposition on the fourth followed by the fifth leaf in CSH 1 seedling was more likely to cause 'deadhearts', while on third, second and first leaf resulted in significant reduction in deadhearts (Sukhan and Jotwani, 1979c)*. There is also an inverse correlation between the distance of deposition of eggs from the base of the leaf blade and production of deadheart in the infested seedling (Mowafi, 1967). While the number of eggs deposited and deadheart showed significant and positive correlation (Sharma *et al.* 1977), group differences between susceptible and resistant varieties for deadhearts percentage was established by Rana *et al.* (1975). These studies indicated that varieties preferred for oviposition showed a high degree of deadheart percentage.

The oviposition preference may be influenced in inter and multiple cropping systems. Venugopal and Palaniappan (1976) reported that shoot fly damage was more severe when sorghum was intercropped with black gram, groundnut, green gram, and lablab. On the contrary, no difference in deadheart percentage was observed when the sorghum hybrid, CSH 1 was intercropped with green gram, black gram, groundnut, cowpea and red gram. Preliminary studies indicated that a combination of maize and sorghum reduced shoot fly damage in sorghum (Omolo and Sheshu Reddy, 1985).

2.3.2 ANTIBIOSIS

Since non-preference for oviposition is not a practical strategy, antibiosis alone or in combination with oviposition non-preference would be highly desirable as an operating mechanism. The presence of low level antibiosis indicating low larval survival rate was reported by Soto (1972, 1974). Singh and Jotwani (1980b) and Raina *et al.* (1981) have presented direct evidence of antibiosis in selected cultivars.

Some of the resistant cultivars showed that the pre-oviposition period was extended to 5-6 and 6 days when flies are released on IS 1082 and IS 2312, respectively as compared to 3.1 days on CSH 1 (Raina *et al.* 1981). Singh and Narayana (1978) reported that the fecundity of female shoot flies was higher when raised on a susceptible cultivars Swarna and CSH 1 as compared to moderately resistant cultivars, IS 2133, and IS 5604. Raina *et al.* (1981) noticed that IS 2146 and IS 2312 and to some extent IS 2195, IS 3962 and IS 5613 caused mortality among first instar larvae. Larvae grew poorly confining themselves mostly to the upper portion of the central shoot. Survival of the first instar larvae not only depended on the ability of the adult female to select a suitable oviposition site on the leaf, but also the success to penetrate the leaf sheaths and the distance between the infestation site and the growing point

(Delobel, 1982). Similar findings by Sharma and Rana (1983) has resulted in a selection criteria for antibiosis which was found heritable in F_1 and F_2 generations of high yielding cultivars. Rana *et al* 1981. attributed resistance to the cumulative effect of non preference, antibiosis and some morphological characters.

2.3.3 Tolerance/recovery resistance

Early attack on the main shoot induces the production of tillers many of which are able to escape further attack and produce harvestable earheads, so that yield is not much reduced. This type of reaction was found in two East African varieties namely, Serena and Namatare (Doggett and Majisu, 1965, 1966; Doggett et *al*., 1970). Serena is also non-preferred. Blum (1972) reported that resistant cultivars of sorghum had a very high rate of tiller survival compared with susceptible cultivars. He also suggested that tiller survival was related to the rate of growth, so that the faster the tiller grew the greater were it's chance of avoiding infestation. Tiller development consequent to "deadheart" formation in the main shoot and subsequent survival and recovery depend on the level of primary resistance. Varieties with high recovery resistance appear to yield more under shoot fly infestation.

Recovery resistance does not appear to be an useful mechanism particularly when shoot fly populations progressively increase as the rainy season continuous (Singh *et al.* 1986).

2.4 BASIS OF RESISTANCE

2.4.1 Physio-morphological factors

2.4.1.1 Role of silica crystals in resistance

Varieties with primary resistance are not severely attacked by the shoot fly. Ponnaiya (1951b) reported the presence of irrigular shaped silica bodies in the plant tissue from the fourth leaf onwards in resistant varieties and from the sixth leaf onwards in susceptible ones. He also suggested that the relatively slow appearance of these silica bodies in the susceptible varieties make them prone to shoot fly attack for a longer period. Blum (1967, 1968) and Langham (1968) found small prickle hairs on the abaxial epidermis of first, second and third leaf sheaths in some resistant varieties which deter penetration of the young larvae. Delobel (1983) found that in stressed CSH 1 seedlings, the lightness of the whorl leaves prevents newly hatched larvae from entering the shoots and this also causes highly larval mortality and premature pupation.

2.4.1.2 Trichomes and Glossiness

Most resistant varieties have also been found to have glossy (pale green smooth and shining leaves) expression in the seedling stage (Jotwani *et al.* 1971; Maiti *et al.* 1980). A large proportion (84%) of the glossy lines (accounting for less than 1% of sorghum germplasm) are Peninsular Indian origin, but some are from Nigeria, Sudan, Ethiopia, North Cameroon, Kenya, Uganda, South Africa, and Mexico. Most of them belong to durra group and some others to taxonomic groups such as *guinea*, *caudatum* and *bicolor* (Maiti *et al.* 1984). The long and narrow leaves and faster seedling growth as indicated by the length of leaf sheaths and seedling height, coupled with toughness of leaf sheaths are also reported to contribute towards resistance to shoot fly (Singh and Jotwani, 1980d).

The majority of shoot fly resistant cultivars have a high density of leaf trichomes. Based on the report that trichomeless cultivars of pearl millet accumulate more dew and stay wet longer (Burton *et al.* 1977), Raina *et al.* (1981) suggested that a similar situation in sorghum would facilitate the movement of freshly hatched larvae to the base of the central shoot. Maiti and Bidinger (1979) noticed that trichomes on the abaxial surface on the leaf deterred egg laying. In addition, Maiti *et al.* (1980) did not observe any difference in cuticle thickness or in the degree of lignification of leaves between trichomed and trichomeless lines. The resistant cultivars IS 2146, IS 3962, and IS 5613 had a high density of trichomes on the abaxial leaf surface, while susceptible hybrid, CSH 1 was found to lack trichomes. However, under heavy infestation, the density of trichomes appear not to make any difference between preference or non-preference for a cultivar. Agarwal and House (1982) found that the level of resistance was greater when both the glossy and trichome traits occur together. Umari *et al.* (1983) reported shoot fly egg laying was highly significantly and negatively associated with trichomes and glossy traits. They suggested that the glossy expression in seedling sorghum can be utilized as a simple and reliable selection criterion for shoot fly resistance.

2.4.1.3 Leaf surface wetness

Oviposition on the middle region of the lower side of a leaf and early morning hatching both seem to have significance. The location protects the eggs from being washed away by rain and freshly hatched larvae use the morning dew to glide down until they reach the leaf sheath (Rivnay 1960). Blum (1963) observed that when freshly hatched shoot fly larvae were placed on sorghum leaves in the laboratory, they repeatedly fell down unless the plants were moistened with a fine spray of water.

The time of hatching coincides with the presence of moisture on the leaf, a condition favorable to the movement of the larvae to the base of the leaf (Raina, 1981). Nwanze *et al.* (1990) reported that the susceptibility of sorghum to shoot fly was affected by seedling age and was highest when seedlings were 8-12 days old, which corresponds with high moisture accumulation in the central leaf (the path of the larvae as it moves downwards, after hatching towards the growing apex). They also concluded that moisture accumulation was higher in susceptible CSH 1 than in resistant IS 18551.

2.4.1.4 Epicuticular waxes

The role of epicuticular wax content in impeding cuticular water loss is very complex and not only does the quality of wax play a role, but the chemical composition and physical structure of the surface wax influence cuticular water loss as well (Hadley, 1981). The cutin-wax complex affects leaf wettability and differ considerably from species to species in the ease with which they are wetted. Variation in wettability achieved are often found between leaves of different ages and between the upper and lower leaf surfaces (Martin and Batt, 1958; Silva Fernandes, 1965a). Wax can physically impede the movement of an insect across the leaf surface. The movement of the first larvae of the spotted stem borer, *Chilo partellus* may be considerably impeded by wax on the culms of sorghum (Bernays *et al.* 1983). Larvae accumulate wax around their prolegs as they move over the plant surface and this impedes their progress.

In addition to the effect of thick surface wax on larval movement, it has been shown that on some resistant genotypes there is a disorientation effect which has been attributed to the chemical composition of epicular wax (Woodhead, 1987). The surface wax of sorghum clearly has considerable influence on larval behavior and the evidence suggests that differences must exist in the chemistry of waxes from different cultivars of the same species.

2.4.1.5 Shoot fly behavior in relation to sorghum resistance mechanisms

The sorghum shoot fly, is relatively specific to sorghum (Davies and Reddy 1981) and females withhold egg laying when presented with other grass species (Ogwaro 1978a). The inference is that sorghum exhibits some specific characteristics that are perceived by the fly at or close to the plant surface that stimulate oviposition. Ogwaro 1978a described the shoot fly probing at the leaf surface with its legs and ovipositor in the process of host selection. There are only few chemoreceptors on the ovipositor, but contact chemoreceptors and basiconic sensilla, presumably with an olfactory function, and numerous mechanorceptors are present on the tarsi (Ogwaro and Kokwaro 1981). Consequently, the insect has the capacity to respond to physical and chemical features of the plant surface (Chapman *et al.*, 1984). Woodhead *et al.* (1982) showed that unusually large amounts P-hydroxybenzaldehyde are some times present on the surface wax of young sorghum plants, but there is no evidence linking this to shoot fly behavior.

