

**DROUGHT TOLERANCE STUDIES IN SUNFLOWER
(*Helianthus annuus* L.): FIELD EVALUATION
OF SUNFLOWER GERMPLASM FOR RELATIVE
DROUGHT RESISTANCE AT TWO CROP
GROWTH STAGES**

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DEPARTMENT OF CROP PHYSIOLOGY
UNIVERSITY OF AGRICULTURAL SCIENCES
G. K. V. K. BANGALORE-560 065
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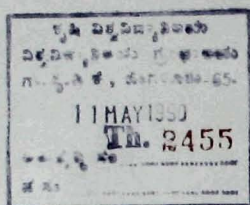
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in partial fulfilment of the requirements
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**IN
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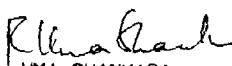


DEPARTMENT OF CROP PHYSIOLOGY
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BANGALORE

CERTIFICATE

This is to certify that the thesis entitled "DROUGHT TOLERANCE STUDIES IN SUNFLOWER (*Helianthus annuus* L.): FIELD EVALUATION OF SUNFLOWER GERMPLASM FOR RELATIVE DROUGHT RESISTANCE AT TWO CROP GROWTH STAGES" submitted in partial fulfilment of the requirement for the degree of MASTER OF SCIENCE (AGRICULTURE) in CROP PHYSIOLOGY to the University of Agricultural Sciences, Bangalore is a record of research work carried out by Mr. RAVISHANKAR. K.V. under my guidance and supervision and that no part of the thesis has been submitted for the award of any other degree, diploma, associateship, fellowship or other similar titles.

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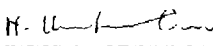

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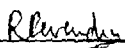
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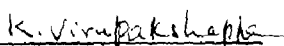
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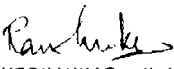
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(RAVISHANKAR, K.V)

LIST OF ABBREVIATIONS USED

DAS	Days after sowing
OFF	Days taken to fifty per cent flowering
DSI	Drought susceptibility index
FSW	Filled seed weight (g)
HD	Head diameter (cm)
K/H	Kernel to hull ratio
LA	Leaf area (cm ²)
PC	Phenotypic correlation
TDM	Total dry matter (g)
TW	Test weight (g)
WUE	Water use efficiency

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INTRODUCTION

INTRODUCTION

Oil seeds form one of the major crops of India. They occupied nearly 19 million hectares of gross sown area next only to food grains in 1986-87. In spite of having the highest acreage under oil seeds, India's production is very low compared to other countries in the world. This has resulted in lower per capita availability of oils and fats (5.9 kg, 1986-87) against the requirement of 14 kg (Suresh Pal, 1989). To meet the demand in 1986-87 alone, India imported edible oil worth rupees 1000 crores. The growth in oil seed production needs immediate attention to bridge the gap between supply and demand. To fulfill the vegetable oil requirement and enhance the nutritional status of the people, the oil seed production needs to be doubled by 2000 AD.

Realising the importance to accelerate the efforts to achieve self reliance in oil seed production, the Government of India has set up a National Technology Mission on oil seeds.

Among the oil seeds, sunflower is becoming very popular and is rapidly replacing other crops such as kharif groundnut, rabi jowar and durum wheat which are less remunerative to the farmers. Because of the fact that it can be grown under wide range of soils and

agroclimatic zones, the area under sunflower is steadily increasing. Another reason for its popularity is due to its high seed oil content and higher poly-unsaturated fatty acid content in the oil which has an important role to play in human diet. In India it is grown in 9.91 lakh hectares with a production of 4.35 lakh tonnes. Nearly 90 per cent of this area is under southern peninsula i.e., in Karnataka, Maharashtra, Andhra Pradesh and Tamil Nadu. Karnataka ranks first in the area and production with 5.84 lakh hectares and 3.09 lakh tonnes amounting to 59 per cent of total area and 71 per cent of total production.

However, the productivity is rather very low compared to other sunflower growing countries. This poor productivity is because much of the sunflower is grown as a rainfed crop in the kharif season. Due to vagaries of monsoon under kharif, the crop experiences prolonged and intermittent moisture stress and as a consequence suffers from poor growth and productivity.

Keeping this in view, one of the thrust area programmes in sunflower crop improvement is to identify sources of drought resistance/tolerance for use in breeding programmes. As a part of the efforts directed towards this programme, it is also necessary to improve our understanding of the effect of moisture stress on the various growth and yield characteristics.

In this regard, the present study proposes to identify drought resistance/tolerance sources from among the germplasm collections and to investigate some of the water relation parameters involved in drought resistance/tolerance.

The salient objectives of the study are

- i) To compare the growth and yield of sunflower germplasm under field condition when subjected to moisture stress at early vegetative and at late vegetative/early reproductive phase with that under completely irrigated condition.
- ii) To understand the nature of relationship between yield and various independent growth characters, as affected by moisture stress.
- iii) To investigate several water relation parameters in a few identified genotypes and wild species of sunflower.

REVIEW OF LITERATURE

11. REVIEW OF LITERATURE

The area under sunflower cultivation has been steadily increasing since its introduction to India. A major portion of the acreage is accounted by Karnataka (Fig.1). Much of this area is cultivated under rainfed conditions. Because of the highly unpredictable distribution of monsoon rainfall, the crops are usually subjected to moisture stress of varying degree and at different growth stages. The effect of intermittent moisture stress on crops ranges from inadequate biomass accumulation to poor seed development. Since, sunflower forms an important oilseed crop in enhancing the national edible oil production much effort has been recently put in understanding the effect of moisture stress on the growth, yield and oil characteristics to enable the crop improvement for rainfed situations. We review below several aspects of sunflower growth, yield and oil attributes as affected by moisture stress.

Effect of moisture stress on leaf area development

An important basic feature of crop production that has been demonstrated in several crops including sunflower is the direct relationship between growth as measured by LAI and the amount of water transpired (Tanner and Sinclair, 1983; Connor et al 1985). This relation is particularly important because the former

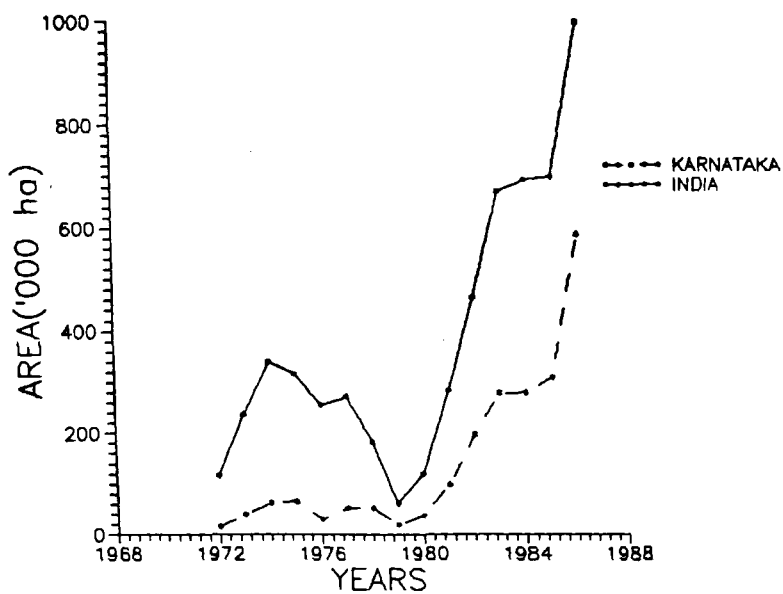


Fig. 1 Area under sunflower crop in Karnataka and India for 1972-87 (Anonymous, 1989)

has been shown to be positively correlated with the yield (Muriel and Downes 1974; Rawson *et al.*, 1980; Rawson and Turner, 1982a). Moisture stress at the early vegetative phases therefore, adversely affects crop yield by reducing the leaf area growth and the biomass.

Reduced leaf area under moisture stress may be due to the reduced leaf expansion rate and or due to inhibition of emergence of the leaf primordia. Marc and Palmer, (1976) and Yegappan *et al.*, (1980) showed a reduction in the number of leaves per plant following moisture stress in sunflower. They also showed that the inflorescence primordia initiation was generally insensitive to moisture stress upto -3.0 MPa, while subsequent development was affected.

The leaf expansion rates in sunflower has been shown to be very sensitive to decreasing water potentials (Boyer, 1970). For example at water potentials less than -4 bars, the cell enlargement in sunflower ceased while it continued though at lower rates in soybean and maize. The sensitivity of leaf enlargement to moisture stress has been shown to be much higher than for other physiological processes such as photosynthesis and respiration. Considerable inhibition in leaf growth was observed by Boyer (1970) even in well watered plant as the mid-day water potential reduced to -4 bars.

Takami *et al.*, (1982) reported that at similar water potentials, the leaf expansion was greater in light than in dark. They attributed this to the better maintenance of turgor due to lowered osmotic potential under light. The same group showed that, the leaf expansion rate was markedly reduced in four diverse sunflower cultivars subjected to slow stress. Generally, leaf expansion reduced as the pre dawn leaf water potential decreased from -0.35 to -0.6 MPa and ceased at a leaf water potential of 1.0 MPa when the pre dawn turgor pressure was zero.

Rawson *et al.*, (1980) and Rawson and Turner, (1982b) conducted several studies to compare the leaf area development of sunflowers grown under stored moisture with that under full irrigation. They reported that the final leaf number did not vary significantly among the treatments. However there was significant differences in the total leaf area among the treatments. Under stored moisture condition, there was nearly 60 per cent reduction in leaf area per plant. Late duration varieties that had large leaves showed the highest rate of leaf expansion.

The above reports clearly indicate the sensitivity of leaf expansion to moisture stress. Rawson and Turner (1982b), Takami *et al.*, (1983) and Connor and Jones (1985) have also shown that the stressed sunflower

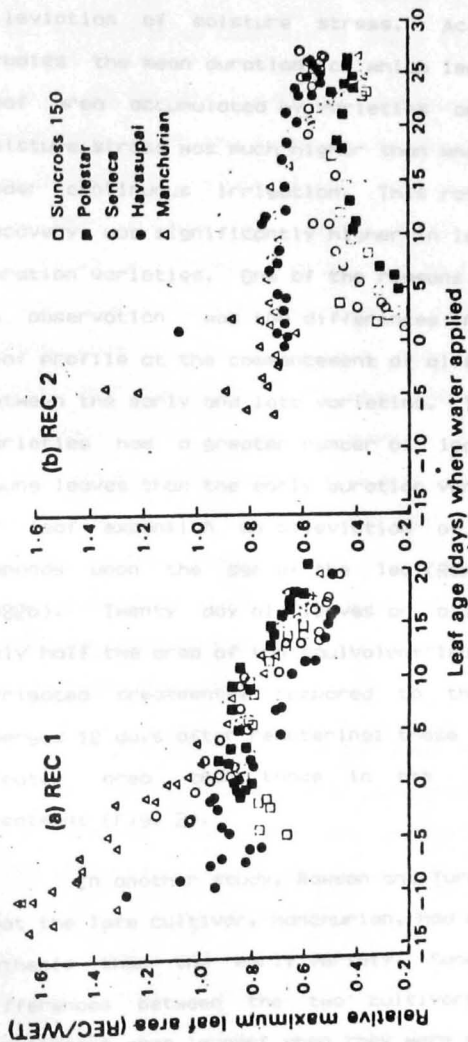


Fig. 2 Effect of leaf age at the time of water application on final leaf size in five sunflower cultivars rewatered 44 days (REC-1) or 54 days (REC-2) after sowing. The final leaf size is expressed relative to that in the irrigated (WET) treatment (Rowson and Turner, 1982b).

leaves respond very rapidly in resuming leaf expansion on alleviation of moisture stress. According to these studies the mean duration for which leaves grow and the leaf area accumulated by varieties on alleviation of moisture stress was much higher than when they were grown under continuous irrigation. This rate of leaf area recovery was significantly higher in late than in early duration varieties. One of the reasons proposed for such an observation was the differences in composition of leaf profile at the commencement of alleviation of stress between the early and late varieties. The late duration varieties had a greater number of leaf primordia and young leaves than the early duration varieties. The rate of leaf expansion on alleviation of moisture stress depends upon the age of the leaf (Rawson and Turner, 1982b). Twenty day old leaves on alleviation achieve only half the area of the equivalent leaves in the fully irrigated treatments, compared to those leaves that emerged 10 days after rewatering; these leaves achieved a greater area than those in the fully irrigated treatment (Fig. 2).

In another study, Rawson and Turner (1983) showed that the late cultivar, Manchurian, had more leaf area at anthesis than the early variety, Suncross 150. The differences between the two cultivars in leaf area development were largest when they were subjected to late irrigations; presumably because Manchurian was still in

its vegetative phase while the early maturing Suncross 150 was close to anthesis or grain filling.

An important effect of moisture stress though less realized, is on the canopy architecture. Moisture stress modifies the pattern of leaf size and growth with node position (Connor and Jones, 1985). In continuously stressed sunflower, the maximum leaf size occurred at lower nodes; and the expansion of leaves at potentially productive nodes of middle and upper canopy was restricted resulting in the reduction of LAI. Rawson and Constable (1980) found differences in the rates of leaf appearances, final leaf number and patterns of display of leaf profile among cultivars subjected to moisture stress. The change in the canopy architecture due to moisture stress did not however alter the positive relation between the leaf area at anthesis and seed yield (Rawson et al., 1980).

Leaf senescence in sunflower is not an important component affecting leaf area development until anthesis, when further leaf growth has ceased (Connor and Jones, 1985). They reported a marked senescence of basal leaves in response to moisture stress at anthesis, the response was minimal when the stress was imposed at mid-grain filling stage. Interestingly, in the genotypes where irrigation was commenced at either budding or anthesis, the leaf senescence was delayed and played an important

role in the maintenance of LAI during seed filling. In rainfed crops, that experience continuously depleting soil water reserve, the leaf senescence was marked and continuous.

Leaf senescence has been considered as an optional mechanism to maintain tissue water status under prolonged periods of moisture stress especially when the evaporative demands are high(Connor and Jones,1985). However, such an option would be effective, only when the crop growth cycle is long relative to the stress period, since the crop must maintain sufficient capacity for further vegetative and reproductive growth when the water availability resumes.

In summary, the leaf area development in sunflower under moisture stress, seems to be governed by two major aspects, namely, leaf expansion and senescence. While the crop is highly sensitive to reduction in soil water potential as evident by cessation of leaf expansion, the recovery growth on alleviation is substantial, often overcoming the leaf expansion rates of fully irrigated plants (Rawson and Turner, 1982b). The leaf senescence seems to be restricted generally to basal leaves and also occurs at or after anthesis when leaf expansion is ceased. Since, the positive relationship between the leaf area development and seed yield is valid under moisture stress as well, effective screening programmes for higher yields under moisture stress,

should emphasise selection for germplasm/genotypes with maximum leaf area expansion rates on alleviation of stress.

Effect of moisture stress on leaf diffusive processes

Leaf diffusive conductances and leaf water potential form important physiological response of plant to water stress in regulating their water status. A number of studies have been conducted to understand the leaf diffusive processes of sunflower as affected by moisture stress. Connor and Jones (1985), reported the behaviour of stomata of plants that were grown under rainfed condition and weekly irrigation. In spite of the decrease in the mean daily leaf water potential to -2 and -3 MPa, the stomata remained open throughout the day, i.e., the leaf conductance did not show any relationship with either leaf water potential or atmospheric water deficits on daily basis. However the mean leaf conductance under rainfed situation declined throughout the cropping season and was about half that in the irrigated during the post anthesis period. Such gradual decrease in leaf conductance was reversible on irrigation and attained values similar to that of irrigated control. Similar responses were observed by Rawson and Constable (1980) in sunflower.

The rates of photosynthesis were occasionally reduced in plants growing under stored moisture where the

leaf water potential fell below -1 MPa, but on a diurnal scale the reductions were very small. English *et al.*, (1979) reported that the diurnal pattern of photosynthesis and leaf conductance were relatively unaffected by water potential as low as -2.0 to -2.5 MPa during mid-day.

