secondary root lengthening and were dark in color.

Cadmium

Leaves turned a fiery red from margin to midrib; severly affected, they became bright red over the entire leaf. Roots were dark red, small, and had no growth on secondary roots.

Chromium

Leaves turned light reddish-brown from tip toward base and from margin to midrib. Some leaves had somewhat dark reddening on tips and margins. Roots were darker and stubbier and growth was inhibited extensively.

Cobalt

Leaves had symptoms similar to Fe deficiency, except that the symptoms appeared only in the leaf just emerging from the whorl or on the sheath next to the whorl and not in the leaf tip sections. The symptoms were more diffuse than those typical of Fe deficiency. Roots showed some stubbiness.

Lead

Leaves turned reddish-brown and had necrotic dead spots with red around them. Leaf tips were affected more than the leaf base and symptom severity progressed from margin to midrib. Roots were stubbier and had fewer auxiliary roots, but were normal than roots grown with Cd.

Mercury

Leaves turned blackish-brown with dark and necrotic lesions. Leaves were wilted and became water-soaker, were leathery, and curled extensively. Leaves did not turn lighter in color. Roots were somewhat inhibited in growth, but otherwise were relatively normal.

Nickel

Leaf symptoms were similar to Fe deficiency. These symptoms did not extend as far out toward the leaf tip as noted for typical Fe deficiency. Roots were stubbier and showed symptoms resembling those of excess Al, but not as severe.

Selenium

Leaves showed symptoms that were indistinguishable from Mo exces which were similar to P deficiency. Roots showed no abnormal symptoms with excess Se.

Strontium

Leaves became necrotic in a spotchy pattern at the margins with a lighter color appearing in the margin progressing toward the midrib. Roots were dark red, coarse, stubby and somewhat slimy.

9

IMPROVEMENT OF CROPS: THE ROLE OF MORPHOPHYSIOLOGICAL TRAITS

INTRODUCTION

The productivity of a crop depends on the efficiency with which morphophysiological traits manifest themselves in diverse environments. To date, breeding criteria for sorghum have largely been on the basis of morphological characteristics, and very little attention has been paid to physiological traits. Because of the synthesis of crop growth and development in sorghum, the author urges plant breeders to modify their approach to increase productivity in diverse environments and breed cultivars adaptable to them. Identification of traits related to several abiotic and biotic stress factors affecting stages of crop development is desirable, and these need to be taken into account of any crop improvement program.

To formulate an efficient breeding program, breeders need to study the genetic variability of different traits in existing germplasm and breed materials of the crop to be investigated. Through different selection procedures they will identify a particular plant type or trait pertaining to yield and other desirable qualities, and use them in different crossing programs after establishing their purity. A wide range of genetic variability and genotypes showing the stability of yield under adverse climatic conditions are utilized by adopting suitable breeding techniques for a particular crop.

To formulate an efficient breeding program, it is desirable to identify morphophysiological traits related to resistance and yield, and search for variability of these traits existing in sorghum germplasms and incorporate them into elite breeding lines. Morphophysiological traits existing in sorghum germplasm and offering great scope of selection have been been discussed in earlier chapters, and some techniques for their evaluation and probable role in sorghum crop improvement have already been described.

Grain yields in sorghum have substantially increased with the use of high-yielding, management-responsive F1 hybrids and varieties, but these cultivars have miserably failed under adverse conditions prevailing in the SAT. Therefore, we should be aware of the problems that farmers face and test improved farming techniques before suggesting their adoption. Better agronomic practices and use of improved cultivars have significantly contributed to the enhancement of sorghum yields. Though the degree of improvement accomplished so far has been high, there is ample scope for increasing production by improving genetic stock and breeding material. In order to accelerate progress towards better yields, there is a need to promote the collection, conservation, evaluation and utilization of germplasms for different traits which will improve crop productivity.

This chapter presents a brief summary of the development of simple techniques and their utilization in the identification of stress factors at various stages of plant development in sorghum. It discusses in some detail the morphophysiological traits related to plant productivity under optimum and adverse conditions, selection of techniques for evaluation of germplasms and elite lines for multistress resistance and some hypotheses. It also discusses the need to simultaneosly incorporate several traits into elite breeding stocks and gain better understanding of the pest-plant-environment relationships to deal with these problems.