2.4.1.6 Shoot fly Attraction from Distance

The shoot fly *A.soccata* Rondani is attracted by decomposing fishmeal (Reddy et al 1981) as well as by ammonium sulfide and sakatole, but how this is related to the host plant is not clear. Reddy et al (1981) found that dead hearts caused by *A.soccata* were attractants in one experiment, but not in another and it was inferred that since mainly females are attracted, the behavior related to locations of the host plant for oviposition. However, *A.soccata* normally oviposits on healthy plants and the attraction to fishmeal is probably related to feeding on protein for vitellogenesis rather than for oviposition. Reddy *et al.* 1981 indicated that most of the flies which are attracted are immature and suggest that the attraction varies with the vitellogenesis is known to occur in other Muscidae (Dethier 1976).

Fewer eggs are laid by *A.soccata* on sorghum cultivars that are pale green in color (Jotwani 1981). Although there is firm evidence on this species, it is known that other species of fly are attracted differentially to their host plants by difference in spectral reflectance patterns from the leaf surface (Prokopy and Owens 1978). Singh and Jotwani 1980c showed that in 17-and 24-day old plants) the number of eggs laid was correlated with the percentage of chlorophyll in the leaves, but it is not known if the choice is made before or after the insect a lights on the leaf.

2.4.2 Biochemical factors

Very little is known about the biochemical basis of sorghum resistance to shoot fly. Chemical analysis of sorghum plants revealed that compounds such as hordenine (B-P-hydroxyphenetyl dimethylamine, alkaloid and durrin (a cynogenic glycocide) were present at high levels in the seedling stage but disappeared completely as plants grew older (Reti 1969, Cooper 1973; Culvenor, 1973). These compounds may probably be acting as toxins, feeding stimulants/deterrents or be involved in the recognition of the host by the female shoot flies. But, Thirumurthi and Subaramanian 1976 found no relationship between HCN content in sorghum seedlings and shoot fly resistance. Although Thirumurthi (1970) reported higher concentration of sugars in resistant varieties, this needs further confirmation. Investigations into the role of sorghum plant chemicals in stimulating oviposition of the shoot fly has been studied by Unnithan *et al* (1987). Observations suggested that certain acetone-extractable chemicals of CSH 1 seedling are important for stimulating oviposition by the shoot fly. Biochemical analyses of sorghum cultivars resistant and susceptible to the shoot fly have revealed significant differences in sugars, reducing sugars, nitrogen and certain amino acids. Preliminary observations of Dabrowski and Patel (1981) suggested that the interaction of feeding causes source biochemical changes which leads to decay. Woodhead and Bernays (1978) found that the concentration of some phenolic compounds is initially high in sorghum seedlings. These compounds possibly play a significant role in the physiological relationship between shoot fly and sorghum seedlings. But Khurana and Verma (1983) reported that total phenol content is negatively correlated with shoot fly susceptibility. Higher nitrogen content (Singh and Narayana, 1978), phosphorus in plant (Khurana and Verma, 1983) and lysine content in leaf-sheath (Singh and Jotwani, 1980c) have been correlated with shoot fly susceptibility. Lysine may play an important role in the growth and development of shoot fly larvae in resistant cultivars. Khurane and Verma (1982) observed higher quantities of total amino acid contents in resistant than in susceptible sorghum.

2.6. Seasonal Variation in Sorghum Resistance to Shoot fly

Both humidity and temperature continuously interact to produce conditions within the plant canopy that play a key role in regulating insect growth, survival and fecundity, (Benedict 1988). Further it was suggested that behavior, temperature, and humidity interact to effect plant growth, expression of resistance and plant attractiveness to herbivores and beneficial insect, through plant produced allomones, synomones, and Kairomones (Nordlund 1981).

Temperature is one of the most important physical factors of the environment, affecting the physiological and behavioral interaction of insect and plants (Benedict 1988). In relation to host plant suitability, temperature-induced stress is further defined as an external constraint to full genetic expression of plant morphological or biochemical mechanisms against herbivores (DiCosmo and Towers 1984). Temperature-induced stress is a relative phenomenon, similar to the phenomenon of host plant resistance to insects in that a given environmental temperature may be stressful to one organism's growth, reproduction, or defense but near optimum for another organism (Benedict, 1988).

Tingey and Singh (1980) described three mechanisms whereby temperature can induce changes in host plant suitability to insect herbivores. (1) Temperature-induced stress can cause changes in plant physiology that affect the expression of genetic resistance, resulting in changes in levels of allelochemicals, morphological defense mechanisms and/or nutritional quality of the host. Insect herbivores feeding on such temperature-stressed plants would have altered growth, development, reproduction survival and/or behavior (i.e., increased or decreased antibiosis, and/or non-preference effects). (2) Temperature-induced stress can directly affect plant physiology, resulting in altered plant growth and development and thus changing plant response to insect injury. Therefore only the plant's response to insect damage is changed (i.e., increased or decreased tolerance). (3) Temperature induced stress can directly affect insect behavior and physiology, and thus change herbivore growth, reproductive biology, and population dynamics. These three mechanisms of temperature-induced change in the host-plant-insect interrelationship should be thought of as factors that modify (increase or decrease) directly or indirectly, herbivore "capability" or "fitness" to utilize food resource.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

Studies on the seasonal variation in resistance of Somalian Sorghum germplasm to shoot fly were conducted in four experimental sowings in three seasons at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Patancheru, Andhra Pradesh, between December 1990 to February 1992. The studies were carried out under natural field conditions over different seasons viz. late postrainy 1990-91, early rainy 1991 and early postrainy 1991-92 season. To study agronomic performance and yield potential of test material, a separate trial was planted in the early 1991 rainy season (17 June) before the build up of shoot fly population. Recommended agronomic practices were carried out where applicable.

3.1 Material: (Somalian Sorghum Germplasm)

Studies were undertaken on 265 Somalian Sorghum Germplasm collection (collected from southern Somalia in August 1987 by ICRISAT Genetic Resource Unit (Appendix A) The collection was reported to have variation in height, pericarp color and seed form which may indicate genetic diversity among them (Prasada Rao 1987). The source material is potentially grown in southern Somalia as food and fodder under traditional farming system with high levels of insect damage and drought. The area of collection covers the districts surrounding the Bonka Dryland Agricultural Research Station, Baidao, Somalia (Fig.1).

3.2 Sowing and Harvesting Dates

Materials were sown during peak shoot fly activity at ICRISAT Center in order to provide optimum insect pressure for meaningful evaluation. Season, sowing dates and soil type are indicated below:

Season	Soil type	Sowing date	Harvesting
Postrainy (late)	Black Vertisol	17 Dec.90	Apr. 1991
Rainy (early)	Black Vertisol	17 Jun.91	Oct. 1991
Rainy (late)	Black Vertisol	17 Jul.91	Nov. 1991
Postrainy (early)	Black Vertisol	5 Oct.91	Feb. 1992

3.3 Research Methodology

Evaluation of germplasm included shoot fly susceptible (CSH 1) resistant (ICSV 705, IS 18551) and a local (IS 1054) cultivar as control. In view of seasonal variation in the natural shoot fly population, entries were subjected to different levels of shoot fly infestation in each season. Genotypes were grouped into different categories in accordance with field observations and their levels of expression of resistance. Seasonal variation in environmental factors temperature, humidity and rainfall and

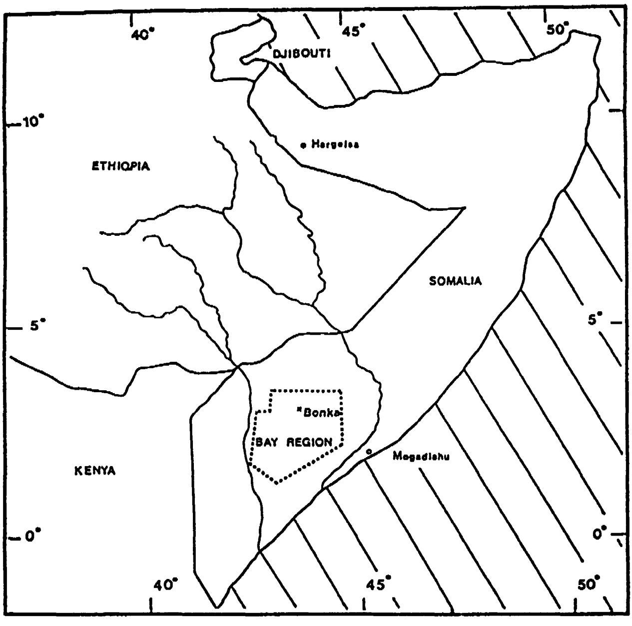

Fig. 1: Map of Somalia showing the location of the Bay region and the Bonka Dryland Agricultural Research Station. (from Eagleton et al., 1990).

their influence on varietal resistance were monitored. Entries which were consistent in performance over seasons for primary or secondary resistance were noted.