The relative constancy of gas exchange per unit leaf area of sunflower grown under different water regimes is probably because of the fact that the area of stomatal apparatus per unit leaf area remains unaltered (Rawson and Constable, 1980).

However on pooling data from various moisture stress treatments, Rawson and Turner (1983), showed that the leaf conductance was linearly related to leaf water potential ($r = 0.6$, $n=36$).

Intriguingly, vertically wilted leaves of sunflower were found to have considerable rates of net photosynthesis (Rawson, 1979). Irrespective of the position of the leaf the vertically wilted leaves had a net photosynthesis of about 50 per cent of that of control. Further, in such leaves the WUE also was improved because of a change in leaf temperature.

Studies of Connor *et al.*, (1985) indicated that stomatal activity played a minor role in response to water stress. The major differences in the daily carbon

gain could not be attributed to changes in leaf diffusive conductances. Despite partial closure of stomata during the after-noon, plants could maintain a high level of leaf conductance in rainfed situation leading to large adjustments in leaf area. Both, irrigated and rainfed crops showed equal efficiency of utilisation of intercepted radiation up to anthesis.

In most of these studies where the plants were subjected to water stress, leaf conductances were maintained at high level. Under moisture stress, restricted development of leaf area in the early vegetative growth and enhanced senescence of leaf during reproductive phase plays a role in minimising transpirational area of the plant. Thus the plants under these conditions maintain normal conductance and photosynthetic rates with the available water.

Effect of moisture stress on yield and its components:

a) Effect of moisture stress on seed yield

Seed yield of sunflower is a function of a number of components such as number of seeds per capitulum, test weight (100 seed weight) etc., Several studies (Lakshmana Rao, 1983; Lakshmanaiah, 1978; Rajan 1976) have reported the influence of these parameters on the seed yield under normal conditions of growth. Very few studies have been conducted to examine the nature of

influence of these characters on yield under moisture stress condition, considering that each of the characters are differentially affected by moisture stress. In the following section we review briefly several studies pertaining to this aspect.

Talho and Osman (1975) observed that sunflower crops subjected to moisture stress at different growth stages exhibited a marked reduction in all the yield parameters. When stress was imposed at the early elongation stage of the vegetative phase, the seed weight per plant reduced from 44.5 g (under irrigation) to 16 g, the number of seeds from 720 to 312 and 100 seed weight from 6.18 g to 5.12 g. Moisture stress at flowering and ripening stages considerably reduced test weight, seed weight and number of seeds per plant.

Though the seed yield was positively related to the maturity duration, Rawson and Turner (1982a) showed that the lack of irrigation or moisture stress reduced the seed yield to significantly greater extent in late cultivars than in early cultivars. Plants that were rewatered after a period of stress (44 DAS) did not exhibit any substantial reduction in the average seed weight. However, crops that were grown continuously on stored moisture yielded only 32 g per plant compared to 107 g obtained from plants that were irrigated; the average weight of seed also reduced from 78 to 57 mg in plants grown under stored moisture. However, in another

study, Rawson and Turner (1983) obtained higher seed yields from the late duration cultivar, Manchurian, despite a greater degree of wilting in it, compared to an early cultivar Suncross 150.

Sarkar and Bhattacharya (1980) reported that yield parameters such as number of filled seed per head, test weight and seed yield increased with available soil moisture. Fereres *et al.*, (1986) found significant decrease in the yield parameters such as seed number, plant height and head diameter among 59 genotypes of sunflower subjected to moisture stress.

Dulay and Singh (1983) showed that moisture stress at seedling stages resulted in higher reduction in seed yields than when the stress was imposed during capitulum initiation and anthesis stage.

In a study on fifty sunflower germplasm lines, Sheshagiri Rao (1989) reported significant reduction in seed yield, plant height, filled seed number, head diameter, test weight and TDM when they were subjected to moisture stress at an early growth stage. Interestingly, harvest index, days to 50 per cent flowering, kernel and seed oil per cent were not affected by moisture stress. Almost similar effect was noticed when the genotypes were subjected to moisture stress at an advanced stage of crop growth. Yield and yield components were relatively more affected when stress was imposed at an advanced

stage (late vegetative or early reproductive stage) compared to at an early stage (early vegetative phase).

b) Effect of moisture stress on harvest index

Partitioning of dry matter into seed yield is reflected by the harvest index. The distribution of dry matter to the seed was found to be influenced by the time at which irrigation was provided in the early cultivar (Rawson and Turner, 1983). The harvest index was highest when water was applied just prior to anthesis and it did not differ from the rainfed control when irrigation was resumed early in vegetative phase. In contrast, the harvest index of the late cultivar remained low in all the moisture stress treatments imposed.

According to Connor et al., (1985) the reduction of early vegetative growth by restricted irrigation and application of water from budding led to better allocation of biomass in favour of yield compared to the crops that were completely irrigated. Rawson and Turner (1982a) observed that yields were not reduced when the irrigation was delayed till the 44th day after sowing, because of higher proportion dry matter allocation to the grain.

Fereres et al., (1986) reported that water deficits reduced the harvest index in all genotypes, but the decrease was varied among the genotypes. Harvest

index and grain yield were strongly correlated under dryland condition for genotypes of similar duration. The reduction in harvest index under moisture stress was mainly due to alteration in seed number with less variation in individual seed weight (Fereses *et al.*, 1986).

Geshagiri Rao (1989) found no significant differences in the harvest index among genotypes grown under normal irrigation (control) or under prolonged moisture stress at early and late vegetative stages.

c) Effect of moisture stress on seed oil content:

The seed oil content in sunflower varies widely from 22.56 to 42.51 per cent (mean = 32.14 ± 2.2 , Anonymous, 1989). Analysing 305 collections including 28 species, Thompson *et al.*, (1981) found that the seed oil content ranged from 20 to 40.8 per cent with considerable variability in the fatty acid composition of the oil.

The seed oil content is influenced by several independent attributes in the plant. For instance, Giriraj *et al.*, (1979) reported that seed oil content is negatively correlated with the leaf number. Zali *et al.*, (1977) found a negative correlation between seed oil content and seed yield, head diameter and leaf number. On the other hand Shabana (1975) reported a positive correlation between seed oil content and plant height and test weight.

Lakshmanaiah (1978) found that oil content was positively and significantly correlated with seed yield, plant height and seed filling. However the seed oil content and the hull weight were highly negatively correlated. In an attempt to understand the contribution of various characters to oil content, Lakshmanaiah (1978) conducted path co-efficient analysis. He observed that there was no single character substantially influencing the oil content among the characters studied; the residual coefficient was 0.757. Similar results were obtained by Sheshagiri Rao (1989) for kernel oil content in yet another study.

There are conflicting reports on the effect of moisture stress on the oil content. For instance, Soinit et al., (1975), Prunty (1981), Rowson and Turner (1982a, 1983) and Sheshagiri Rao (1989) found that oil content of sunflower varieties did not decrease with moisture stress. However, several workers, such as Hall et al., (1989), Talha and Osman (1975) found that oil content and oil yield were significantly reduced by moisture stress.

Sheshagiri Rao (1989) found almost no reduction in kernel and seed oil content in a study comprising 50 genotypes subjected to moisture stress at two different stages of the plant growth.

Some of the environmental factors also had no effect on oil content of other crops. Kittock and Williams (1970) found no variation in oil content of castor bean when they were grown in different spacings. Genter *et al.*, (1956) showed that none of the factors in a NPK factorial experiment affected the oil content of corn grain. Baker and McKenzie (1972) found no significant interaction between cultivar X year or cultivar X site for oil content of oats. These studies suggest the relative constancy of seed oil, uninfluenced by environmental variation. Interestingly, Brooks *et al.*, (1982) did not find a decrease in sucrose, protein and amino acid content per unit weight of the grain when wheat and barley were subjected to moisture stress.

Effect of moisture stress on the association among characters

A number of independent variables shape the final seed yield in plants. Each of these independent variables may influence the seed yield directly and indirectly because of their inter-correlation with other independent variables.

A summary of some of the more recent studies indicating the correlation of various independent variables with seed yield in sunflower is presented in Table 1. It might be noted that five of these studies pertain to sunflower grown under both irrigated and stressed conditions. The latter involved either growing

Table 1-A summary of some recent papers indicating the correlation of various independent variables with seed yield in sunflower.

Sl.No.	Independent variables	Correlation		References
		ave	-ve	
1.	Maturity	§		Varshney and Basudeo Singh(1977); Hong and Evans(1985).
2.	Plant height	§		Varshney and Basudeo Singh(1977); Deshmukh et al(1980)§; Lakshmaniah(1978); Pathak(1975); Giringa et al. (1979); Hong and Evans(1985).
3.	Head diameter	§	§*	Varshney and Basudeo Singh(1977); Velkov(1980); Lakshmaniah(1978); Baldzi(1976)§; Rajan(1976)§. Giringa et al. (1979); Fereres et al. (1986)§. Deshmukh et al(1980)§.
4.	Stem diameter	§		
5.	100 seed weight	§	§*	Deshmukh et al(1980)§; Srinivasa(1980)§; Lakshmana Rao(1983); Lakshmaniah(1978); Pathak(1975). Sheshgiri Rao(1989)§. Deshmukh et al(1980)§.
6.	Stem weight	§		
7.	Leaf area	§		Yeggonam et al. (1982)§; Rawson and Turner(1982)§; Conner and Jones(1985)§; Turner(1983)§; Sheshgiri Rao(1989)§.
8.	Seed number	§		Lakshmaniah(1978); Baldzi(1976); Fereres et al. (1986)§; Rajan(1976).
9.	Seed volume	§		Lakshmaniah(1978).
10.	TDM	§		Pathak(1975); Sheshgiri Rao(1989)§.
11.	Hull content	§		Pathak(1975).
12.	Seed oil content	§*		Zell et al. (1977)§.
13.	Days to flowering	§		Hong and Evans(1985).
14.	Harvest index	§		Fereres et al. (1986)§.

* indicates authors reporting negative correlation.

§ refer to studies under both irrigated and moisture stressed conditions.

the crop under rainfed situation, stored moisture or withdrawal of irrigation to prolonged periods during crop growth.

Though it is found that many of the characters such as maturity duration, plant height, head diameter, test weight, leaf area, seed number, seed volume, TDM are positively and significantly correlated with seed yield, their relative contribution to yield either directly or indirectly could be different. Few studies have attempted to estimate the relative contribution of independent variables to yield under moisture stress conditions.

Path analysis is a modified regression analysis Dewey and Lu, (1957); many workers have used this method to estimate the extent of contribution of independent variables to dependent variable. Varshney and Basudeo Singh (1977) reported that plant height, head diameter and seed filling contributed to yield directly and positively; the direct effect of maturity on seed yield was negative. Path analysis studies by Naskar *et al.*, (1982, 1988) showed that the direct contribution of plant height towards yield was highest followed by 100 seed weight and capitulum size. Velkov (1980) found that the head diameter had the direct largest positive contribution to achene yield. According to Lakshman Rao (1980), harvest index had the maximum direct positive

effect and positive indirect effect through plant height and total dry matter. The 100 seed weight had maximum positive indirect effect on seed yield through total dry matter (Table 2).

In a study on 144 sunflower genotypes Lakshmaniah (1978) found that head diameter had maximum direct effect on seed yield; further it had maximum indirect effect on seed yield through 100 seed weight, seed number and plant height. The total seed number per head and the plant height also contributed directly and positively to seed yield.

Seed number per head was reported to have highest direct effect on seed yield followed by plant height and head diameter under moisture stress (Feres et al., 1986).

Sheshagiri Rao (1989) compared the relative contributions of various parameters to yield under completely irrigated (control) and stressed conditions at two stages of crop growth. He found that test weight had the maximum direct effect on seed yield in control and late stress condition while head diameter contributed highest to seed yield under early stress. The pattern and magnitude of the direct and indirect contribution of various independent variables and seed yield was found to be substantially altered by moisture stress.

Table 2. A summary of recent papers indicating direct positive and direct negative contribution of few independent variables to seed yield.

Sl.No.	Independent variable	Contribution		References
		Direct +ve	Direct -ve	
1.	Plant height	+		Varshney and Basudeo Singh(1977); Naskar et al., (1982,1988); Lakshmaniah(1978).
2.	Head diameter	+		Varshney and Basudeo Singh(1977); Naskar et al., (1982,1988); Lakshmaniah(1978); Welkov(1980).
3.	Days to maturity		+	Varshney and Basudeo Singh(1977); Sheshagiri Rao(1989)
4.	100 seed weight	+		Naskar et al., (1982,1988); Sheshagiri Rao(1989).
5.	Seed number	+		Lakshmaniah(1978); Ferreres et al., (1986).
6.	Harvest index	+		Lakshmana Rao(1980); Ferreres et al., (1986).

Performance of genotypes under moisture stress as influenced by their duration

Under intermittent moisture stress, the performance of genotypes primarily depends upon its capability to recover on alleviation of moisture stress. Recovery growth to that of control levels are extremely poor in short than in long duration genotypes (Rawson and Turner, 1982b). The differences in survival and growth performances may not be due to the their differences in intrinsic drought tolerance mechanism but might be due to avoidance. Nevertheless they constitute an important approach to crop improvement under rainfed conditions.

In sunflower cultivars where the anthesis was only 14 days later than the early cultivars, the seed yield in the irrigated plots increased to 150 g per plant when compared to 75 g in early cultivars (Rawson and Turner, 1982a). The two-fold increase in the yield was attributed to a more rapid development of leaf area in the late cultivar. The increase in the yield in these cultivars was independent of harvest index and in fact, decreased in the late cultivar (Turner and Rawson, 1982a). Thus the increased yield of late cultivars may be a function of their duration than due to their intrinsic genetic potential.

Turner and Kramer (1980), suggested that late maturing genotypes are better adopted to conditions of

moisture stress due to the establishment of larger leaf area on availability of water. Gimenez and Fereres (1986) reported that late maturing genotypes of sunflower performed either on par or better than early maturing type under moisture stress and attributed it to a greater ability of the former to extract soil moisture.

Under extremely dryland conditions, early maturity is usually considered advantageous for sustained yield and has been documented in several small grain cereals (Turner and Begg, 1981). However, in sunflower, especially when the crop is grown under stored soil moisture the early cultivars were shown to have no advantage over the late cultivars (Rawson and Turner, 1982a, 1983). Turner and Rawson (1982) obtained similar yields under rainfed situation in all the cultivars irrespective of their duration under rainfed situation.

Sources of drought tolerance/resistance among sunflower germplasm and species

The genus Helianthus is wide spread in its geographical occurrence, ranging from swampy areas to deserts (Thompson et al., 1981). It is therefore likely, to expect natural sources of drought resistance/tolerance to moisture stress. Among nearly 305 germplasm line consisting of 23 species, Thompson and Zimmerman (1981, cf: Shehagiri Rao 1989) identified several genotypes tolerant to drought.

Sabrado and Turner (1983a) compared the tissue water relations and productivity of two cultivars of Helianthus annuus and two wild species namely H. nuttallii and H. petiolaris. All the species showed substantial reduction in leaf area and dry matter accumulation. However, there was significant decrease in osmotic potential in full turgor and zero turgor, and decrease in the turgor to dry weight ratio only in the two cultivated species. These results were further confirmed by Sabrado and Turner (1983b).

Another species, H. argophyllus, was found to be relatively drought tolerant. In this species, the leaf pubescence helps in reducing the radiation load. A hybrid between H. argophyllus and H. annuus was found to be relatively drought resistant. In the hybrids, the rate of water loss was about 39 per cent of that recorded for H. annuus parent (Ixoras and Volinesue, 1984). It was concluded that the H. argophyllus could serve as a useful source of drought tolerance in the development of sunflower for rainfed conditions.

MATERIAL AND METHODS

III. MATERIALS AND METHODS

The major objective of the study was to screen and identify drought resistance/ tolerant sources of sunflower for inclusion in the sunflower improvement programme for rainfed situations.