Sorghum crops in SAT environments face different biotic and abiotic stress factors at different stages of crop development. There is a necessity to select genotypes resistant to stress factors that affect the sorghum crop in these environments, having determined the range of variability in morphology and growth patters in diverse environments, several research requirements come into focus. In this chapter, problems occuring at different stages of crop development and productivity are identified.

SEED CHARACTERICS AND SEEDLING ESTABLISHMENT

There is great diversity in seed morphological characteristics and good correlation exists among different morphological and physiological characterics of sorghum at seed and early seedling establishment stages. For example, seed size and first leaf area are found to correlate with good emergence and high seedling vigor. Therefore, selection for better stand establishment on the basis of seed morphological and physiological traits is possible.

Poor stands are one of principal causes for low yields in SAT. Several stress factors are responsible for this. Here are a few examples of how sorghum germplasm could be screened for several stress factors.

Seed viability following wetting and drying

Some sorghums genotypes retain their viability even after germinated seeds were subjected to a dry spell. This is an important desirable characteristic in dry sowing where a small shower will not affect seed viability. A number of viable genotypes have been identified which should be tested in dry sowing environments. In the light of the earlier literature, it is expected that lines selected for this stress may be resistant to water stress. Biochemical characteristics related to resistance to this stress factor need to be investigated.

Grain quality, germinability and dormancy

Lack of high seed quality is one of the major causes for poor emergence. The environment and season in which seed is produced affect seed quality to a great extent. Infestation of grain with mold and preharvest germinability during the rainy season causes grain deterioration in sorghum. Early germinability causes hydrolysis of starch in the grain which encourages the growth of saprophytic fungus, thereby causing further deterioration of grain quality. This causes poor emergence and

poor seedling vigor in sorghum. Techniques have been developed and lines have been identified for these genetic and biotic stress factors, *viz.* resistance to preharvest sprouting and grain mold. Dormancy of grain during and after maturation reduces grain weathering and improves grain quality.

Sorghum genotypes vary widely for germinability at early and late stages of grain development. This has a direct impact on grain weathering and quality during the rainy season. There is much variation in mold development at different stages of grain development. Some genotypes with less germinability and less mold infestation at major stages of grainfilling were identified. These lines should be tested in a grain mold nursery for effective selection. More research needs to be directed to select lines resistant to preharvest sprouting and grain mold.

Seedling emergence and seedling vigor

Several management and biotic factors like depth of planting, soil temperature, soil crusting and compaction, poor vigor and susceptibility to water stress at the seedling stage, cause poor emergence and seedling. Extensive research has been undertaken to understand these stress factors and select lines resistant to individual stress. In the process, we may also discover genotypes showing multiple resistance.

Initially, major attention needs to be paid to improve grain quality. Genotypes could then be selected for better grain characteristics like large seed size, large embryonic area, first leaf area, and good grain quality with high protein content. Genotypes thus selected could be tested for better performance under adverse situations like emergence from deeper depth of planting, high soil surface temperature, crust and compaction and seedling growth under water stress. Consequently, lines could be selected that are resistant to stress factors.

Several morphological traits related to resistance to stress factors could be identified. For example, rapid mesocotyl and coleoptile elongation are found related to better emergence from deeper depths of planting. There are reports that long coleoptile and large coleoptile crosssectional area are associated with better emergence through soil crust and compaction. Genotypes showing high seedling vigor show better emergence through soil crust and are also tolerant to water stress at the seedling stage. Again, genotypes showing glossy leaf characteristics at the seedling stage show good tolerance to water stress and several insects. Genotypes resistant to drought at the seedling stage are also resistant at the adult growth stage.

Research needs

Seed characteristics

1. Identification of seed morphological characteristics linked with seedling development/yield attributes or host resistance to insects/diseases.
2. Determination of the relationships between certain characteristics like grain hardness, corneous endosperm content, water uptake, grain cooking quality and disease resistance traits.
3. Identification of drought resistant genotypes which show maximum seed viability.
4. Categorization of genotypes with different ranges of germinability and screening these for resistance to grain molds.