3.4 Field Design

For initial screening, late postrainy season (17 Dec.1990), the entries were sown in unreplicated single row plots, (4 m X 0.75 m) with 40 plants plot or row. Each experimental area consisted of 18 blocks of 16 rows. CSH-1 (susceptible control) was randomly distributed within each block whereas IS 18551 (resistant control) was replicated after every block. The total effective experimental area for each season was 0.12 ha (100 m X 12 m)

3.5 Field Screening

Results from of previous studies on shoot fly populations at ICRISAT Center, facilitated the sowing of test material at the appropriate time for obtaining optimum shoot fly pressure (Fig 2). This ensured that test material were exposed to uniform insect pressure for effective screening under field conditions. The interlard fishmeal technique developed at ICRISAT was adopted to screen the material in the field (Taneja and Leuschner, 1985). An interlard of susceptible cultivar. CSH 1 was planted 20 days prior to the test material in four rows on either side of the experiment leaving 16 rows for the test material. This method ensures the infestation of the test material by flies

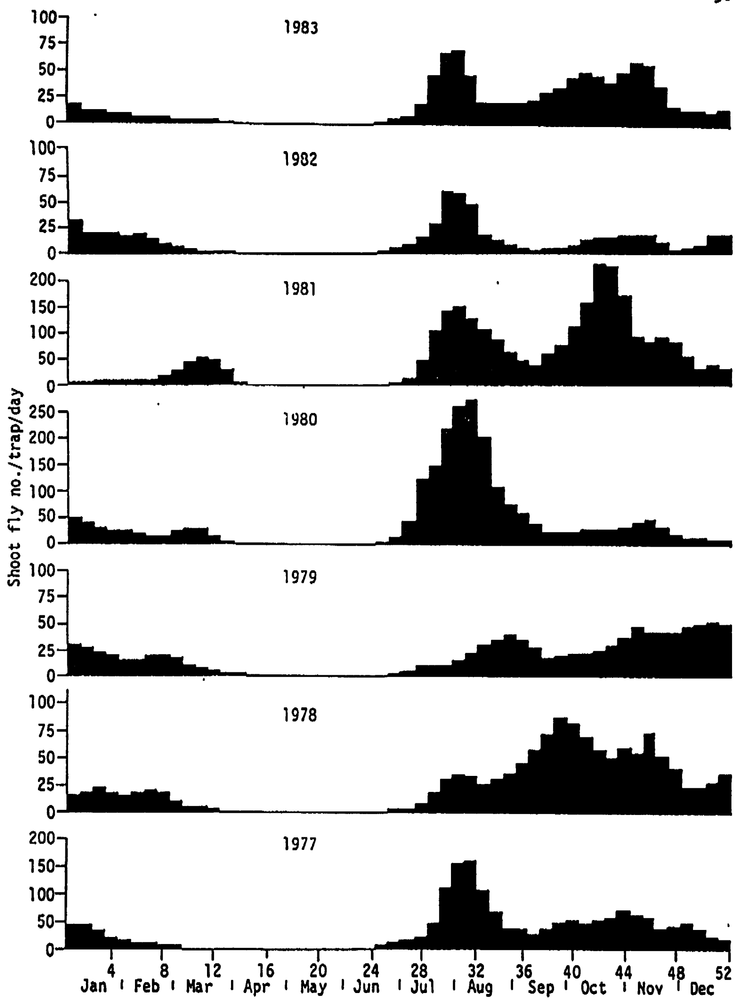

Fig 2: .. Shoot fly (*Atherigona soccata*) catches in fishmeal-baited traps at ICRISAT Center, Patancheru, India (1977-83). (From Taneja and Leuschner, 1985).

emerging from the infester rows. To further ensure high and uniform shoot fly infestation, fishmeal was uniformly spread across the field In order to assess crop performance in the absence of shoot fly infestation, one set of the test material was sown early in the rainy season (17 July 1991) when shoot fly infestation is extremely low and insignificant.

3.6 Field Observations

1. Total number of plants / plot
2. Plants with eggs /plot*
3. Total number of eggs per plant.
4. Deadheart plants at 21 DAE*.
5. Deadheart plants at 28 DAE*.
6. Visual rating at 35, 50, and 90 DAE.
7. Number of tillers / plant at 35 DAE.
8. Total number of heads / per plot.
9. Harvestable heads (main plants) / plot.
10. Harvestable heads (tillers / per plot.
11. Head weight (main plants) / plot.
12. Head weight (tillers) / plot.
13. Grain weight (main plants) / plot.
14. Grain weight (tillers) / plot.
15. Total grain weight (main plant + tiller plant).
16. Yield/ha

* Later converted to percentages.

3.6.1 Egg counting

Eggs were counted at 15 DAE for observation on non-preference for oviposition. Twenty out of 40 plants were examined in each plot for shoot fly eggs. Percent plants with eggs was calculated on the basis of number of plants examined. The comparative levels of shoot fly infestation in the test material were estimated by using the data from the control as the standard.

3.6.2 Deadheart count

Total number of deadhearts was counted for each plot 21 and 28 DAE. Percentage deadheart plants was calculated on the basis of total plants / plot. The counting of deadhearts was repeated at 28 DAE to ensure that all daedheart plants which formed after 21 DAE were also recorded, especially during the winter season when plant growth is slower.

3.6.3 Number of tillers

Tiller count was carried out at 35 DAE. Since highly susceptible varieties may respond to shoot fly attack by producing synchronous tillers, many of which were able to escape major insect damage and to give productive heads (Doggett, 1972), information on tiller production becomes a good measure of recovery resistance.

3.6.4 Recovery Rating

As an important agronomic character, visual ratings for recovery was done at 35, 50 and 90 DAE using the 1-9 scale developed by Nwanzeet *al* (1991) . The scores at 1-5 were given for healthy, undamaged plants and for entries with good recovery in growth of all plants, while the score of 9 was given for heavily damaged plants in entries with no tillers, and also lacking uniformity in growth and recovery. This observation was repeated before harvest to see how best an entry had improved during the course of the growth period to develop productive, harvestable heads.

3.6.5 Tiller survival

Tiller survival was recorded as the number of tillers producing harvestable heads in relation to the total number of tillers after main stem damaged was recorded at 28 DAE. Basal tillers were counted at 35 DAE.

3.6.6 Harvestable heads

The harvestable heads were counted and harvested at 120-130 DAE. Late maturing tiller heads which were not in synchrony with the main plant growth and development were discarded.

3.6.7 Head and grain weight

Heads of main plants were harvested, threshed, and processed separately from the tiller plants in order to evaluate their production under shoot fly infestation. The morphological differences in head types were not considered in this study. On the other hand, 1000 grain weight which reflect the grain size of the entries was recorded. The total number of harvestable heads tiller was recorded separately and tiller grain yield was calculated to assess its contribution to total grain yield. In view of contribution of tillers, both head and grain weight parameters of the tillers were included in statistical analyses of results.

3.7 Environmental factors

Meteorological data sets on maximum and minimum temperature, relative humidity and rainfall were collected for each season.

3.8 Statistical analysis and procedures

The data obtained for each season were analysed. Biological parameters for each trial were analysed with respect to prevailing environmental conditions. The best performing genotypes for each parameter in each experiment were selected and compared for their performance and frequency of occurance across seasons and yield potential. All data were subjected to statistical analysis of variance.

RESULTS

CHAPTER IV

RESULTS

5.1 LATE POSTRAINY SEASON TRIAL, 1990

Shoot fly infestation on the first experiment in the postrainy season, sown on 17 December 1990, was high and this resulted in stunted crop growth. The average number of eggs per plot was 19 eggs at 14 DAE, while the average percent plants with eggs was 70%. The entries which were least preferred for oviposition are presented in Table 1.

Table 1: Best performing entries in relation to less preferred for oviposition, postrainy season 1990-91

Genotype	Number of eggs/plant	Plants with eggs (%)
IS 32516	1.0	35
IS 32513	1.0	30
IS 32519	1.0	10
IS 32521	1.0	20
IS 32538	1.1	40
IS 32520	1.1	30
IS 32550	1.0	20
IS 32517	1.0	45
IS 32540	1.0	20
IS 32525	1.0	15
IS 32530	1.0	10
IS 32512	1.1	14
Controls		
IS 18551	1.0	10
ICSV 705	1.0	35
IS 1054	1.0	35
CSH 1	1.6	76
Mean	1.5	70
SEM ±	0.47	1.29

The incidence of shoot fly (plants with deadheart) in the postrainy (late) season was generally high. At 21 DAE an average of 46% deadheart were recorded and this increased to 89% at 28 DAE. Most entries were highly infested and only a small number showed low deadheart damage (Table 2).

Table 2: Sorghum entries with lowest shoot fly damage, late postrainy season ICRISAT Center

Genotype	Percent dead heart plants per plot
IS 32516	65
IS 32513	65
IS 32519	78
IS 32525	78
IS 32538	50
IS 32594	73
IS 32571	65
IS 32689	30
IS 32517	63
IS 32540	68
Controls	
IS 18551	18
ICSV 705	65
IS 1054	50
CSH 1	85
Mean	89
SEM ±	0.52
Mean for all entries (269)	89

Generally, the entries which were less prefered for oviposition and had low deadheart damage, were poor performing in other parameters, especially for recovery. Entries performed differently for various parameters.