As outlined previously, under the normal kharif (June-September) conditions of growth, the crops usually suffer from intermittent moisture stress due to non-uniform precipitation pattern. The degree of stress that a crop experiences depends upon the period to which, and the growth stage at which, the dry spells occur. The nature and degree of such intermittent spells cannot be modelled accurately and realistically because the spells are highly variable from year to year. Thus for effective screening of the germplasm for drought resistance and tolerance, it is essential to subject the germplasm at different stages of their growth to defined stress levels. Field evaluations of this sort can essentially be done in the rain free periods of summer. In this chapter the details regarding various experimental methods followed are provided.

3.1 Plant material

The material for the study comprised 24 germplasm lines including seven commercial cultivars (Table 3) obtained from the All India Co-ordinated Research

Table 3. List of genotypes used in the study.

Sl. No.	Acc. No
1	BSH-1
2	66
3	88
4	179
5	217
6	226
7	266
8	275
9	314
10	333
11	418
12	430
13	436
14	438
15	KBSH-1
16	872
17	154
18	37
19	EC-68415
20	MFSH-8
21	Morden
22	MFSH-17
23	EC-68414
24	188

Programme(AICRP) on Sunflower and the Project Co-ordinating Unit, Sunflower, Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences, Bangalore. For laboratory evaluation of the water relation parameters of the cultivated and wild species, seeds of Helianthus argophyllus, H. praecox and H. petiolaris were obtained from the Project Co-ordinating Unit, Sunflower, GKVK and Cytogenetics Division, University of Agricultural Sciences, Hebbal, Bangalore.

3.2 Experimental location and climate

The field and laboratory experiments were conducted in the GKVK Campus, University of Agricultural Sciences, Bangalore(12° 58'N, 77° 35'E; 930mt MSL) during summer (January-May) 1989. The soil is red loam. The physical and chemical properties of soil and the climatological data for the experimental period are provided in Appendices 1 and 2 respectively.

3.3 Experimental details

3.3-1 Experiment-I: Field evaluation of sunflower germplasm for drought resistance/tolerance.

This experiment was designed,

- i) To compare the growth and yield of sunflower germplasms when subjected to prolonged moisture stress at two different stages of crop growth

namely at early vegetative and at late vegetative/early reproductive phase, with that under completely irrigated condition.

- ii) To understand the nature of relationship between yield and various independent variables as affected by moisture stress at the two stages of crop growth and
- iii) To estimate the direct and indirect contributions of various independent variables to seed yield and kernel oil percentage as affected by moisture stress.

3.3.2 Method

The experiment consisted of three moisture treatments, namely

- (a) irrigated control: where the germplasm was irrigated at weekly interval throughout the cropping season,
- (b) early stress: where the irrigation was withheld between 40 and 71 days after sowing and
- (c) late stress: where the irrigation was withheld between 58 and 93 days after sowing.

In the treatments (b) and (c), irrigation was resumed on the 72nd and 94th day after sowing respectively.

3.3.3 Layout

The experiment was laid out in a split-plot design with two replications for each treatment. A typical plot measured 3 X 2.7 square metres with two rows (Row length 2.7 meter) of three genotypes each. The standard layout design was slightly modified with the three moisture treatment blocks (control, early and late stress) separated from each other by three metres to avoid seepage of water from the irrigated block to the adjacent moisture stressed block. Recommended agronomic practices with regard to spacing, fertilizer application and plant protection measures were followed (Seetharam and Virupakshappa, 1989).

3.3.4 Sampling of plants

The data on the various biometric characters were recorded on five randomly selected plants per replication for each of the germplasm lines. All the observations except that on leaf area and days to 50 per cent flowering (DFF) were recorded at or after harvest.

3.3.5 Observations recorded

3.3.5.1 Leaf area(cm^2) per plant:

The leaf area data was recorded at three periods during the crop growth, to indicate the increment in leaf area during and on alleviation of the stress.

Thus, under early stress, the leaf area was recorded on the tagged plants on the day of imposition of stress(40th day), followed by on 71st day(end of stress), and on 93rd day (to indicate the recovery growth). Comparable measurements on the respective dates were made on the fully irrigated control plants.

Under late stress, the leaf area data was taken on the 58th day (beginning of stress) and 93rd day (end of stress) after sowing. The leaf area on the control plants was also recorded on similar days.

The leaf area was measured by recording the maximum length and breadth of each leaf in a plant and computed by multiplying their product with a factor of 0.69 and expressed as mean leaf area per plant.

3.3.5.2 Plant height(cm):

The height of the plant was measured from the base of the stem to the capitulum.

3.3.5.3 Head diameter(cm):

The maximum width of capitulum at harvest was recorded.

3.3.5.4 Seed yield(g):

The total seed weight per plant was obtained by recording the weight of seeds after they were dried in shade.

3.3.5.5 Filled seed weight(g):

Seeds obtained after threshing of each capitulum was winnowed to remove chaffy seeds. The weight of the filled seed was then recorded.

3.3.5.6 Test weight(g):

Weight of 100 randomly selected seeds was recorded.

3.3.5.7 Total dry matter(g):

Sun dried stalk, at harvest and oven dried thalamus after threshing, were weighed and summed with the total seed weight to obtain the total dry matter per plant.

3.3.5.8 Days to maturity:

The number of days taken to physiological maturity as indicated by the yellowing of thalamus from the date of sowing was recorded.

3.3.5.9 Seed oil content(per cent):

Twenty five seeds of each genotype was used to estimate the seed oil content using pulsed NMR(Nuclear Magnetic Resonance) spectrometer (Bruker, Minispect, P201). The seed oil content was expressed as percentage.

3.3.5.10 Kernel oil content(per cent):

Twenty five seeds from each genotype per replication were dehulled and used to obtain the kernel oil percentage by employing the NMR facility as mentioned above.

3.3.5.11 Kernel to hull(K/H) ratio:

The weight of 25 randomly selected filled seeds was recorded(A); these seeds were dehulled and the kernel weight was recorded(B). The kernel to hull ratio was then computed as $B/A-B$.

3.3.5.12 Harvest Index:

The ratio of the total seed weight to the total dry matter was computed to indicate the harvest index.

3.3.6 Statistical analyses:

Statistical analyses was conducted on the mean of 5 plants per replication.

3.3.6.1 Analysis of variance

The data on the various parameters was analysed in a RBD two-factorial design (Sundaraj et al 1972) which partitions the sources of variation into genotype, stress and genotypeXstress interaction.

3.3.6.2 Correlation analysis:

Simple correlation analysis among the various variables were performed separately for each of the three moisture treatments following Snedecor and Cochran(1967).

3.3.6.3 Path co-effecient analysis:

Path co-effecient analysis or modified regression analysis was conducted following Dewey and Lu (1957) to estimate the direct and indirect path contribution of several independent variables to yield and kernel oil content under the three moisture treatments separately.

3.3.6.3 Duration group wise analysis:

The germplasm in the study ranged in their duration with respect to days taken to fifty per cent flowering from 55 to 75 days. To understand if the growth and yield performance of the genotypes under different moisture treatment is influenced by their duration, the analysis was done within duration groups.

3.3.6.4 Relative performance of genotypes:

The relative growth and yield performance of genotypes as affected by moisture stress was assessed by estimating both absolute and the per cent reduction over the irrigated control for several important parameters such as leaf area, TDM, filled seed weight and test weight. Similar analysis was also conducted using duration-wise data.

3.3.6.5 Standardised normal(Z) distribution:

The standardised normal(Z) distribution scores for each germplasm based on TDM and filled seed weight was computed and plotted to categorise the germplasm into one of the four possible quadrants, namely high TDM-high seed yield; high TDM-low seed yield; low TDM-low seed yield; and low TDM-high seed yield. For each character and genotype the standardised Z scores was obtained as

$$\text{follows } Z = \frac{X_i - \bar{X}}{s}$$

where $\bar{X}$ = mean over all genotypes for a character

X_i = value of the i th genotype

σ = standard deviation

3.3.6.6 Drought susceptibility Index (DSI):

Drought susceptibility Index (DSI) indicates the performance of a genotype under stress condition compared to its maximum potential under irrigated condition (Fischer and Maurer, 1978). This is calculated based on the formula

$$DSI = (1 - Y_s/Y_c)/D$$

where Y_s = yield under moisture stress condition

Y_c = yield under irrigated condition

D = mean yield reduction under moisture stress (over all the cultivars) also termed as 'drought intensity'

The DSI for each genotype was computed for the filled seed weight and TDM, under early and late stress separately. The standardised normal distribution scores for DSI (filled seed weight and TDM) were calculated (as mentioned in 3.3.6.5) to categorise all the genotypes into highly susceptible and low susceptible in terms of filled seed weight and TDM. A separate standardised normal distribution scores for the genotypes belonging to II duration category (61-65 DFF) was also calculated.

3.4 Experiment-II: Evaluation of water relation parameters of selected germplasm under laboratory conditions.

Based on the absolute TDM and filled seed yield performance, a best and a poor performer belonging to II duration category(61-65 DFF) were each selected from the early and late stress treatment respectively.

The good and the poor performing pair from the two stresses were separately raised in containers for 30-35 days. Leaf material from these plants were used in determining the rate of water loss and loss of their membrane integrity under live wilting stress.

3.5 Experiment-III: Comparative evaluation of water relation parameters between the cultivated and wild species of *Helianthus*.

To evaluate the performance of the cultivated compared to wild species, the plants of *Helianthus annuus*(acc.no.188), *H. argophyllus*, *H. praecox* and *H. petiolaris* were raised in containers for 30-35 days. The leaves of these material were then used to estimate the differences in the rate of water loss and loss of membrane integrity when subjected to the live wilting stress.

3.6 Method:

3.6.1 Rate of loss of fresh weight:

Fully expanded 2nd or 3rd leaf from the experimental material of experiment-II and III were excised with the petioles intact in water. The leaves were allowed to regain turgid weight by incubating them in distilled water for 30 minutes under shade.

The initial turgid weight and the area (using a LICOR leaf area meter) of the leaves were recorded after excising the petiole; these were then allowed to wilt under shade ($90 \mu\text{Ein/m}^2/\text{sec}$). The leaves were periodically weighed and the per cent loss in fresh weight was computed and expressed as mg loss per cm^2 of leaf area.

3.6.2 Rate of transpirational loss of water:

The fully expanded 2nd or 3rd leaf from the experimental material of experiments II and III were excised in water with their petioles intact. The petiole length of each leaf was maintained at a certain minimum value. The leaves were allowed to regain their turgid weight by incubating them in distilled water for 45 minutes. Each of the leaves were then transferred to test tubes containing 5.0 ml distilled water, such that only lower 4 cm portion of the petiole was immersed in the water. The volume of the water remaining in the test tube

after 3 hours was measured and subtracted from the initial volume (5.0 ml) to indicate the volume of water transpired. The transpirational loss was expressed as the volume of water lost/cm² of leaf area.

3.6-3 Loss of membrane integrity under live wilting stress:

The loss of membrane integrity in tissues subjected to live wilting stress was measured following Uma Shankar (1984).

Procedure:

The fully expanded 2nd or 3rd leaf from the material of experiment-I] and III] were excised with their petiole intact in water, and allowed to regain turgidity by incubating in distilled water for 45 minutes. The initial turgid weight of the leaves was recorded after excising the petioles and these were allowed to live wilt under shade.

After the leaves had lost 40% and 60% of their fresh weight (as determined by procedure outlined in method 3-6.1), leaf punches of 1 cm diameter were made. These punches were washed for 1 to 2 minutes to leach their solutes from the cut ends and blotted. 10 leaf punches of each genotype/species was incubated in beaker containing 10 ml distilled water for 3 hours. The leakage of solutes in the bathing medium was estimated by recording its

absorbance at 273nm using a UV-double beam spectrophotometer (Shimadzu-UV-200S). This is referred to as the initial leakage of solutes.

Following this, the beakers were incubated in hot water bath (100 C) for 15 minutes. After suitable dilution, the absorbance of the bathing medium was again read at 273nm to indicate the final absorbance due to the total solutes contained in the tissue. The percentage leakage of solutes which is a direct reflection of the extent of loss of membrane integrity was calculated as:

$$= \frac{\text{Initial absorbance of bathing medium}}{\text{Final absorbance of bathing medium}} \times 100$$

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

10

In this chapter the results of the various experiments conducted to evaluate sunflower germplasm lines for drought tolerance/resistance are provided.

The field experiments involved the screening of 24 genotypes, including 7 cultivars for their relative growth and yield performance under prolonged periods of moisture stress during summer 1989. In a few selected genotypes, the leaf water relations and maintenance of membrane integrity under live wilting stress was studied. Simple assessment of the leaf water relation of three wild species of Helianthus, namely H. argophyllus, H. praecox, H. petiolaris in comparison with H. annuus was also made. These results are presented under separate sections.

Range, mean and other basic statistics for various growth, yield and oil parameters of 24 sunflower germplasm grown under fully irrigated (control), early and late stress conditions

The mean for the various growth, yield and oil parameters for 24 sunflower germplasm grown under irrigated control, early and late stress conditions is given in Appendices- 3, 4, and 5 respectively.

Data on the range, mean and standard error of the various growth, yield and oil parameters under fully

Table 4a. Range, mean and standard error for 13 characters of the sunflower genotypes grown under fully irrigated condition.

Characters	Range		Mean	Standard error($\pm$)	P
	Minimum	Maximum			
DFF	58.50	73.00	64.02	0.884	<0.01
Plant ht.(cm)	92.40	217.30	158.84	5.703	<0.01
Head dia(cm)	9.85	16.30	13.66	0.356	<0.05
Seed yield(g)	20.25	69.25	43.25	2.398	NS
Filled seed(g)	16.85	54.95	37.84	2.028	NS
Test weight(g)	4.07	7.26	5.73	0.170	<0.05
Leaf area (cm ²)	1930.00	5399.00	2967.00	142.15	<0.01
TDM(g)	61.70	163.45	114.59	5.348	<0.01
Days to maturity	89.00	106.50	99.47	0.743	<0.01
Seed oil(%)	27.85	41.05	36.22	0.779	<0.01
Kernel oil(%)	43.35	53.90	47.28	0.050	<0.01
Kernel/hull	0.96	2.76	1.61	0.085	NS
Harvest index	24.47	44.44	37.44	0.971	<0.05

Table 4b. Range, mean and standard error for 13 characters of the sunflower genotypes grown under early stress condition.

Characters	Range		Mean	Standard error($\pm$)	P
	Minimum	Maximum			
DFF	59.00	74.50	64.35	0.783	<0.01
Plant ht(cm)	67.44	155.60	116.06	3.557	<0.01
Head dia(cm)	5.75	12.50	9.54	0.345	<0.01
Seed yield(g)	6.35	54.16	21.23	2.091	<0.01
Filled seed(g)	12.30	39.75	17.63	1.728	<0.01
Test weight(g)	2.28	5.25	3.75	0.166	<0.01
Leaf area (cm ²)	488.50	1770.00	991.37	66.854	<0.05
TDM(g)	23.50	121.01	55.71	4.165	<0.01
Days to maturity	97.00	111.00	102.60	0.751	<0.01
Seed oil(%)	27.95	44.30	38.87	0.913	<0.01
Kernel oil(%)	41.05	53.70	49.39	0.584	<0.01
Kernel/hull	0.80	3.11	2.15	0.121	<0.01
Harvest index	26.93	45.11	36.43	1.076	NS

Table 4c. Range, mean and standard error for 13 characters of the sunflower genotypes grown under late stress condition.