Selection for seedling vigor

1. Identification of high vigor lines with good agronomic attributes from germplasm and breeding lines.
2. Heritability of seedling vigor in high X low, high X high using the regression method.
3. Performance of high vigor lines under favorable and unfavorable conditions viz., crusted, low phosphate, low and high fertility, saline soils and under different depths of planting and kinds of weed competition.
4. Relationship between elongation of the primary root, emergence of secondary roots and crop establishment.
5. Utilization of high vigor lines in crossing with standard breeding lines for yield improvement using pedigree selection.
6. Mobilization efficiency of seed reserves of the lines showing emergence from deeper depth and high vigor needs.

Emergence through crust

1. Standardization of techniques using perfos and sprinklers.
2. Identification of lines with good emergence ability and determination of the causal factors responsible for better emergence.
3. Identification of lines with good agronomic traits.
4. Study of the resistance mechanism that inhibits emergence through crust.

Standardization of techniques for drought resistance at seedling stage 1

Germination

1. Germination under carbowax (polyethylene glycol) induced stress.
2. Ggermination and emergence under moisture stress.

Tolerance of stress by the seedlings

1. In cylinders.
2. In wooden flats/brick flats.
3. In field using perfos and sprinklers.
4. Assesing the relative efficiency of the different techniques and their potential.
5. Correlation between laboratory and field experimentation.

Selection of lines resistant to drought and study of resistance mechanism

1. Identification of seedling drought-resistant lines with good agronomic attributes and identification of a marker for drought tolerance.
2. Survey of world germplasm in order to locate the geographical distribution of resistant lines and their taxnomic status.
3. Mechanism of drought resistance: **i**- seedling roots, **ii**- anatomical structure in relation to water use efficiency, **iii**- scanning microphotographical examination of epidermis and wax, and **iv**- physical and biochemical studies of resistant and susceptible genotypes.
4. Inheritance and heritability of seedling drought tolerance in resistant X susceptible crosses.
5. Performance of resistant lines and progenies under different conditions, i.e., crop establishment, depth of planting, moisture stress, and pest resistance (shootfly, shoot bugs, etc.).
6. Incorporation of drought resistance into male sterile lines by backcrossing if feasible.

7. Relationships between drought resistance at seedling stage with that at advanced stages: GS1, GS2 and GS3.

PANICLE DEVELOPMENT

The productivity of sorghum depends on the efficiency of panicle development and the influence of the environment on it. Drought directly affects the initiation of panicle (GS1), the development of spikelets, flowering and grain maturity. Research has been undertaken on the effects of weather on panicle productivity and grain yield. For example, water stress delays panicle initiation, development of spikelet primordia, days to flowering, quickens the grainfilling period, but reduces grain size. Genotypes tolerant to unfavorable conditions in terms of panicle growth need to be selecte and those showing less interrupted panicle growth under water stress could be selected for their resistance.

More investigation is needed on the effects of water stress factors and the effect of light intensity on the sequential development of panicle. Several unfavorable environmental conditions like lack of water, low light intensity and nutrient availability, high temperature, etc., drastically reduce the productivity of the panicle. Under these stress situations, crops are often prevented from expressing their full genetic potential. It is therefore necessary to study in detail the effect of different environmental components on panicle differentiation and productivity, and to determine the optimum and minimum of each component of panicle growth.

Under severe water stress, differentiation may be delayed but not suspended. This in turn causes reduction in floret number and affects pollen tube growth and grain development. No detailed studies have been undertaken on the developmental aspects of panicle growth and vegetative growth simultaneously.

In SAT, uncertainty of rainfall and fluctuations in weather continue to have a direct impact on crop yield potential. Studies indicate that the change in weather directly influences the growth stages in sorghum-panicle initiation (GS1), days to flowering, grainfilling period and crop maturity. This in turn influences partitioning and translocation of photosynthates in the source and sink, thereby influencing the yield potentials in sorghum. Translocation of photosynthates in grain also varied in different genotypes. It is necessary to select genotypes which translocate major part of the photosynthates into grain under normal and stress conditions.

Temperature plays an important role in determining growth stages. The effect of weather in growth stage modeling needs to be emphasised. Breeding of genotypes needs to be concentrated in a particular season for adaptation in that season.

Compact panicle in sorghum provides favorable environments for infestation of disease and insects in tropical climates. Lax panicles may be good under this situations. Therefore, a new sorghum ideotype should be formulated.