Total head production average 48 per plot, but harvestable heads averaged 35 only per plot (Table 3).

Several heads were produced by tillers and were not harvested due to late maturity.

Table 3: Best performing entries based on harvestable heads and grain yield late postrainy season, 1990-91

Genotype	Main plant heads	Tiller heads	Total No.of heads produced	Harvestable heads(T+M)	Grain yield (kg ha^{-1})
IS 32708	2	41	42	38	4113
IS 32706	5	40	49	45	3705
IS 33601	1	52	72	53	3524
IS 32717	1	53	59	54	3395
IS 32737	2	54	53	53	3345
IS 32719	3	49	49	52	3210
IS 32709	3	58	60	32	3198
IS 32725	1	44	53	45	3172
IS 33600	2	41	77	45	3148
IS 32735	2	47	65	49	2994
IS 32587	3	81	89	84	2985
IS 33602	1	76	103	77	2950
IS 32677	1	62	79	63	2908
IS 32513	13	27	45	40	2354
IS 32521	8	45	53	53	2283
IS 32585	3	54	87	57	2852
Control					
IS 18551	26	30	40	40	1483
ICSV 705	3	30	50	33	1483
IS 1054	20	19	54	39	1983
CSH 1	4	28	37	32	2578
Mean	4	35	48	39	1845
SEM ±	0.22	0.78	0.93	0.82	43.45

T = Tiller; M = Main plants

The mean yield of the all entries (1845 kg/ha) was higher than the controls indicating the superiority of some entries in other parameters.

During the late postrainy season (Appendix B) minimum temperature was $20^{O}C$ and maximum temperature recorded was

$38^{o}C$ until the 12 week (Figure 3b). Temperatures started to increase and coincided with the boot-leaf stage of crop growth at 8 week until crop harvest. Total rainfall during the postrainy season was 52 mm and it was received during the last week of the season (Figure 3a). Over 62% of the seasons rain was received at crop harvest. The seasonal mean relative humidity recorded at 07 hr (minimum) and 14 hr (maximum) were 31.7% and 82.9 respectively. The relative humidity was 40.1% at 07 hours which was the minimum relative humidity and 92% at 14 hr, maximum relative humidity (Figure 3c).

5.2 Early Rainy Season Trial, 1991

The early rainy season experiment sown on 23 June, 1991 to estimate the yield potential entries without shoot fly damage (Plate 1). Head production was very low, averaging 20/plot of 40 plants. Most plants were more vegetative than reproductive.

Entries were ranked on the basis of number of harvested heads, head weight, grain weight, 1000 grain weight and yield kg/ha. The average yield kg/ha was 1411 including the checks (Table 4).

Total precipitation during the growing period was 571 mm and rainfall was received in 16 out of 19 weeks. The weekly mean rainfall was 30.5 mm. (Appendix C).

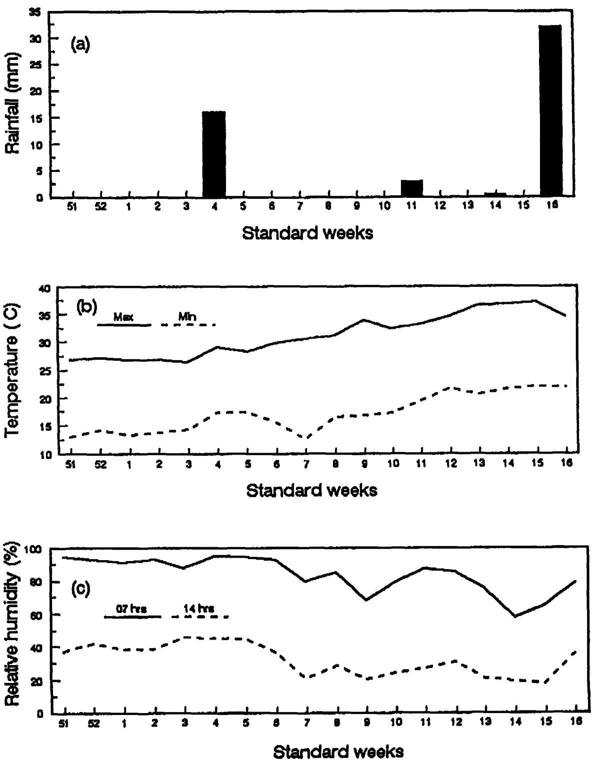

Fig 3: Fluctuation of climatic factors during postrainy season (December 1990 to April 1991)

At ICRISAT Center (a) Rainfall, (b) Temperature (c) Relative humidity

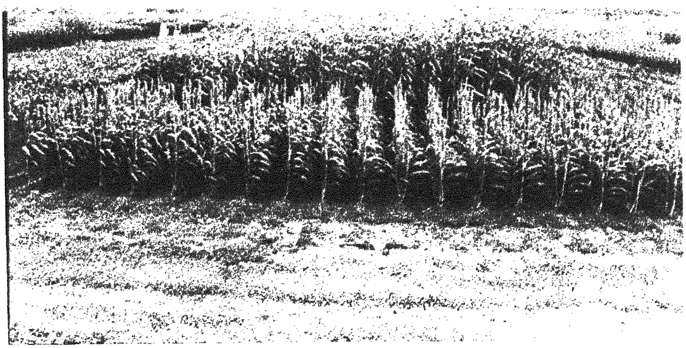

Plate 1: Early rainy season trial (DOS: 23 June 1991) for yield potential of entries (Note: Low frequency of heads in test entries; foreground: boarder rows of CSH 1)

The average maximum temperature was 30.5°C and the average minimum temperature was 21.7°C. The minimum and maximum relative humidities recorded at 0700 and 1400 h respectively were 56.8% and 90.28%.

Table 4: Best grain yielding entries in 1991 early rainy season crop sown on 17 June 1991

Genotype	Number of harvestable heads	Head wt. per plant (g)	Grain yield kg ha^{-1}	1000 grain weight (g)
IS 32619	32	16	3728	31
IS 32690	24	55	3183	37
IS 32731	32	33	3133	27
IS 32681	24	49	3057	33
IS 32714	25	48	2993	34
IS 32569	32	35	2847	28
IS 32678	25	38	2468	31
IS 32597	30	32	2423	21
IS 32683	25	38	2336	33
IS 32666	31	29	2203	30
IS 32663	24	37	2193	31
IS 32701	23	37	2183	31
IS 32568	25	34	2040	33
Control				
IS 18551	36	4	167	15
IS 1054	36	25	2290	27
ICSV 705	20	14	493	20
CSH 1	20	24	1175	25
Mean	20	33	1411	28
SE ±	0.50	-	53	0.34

5.3 LATE RAINY SEASON TRIAL, 1991

This trial was heavily infested by shoot fly and most test entries showed 100% oviposition and deadheart. The resistant controls were less attacked (Table 5) (Plate 2).

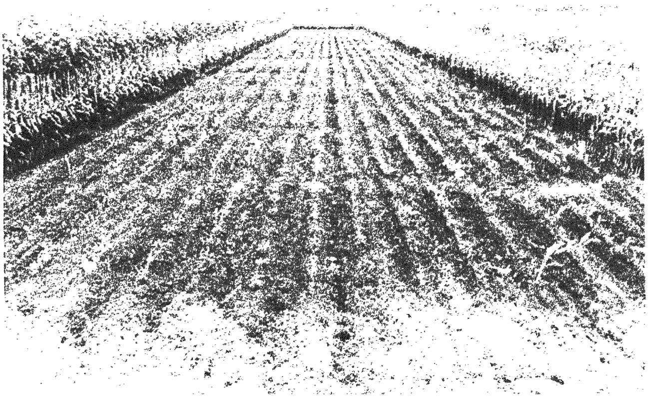

Plate 2: Severity of shoot fly damage in test entries sown in the late rainy season on 5.10.1991.

Egg count at 21 DAE averaged 99% while deadheart averaged 99% in all test entries except in the resistant control (Table 5).

Table 5: Sample of test entries showing severity of shoot fly damage in sorghum sown during the late rainy season 17 July, 1991.

Genotypes	Percent plant with eggs	Percent deadheart plants per entry
IS 32530	90	100
IS 32553	90	100
IS 32687	90	100
IS 32731	90	95
IS 32626	100	97
IS 32680	100	98
IS 32512	100	100
IS 32521	100	100
IS 32530	90	100
IS 32525	90	100
Control		
IS 18551	21	40
ICSV 705	70	50
IS 1054	65	40
CSH 1	100	100
Mean	99	99
SEM ±	0.42	0.40

Based on recovery resistance, although tillering was high, (mean of 3 tillers/plant) but few tillers survived and only 41% of surviving tillers produced harvestable heads. The best performing entries in this category produced synchronious tillers which yielded well (Table 6).