Characters	Range		Mean	Standard error($\pm$)	P
	Minimum	Maximum			
DFE	59.50	74.00	64.31	0.964	<0.01
Plant ht.(cm)	91.90	210.09	146.32	4.534	<0.01
Head dia(cm)	7.60	14.65	11.16	0.321	NS
Seed yield(g)	7.35	53.65	26.92	2.095	<0.01
Filled seed(g)	5.50	47.30	22.04	1.807	<0.05
Test weight(g)	2.01	5.96	4.07	0.190	<0.01
Leaf area (cm ²)	1570.00	5114.05	2728.93	161.285	<0.01
TDM(g)	34.25	139.30	75.11	4.480	<0.01
Days to maturity	90.50	110.0	98.60	1.116	<0.01
Seed oil(%)	30.35	40.05	34.59	0.488	<0.01
Kernel oil(%)	40.50	53.10	46.51	0.603	NS
Kernel/hull	0.71	2.13	1.51	0.079	<0.01
Harvest index	21.45	46.73	35.09	1.264	<0.01

irrigated (control), early and late stress conditions are given in Table 4a, 4b and 4c respectively.

Under fully irrigated (here after referred to as control) condition, some of the important characters for which genotypes differed significantly were DFF, plant height, head diameter, test weight, seed and kernel oil, TDM and leaf area. The genotypes did not differ significantly for seed yield, filled seed weight and kernel/hull ratio (Table 4a).

Under early stress, where genotypes were subjected to moisture stress between 41 and 71 days after sowing, significant genotypic differences existed for all the parameters (Table 4b). Under late stress where stress was imposed between 58 and 93 days after sowing, the genotypes differed significantly in all parameters except kernel/hull ratio and kernel oil content (Table 4c). These results indicated that the early and late stress affected the genotypes differentially.

Table 5 summarises the means of the various characters under control, early and late stress. Except for DFF and harvest index, moisture stress significantly affected the mean of all the other characters. Significant genotypic differences were found for all the characters studied. The stress X genotype interaction was significant for plant height, head diameter, days to maturity, seed oil content and harvest index.

Table 5. Analysis of variance of the twelve characters between the control, early and late stress conditions.

Characters	Control	Early stress	Late stress	Stress (A)	Genotype (B)	AxB
DFP	64.02a	64.35a	64.31a	NS	**	NS
Plant ht(cm)	158.84a	116.06b	146.32c	**	**	**
Head dia(cm)	13.66a	9.54b	11.16c	**	**	**
Seed yield(g)	43.25a	21.22b	26.92c	**	**	NS
Filled seed(g)	37.84a	17.63b	22.04c	**	**	NS
Test weight(g)	5.73a	3.75b	4.07c	*	**	NS
TDM(g)	114.59a	55.71b	75.11c	**	**	NS
Seed oil(%)	36.22a	38.87b	34.59c	**	**	**
Kernel oil(%)	47.28a	49.39b	46.51a	**	**	NS
Kernel/hull	1.61a	2.19b	1.51a	**	**	NS
Days to maturity	99.5a	102.6b	98.6c	**	**	**
Harvest index	37.4a	36.4ab	35.1b	NS	**	*

*Significant at P (<0.05)

**Significant at P (<0.01)

NS - Non significant

Table 6. Per cent reduction of the various characters control in early and late stress conditions.

Characters	Control	Early stress	Per cent reduction	Late stress	Per cent reduction
DFF	64.02	64.35	-	64.31	-
Plant ht.(cm)	158.84	116.06	26.93	146.32	7.88
Head dia(cm)	13.66	9.54	30.16	11.16	18.30
Seed yield(g)	43.25	21.22	50.93	26.92	37.75
Filled seed(g)	37.84	17.63	53.40	22.04	41.75
Test weight(g)	5.73	3.75	34.55	4.07	28.97
TDM(g)	114.59	55.71	51.38	75.11	34.45
Seed oil(%)	36.22	38.87	-	34.59	-
Kernel oil(%)	47.28	49.39	-	46.51	1.62
Kernel/hull	1.61	2.19	-	1.51	5.90
Days to maturity	99.50	102.60	-	98.60	0.90
Harvest index	37.40	36.40	2.67	35.10	6.14

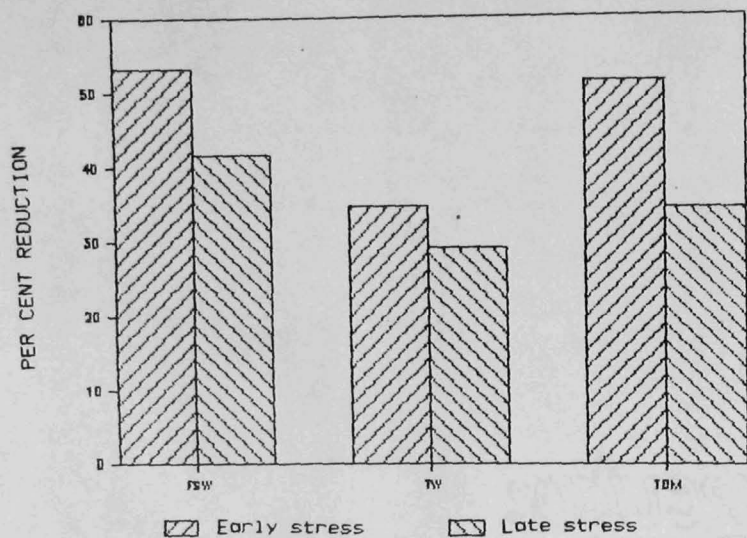


Fig. 3 Over all per cent reduction under early and late stress compared to control for filled seed weight(FSW), test weight(TW) and TDM

The percentage reduction in the means of the various characters as affected by early and late stress is given in Table 6. Seed and kernel oil per cent and kernel/hull ratio were affected very negligibly due to moisture stress. For instance, the per cent reduction in seed and kernel oil percentage and kernel/hull ratio under late stress was only 1.62, 4.5 and 5.9 per cent respectively. Under early stress, there was virtually no reduction in these traits; on the contrary there was a small increase in all the three parameters. The mean total dry matter decreased from 114.59 g per plant in irrigated condition to 55.71 g per plant in early stress, and 75.11 g in late stress. Thus there was nearly 15 to 20 per cent greater reduction in total dry matter under early stress compared to late stress. The filled seed weight decreased by 53.4 and 41.75 per cent under early and late stress respectively (Fig. 3). The decrease in the test weight from the irrigated control treatment was 34.5 and 28.9 per cent under early and late stress respectively.

In summary, most of the growth and yield parameters are adversely affected by moisture stress. The effect of moisture stress at the early vegetative phase (41-71 DAS) seems to be more detrimental than when the stress is imposed at late vegetative/early reproductive phase.

Association between performance of genotypes under control, early and late stress condition.

To study if the performance of various genotypes under early and late stress with respect to the growth, yield and oil parameters is related to their performance under fully irrigated condition, a correlation analysis for the various parameters between them was conducted (Table 7; Fig. 4a, 4b). Highly significant positive correlation was obtained for the performance of genotypes between control and early stress for characters such as filled seed weight($r=0.58$), total dry matter($r=0.68$), kernel/hull ratio($r=0.45$), test weight($r=0.43$), leaf area($r=0.57$) and kernel($r=0.44$) and seed oil($r=0.89$) percentage. Between the control and late stress performance, significant positive correlation was obtained for TDM($r=0.70$), seed oil($r=0.60$), test weight($r=0.63$) and leaf area($r=0.66$). However, the performance of the genotypes based on filled seed weight, kernel oil content and kernel/hull ratio was not significantly correlated. These results indicate that to a large extent, the performance of the genotypes with respect to various growth and yield parameters under fully irrigated condition, might offer reasonable prediction regarding their absolute performance under early and late stress conditions.

However, such predictability could not be made on the per cent reduction in the various characters due

Characters	Filled seed wt (g)	TDM (g)	Kernel oil (%)	Kernel Hull	Seed oil (%)	Test weight	Leaf area (cm ²)
FSW(g)	E 0.508** L 0.323NS	-	-	-	-	-	-
TDM(g)	E - L -	0.678** 0.703**	-	-	-	-	-
Kernel oil (%)	E - L -	-	0.447* 0.342NS	-	-	-	-
Kernel/ hull	E - L -	-	-	0.417* 0.396NS	-	-	-
Seed oil (%)	E - L -	-	-	-	0.889** 0.605**	-	-
Test weight (g)	E - L -	-	-	-	-	0.426* 0.634**	-
Leaf area (cm ²)	E - L -	-	-	-	-	-	0.556** 0.662**

E - Early stress
L - Late stress

*Significant at P (<0.05)
**Significant at P (<0.01)

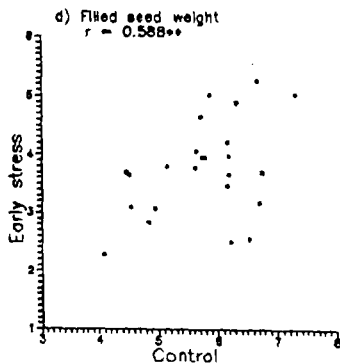
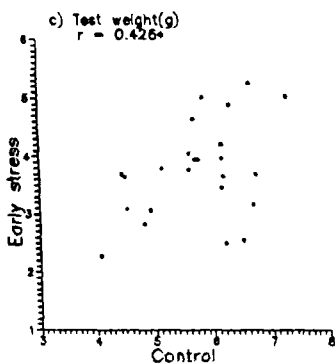
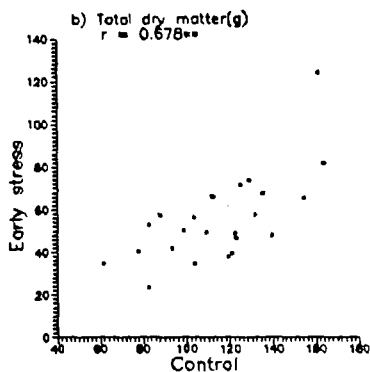
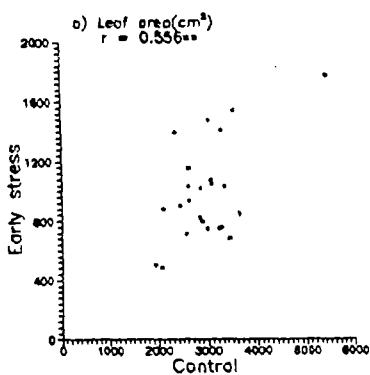


Fig. 4a Correlation between the control and early stress for a) leaf area, b) TDM, c) test weight and d) filled seed weight.

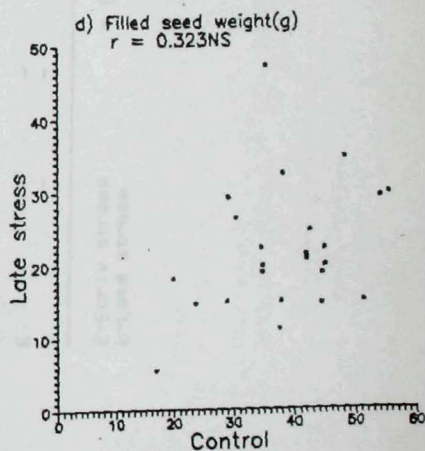
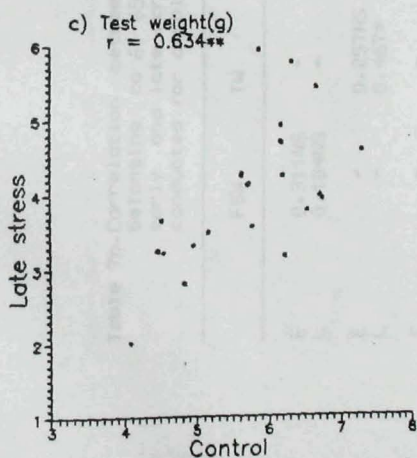
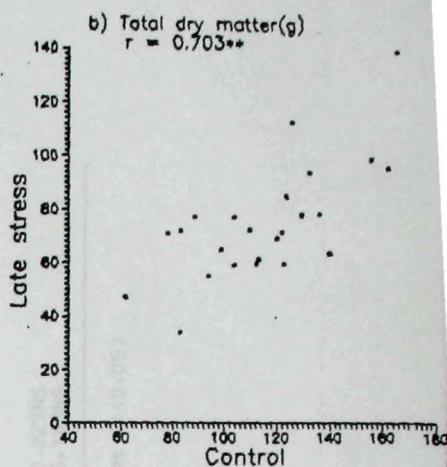
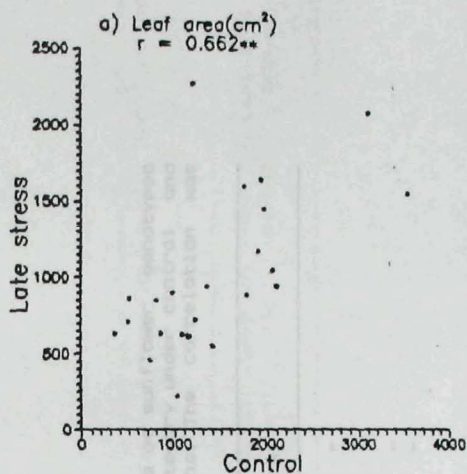


Fig. 4b Correlation between the control and late stress for a) leaf area, b) TDM, c) test weight and d) filled seed weight.

Table 7b. Correlation between performance of sunflower genotypes belonging to 61-65 duration category under control and early and late stress conditions. The correlation was conducted for absolute values.

	FSW	TW	TDM	LA
E	0.311NS	-	-	-
L	0.184NS	-	-	-
E	-	0.257NS	-	-
L	-	0.467*	-	-
E	-	-	0.346NS	-
L	-	-	0.203NS	-
E	-	-	-	0.227NS
L	-	-	-	0.188NS

* Significant at $P(<0.05)$

E-Early stress
L-Late stress

Table 8a. Correlation between the absolute control performance and per cent reduction under early and late stress conditions for various characters (N=24).

Characters	Filled seed wt (g)	TDM (g)	Kernel oil (%)	Kernel Hull	Seed oil (%)	Test weight	Leaf area (cm ²)
FSW (g)	E -0.082NS L 0.295NS	-	-	-	-	-	-
TDM (g)	E - L -	0.011NS 0.203NS	-	-	-	-	-
Kernel oil (%)	E - L -	-	0.437* 0.470*	-	-	-	-
Kernel/hull	E - L -	-	-	0.341NS 0.456*	-	-	-
Seed oil (%)	E - L -	-	-	-	0.005NS 0.793**	-	-
Test weight (g)	E - L -	-	-	-	-	0.267NS -0.063NS	-
Leaf area (cm ²)	E - L -	-	-	-	-	-	0.161NS 0.470*

E - Early stress
L - Late stress

*Significant at P (<0.05)
**Significant at P (<0.01)

Table 8b. The correlation between the absolute performance under control and per cent reduction under early and late stress for sunflower genotypes belonging to 61-65 DFF duration category.

	FSW	TW	TDM	LA
E	0.291NS	-	-	-
L	0.387NS	-	-	-
E	-	0.459**	-	-
L	-	0.157NS	-	-
E	-	-	0.355NS	-
L	-	-	0.524***	-
E	-	-	-	0.222NS
L	-	-	-	0.338NS
E-Early stress			** Significant at P(<0.05)	
L-Late stress			*** Significant at P(<0.01)	

to early and late stress (Table 8). Thus under early stress, except for kernel oil content there was no significant correlation between the absolute growth and yield performance of genotypes under control condition with that of the per cent reduction in their characters over the control. In late stress, only kernel/ hull ratio, seed and kernel oil content were correlated .

Similar correlation analyses was also conducted for the II duration group (61-65, see Table 12) to know whether the above observed pattern exists (Table 7b, 8b). However, except test weight under late stress, all other characters were not correlated with their absolute control performance. The per cent reduction of test weight under early stress and TDM under late stress showed significant correlation with their control absolute performance (Table 8b).

Correlation among the various growth, yield and oil parameters under irrigated, early and late stress conditions

Simple correlation analysis were conducted for several growth, yield and oil parameters for the sunflower genotypes subjected to complete irrigation, early and late stress separately (Table 9a, b, c). In the following, several prominent associations are highlighted.