ROOT GROWTH AND DEVELOPMENT

Due to difficulties in the extraction of roots from the soil very little progress has been made in root studies. Some simple techniques need to be evolved to facilitate root studies. More concerted research needs to be directed to the root systems as they play a vital part in plant growth and uptake of nutrients. The relationship between the seedling and the adult root system needs to be investigated. The seedling root system should also be studied both under water stress and nonstress situations. Efficiency of root elongation under water stress could be correlated to drought resistance. We need to assess whether seedling resistance could be correlated with the resistance at adult stage. If this hypothesis is confirmed, a large number of genotypes could be evaluated at the seedling stage for both under stress or nonstress situations and lines could be classified on the basis of the intensity of their root systems. Clipping treatment could be attempted to investigate this, as well as testing under artificial conditions by permitting only the desired member to grow.

Some anatomical characteristics like intensity of sclerenchyma in the root pericycle and silica particles in endodermis may be correlated with drought resistance. Research into the root systems indicates that more than 80% of the root mass is located in the upper 20-30 cm of the soil profile, thus it will be easier to extract and study the root system from the upper layer. Genotypes thus selected could be assessed later on for deeper root systems. Recombination of profuse root systems at the upper layer and a number of deeper roots may do well under water stress situation. However, simple techniques need to be developed to evaluate genotypes *vis-a-vis* their root systems.

The methodology for studying root growth and development is complicated. A brickchamber technique has been developed for root development studies at ICRISAT. This technique is capable of distinguishing genotypes in their pattern of root growth. The development of roots in brick chambers was almost similar to the one found in the field, and a sorghum hybrid CSH8 which showed some level of drought resistance under the field conditions produced a better root system (biomass) compared to V302, a drought susceptible cultivar. Comparative study of the phenology and root growth of sorghum cultivars in alfisol and vertisol was made in a brick chamber.

GLOSSY SORGHUM GERMPLASMS: STUDIES ON THE RESISTANCE TO BIOTIC AND ABIOTIC STRESSES (Maiti, 1991-92; sabbatical stay at ICRISAT)

World sorghum germplasm can be classified into 2 distinct morphological types, glossy and nonglossy, based on visual characteristics at the seedling stage. Out of 17,536 accessions observed only 495 were glossy, and although they originate from a wide geographic and taxonomic distribution, the majority came from the Indian penninsular region and from the taxonomic race Durra. Glossy lines show variability in seedling morphology, seedling vigor, leaf surface structure, physiological, biochemical and agronomic traits. They show multiple resistance to shootfly, stem borer and several other insects and abiotic stresses like drought, salinity, high temperature and nutrient uptake. Other characteristics include higher water use efficiency and better growth under water stress situation compared to nonglossy ones. Therefore, glossy sorghums may serve as basic resistance sources and diverse genepools for improving biotic and abiotic stress resistance. Sources of economically useful traits were identified for future incorporation in the improved cultivar. Besides, sorghum germplasm with high glossy score can serve as an important source to improve forage and grain yield. Therefore, glossy sorghum germplasm associated with multiple resistances shows a wider genetic base for specific traits and can be explored in genetic improvement for the semiarid regions of the world.

Taxonomic groups and geographic distribution

Only 477 out of 495 glossy sorghum accessions were classified (Table 9.1). Glossy lines appear in all the basic races and intermediate races except Bicolor-Guinea and Bicolor-Kafir. While 10% of germplasm collections from India (Durra race) are glossy, only 2% from Nigeria and about 1.5% from USA have glossy trait. Glossy lines have a diverse geographic origin (Table 9.2). Durra sorghum of India are mostly from the drier central parts of the country where the existance of shootfly and drought resulted in expresion of resistance to these condition by some sorghum lines (Maiti *et al.*, 1984).

Table 9.1 Taxonomic distribution of glossy lines in the world sorghum germplasm accessions evaluated at ICRISAT (Maiti *et al.*, 1984).

Taxonomic groups	# lines	Taxonomic groups	# lines
Durra	400	Caudatum	3
Durra-bicolor	31	Bicolor	2
Durra-caudatum	26	Guinea-caudatum	2
Guinea	8	Caudatum-bicolor	1
Durra-kafir	3	Durra-guinea	1
Total	**477**		

Table 9.2 Distribution of glossy lines by countries in the world germplasm collection evaluated at ICRISAT (Maiti *et al.*, 1984).