Table 6: Best performing entries based on tiller recovery late rainy season 1991

Genotype	Total No.of tillers produced/plot	Total No.of heads produced	Harvestable heads(T+M)	Yield (kg/ha)
IS 32727	131	23	13	1397
IS 32613	141	57	32	1363
IS 32725	176	25	19	1327
IS 32724	223	41	33	1260
IS 32670	123	15	12	1187
IS 32585	156	36	25	1170
IS 32719	178	26	22	1153
IS 32591	164	48	28	1133
IS 32578	112	45	28	1123
IS 32712	137	33	26	1077
IS 32675	126	51	25	1043
IS 32583	121	52	27	1023
IS 32686	125	21	18	1013
IS 32549	83	59	20	1010
Control				
IS 18551	61	33	24	800
ICSV 705	71	23	21	1495
IS 1054	21	14	-	-
CSH 1	131	22	1	480
Mean	121	29	12	494
SEM ±	2.05	0.83	0.40	17.03

Environmental conditions in the late rainy season were different from the other seasons (Fig.4). Out of 18 weeks of crop growth, it rained 12 weeks with a weekly average rainfall of 18.70 mm. The total rainfall during the season was 336.7 mm. The relative humidity was generally very high compared to other seasons. The weekly average maximum relative humidity recorded at 1400 hr was 90.2% while the corresponding minimum value at 0700 hr was 51.7%.

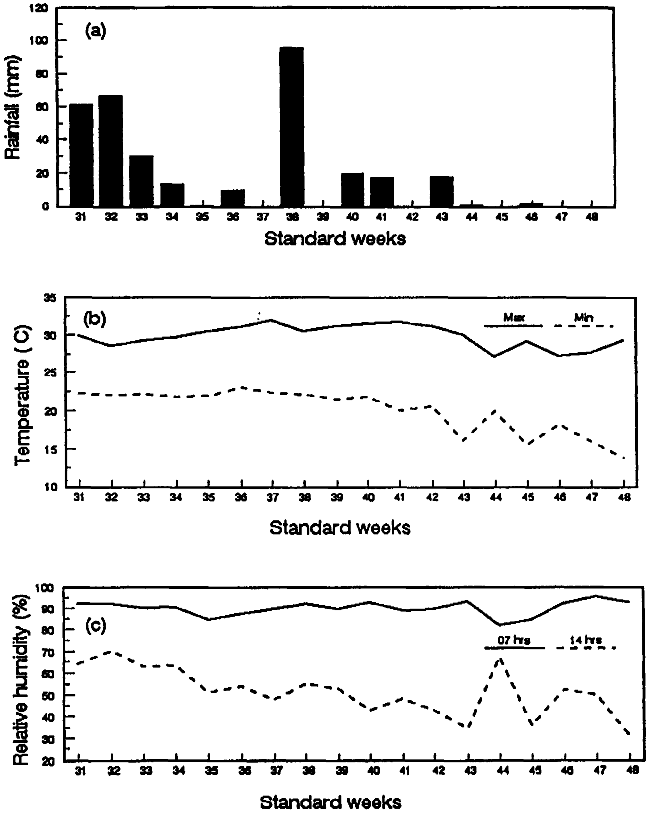

Fig 4: Fluctuation of climatic factors during late rainy season (July-December 1991)

At ICRISAT Center (a) Rainfall, (b) Temperature (c) Relative humidity

5.4 EARLY POSTRAINY SEASON TRIAL, 1991-92

This trial extended over a crop growing period from October 1991 - February 1992. It was generally less infested by shoot fly but crop growth was poor and yields were very low. The least infested entries based on oviposition and deadheart are presented in in Table 7.

Table 7: Sample of test entries showing low shoot fly damage in sorghum sown during the early postrainy season 5 October, 1991

Genotypes	Number of eggs/plant	Percent plants with eggs	Percent deadheart plant/plot
IS 32513	1.0	20	41
IS 32525	1.0	25	15
IS 32717	1.0	25	15
IS 32569	1.0	25	40
IS 32588	1.0	25	15
IS 32512	1.0	35	34
IS 32530	1.0	45	45
IS 32617	1.1	8	0
IS 32584	1.0	33	16
IS 32745	1.0	40	11
IS 32704	1.1	8	3
Control			
IS 18551	0.0	0	16
ICSV 705	1.0	10	10
IS 1054	1.0	10	10
CSH 1	1.8	83	85
Mean	1.7	71	55
SEM ±	0.48	1.15	1.39

The three resistant controls were least preferred for oviposition.

Deadheart damage was considerably low and the average per plot was 55%.

Visual rating of the material at 50 days after emergence and before the harvest were relatively poor and crop growth was not outstanding. Tiller production averaged 3/plant but survival was only 1/plant (25/plot). This was reflected in head production, with 41 heads/plot for both main plants and tillers. However, mean harvestable heads per plot was 30 heads for both main plants and tillers. The average overall yield/plot was 1249 kg/ha (Table 8).

Table 8: Best performing entries based on harvestable heads and grain yield kg/ha, postrainy late 1991-92

Genotype	Total No. of heads produced	Main plant heads	Tillers heads	Total No. of tiller production	Harvest-able heads(T+M)	Yield kg/ha
IS 32612	50	6	31	69	37	4700
IS 32719	48	5	30	70	35	3867
IS 33596	45	7	27	67	34	3057
IS 33604	70	6	50	90	56	2933
IS 32722	55	5	47	103	52	2831
IS 32735	59	8	40	121	48	2738
IS 32681	43	9	24	79	33	2707
IS 32682	46	1	39	98	40	2565
IS 32733	46	5	35	99	40	2551
IS 32691	45	7	26	82	33	2438
IS 32732	65	9	44	102	53	2429
IS 33617	87	1	56	99	57	2427
Controls						
IS 18551	37	20	15	16	37	1460
ICSV 705	39	31	6	19	39	1756
IS 1054	39	19	16	87	39	1634
CSH 1	33	4	19	63	23	1235
Mean	41	5	25	87	30	1249
SEM ±	0.98	0.06	0.75	2.01	0.80	40.04

In general, the postrainy (early) season, the yield of all tested material and checks were very low than we will observe how far they differ under different climatical factors.

It rained in 3 weeks out of 18 growing weeks with a total rainfall of 21 mm (Appendix E). The weekly maximum average temperature recorded was 28°C while the value for minimum weekly average temperature was 14°C (Fig.5). The weekly average maximum humidity recorded at 1400 hr was 88% and the corresponding. minimum value at 1077 hr was 35%. The average total eggs per plot was 16, while percent plants with eggs/plot was 71%.

5.5 SEASONAL VARIATIONS

Shoot fly oviposition varied significantly between seasons (Fig.6). This trend was more apparent in the test entries than in the controls. The highest oviposition occurred in late rainy season sowing. Entries with less oviposition across seasons are presented in Table 9.

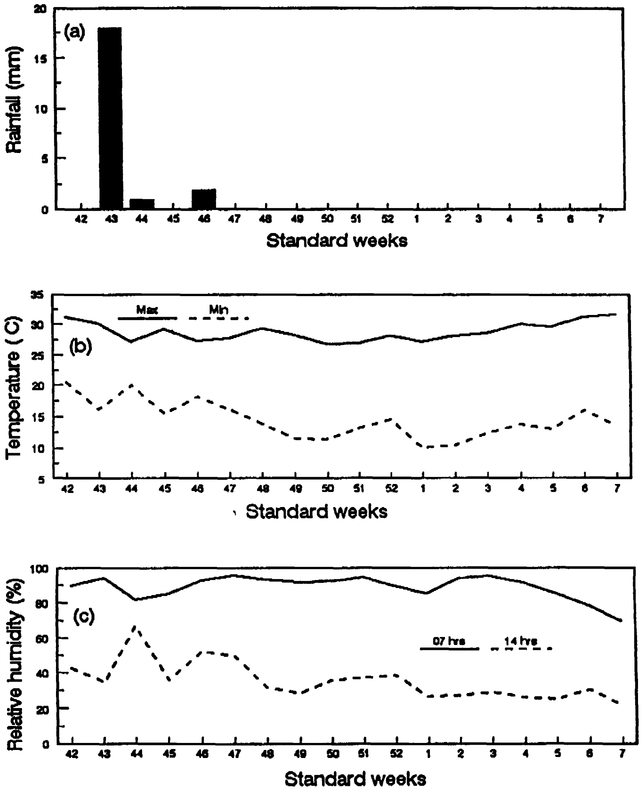

Fig 5: Fluctuation of climatic factors during early postrainy season (Oct 1991 to Feb 1992))

At ICRISAT Center (a) Rainfall, (b) Temperature
(c) Relative humidity

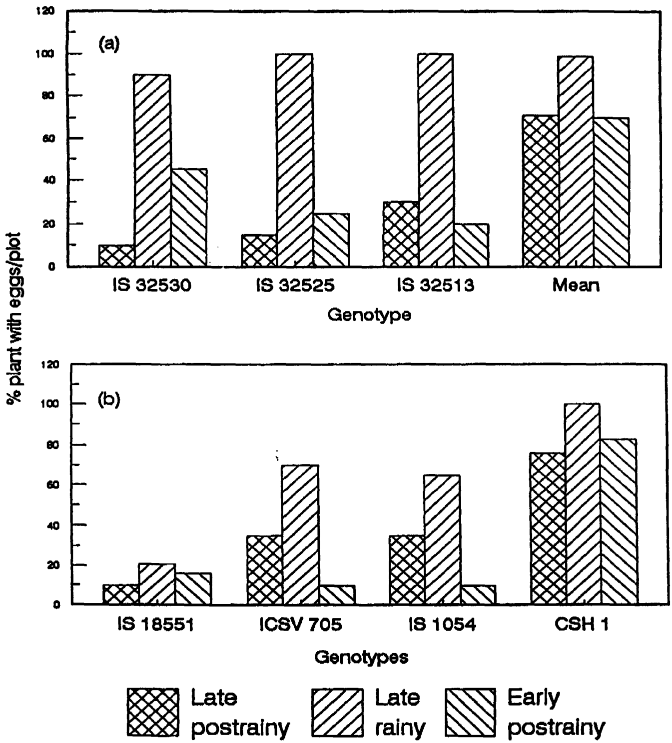

Fig 6: Variation in shoot fly oviposition on sorghum in early and late rainy and postrainy season sowing dates