The TDM was significantly and positively correlated with DFF, plant height, head diameter, filled seed weight and test weight under all the three conditions of growth. Its correlation with seed oil was negative under control and early stress. Similarly, the correlation between the leaf area at flowering and other growth and yield parameters was highly positive and significant except kernel/hull ratio and kernel and seed oil content. Thus the influence of moisture stress on the association of these two important growth parameters, namely TDM and leaf area with other yield attributes remains unaltered though the magnitude of their association is weakened. The correlation of filled seed weight was significant and positive with head diameter, DFF and test weight; it was poorly correlated with seed oil content, kernel oil content and kernel/hull ratio. The magnitude of association of test weight with filled seed weight increased from control to early and late stress treatments.

The 100 seed weight (test weight) was either not correlated or very weakly correlated to seed and kernel oil percentage. The test weight was significantly and negatively correlated to kernel/hull ratio under early stress only; it was not correlated under control and late stress conditions. Finally, the per cent seed oil content was found to be significantly and positively associated with kernel/hull ratio under control and early stress

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	
X1	1.00	0.695**	0.337*	0.506**	0.441**	-0.380**	0.231NS	-0.030NS	0.676**	-0.041NS	0.473**	0.480**
X2		1.00	0.392**	0.630**	0.557**	-0.464**	0.368**	-0.022NS	0.752**	-0.099NS	0.377**	0.508**
X3			1.00	0.561**	0.561**	-0.060NS	0.565**	0.235NS	0.671**	0.280NS	0.134NS	0.330**
X4				1.00	0.955**	-0.232NS	0.627**	-0.036NS	0.902**	0.128NS	0.363**	0.642**
X5					1.00	-0.198NS	0.621**	-0.017NS	0.856**	0.179NS	0.319*	0.565**
X6						1.00	-0.244NS	0.431**	-0.366*	0.570**	-0.114NS	-0.325*
X7							1.00	0.095NS	0.607**	0.050NS	0.264NS	0.489**
X8								1.00	-0.006NS	0.263NS	0.175NS	-0.104NS
X9									1.00	0.009NS	0.424**	0.650**
X10										1.00	-0.046NS	-0.114NS
X11											1.00	0.344*
X12												1.00

X1-10FF; X2-Plant height; X3-Head diameter; X4-Seed yield; X5-Filled seed weight; X6-Seed oil content; X7-Test weight
X8-Kernel/hull ratio; X9-1000 dry matter; X10-Kernel oil content; X11-Days to maturity; X12-Leaf area
* Significant at P (0.05)
** Significant at P (0.01)

Table 9b. Correlation matrix of the various characters of sunflower genotypes grown under early stress condition.

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12
X1	1.00	0.390**	0.327**	0.399**	0.297*	-0.642**	0.220NS	-0.540**	0.348*	-0.533**	0.288*	0.154NS
X2		1.00	0.678**	0.693**	0.686**	-0.503**	0.594**	-0.609**	0.711**	-0.330*	0.270NS	0.485**
X3			1.00	0.800**	0.760**	-0.266NS	0.757**	-0.501**	0.814**	0.013NS	0.433**	0.685**
X4				1.00	0.922**	-0.370**	0.778**	-0.483**	0.971**	-0.119NS	0.466**	0.764**
X5					1.00	-0.350*	0.727**	-0.427**	0.882**	-0.105NS	0.548**	0.741**
X6						1.00	-0.235NS	0.527**	-0.335*	0.752**	-0.117NS	-0.129NS
X7							1.00	-0.511**	0.767**	0.052NS	0.282NS	0.570**
X8								1.00	-0.501**	0.434**	-0.037NS	-0.353*
X9									1.00	-0.103NS	0.463**	0.765**
X10										1.00	-0.090NS	-0.022NS
X11											1.00	0.433**
X12												1.00

X1-Off; X2-Plant height; X3-Head diameter; X4-Seed yield; X5-Filled seed weight; X6-Seed oil content; X7-Test weight
 X8-Kernel/hull ratio; X9-Total dry matter; X10-Kernel oil content; X11-Days to maturity; X12-Leaf area

* Significant at $p < (0.05)$

** Significant at $p < (0.01)$

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12
X1	1.00	0.546**	0.291*	0.552**	0.517**	-0.017NS	0.417**	-0.152NS	0.546**	0.300*	0.620**	0.537**
X2		1.00	0.556**	0.576**	0.513**	-0.083NS	0.475**	-0.094NS	0.664**	0.076NS	0.519**	0.741**
X3			1.00	0.690**	0.679**	0.192NS	0.631**	-0.150NS	0.705**	0.311*	0.527**	0.643**
X4				1.00	0.946**	0.184NS	0.836**	-0.058NS	0.885**	0.411**	0.457**	0.779**
X5					1.00	0.314*	0.836**	0.007NS	0.799**	0.494**	0.416**	0.684**
X6						1.00	0.123NS	0.232NS	0.075NS	0.411**	0.061NS	-0.092NS
X7							1.00	-0.064NS	0.802**	0.317*	0.400**	0.560**
X8								1.00	-0.068NS	0.314*	-0.232NS	-0.167NS
X9									1.00	0.350*	0.535**	0.758**
X10										1.00	0.243NS	0.156NS
X11											1.00	0.446**
X12												1.00

X1-Off; X2-Plant height; X3-Head diameter; X4-Seed yield; X5-Filled seed weight; X6-Seed oil content; X7-Test weight

X8-kernel/hull ratio; X9-total dry matter; X10-kernel oil content; X11-days to maturity; X12-leaf area

* Significant at P (0.05)

** Significant at P (0.01)

conditions. The kernel oil content was also found to be correlated with kernel/hull ratio but only under early and late stress conditions.

In summary the results of the correlation analyses indicate that, moisture stress at early and late stages of crop growth, does not alter the nature of association among the characters substantially, except altering the magnitude of the association. The differences in the magnitude of the association among various characters, may however affect the contribution of these variables to seed yield under the stress treatments compared with that under control.

An attempt has been made here to determine the relative direct and indirect contributions of several independent variables to seed yield and kernel oil content by conducting path co-efficient analysis.

Path co-efficient analysis

The path co-efficient analysis is a modified regression analysis employed to estimate the direct and indirect contributions of a few selected independent variables to the dependent variable.

a) For filled seed weight:

In this study the direct and indirect contribution of DFF, head diameter, test weight, TDM and

Table 10a. Direct and indirect contribution of five characters to filled seed weight under control condition.

Characters	DFF	HD	TW	TDM	LA	PC
DFF	-0.2362	-0.0375	0.0283	0.6908	-0.0043	0.441
HD	-0.0796	-0.1114	0.0693	0.6856	-0.0030	0.561
TW	-0.0546	-0.0629	0.1226	0.6203	-0.0044	0.621
TDM	-0.1597	-0.0747	0.0744	1.0218	-0.0059	0.856
LA	-0.1134	-0.0367	0.0600	0.6642	-0.0090	0.565

Residual factor 0.2209

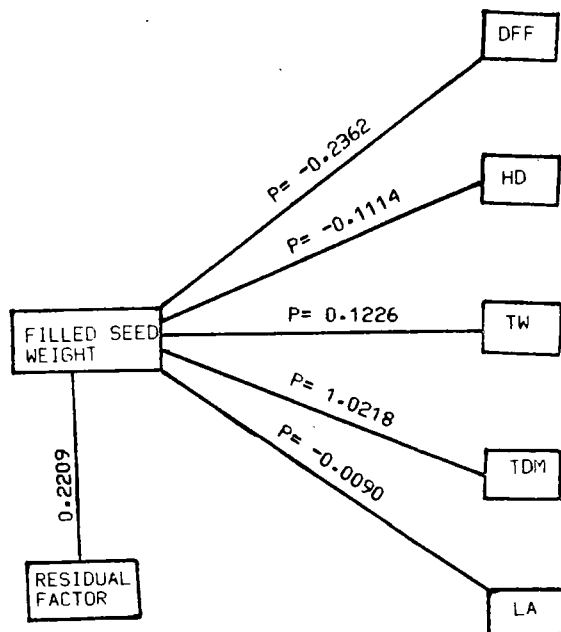


Fig. 5a Path diagram of contribution of five characters to filled seed weight under fully irrigated condition.

Table 10b. Direct and indirect contribution of five characters to filled seed weight under early stress condition.

Characters	DFF	HD	TW	TDM	LA	PC
DFF	0.0130	0.0157	0.0254	0.2182	0.0248	0.297
HD	0.0042	0.0480	0.0872	0.5104	0.1101	0.760
TW	0.0029	0.0363	0.1152	0.4810	0.0916	0.727
TDM	0.0045	0.0390	0.0884	0.6271	0.1230	0.882
LA	0.0020	0.0329	0.0657	0.4797	0.1607	0.741

Residual factor 0.2037

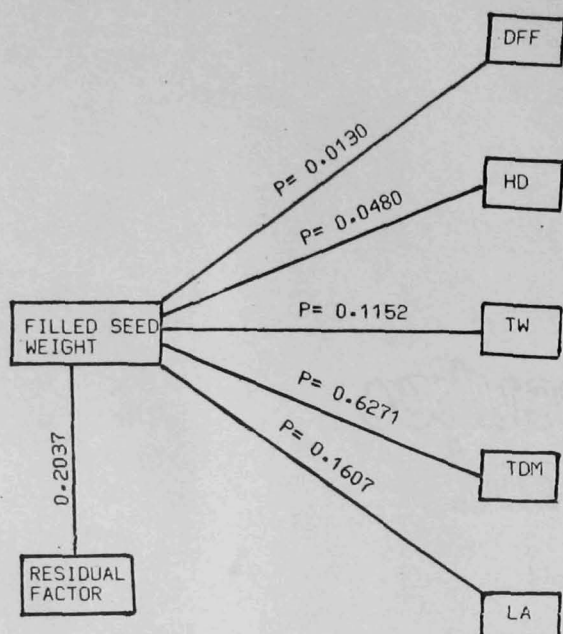


Fig. 5b Path diagram of contribution of five characters to filled seed weight under early stress condition.

Table 10c. Direct and indirect contribution of five characters to filled seed weight under late stress condition.

Characters	DFF	HD	TW	TDM	LA	PC
DFF	<u>0.1198</u>	0.0415	0.2299	0.0317	0.0941	0.517
HD	0.0349	<u>0.1427</u>	0.3479	0.0409	0.1126	0.679
TW	0.0500	0.0900	<u>0.5514</u>	0.0465	0.0981	0.836
TDM	0.0654	0.1006	0.4422	<u>0.0580</u>	0.1328	0.799
LA	0.0643	0.0917	0.3088	0.0439	<u>0.1752</u>	0.684

Residual factor 0.2141

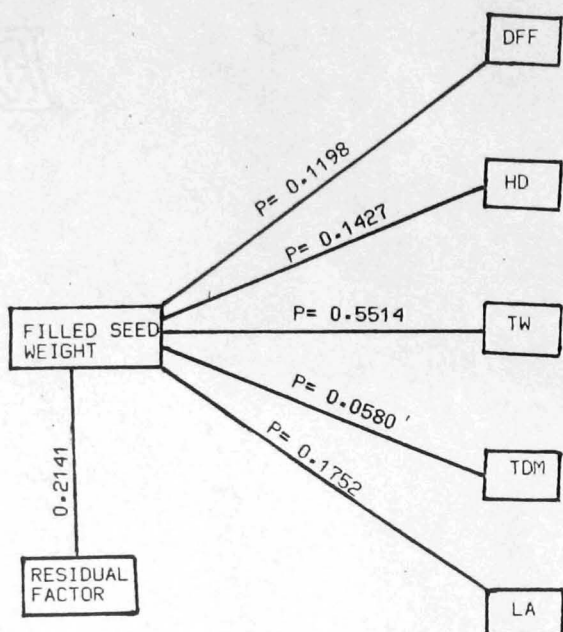


Fig. 5c Path diagram of contribution of five characters to filled seed weight under late stress condition.

leaf area on the filled seed weight was estimated separately for control, early and late stress treatments (Table 10a, b, c).

In fully irrigated treatment, the TDM contributed the highest direct effect ($P = 1.0218$) towards seed yield. The indirect contribution of TDM was highest through DFF, though negative (-0.1597). The direct contribution of test weight, head diameter, leaf area and DFF was 0.1226 , -0.1114 , -0.009 and -0.2362 respectively (Table 9a and Fig.5a). The indirect contribution of these variables to yield was substantial only through TDM.

These selected independent variables seem to explain the major contribution to seed yield considering that the residual factor obtained is only 0.2209 .

The contribution of the various independent variables to filled seed weight under early stress was almost similar to that under control. The TDM contributed the highest direct effect (0.6271), followed by leaf area (0.1607), test weight (0.1152), head diameter (0.048) and DFF (0.013). The indirect contribution of the various characters was highest through TDM (Table 10b:Fig.5b). In the early stress treatment also, the residual factor was small (0.2307).

The direct and indirect path co-efficients of the independent variables to seed yield was substantially

altered under late stress conditions compared to that under control and early stress. The highest direct path contribution was obtained from test weight (0.5514) followed by leaf area (0.1572), head diameter (0.1427) and DFF (0.1198). The indirect contribution of the independent variables to filled seed weight was highest through test weight. The residual contribution was 0.214 (Table 9c; Fig.5c).

The above results indicate that despite the highly significant and positive correlation of the various independent variables to filled seed weight, their direct contribution to filled seed weight is markedly different. The results show that the pattern of contribution of the independent variables such as DFF, leaf area, TDM, test weight and head diameter to seed yield are similar for the genotypes when subjected to complete irrigation and moisture stress between 40 and 71 days after sowing, though the magnitudes of the contribution were different. However, the contribution to filled seed weight when the crop was subjected to stress at later stages between 58 and 93rd day is markedly different from that under control and early stress. While the highest direct contribution to filled seed weight under control and the early stress was accounted by TDM, that under late stress was by test weight.

b) For kernel oil content(%)

The direct and indirect contribution of DFF, filled seed weight, test weight, TDM and kernel/hull ratio to the kernel oil content was also estimated under fully irrigated, early and late stress conditions (Table 11a, b, c).

Filled seed weight contributed highest positive direct effect ($P = 0.7235$) to the kernel oil. The indirect effect of the various characters through TDM was high and negative. However, the contribution of the selected independent variables is not substantial considering the high residual effect (0.8095) (Table 11a; Fig. 6a).

The direct contribution to per cent kernel oil under early stress was highest through test weight (0.4237) followed by kernel/hull ratio (0.4016). The contribution through DFF and filled seed weight was negative (-0.3783 and -0.2039 respectively). Except for DFF, the indirect contribution of other variables through test weight was high. The characters considered appear to explain the kernel oil content better under early stress given that the residual factor was only 0.5894 (Table 11b; Fig. 6b).

In contrast to early stress, the highest positive direct effect on kernel oil under late stress was from

Table 11a. Direct and indirect contribution of five characters to kernel oil content under control condition.