Origin	Total	Glossy (%)	Origin	Total	Glossy (%)
India	4027	417 (10.36)	Ethiopia	4113	3 (0.07)
Nigeria	1173	25 (2.13)	South Africa	659	2 (0.30)
U.S.A.	1867	24 (1.28)	Mexico	234	2 (0.36)
Sudan	2255	11 (0.48)	Kenya	761	1 (0.13)
Cameroun	1835	8 (0.43)	Uganda	612	1 (0.16)
Total	**17356**	**495**			

Characterization of glossy trait

Seedling morphology and vigor: Glossy lines are rare in sorghum germplasm: out of 17,536 lines observed, only 495 were found to possess the glossy trait, but 32,000 germplasm accessions have not been screent for glossiness.

Glossy lines have light yellow green leaves with a shiny surface appearance in sunlight. Nonglossy "normal" sorghum lines have dark green and generally broad and pendant leaves. Leaves may be broad, semibroad or narrow depending on genotypes. Seedlings in glossy lines are generally erect and leaves are stiff, but broad and slightly pendant leaves are also not uncommon. The time of appearance of glossiness differs among genotypes. In some, it may appear as early as the first day after seedling emergence, while in others as late as 10-15 days after emergence. Variation in soil fertilities have no effect on glossy expression (Maiti *et al.*, 1984). Traere *et al.* (1989) reported that some leaves may be nonglossy in the same line, but recent observations showed that all leaves in a glossy plant were glossy, but considerable variations in the intensity of glossiness has been observed. This variation can be quantified on a 1-5 scale (1 = most glossy, 4 = least glossy, 5 = nonglossy). Glossy lines also vary greatly in seedling vigor which is evaluated through a visual scoring method (1 = most vigorous and 5 = least vigorous; Maiti *et al.*, 1981).

Biophysical and biochemical distinction between glossy and nonglossy sorghum

Nonglossy lines have deep green and pendant leaves, while the glossy lines have light yellow-green and stiff leaves with shining leaf appearance at the seedling stage. The biochemical factors leading to visual differences between glossy and nonglossy lines are not yet known. The light yellow-green color of the glossy leaves may be related to the chlorophyll content and the shining (glossy) leaf surface to the epicuticular wax. The visual difference between glossy and non-glossy trait disappears at advanced seedling stages (Maiti *et al.*, 1991).

Chlorophyll

Genotypes with low chlorophyll a and b contents were reported to be resistant to shootfly (Mate *et al.*, 1988). Drought tolerance in sorghum is associated with an increased number of leaves and increased chlorophyll content (Hou *et al.*, 1987). High solar intensity increased the rate of synthesis of carotenoids, chlorophyll a and b in both unstressed and drought treatment (Masojidek *et al.*, 1991). Many variations in chlorophyll and epicuticular wax contents were observed among glossy lines at 20-day seedling stage (Maiti *et al.*, 1991). Chlorophyll contents of 6 glossy and 6 nonglossy lines are shown in Table 9.3.

Table 9.3 The mean values of chlorophyll content (mg/g) of glossy (G) and nonglossy (NG) sorghum lines at 7, 14 and 21 days after emergence (DAE).

DAE	Total chlorophyll		Chlorophyll a/b	
	G	NG	G	NG
7 days	2.61	3.22	1.63	2.04
14 days	2.61	3.22	2.57	2.35
21 days	3.73	3.65	1.78	1.84

Glossy and nonglossy sorgum genotypes did not show significant differences in chlorophyll content, but significant differences for these components were observed between stages (Figs. 9.1-9.3) and glossy lines (Fig. 9.4). Nonglossy lines did not show significant differences in these components (Table 9.4). Correlation analysis among sorghum genotypes at different stages showed that there were no significant correlations with chlorophyll content, whereas significant correlations (P = 0.05) were found among genotypes within the stage.

Table 9.4 Analysis of variance (F-ratio) of chlorophyll content (mg/g, fresh weight) (* P = 0.05).