(a) Mean of all test entries

(b) Controls

Table 9: Variation in shoot fly oviposition across seasons on selected sorghum entries

Genotype	Percent plants with eggs		
	Late postrainy 1990-91	Late rainy 1991	Early postrainy 1991-92
IS 32547	50	100	8
IS 32513	30	100	20
IS 32525	15	100	25
IS 32530	10	90	45
IS 32529	20	100	65
IS 32543	30	100	65
IS 32529	20	100	65
IS 32522	20	100	35
IS 32512	10	100	35
IS 32567	8	100	35
IS 18551	10	21	16
ICSV 705	35	70	10
IS 1054	35	65	10
CSH 1	76	100	72
Mean	70	99	71
SEM ±	0.47	0.42	1.15
CV (%)	175	69	223
Mean			25
SEM			0.01

1 For 269 entries across seasons

Seedling damage, (i.e. deadheart), followed similar pattern, except for the resistant controls, all entries in the late rainy season sowing suffered 100% deadheart damage (Fig.7). Deadheart damage was lowest in the early postrainy season crop (55%) while for late postrainy 89% deadheart was recorded (Table 10).

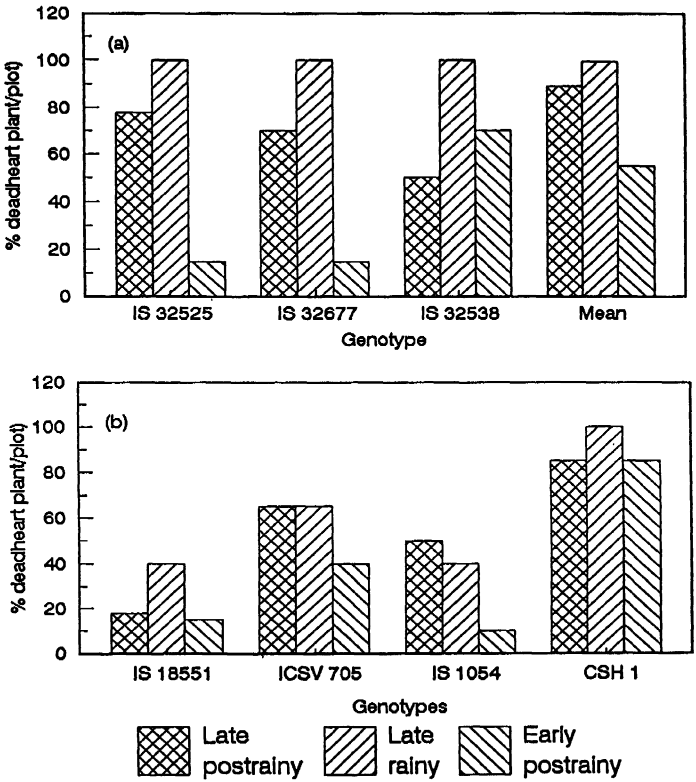

Fig 7: Variation in shoot fly damage (deadheart) sown on different dates during rainy and post rainy seasons

(a) Mean of all test entries

(b) Controls

Table 10: Variation in shoot fly damage across seasons on best performing sorghum entries

Genotype	Per cent deadheart plants		
	Late postrainy 1990-91	Late rainy 1991	Early postrainy 1991-92
IS 32547	88	100	85
IS 32538	50	100	70
IS 32617	85	100	10
IS 32677	70	100	15
IS 32525	78	100	15
IS 32584	78	100	16
IS 32559	80	100	15
IS 18551	18	40	16
ICSV 705	65	65	40
IS 1054	50	40	10
CSH 1	85	100	83
Mean	89	99	55
SEM ±	0.52	0.40	1.39
Mean			1.33
SEM			0.02
CV %			18

1 For 269 entries across seasons

Yield analysis of variance of the three seasons showed significant differences (P = 0.01 and P = 0.05) for entries and seasons. The overall average yield of early postrainy season sowing was the highest, 1845 kg/ha, followed by early postrainy season sowing of 1249 kg/ha while for rainy season sowing it was only 494 kg/ha (Table 11).

Table 11: Entries with highest yield kg/ha in the three seasons

Genotype	Late postrainy 1990-91	Late rainy 1990	Early postrainy 1991-92
IS 32719	3210	1153	3857
IS 32612	1982	350	4700
IS 32708	4113	863	1836
IS 32727	2978	1397	2355
IS 33596	2382	650	3057
IS 32681	2926	390	2207
IS 32722	2467	647	2831
IS 32725	3172	1327	2834
IS 32717	3395	70	1714
IS 33600	3148	557	1973
IS 18551	2029	800	1460
ICSV 705	1483	1495	1756
IS 1054	1983	756	1634
CSH 1	2578	1056	1235
Mean	1854	494	1251
SEM ±	43	17	40
Mean			1199
SEM			0.64
CV %			43

1 For 269 entries across seasons

The late postrainy season, average maximum temperature was 38°C, average minimum temperature was 20°C, total rainfall was 52 mm, and the figures for maximum and minimum relative humidity were 82% and 31% respectively. Overall averages for population of plants with eggs were 70%, deadheart 89% and yield kg/ha 1845 respectively (Table 12). The late rainy season, average maximum temperatures was 30°C, average minimum temperature was 20°C, total rainfall was 336 mm and figures for maximum and minimum relative humidity were 90% and 51% respectively. Overall averages for population of plants with eggs were 99%, deadheart 99%

and yield kg/ha 494. The early postrainy season, average maximum temperature was 28°C, average minimum temperature was 14°C, total rainfall 21 mm and figures for maximum and minimum relative humidity were 88% and 36%. Overall averages for population of plants with eggs were 71%, deadheart 55%, and yield kg/ha 1249.

Table 12: Summary of climatic factors[1] shoot fly infestation and yield parameters of three seasons

Seasons	Temp.° Max	Min	Total rainfall (mm)	Relative humidity(%) Max	Min	Plants with egg	Deadheart %	Yield kg/ha
Late postrainy (17 Dec.1990)	38	20	52	82	31	70	89	1845
Late rainy (17 Jul 1991)	30	20	336	90	51	99	99	494
Early postrainy (5 Oct 1991)	28	14	21	88	38	71	55	1249

DISCUSSION

CHAPTER V

DISCUSSION

These studies have shown that during the late postrainy season 1990-91, plant recovery was high (Table 3). Out of 265 lines only IS 32513 and IS 32519 had low egg laying (Table 1), deadhearts (Table 2), and high grain yield (Table 3). IS 32517 and IS 32540 had lower number of eggs and deadhearts than the season average and controls. Average yields were 1845 kg/ha.

Early rainy season crop was free of shoot fly damage. Shoot fly populations are extremely low during the dry period and the early planted crop escapes shoot fly damage (Ponaiya 1951a; Rivnay 1971; Clearwater and Othieno 1977). Yield was not as high as expected. Only a few heads were produced, may be due to the photoperiod sensitivity of Somalian sorghum germplasm. This trial is not comparable to the highly infested trials which yielded more under the high and moderate shoot fly infestation.

In the late rainy season, sown on 17th July 1991, shoot fly damage was severe (Table 5). None of the test entries had low oviposition and deadheart damage. Some of the test material performed better than the others in tiller recovery and grain yield (Table 6). The third trial, sown on 5th October 1991, indicated low egg laying and deadheart damage. IS 32617 had low egg laying and deadhearts (Table 7) with a good high grain yield (Table 8). This season was dry with a total rainfall of 21 mm. Temperature decreased with crop growth (Fig 4), but increased as the crop neared maturity.

Environmental conditions (temperature, R.H and rainfall) tend to influence shoot fly damage, (Taneja and Leuschener 1985). The seasonal variation in egg laying showed highly significant differences among the seasons and entries (Table 9). Egg laying varied between late postrainy, late rainy and early postrainy seasons resulting in an average of 70, 99 and 71 per cent plants with eggs respectively. Shoot fly incidence is effected by seasonal conditions and meteorological factors such a humidity and temperature (Usman, 1968; Jotwani *et al*. 1970). Maximum relative humidity, in the range of two weeks before the egg count was 92%. But the minimum relative humidity was 41% in late postrainy, 67% in late rainy and 39% in early postrainy season. The season with higher minimum relative humidity, (late rainy 67%) had greater egg laying. The most significant factor responsible for egg laying appears to have been the temperature (maximum and minimum) (Taneja and Leuschner 1985). The maximum temperatures of the three seasons, at the egg count did not vary. The weekly average maximum temperatures were: late postrainy season, 27^{o}C, late rainy season, 29^{o}C, and early postrainy season; 31^{o}C and the average minimum temperatures at egg count were: late postrainy season, 14^{o}C, late rainy season, 22^{o}C and early postrainy season was 18^{o}C. Egg laying and minimum temperature were highest in the late rainy season trial.