	OFF	TDM	FSW	TW	K/H	PC
DFP	0.0889	-0.4257	0.3191	-0.0148	-0.0084	-0.041
TDM	0.0601	-0.6298	0.6193	-0.0390	-0.0017	0.009
FSW	0.0392	-0.5391	0.7235	-0.0399	-0.0048	0.179
TW	0.0205	-0.3823	0.4493	-0.0642	0.0266	0.050
K/H	-0.0027	0.0038	0.0123	-0.0061	0.2803	0.263

Residual factor: 0.8093

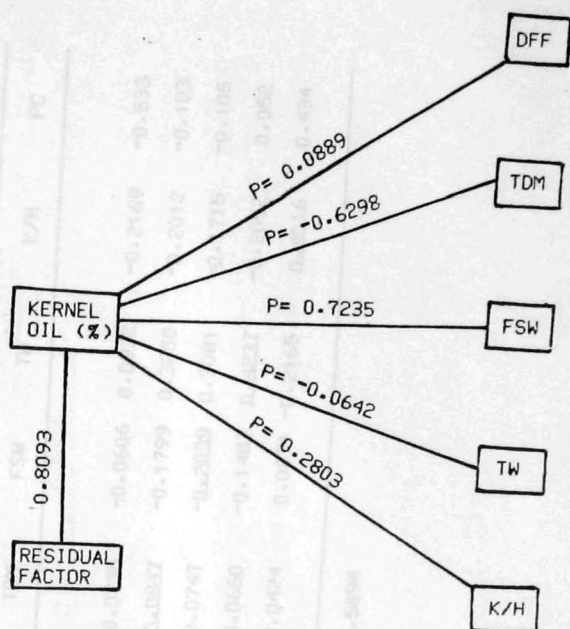
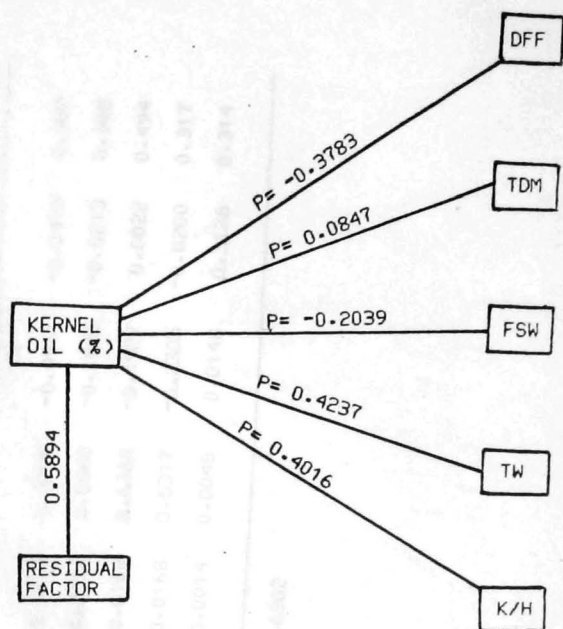


Fig. 6a Path diagram of contribution of five characters to per cent kernel oil under fully irrigated condition.

Table 11b. Direct and indirect contribution of five characters to kernel oil content under early stress condition.

	DFF	TDM	FSW	TW	K/H	PC
DFF	-0.3783	0.0295	-0.0606	0.0932	-0.2169	-0.533
TDM	-0.1316	0.0847	-0.1799	0.3250	-0.2012	-0.103
FSW	-0.1123	0.0747	-0.2039	0.3081	-0.1715	-0.105
TW	-0.0832	0.0650	-0.1483	0.4237	-0.2052	0.052
K/H	0.2043	-0.0424	0.0871	-0.2165	0.4016	0.434

Residual factor: 0.5894



F19. 6b Path diagram of contribution of five characters to per cent kernel oil early stress irrigated condition.

Table 11c. Direct and indirect contribution of five characters to kernel oil content under late stress condition.

	DFF	TDM	FSW	TW	K/H	PC
DFF	0.1263	-0.0115	0.3288	-0.0961	-0.0475	0.300
TDM	0.0689	-0.0210	0.5082	-0.1849	-0.0213	0.350
FSW	0.0653	-0.0168	0.6360	-0.1927	0.0022	0.494
TW	0.0527	-0.0168	0.5317	-0.2305	-0.0200	0.317
K/H	-0.0192	0.0014	0.0045	0.0148	0.3126	0.314

Residual factor: 0.6302

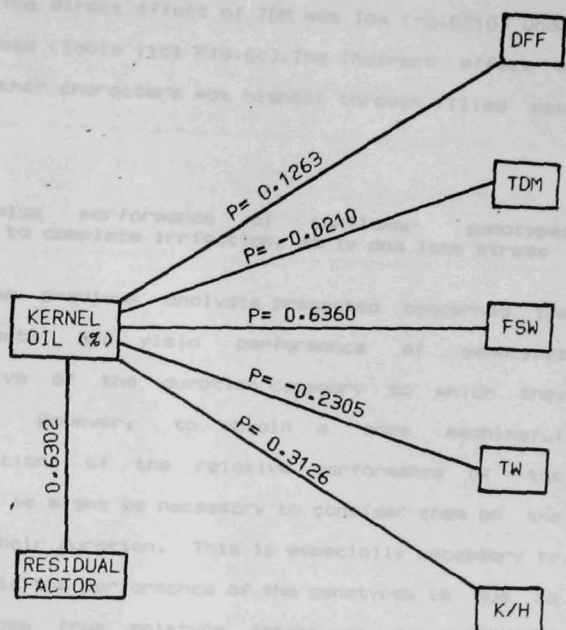


Fig. 6c Path diagram of contribution of five characters to per cent kernel oil under late stress condition.

filled seed weight (0.6360) followed by kernel/hull ratio (0.3126). The contribution through test weight was negative (-0.2305). Compared to that obtained under control, the direct effect of TDM was low (-0.0210) under late stress (Table 11c; Fig.6c). The indirect effect of all the other characters was highest through filled seed weight.

Duration-wise performance of sunflower genotypes subjected to complete irrigation, early and late stress

The previous analysis presented concerned the mean growth and yield performance of genotypes irrespective of the duration category to which they belonged. However, to obtain a more meaningful representation of the relative performance of the genotypes, it might be necessary to consider them on the basis of their duration. This is especially necessary to evaluate if the performance of the genotypes is due to their escape from moisture stress or due to their intrinsic resistance/ tolerance to stress.

Accordingly, the genotypes were grouped under four duration classes depending on days taken to 50 per cent flowering under control condition (Table 12). The mean of the genotypes in each duration category for various characters under the three different moisture treatment is given in Table 13. The mean plant height, seed yield, filled seed weight, test weight, TDM and leaf

Table 12. Classification of genotypes into duration classes based on days taken to 50 per cent flowering(DFF) under control condition.

Duration class	DFF	N	Genotypes(Sl.No.)
I	55-60	4	5,17,22,21.
II	61-65	12	1,2,3,6,7,9,10,15,16,18,23,24.
III	66-70	4	8,11,19,20.
IV	71-75	4	4,12,13,14

Table 13. Classification of genotypes into duration-wise mean of various characters under control, early and late stress condition. The duration-wise per cent reduction under early and late stress over the corresponding control is also provided.

Duration N classes	Control	Early stress	Per cent reduction	Late stress	Per cent reduction
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a) Days taken to 50% flowering:

I 4	59.1±0.23	61.1±1.00	-	62.0±1.20	-
II 12	62.1±0.32	62.6±0.48	-	61.7±0.64	-
III 4	67.2±0.07	66.5±1.14	-	65.7±0.94	-
IV 4	71.5±0.61	70.5±1.48	-	73.2±0.59	-

(b) Plant height(cm):

I 4	126.1±14.8	98.5±10.4	21.86	126.6±12.70	-
II 12	153.2±3.70	112.9± 2.2	26.30	141.2± 2.66	7.83
III 4	166.3±6.31	120.5± 6.3	27.54	148.9± 1.17	10.48
IV 4	201.1±8.80	138.5±9.66	31.11	178.7±14.05	11.12

(c) Filled seed(g):

I 4	28.0±3.75	14.3±3.9	48.75	18.7±1.62	33.03
II 12	37.7±2.65	13.4±1.5	64.56	17.6±1.72	53.42
III 4	38.1±3.32	20.8±1.9	45.41	25.4±3.28	33.22
IV 4	47.7±4.59	30.5±3.1	36.04	35.4±4.14	25.89

(d) Test weight:

I 4	5.49±0.64	4.10±0.44	25.31	3.91±0.29	28.68
II 12	5.72±0.24	3.27±0.18	42.83	3.67±0.23	36.83
III 4	5.48±0.36	3.83±0.09	30.01	3.99±0.24	27.08
IV 4	6.22±0.16	4.77±0.28	23.23	5.49±0.27	11.76

(e) Total dry matter:

I 4	84.9±10.4	49.7±7.32	41.46	63.9±6.63	24.72
II 12	111.1±5.46	46.5±3.65	58.08	66.4±4.15	40.22
III 4	118.5±6.88	59.2±4.89	50.05	75.7±5.01	36.09
IV 4	150.9±8.92	85.6±13.2	43.24	111.8±9.85	25.91

Duration	M	Control	Early stress	Per cent reduction	Late stress	Per cent reduction
classes						

(f) Seed oil content(%):

I	4	37.7±1.13	41.7±0.45	-	34.3±0.60	9.01
II	12	36.7±0.81	39.9±0.90	-	34.2±0.61	6.81
III	4	38.4±1.67	39.7±1.94	-	36.6±1.63	4.68
IV	4	31.1±2.30	31.9±2.19	-	33.9±1.47	-

(g) Kernel oil content(%):

I	4	46.8±1.03	51.7±0.88	-	45.6±0.97	2.56
II	12	47.2±0.59	49.4±0.63	-	45.0±0.70	4.66
III	4	49.6±1.46	50.4±0.93	-	49.6±0.88	-
IV	4	45.6±1.38	45.8±1.76	-	48.7±1.49	-

(h) Kernel/hull ratio:

I	4	1.49±0.14	2.38±0.20	-59.02	1.42±0.22	4.87
II	12	1.73±0.12	2.47±0.11	-43.10	1.55±0.11	10.25
III	4	1.61±0.24	2.03±0.02	-25.88	1.62±0.25	-4.95
IV	4	1.36±0.25	1.30±0.32	3.90	1.39±0.21	-2.28

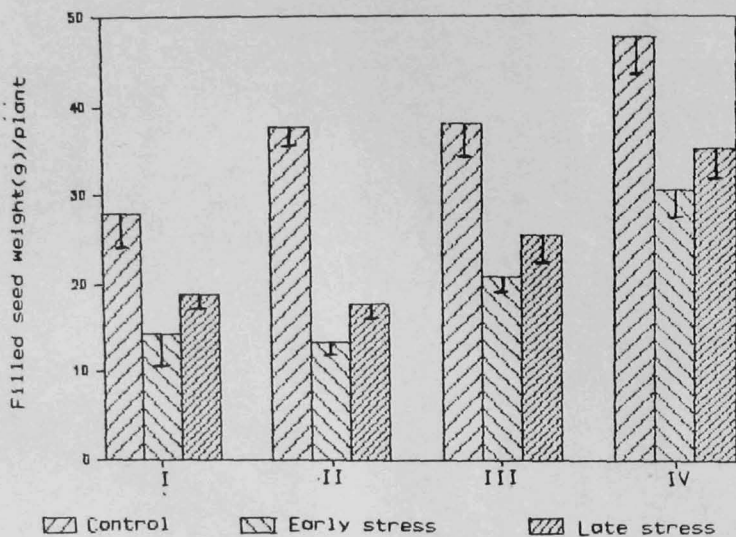


Fig. 7a Duration-wise mean of filled seed weight(g)/plant under control, early and late stress conditions.

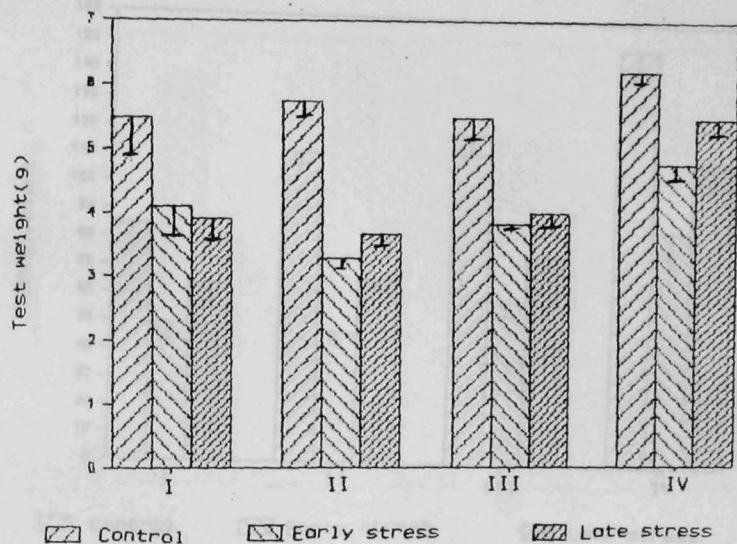


Fig. 7b Duration-wise mean of test weight(g) under control, early and late stress conditions.

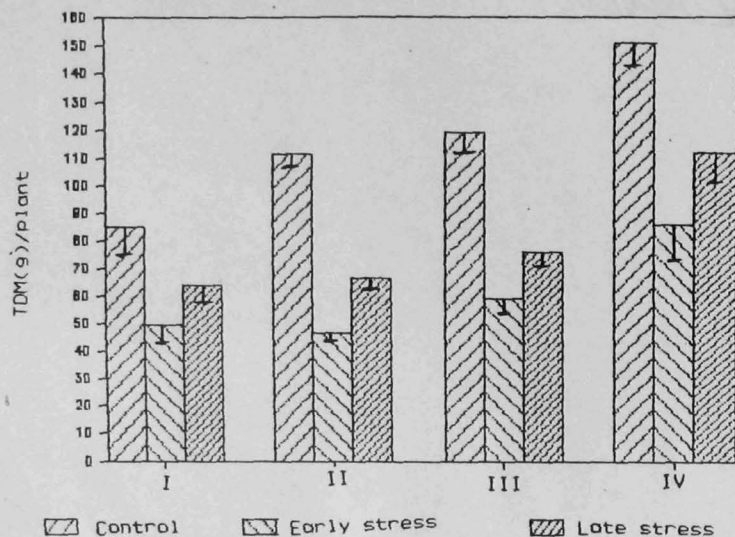


Fig. 7c Duration-wise mean of TDM(g)/plant under control, early and late stress conditions.

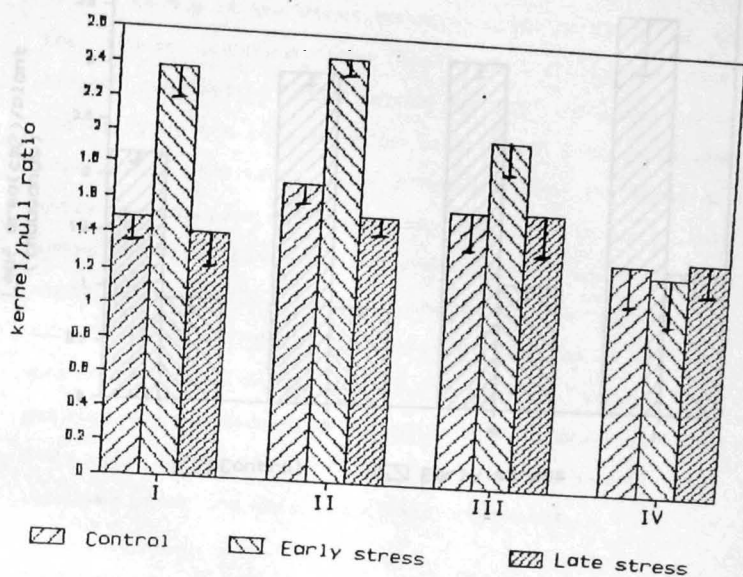


Fig. 7d Duration-wise mean of kernel/hull ratio under control, early and late stress conditions.

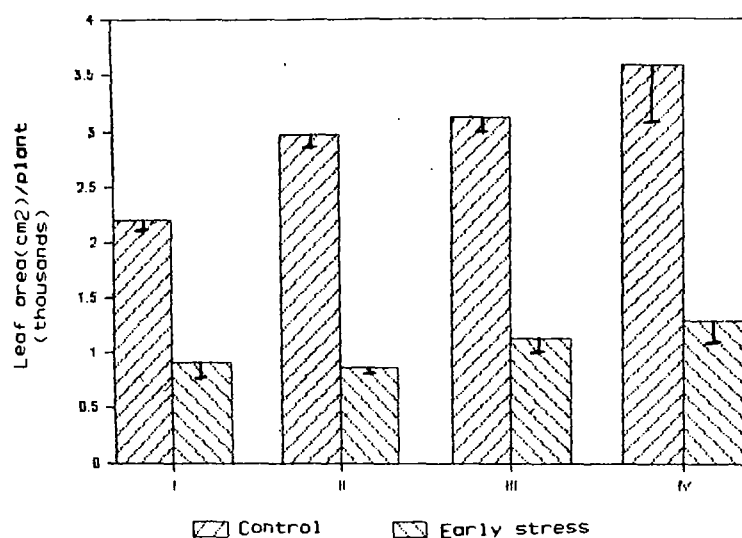


Fig. 7e Duration-wise mean of leaf area (cm²/plant) under control and early stress conditions.

area increased with the duration group under the fully irrigated treatment (Fig. 7a, b, c, e). For instance, the filled seed weight increased from 28g per plant in early duration genotypes (55-60 DFF) to 47.7 g in genotypes of 71-75 DFF duration category. Similarly TDM increased from 84.9 g in the first duration class to 150.9 g in the fourth duration class (Table 13; Fig. 7c). The mean filled seed weight, test weight and TDM increased from the early to the late duration class under both early and late stress condition. Thus, irrespective of the time at which the moisture stress was imposed, on an average, the longer duration genotypes performed better than the early duration genotypes. However, there was no particular duration-wise pattern in the percent reduction of various character over control under early and late stress. No particular duration-wise relation with regards to the seed and kernel oil percent, kernel/hull ratio were observed under the moisture stress treatments.