Source of Variation	df	F-value Chlorophyll a	Chlorophyll b	Chlorophyll (total)
Intervals	2	4.79 *	13.92 *	5.62 *
Glossy	5	2.85 *	3.10 *	3.12 *
N. glossy	5	0.55	1.08	0.67
Glossy vs N. glossy	1	0.50	0.51	0.54

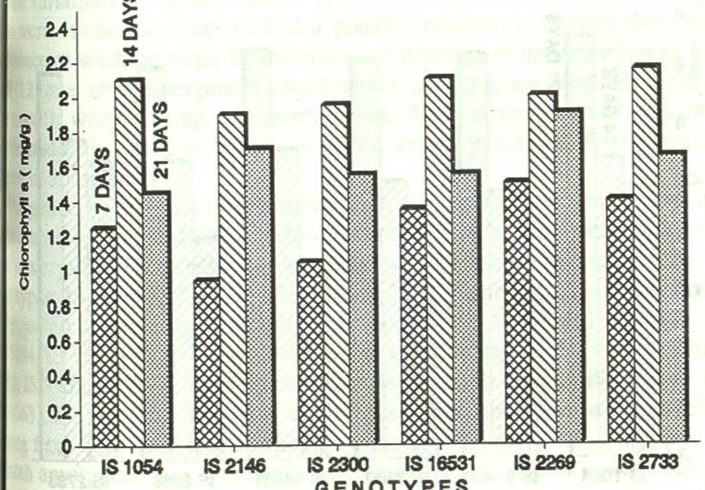


Figure 9.1 Chlorophyll a content in 6 glossy sorghum lines at 7, 14 and 21 days after emergence.

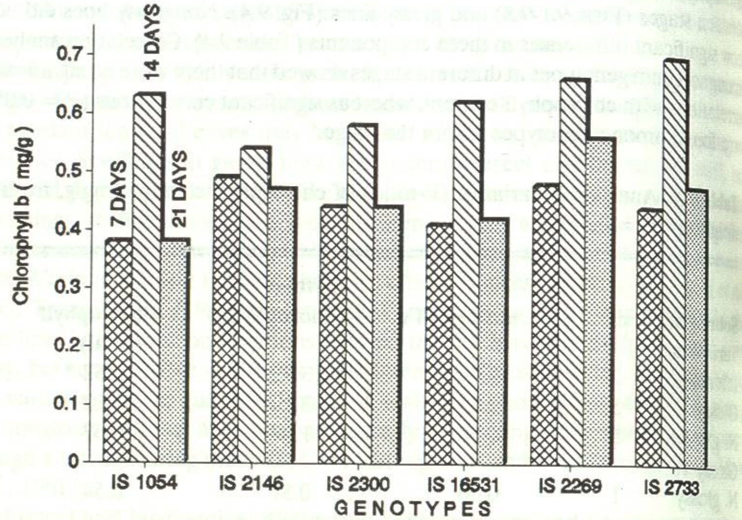


Figure 9.2 Chlorophyll b content in 6 glossy sorghum lines at 7, 14 and 21 days after emergence.

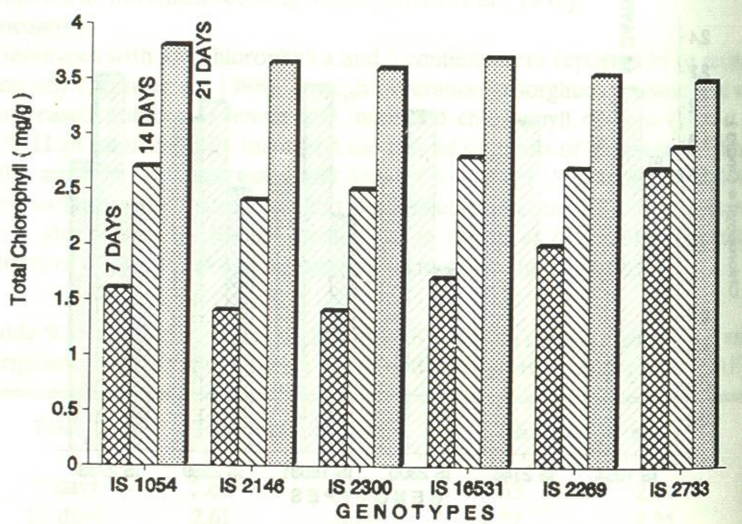
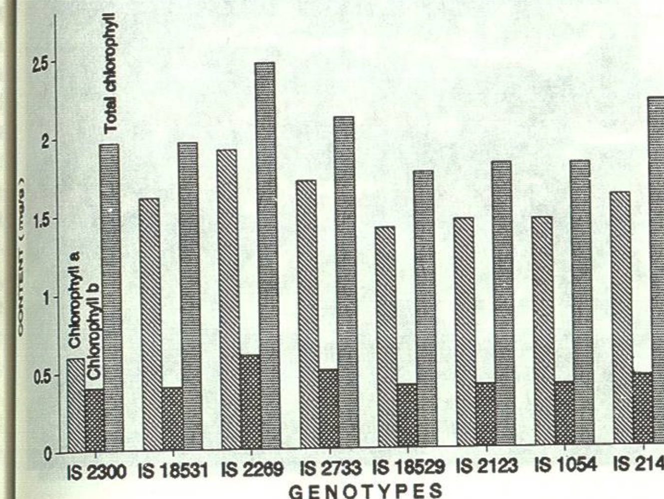