Best performing entries in the three seasons are presented in Figure 6. IS 32530 showed less number of eggs in the late postrainy and more eggs in the early postrainy season, while IS 32547 had less oviposition in early postrainy season, and higher oviposition in the late postrainy season. IS 32525 and IS 32513 responsed similarly in different seasons. IS 18551 was least preferred for oviposition in all the seasons, except the late rainy season, where infestation was very high. It showed 40% plants with eggs.

For deadheart formation, best performing entries are listed in Table 10. There was variation among the entries in different seasons. Deadheart formation showed highly significant difference during seasons. Variation in deadheart formation is mostly influenced by temperature and evening humidity (Taneja and Leuschner 1985). Raina (1981) also showed that the time of egg hatching coincides with the presence of moisture on the leaf, a condition favorable for the movement of the larvae to the base of the leaf. Deadheart formation changed with seasons. The best performing entries in the three seasons (IS 32525 and IS 32627) responded in the same as other genotypes (Table 10). The resistant check IS 18551, had low number of deadhearts in the late and early postrainy seasons but showed 40% deadhearts from seasons in the late rainy (Figure 7). ICSV 705 showed less deadhearts in the heavily damaged crop (late rainy) and no damage in the early postrainy season. The susceptible check CSH 1, was the most susceptible in all the tests. Some of the test entries were worse than the susceptible check.

The results in this study show that there is a relationship between crop season and grain yield (Table 11). The best performing entries in terms of grain yield across seasons were IS 32719 and IS 32725. IS 32612 produced low yield in the late rainy season. Comparing the test entries with the standard checks in different seasons for yield potential, IS 18551 had high yield in the late postrainy season and low yield in early postrainy and late rainy season. IS 1054 responded in the same way as IS 18551. The resistant check ICSV 705, performed well and its yield was high in all the seasons. The susceptible check, CSH 1, had high recovery rate in the late postrainy season, and its yield was good in the late rainy season.

Results of the three seasons showed that the early rainy season had high moisture compared to other seasons and the damage severity was very high during these seasons with an average of 99% oviposition and headheart formation. Blum (1963) observed that when freshly hatched shoot fly larvae were placed on sorghum leaves in the laboratory, they repeatedly fell down unless the plants were moistured with a fine spray of water. Also there was a considerable variation in total maximum and minimum average temperatures of the seasons. Norlund (1981), suggested that behavior, temperature and humidity interact to affect plant growth, expression of resistance and attractiveness to herbivores and beneficial insect through plant produced allomones, and koiromones. Since the trials were raised under different climatical factors, the biological parameters recorded in different seasons indicated variation due to the weather (Table 12). Thus weather has an influence on the expression resistance and susceptibility of sorghum plants which can increase or decrease with the seasons.

CONCLUSION

During the late postrainy season, IS 32513 and IS 32519 showed low egg laying, deadheart formation and had high yield, while IS 32517 and IS 32540 were better than the other entries in deadheart formation and egg laying only. Grain yield in early rainy season trial was low. Late rainy season had severe shoot fly damage and none of the test entries showed appreciable levels of shoot fly resistance. In the early post rainy season of 1991, IS 32617 showed low deadhearts, egg laying and had high grain yield.

Examining the egg laying and deadheart formation over the seasons, very few entries were consistent across seasons. IS 32525, IS 32512 and IS 32530 were the best performing entries (for oviposition) during the late and early postrainy season. IS 32512 and IS 32530 were also least damaged by the shoot fly. Yield potential and recovery resistance of all the entries across the seasons were also investigated, but the repeatability of performance across seasons was very low. IS 32719 was the only entry showing good yield in all the seasons, while IS 32735 showed good performance in late and early postrainy seasons.

The seasonal variation in resistance to shoot fly was related to the prevailing environmental conditions. The late postrainy season had the highest maximum temperature (average 38°C) and this seems to be favorable for the recovery of plants damaged by the shoot fly. In this season, even though the shoot fly damage was very high, most of the test entries produced reasonable grain yield of an average of 1854 kg/ha. Late rainy season had the highest minimum relative humidity (67%) at egg count, high rainfall (336 mm) and the highest minimum temperature (22°C) at the deadheart count, showed the maximum shoot fly damage (99%) and egg laying (99%) compared to the other seasons. In the early postrainy season (average minimum temperature 14°C), the crop recovery was very poor. Therefore, the results from this study showed conclusively that resistance of test entries to shoot fly (egg laying, deadheart formation and recovery) was highly associated with seasonal variation.

SUMMARY

CHAPTER VI

SUMMARY

Studies on the seasonal variation in resistance of Somalian sorghum germplasm to shoot fly were conducted in four experimental sowings in three seasons at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India between December 1990 to February 1992. The studies were carried out under natural field conditions over different seasons viz. late postrainy 1990-91, early rainy 1991 and early postrainy 1991-92 seasons.

Evaluation of germplasm included shoot fly susceptible (CSH 1) resistant (ICSV 705, IS 18551) and a local (IS 1054) cultivars as control. In view of seasonal variation in the natural shoot fly population, entries were subjected to different levels of shoot fly infestation in each season. Genotypes were grouped into different categories in accordance with field observations and their levels of expression of resistance. Seasonal variation in environmental factors temperature, humidity and rainfall and their influence on varietal resistance were monitored. Entries which were consistent in performance over seasons for primary or secondary resistance were noted.

The results obtained for each season were individually analysed. Biological parameters for each trial were analysed with respect to prevailing environmental conditions. The best performing genotypes for each parameter in each season's experiment were selected. They were then matched for their performance and frequency of occurance across seasons and yield potential.

In the late postrainy season, average maximum temperature was 38°C, average minimum temperature was 20°C, total rainfall was 52 mm, and the figures for maximum and minimum relative humidity were 82% and 31% respectively. Overall averages for population of plants with eggs were 70%, deadheart 89% and yield 1845 kg/ha respectively. In the late rainy season, average maximum temperature was 30°C, average minimum temperature was 20°C, total rainfall was 336 mm, and figures for maximum and minimum relative humidity were 90% and 51% respectively. Overall averages for population of plants with eggs were 99%, deadheart 99%, and yield 494 kg/ha. In the early postrainy season, average maximum temperature was 28°C, average minimum temperature was 14°C, total rainfall 21 mm, and figures for maximum and minimum relative humidity were 88% and 36%. Overall averages for population of plants with eggs were 71%, deadheart 55%, and yield was 1249 kg/ha.

These studies have shown that during the late postrainy season 1990-91, plant recovery was high. Out of 265 lines only IS 32513 and IS 32519 had low egg laying, deadhearts, and high grain yield. IS 32517 and IS 32540 had lower number of eggs and deadhearts than the season average and controls. Early rainy season crop was free of shoot fly damage. But only a few heads were produced. This may be due to the photoperiod sensitivity of Somalian sorghum germplasm. In the late rainy season, sown on 17th July 1991, shoot fly damage was severe. None of the test entries had low oviposition and deadheart damage. The third trial, sown on 5th October 1991, indicated low egg laying and deadheart damage. IS 32617 had low oviposition and deadhearts with good high grain yield. For oviposition and deadheart formation over the seasons, very few entries were consistent across seasons. IS 32525, IS 32512 and IS 32530 were the best performing entries (for oviposition) during the late and early postrainy season. IS 32512 and IS 32530 were also least damaged by the shoot fly. Late rainy season had the highest minimum relative humidity (67%) at egg count, high rainfall (336 mm) and the highest minimum temperature (22°C) at deadheart count, were recorded during the late rainy season. Maximum shoot fly damage (99%) and egg laying (99%) compared to the other seasons. In the early postrainy season (average minimum temperature 14°C), crop recovery was very poor. The results from this study showed conclusively that resistance of test entries to shoot fly (egg laying, deadheart formation and recovery) was highly associated with seasonal variation.