Duration-wise leaf area recovery on alleviation of stress

As an index of the ability of the genotype to sustain growth during the period of stress and recovery on alleviation of stress, the leaf area growth during and on alleviation of moisture stress was studied. For the purpose of analyses, the mean of characters over genotypes belonging to a duration group were considered.

For a similar period (40 to 71 days after

Table 14. Leaf area(cm^2) growth during early stress(40 to 71 DAS) and recovery growth(on 93 DAS) after alleviation of stress.

Treatment	40DAS (cm^2/plant)	71DAS (cm^2/plant)	LA growth per day (cm^2/plant)	93DAS (cm^2/plant)	Per cent growth over 71DAS
a) Over all genotypes					
Control	1281 $\pm$ 56.9	2967 $\pm$ 142.2	56.2 $\pm$ 4.22	1430 $\pm$ 157.9	-51.8
EARLY STRESS REDUCTION(%)	1321 $\pm$ 64.6	991 $\pm$ 66.8	-10.9 $\pm$ 2.30	891 $\pm$ 111.6	-10.6
		66.59		37.69	
b) Duration-wise					
I Duration category(55-60 DFF)					
Control	1214 $\pm$ 153.5	2206 $\pm$ 116.4	33.1 $\pm$ 1.9	753 $\pm$ 157	-65.7
Early stress	1352 $\pm$ 91.5	919 $\pm$ 182.2	-14.4 $\pm$ 3.9	432 $\pm$ 60	-52.9
Reduction(%)		58.9		42.5	
II Duration category(61-65 DFF)					
Control	1247 $\pm$ 69.3	2964 $\pm$ 129.5	57.3 $\pm$ 3.3	1313 $\pm$ 165.6	-55.7
Early stress	1243 $\pm$ 75.4	872 $\pm$ 67.9	-12.4 $\pm$ 3.0	644 $\pm$ 95.5	-26.1
Reduction(%)		70.4		50.9	
III Duration category(66-70 DFF)					
Control	1211 $\pm$ 50.4	3120 $\pm$ 188.1	63.6 $\pm$ 7.6	1460 $\pm$ 188.6	-53.2
Early stress	1123 $\pm$ 17.6	1132 $\pm$ 161.5	0.38 $\pm$ 5.7	1252 $\pm$ 98.6	10.9
Reduction(%)		64.4		14.2	
IV Duration category(71-75 DFF)					
Control	1519 $\pm$ 204	3582 $\pm$ 607	68.7 $\pm$ 19.7	2432 $\pm$ 533	-32.1
Early stress	1720 $\pm$ 220	1280 $\pm$ 212	-14.7 $\pm$ 6.3	1726 $\pm$ 229	34.8
Reduction(%)		63.8		29.0	

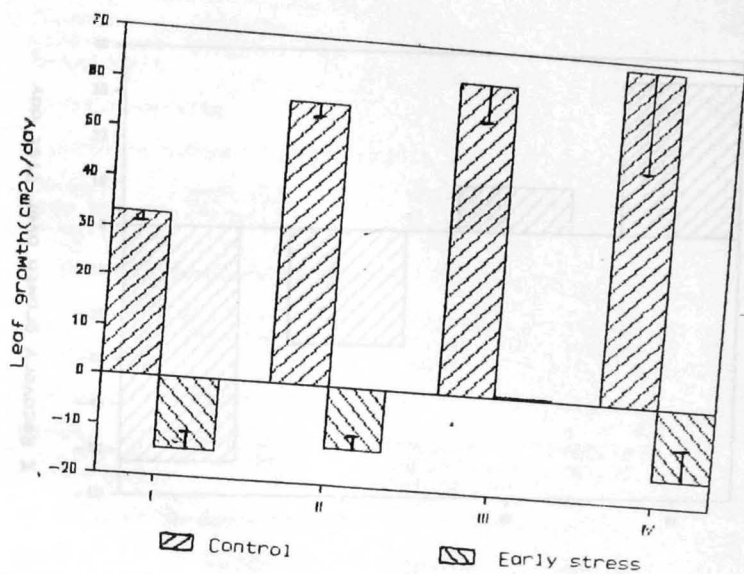


Fig. 8a Duration-wise mean leaf growth rate (cm²/day) for control and early stress between 41 and 71 days after sowing.

Fig. 8a Duration-wise mean of leaf growth rate (cm²/day) for control and early stress between 41 and 71 days after sowing.

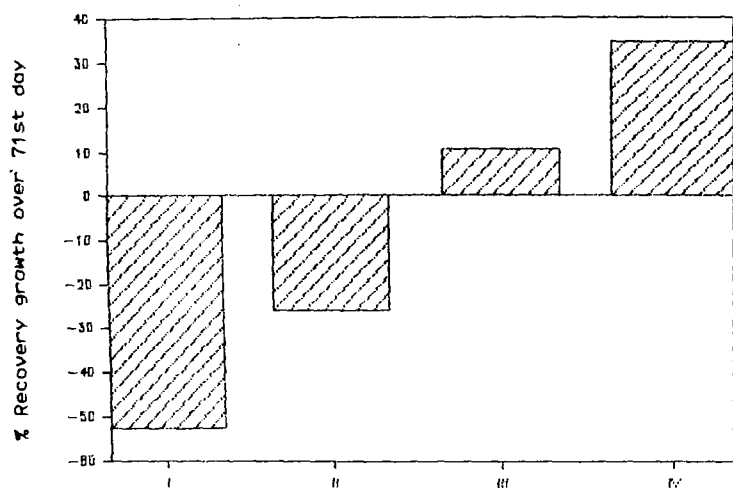


Fig. 8b Duration-wise mean per cent recovery over 71 DAS (day of alleviation) in early stress.

Table 15. Leaf area(cm²) growth during late stress conditio to 93 DAS).

Treatment	58 DAS	93 DAS	LA growth per day (cm ² /plant)
a) Over all genotypes			
Control	2730±101	1430±157	-37.13
Late stress	2728±161	1003±105	-49.3
Reduction(%)		28.5	
b) Duration-wise			
I Duration category(55-60 DFF)			
Control	2425±153	752±156	-47.79
Late stress	2463±212	706±57	-50.22
Reduction(%)		6.1	
II Duration category(61-65 DFF)			
Control	2735±144	1312±165	-40.66
Late stress	2404±136	777±97	-46.99
Reduction(%)		40.7	
III Duration category(66-70 DFF)			
Control	2607±186	1460±188	-32.78
Late stress	2732±139	1085±173	-47.05
Reduction(%)		25.08	
IV Duration category(71-75 DFF)			
Control	3140±302	2432±533	-20.24
Late stress	3962±539	1895±170	-59.05
Reduction(%)		36.78	

sowing), the leaf growth rate was 56.2 in control compared to -10.9 cm^2 per day under early stress over all genotypes. That is, in the latter (early stress), in addition to cessation of leaf growth, extensive leaf death also occurred (Table 14; Fig. 8a). Twenty two days after alleviation of the moisture stress, the genotypes retained only 48.5 per cent of leaf area compared to 89.4 per cent in genotypes subjected to early stress (Table 14).

The mean leaf growth rate per day between 41 and 71 days, increased with duration group under control condition. For instance, the leaf growth rate increased from 33.1 cm^2 /day in the early compared 68.7 cm^2 /day in late duration genotypes (Table 14; Fig. 8a). However, under early stress, there was no distinct pattern in the leaf growth rate/day between the various duration classes. Except for genotypes in the third duration class (65-70 DFF), genotypes in the other duration categories showed no increase in growth; rather there was decrease in growth rate due to leaf senescence.

The per cent recovery growth on alleviation of moisture stress was strongly related to the duration category. While there was no recovery of leaf growth in genotypes belonging to the first and second duration classes, the recovery in leaf area was 10.6 and 34.8 per cent for the third and fourth duration group

respectively (Table 14; Fig. 8b).

The leaf area growth during the period between 58 and 91 days after sowing (late stress) did not involve any leaf growth at all. There was also no particular association of the leaf growth rate with the duration group (Table 15).

Standardized normal distribution of genotypes based on the filled seed weight and TDM under early and late stress

As an attempt to classify genotypes into groups based on their performance under early and late stress, standardized normal distribution of the genotypes was done considering two important parameters, namely, TDM and filled seed weight. Such an exercise offers an opportunity to select for genotypes within and across the duration classes. As seen from figure (Fig. 9) the distribution of genotypes is concentrated in the first and third quadrant. The genotypes in the first quadrant represent those with high TDM and high filled seed weight while those in the third quadrant represent those with low TDM and low filled seed weight. On examining the distribution of genotypes under both the stresses, the genotypes Sl.No. 12, 13, and 14 which belong to the late duration category were found to be the best. In the second duration category (61-65 DFF), the genotype Acc. no. 188 (Sl.No. 24) performed better under early stress. Similar examination reveals that Acc. no. 88 (Sl.No. 3) is

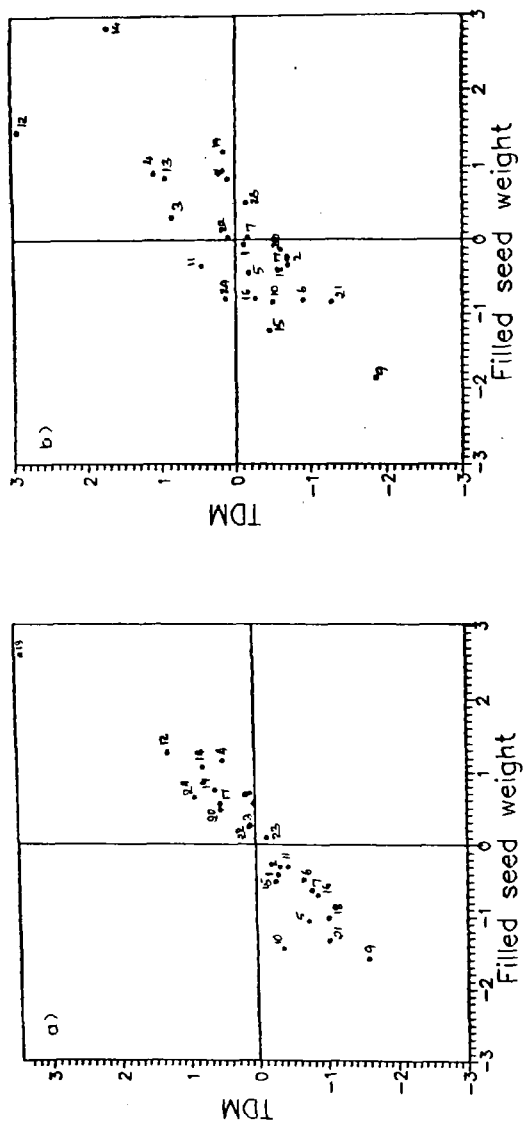


Fig.9 Standardised normal distribution of genotypes under
a) early stress and b) late stress considering
absolute filled seed weight and TDM.

the best performer under later stress. BSH-1(Sl. No.1) and Acc.no. 66 (Sl. no.2) were the worst performers under early and late stress respectively. Selection of the genotypes outlined above, for further confirmation and the possible mechanism by which they are sustained, needs to be examined.

Standardised normal distribution of genotypes based on drought susceptibility index(DSI) for filled seed weight and TDM under early and late stress

Drought susceptibility index, which is a reflection of intrinsic ability to withstand moisture stress was computed for each genotype following Fischer and Maurer (1978). The DSI was calculated for filled seed weight and TDM. The genotypes showed wide variation in DSI indicating the differential effect of moisture stress on genotypes (Table 16). The DSI values were normalised and the Z scores obtained, based on which a standardised normal distribution was plotted (Fig.10). The distribution of genotypes concentrated in I and III quadrant, both under early and late stress. The genotypes in the I quadrant were characterised by high susceptibility in terms of filled seed weight and TDM while the genotypes in the III quadrant were characterised by low susceptibility. In both the stress conditions, the III quadrant was occupied by late duration varieties. In order to classify the genotypes within the duration group (61-65 DFF), separate Z scores

Table 16 Drought susceptibility index of the genotypes based on filled seed weight and TDM under early and late stress conditions.

Genotype No.	Drought susceptibility index			
	Filled seed weight		TDM	
	early stress	late stress	early stress	late stress
1	1.22	1.21	1.06	0.99
2	1.23	1.38	1.17	1.51
3	1.00	1.03	1.09	0.84
4	0.93	1.14	1.12	1.06
5	1.04	0.21	0.94	0.26
6	0.98	1.20	1.08	1.21
7	1.34	1.24	1.31	1.21
8	0.42	0.00	0.88	0.74
9	1.38	1.69	1.39	1.74
10	1.63	1.67	1.27	1.60
11	1.22	1.43	1.21	0.90
12	0.75	0.67	0.97	0.44
13	0.48	1.13	0.45	1.19
14	0.44	0.90	0.83	0.28
15	1.19	1.75	0.95	1.00
16	1.27	1.50	1.33	1.24
17	0.65	1.07	0.79	1.37
18	1.37	1.12	1.29	1.26
19	0.68	0.35	0.97	1.24
20	0.89	1.25	0.80	1.34
21	1.35	0.94	0.85	0.70
22	0.77	0.86	0.68	0.37
23	0.72	0.30	0.71	0.38
24	1.02	1.76	0.83	1.16

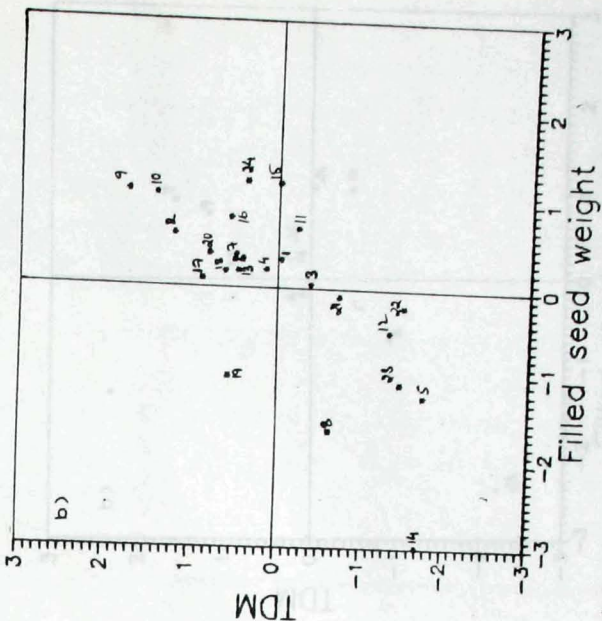
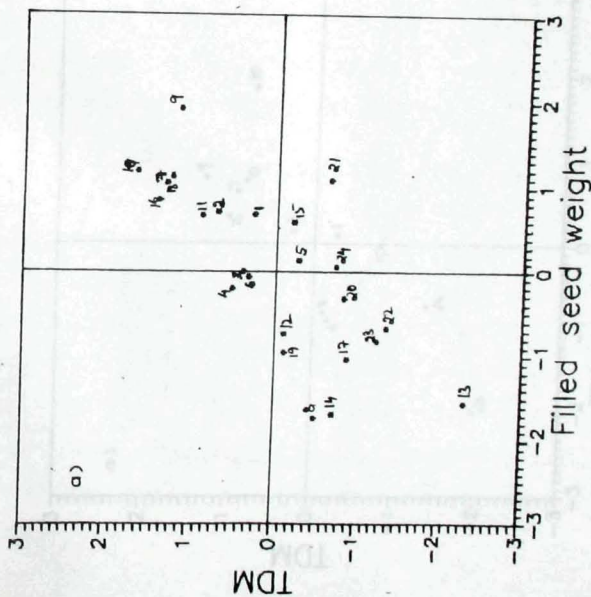