Figure 9.3 Total chlorophyll content in 6 glossy sorghum lines at 7, 14 and 21 days after emergence.



gure 9.4 Chlorophyll content (a, b and total) at 21 days after emergence glossy and nonglossy sorghum lines.

icuticular wax (EW) structure

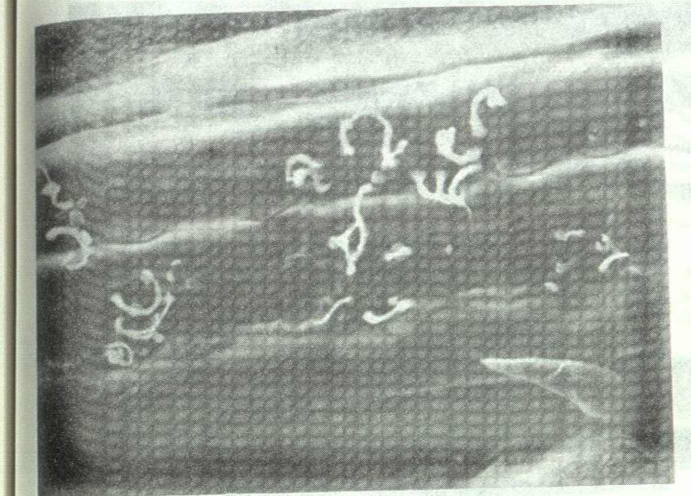
EW may be related to insect resistance (Rodríguez *et al.*, 1983) and drought stance at the seedling stage (Jordan, 1983; Jordan *et al.*, 1984).

The variations in the leaf surface epicuticular wax structure in a set of glossy s were studied in order to find a possible relation to shootfly and drought stance at seedling stage. Epicuticular wax structure of upper surface of fourth f (12 days after emergence) varied widely among glossy sorghum genotypes, smooth waxy coating, coalescence wax, filamentous wax and wax plates. dermal cells varied in cell wall waviness among genotypes. Filamentous wax ied in abundance.

The genotypes showed larger variations in epicuticular wax structure *viz* in the pearance of smooth shining surface, intensity of projected wax threads, its size d wax crystals. The presence of trichomes with sharp tips are prominent in some otypes: IS 1054, IS 5282, IS 5567, and IS 2312. Variations in intensity and size projected filamentous threads is prominent: in globular forms IS 2396, IS 5359, 5484, IS 5567, IS 8977; globular and short wax threads, IS 1054, IS 2205, IS 2, IS 3962, IS 5484, IS 18390; long projected coiled threads, IS 1096, IS 4576, 4663, IS 5282. Wax filaments are oriented along the veins or epidermal cell sing from cork cells located on both sides of silica cells. All glossy lines have ooth amorphous wax spreading over the entire leaf surface which causes the flectance of sun rays thus imparting to the intensity of glossiness (Plates 9.1 & 2).

a)

b)