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APPENDICES

Appendix A: List of Material under test (Somalian Sorghum Germplasm)

S.No.	IS.No	S.No.	IS.No	S.No.	IS.No	S.No.	IS.No	S.No.	IS.No	S.No.	IS.No
1	IS 32512	51	IS 32564	101	IS 32614	151	IS 32664	201	IS 32714	251	IS 33601
2	IS 32513	52	IS 32565	102	IS 32615	152	IS 32665	202	IS 32715	252	IS 33602
3	IS 32514	53	IS 32566	103	IS 32616	153	IS 32666	203	IS 32716	253	IS 33603
4	IS 32516	54	IS 32567	104	IS 32617	154	IS 32667	204	IS 32717	254	IS 33604
5	IS 32517	55	IS 32568	105	IS 32618	155	IS 32668	205	IS 32718	255	IS 33605
6	IS 32518	56	IS 32569	106	IS 32619	156	IS 32669	206	IS 32719	256	IS 33606
7	IS 32519	57	IS 32570	107	IS 32620	157	IS 32670	207	IS 32720	257	IS 33607
8	IS 32520	58	IS 32571	108	IS 32621	158	IS 32671	208	IS 32721	258	IS 33608
9	IS 32521	59	IS 32572	109	IS 32622	159	IS 32672	209	IS 32722	259	IS 33609
10	IS 32522	60	IS 32573	110	IS 32623	160	IS 32673	210	IS 32723	260	IS 33610
11	IS 32524	61	IS 32574	111	IS 32624	161	IS 32674	211	IS 32724	261	IS 33611
12	IS 32525	62	IS 32575	112	IS 32625	162	IS 32675	212	IS 32725	262	IS 33612
13	IS 32526	63	IS 32576	113	IS 32626	163	IS 32676	213	IS 32726	263	IS 33613
14	IS 32527	64	IS 32577	114	IS 32627	164	IS 32677	214	IS 32727	264	IS 33614
15	IS 32528	65	IS 32578	115	IS 32628	165	IS 32678	215	IS 32728	265	IS 33615
16	IS 32529	66	IS 32579	116	IS 32629	166	IS 32679	216	IS 32729	266	IS 33616
17	IS 32530	67	IS 32580	117	IS 32630	167	IS 32680	217	IS 32730		
18	IS 32531	68	IS 32581	118	IS 32631	168	IS 32681	218	IS 32731		
19	IS 32532	69	IS 32582	119	IS 32632	169	IS 32682	219	IS 32732		
20	IS 32533	70	IS 32583	120	IS 32633	170	IS 32683	220	IS 32733		
21	IS 32534	71	IS 32584	121	IS 32634	171	IS 32684	221	IS 32734		
22	IS 32535	72	IS 32585	122	IS 32635	172	IS 32685	222	IS 32735		
23	IS 32536	73	IS 32586	123	IS 32636	173	IS 32686	223	IS 32736		
24	IS 32537	74	IS 32587	124	IS 32637	174	IS 32687	224	IS 32737		
25	IS 32538	75	IS 32588	125	IS 32638	175	IS 32688	225	IS 32738		
26	IS 32539	76	IS 32589	126	IS 32639	176	IS 32689	226	IS 32739		
27	IS 32540	77	IS 32590	127	IS 32640	177	IS 32690	227	IS 32740		
28	IS 32541	78	IS 32591	128	IS 32641	178	IS 32691	228	IS 32741		
29	IS 32542	79	IS 32592	129	IS 32642	179	IS 32692	229	IS 32742		
30	IS 32543	80	IS 32593	130	IS 32643	180	IS 32693	230	IS 32743		
31	IS 32544	81	IS 32594	131	IS 32644	181	IS 32694	231	IS 32744		
32	IS 32545	82	IS 32595	132	IS 32645	182	IS 32695	232	IS 32745		
33	IS 32546	83	IS 32596	133	IS 32646	183	IS 32696	233	IS 32746		
34	IS 32547	84	IS 32597	134	IS 32647	184	IS 32697	234	IS 32747		
35	IS 32548	85	IS 32598	135	IS 32648	185	IS 32698	235	IS 32748		
36	IS 32549	86	IS 32599	136	IS 32649	186	IS 32699	236	IS 32749		
37	IS 32550	87	IS 32600	137	IS 32650	187	IS 32700	237	IS 32750		
38	IS 32551	88	IS 32601	138	IS 32651	188	IS 32701	238	IS 32751		
39	IS 32552	89	IS 32602	139	IS 32652	189	IS 32702	239	IS 32752		
40	IS 32553	90	IS 32603	140	IS 32653	190	IS 32703	240	IS 32753		
41	IS 32554	91	IS 32604	141	IS 32654	191	IS 32704	241	IS 33591		
42	IS 32555	92	IS 32605	142	IS 32655	192	IS 32705	242	IS 33592		
43	IS 32556	93	IS 32606	143	IS 32656	193	IS 32706	243	IS 33593		
44	IS 32557	94	IS 32607	144	IS 32657	194	IS 32707	244	IS 33594		
45	IS 32558	95	IS 32608	145	IS 32658	195	IS 32708	245	IS 33595		
46	IS 32559	96	IS 32609	146	IS 32659	196	IS 32709	246	IS 33596		
47	IS 32560	97	IS 32610	147	IS 32660	197	IS 32710	247	IS 33597		
48	IS 32561	98	IS 32611	148	IS 32661	198	IS 32711	248	IS 33598		
49	IS 32562	99	IS 32612	149	IS 32662	199	IS 32712	249	IS 33599		
50	IS 32563	100	IS 32613	150	IS 32663	200	IS 32713	250	IS 33600		

Appendix B: Meteorological information at ICRISAT Center during the late postrainy season trial (24 December 1990 - 28 April 1991)

Standard weeks	Rainfall (mm)	Temperature(C) Max.	Min	Relative 0700	Humidity 1400
52	0.0	27.2	14.1	92.6	42.0
1	0.0	26.9	13.3	91.3	39.0
2	0.0	26.9	13.8	93.3	38.6
3	16.2	26.4	14.3	87.7	46.0
4	0.0	29.2	17.3	95.1	45.6
5	0.0	28.4	17.4	94.9	44.9
6	0.0	29.9	15.6	92.6	37.1
7	0.0	30.5	12.7	79.6	20.9
8	0.0	31.2	16.5	85.0	28.9
9	0.0	34.0	16.9	68.1	20.6
10	0.0	32.5	17.2	79.1	24.3
11	3.0	33.3	19.5	87.3	27.4
12	0.0	34.7	21.9	85.6	30.9
13	0.0	36.6	20.6	75.3	21.1
14	0.4	36.8	21.7	58.3	19.6
15	0.0	37.2	22.1	65.1	18.3
16	32.0	34.5	22.0	78.9	36.4

Appendix C: Meteorological information at ICRISAT Center during the early rainy season (yield potential) (24 June - 20 October 1991)

Standard week	rainfall (mm)	Temperature (C) Max.	Min.	Relative Humidity(%) 07	14 hr.
25	17.8	32.5	23.3	87.0	51.3
26	74.6	31.0	22.9	90.7	62.0
27	52.5	29.2	22.2	92.0	68.3
28	88.3	28.7	22.1	92.4	74.9
29	0.6	29.0	22.6	89.9	68.0
30	3.6	30.3	22.9	87.0	62.1
31	61.4	30.0	22.6	92.3	64.3
32	66.8	28.6	22.0	92.3	70.1
33	29.9	29.4	22.1	90.4	63.4
34	14.0	29.8	21.8	90.7	63.6
35	0.6	30.5	21.9	84.9	51.3
36	10.0	31.1	23.0	87.6	54.3
37	0.0	31.9	22.3	90.1	48.1
38	96.0	30.6	22.1	92.3	55.4
39	0.0	31.7	21.4	90.1	52.9
40	19.8	31.7	20.1	93.0	43.4
41	17.2	31.7	20.1	89.0	48.6
42	0.0	31.2	20.6	89.9	43.1
43	18.0	30.1	16.2	93.3	34.9

Appendix D: Meteorological information at ICRISAT Center during early rainy season trial (30 July - 29 November 1991)

Standard weeks	Rainfall (mm)	Temperature(C) Max.	Min.	Relative 0700 hr	Humidity 1400 hr
31	61.4	30.0	22.2	92.3	64.3
32	66.8	28.6	22.0	92.3	70.3
33	29.9	29.4	22.1	90.4	63.4
34	14.0	29.8	21.8	90.7	63.6
35	0.6	30.5	21.9	84.9	51.3
36	10.0	31.1	23.0	87.6	54.3
37	0.0	31.9	22.3	90.1	48.1
38	96.0	30.6	22.1	92.3	55.4
39	0.0	31.2	21.4	90.1	52.9
40	19.8	31.5	21.8	93.0	43.3
41	17.2	31.7	20.1	89.0	48.6
42	0.0	31.2	20.6	89.9	43.1
43	18.0	30.1	16.2	93.3	34.9
44	1.0	27.2	20.0	82.2	67.3
45	0.0	29.2	15.6	84.9	36.1
46	2.0	27.3	18.2	92.7	52.7
47	0.0	27.7	16.1	95.7	50.3
48	0.0	29.3	13.9	93.0	31.9

Appendix E: Meteorological information at ICRISAT Center during late rainy season trial (14 October 1991 - 20 February 1992)

Standard weeks	Rainfall (mm)	Temperature (C) Max.	Min	Relative Humidity (%) 0700 hr	1400 hr
42	0.0	31.2	20.6	89.9	43.1
43	18.0	30.2	16.2	93.3	34.9
44	1.0	27.2	20.0	82.1	67.3
45	0.0	29.2	15.5	84.9	36.1
46	2.0	27.3	18.2	92.7	52.7
47	0.0	27.7	16.1	95.7	50.3
48	0.0	29.3	13.9	93.0	31.9
49	0.0	28.3	11.6	91.9	28.7
50	0.0	26.8	11.4	92.4	35.7
51	0.0	26.9	13.1	94.7	37.6
52	0.0	28.2	14.6	89.6	38.8
1	0.0	27.2	10.1	85.3	27.0
2	0.0	28.2	10.4	94.3	27.4
3	0.0	28.5	12.3	95.4	29.4
4	0.0	30.1	13.7	91.1	26.3
5	0.0	29.6	13.0	85.3	25.7
6	0.0	31.3	16.0	78.3	30.7
7	0.0	31.6	13.6	69.7	22.0