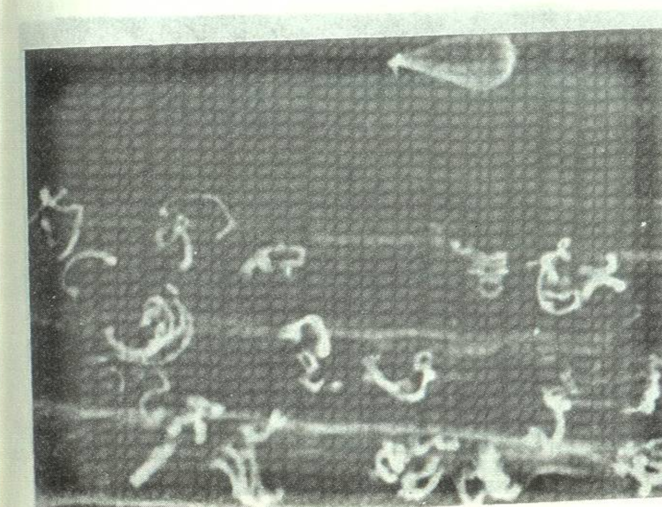
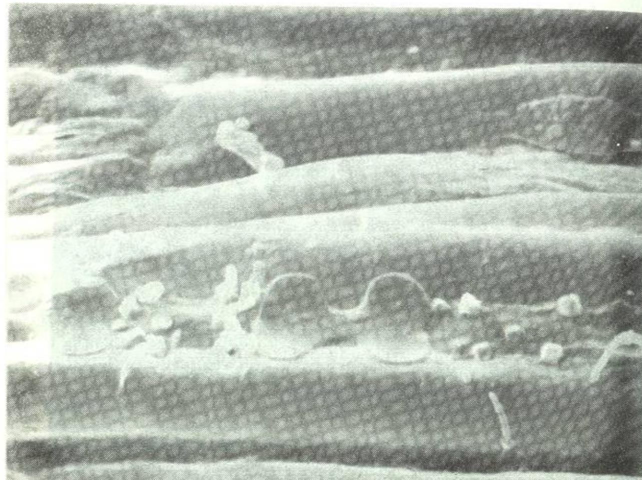
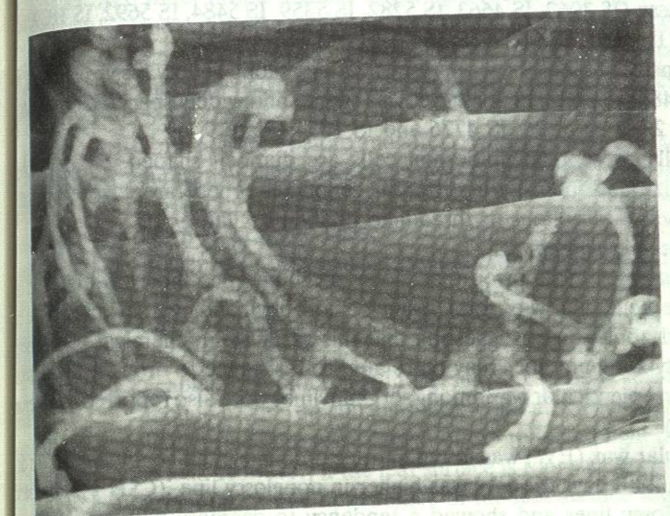


Plate 9.1 Variation in leaf surface structures in some glossy lines. a) IS 4661; b) IS 5642 showing uneven surface and wax filament threads; c) IS 5282; d) Is 2146 having smooth surface, nonglandular trichomes and wax filaments.

a)



b)



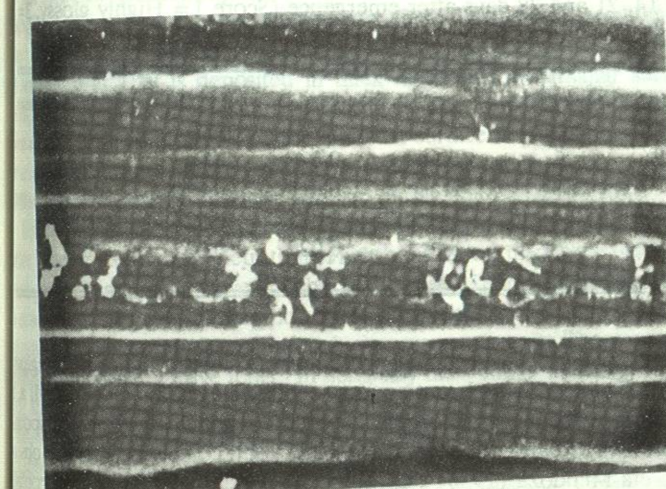


Plate 9.2 Variation in silica crystals and wax filaments projecting from the cor c) IS 4776; d) IS 4473.
cells on both sides of silica crystals: a) IS 2205; IS 5622.