FIG. 10a Standardised normal distribution of genotypes under a) early stress and b) late stress considering drought susceptibility index for filled seed weight and TDM

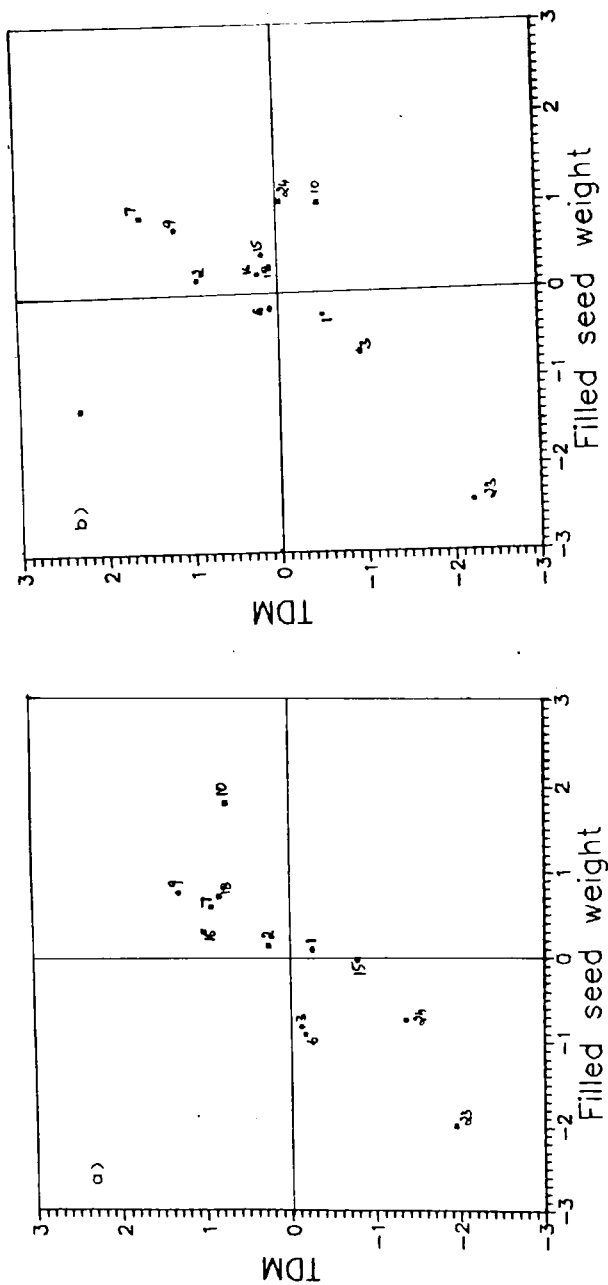
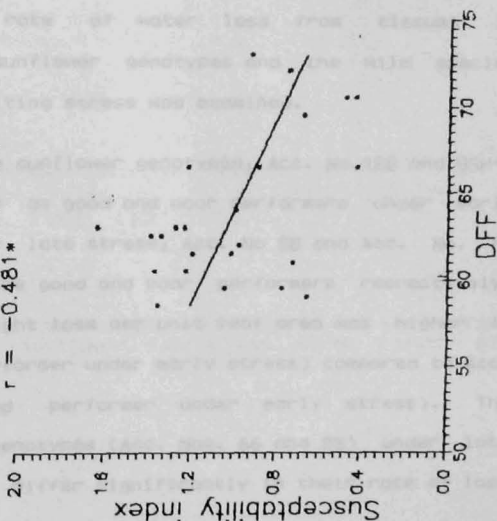


Fig. 10b Standardised normal distribution of genotypes belonging to II duration group under a) early stress and b) late stress considering drought susceptibility index for filled seed weight and IDM

a) Early stress
 $Y = -0.037X + 3.36$
 $r = -0.481^*$



b) Late stress
 $r = -0.307NS$

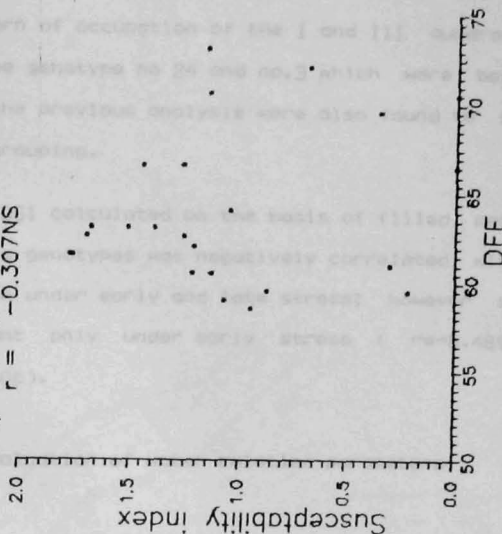


Fig. 10c Correlation between drought susceptibility index and DFF under early and late stress.

were computed. The distribution of genotypes showed a similar pattern of occupation of the I and III quadrant (Fig.10b). The genotype no 24 and no.3 which were best performer in the previous analysis were also found to be best by this grouping.

The DSI calculated on the basis of filled seed weight for the genotypes was negatively correlated with their DFF both under early and late stress; however it was significant only under early stress ($r=-0.481$, $P<0.01$, Fig. 10c).

Comparative evaluation of water relation parameters

a) Rate of fresh weight loss:

The rate of water loss from tissues in contrasting sunflower genotypes and the wild species under live wilting stress was examined.

Among the sunflower genotypes, Acc. No.188 and BSH-1 were selected as good and poor performers under early stress; under late stress, Acc. No 88 and Acc. No. 66 represented the good and poor performers respectively. The fresh weight loss per unit leaf area was higher in BSH-1 (poor performer under early stress) compared to Acc. No. 188 (good performer under early stress). The contrasting genotypes (Acc. Nos. 66 and 88) under late stress did not differ significantly in their rate of loss

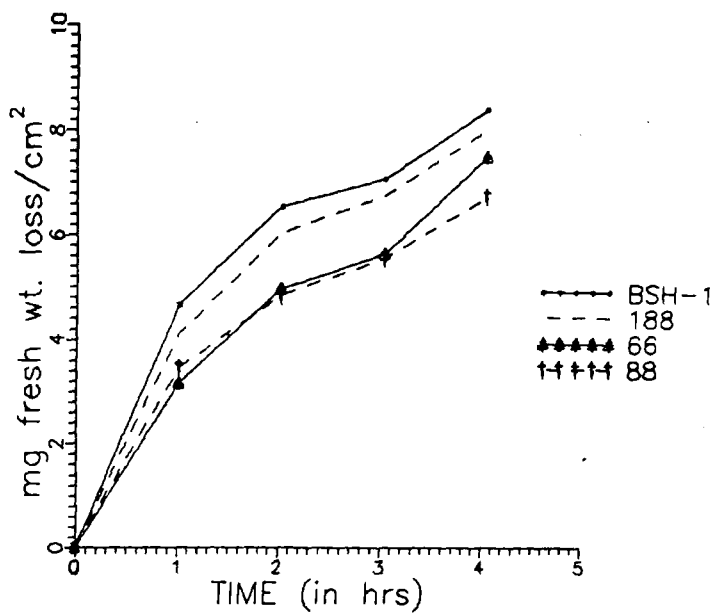


Fig. 11 Rate of fresh weight loss (mg/cm² of leaf area) in selected sunflower genotypes under live wilting condition.

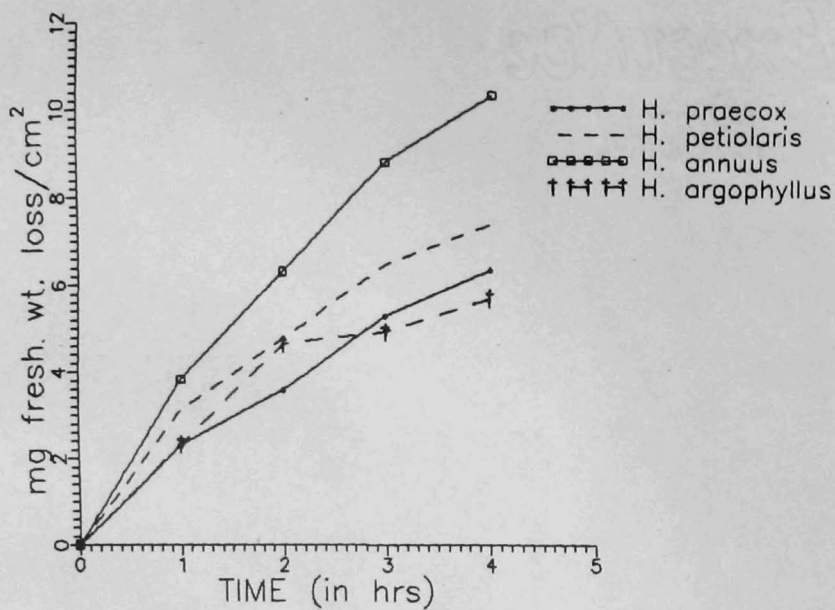


FIG. 12 Rate of fresh weight loss (mg/cm² of leaf area) in *Helianthus* species under live wilting condition.

of fresh weight (Fig.11).

Figure 12 shows the rate of loss of fresh weight per unit leaf area for the various *Helianthus* species studied. *H. annuus* showed the highest loss of fresh weight followed by *H. petiolaris*, *H. procerus* and finally *H. argophyllus*.

b) Rate of water loss:

For the above contrasting sunflower genotypes and wild species, the rate of transpirational water loss per unit leaf area was measured under laboratory conditions. The sunflower genotypes selected for contrasting performance under early stress (BSH-1 and Acc. No.188) did not show any significant difference in rate of transpirational water loss. Similar response was seen in the genotypes selected under late stress (Acc. Nos.66 and 88). BSH-1 and Acc. No.188 lost 1.125 and 1.124 ml of water per 100 cm² of leaf area per 3 hour respectively, where as genotypes Acc. Nos. 66 and 88 lost 1.496 and 1.315 ml of water/100 cm² respectively (Table 17a; Fig.13). However, these genotypes did differ from each other when compared between early and late stress.

H. argophyllus had the highest rate of transpirational water loss (2.126 ml/100cm² of leaf area/3 hr) followed by *H. petiolaris* (1.990 ml). These two species differed significantly from the other two

Table 17a. Rate of water loss in contrasting sunflower genotypes

Genotypes	Rate of transpirational water loss (ml/100 cm ² LA/3 hr)
BSH-1	1.125±0.112a
Acc.No.188	1.124±0.100a
Acc.No. 66	1.496±0.082b
Acc.No. 88	1.315±0.130ab

Table 17b. Membrane leakage in contrasting sunflower genotypes

Genotypes	Membrane integrity (% solute leakage) at 60% fresh wt. loss
BSH-1	78.86±7.22a
Acc.No.188	59.97±5.08a
Acc.No.66	70.60±2.14a
Acc.No.88	61.51±3.08a

Table 18a. Rate of water loss in *Helianthus* species

Species	Rate of transpirational water loss (ml/100 cm ² LA/3 hr)
<i>H. annuus</i> (Acc.No.188)	1.593±0.102a
<i>H. praecox</i>	1.449±0.149a
<i>H. petiolaris</i>	1.990±0.140b
<i>H. argophyllus</i>	2.126±0.091b

Table 18b. Membrane leakage in *Helianthus* species.

Species	Membrane integrity (% solute leakage)	
	At 40% fresh weight loss	At 60% fresh weight loss
<i>H. annuus</i> (Acc. no.188)	38.8±6.05a	74.4±12.1a
<i>H. praecox</i>	29.6±2.22a	39.6±2.01a
<i>H. petiolaris</i>	31.8±1.79a	47.7±3.15a
<i>H. argophyllus</i>	11.4±0.70b	25.1±2.18b

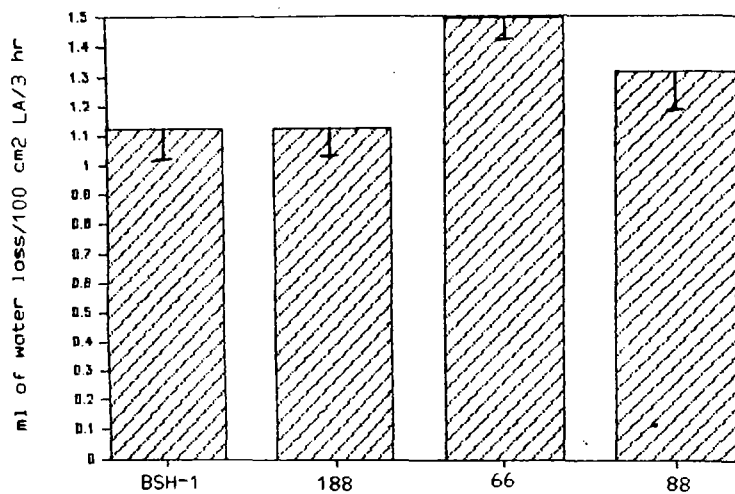


Fig. 13 Rate of transpirational water loss (ml/100 cm² of leaf area) in selected sunflower genotypes.

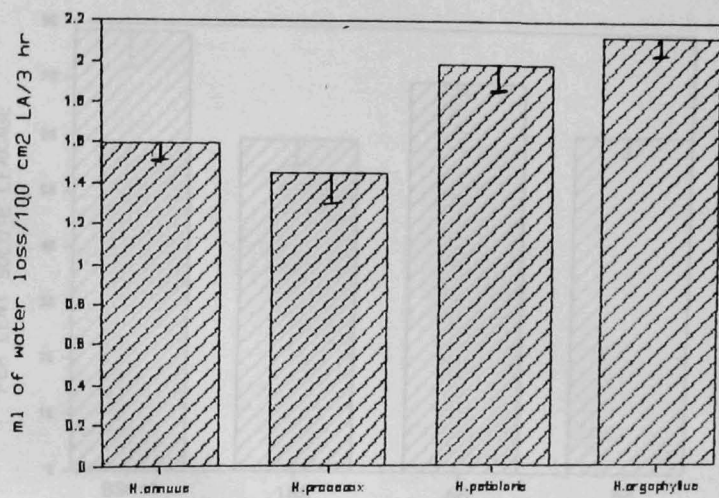


Fig. 14 Rate of transpirational water loss (ml/100 cm² of leaf area) in Helianthus species.

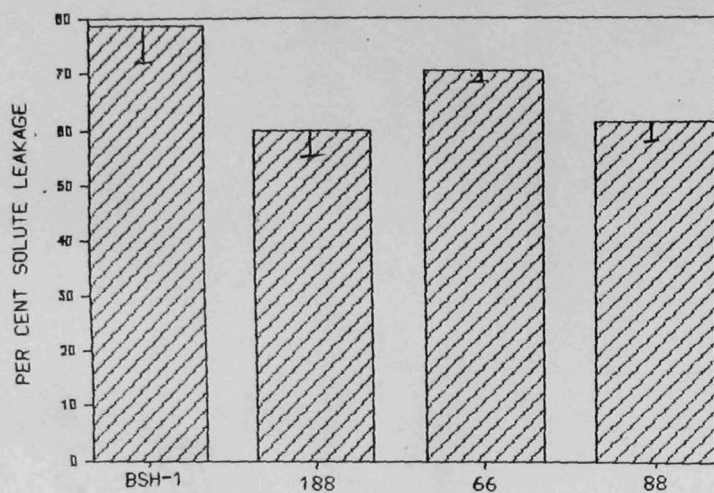


Fig. 15 Per cent solute leakage from the leaf tissues of selected sunflower genotypes under live wilting stress.

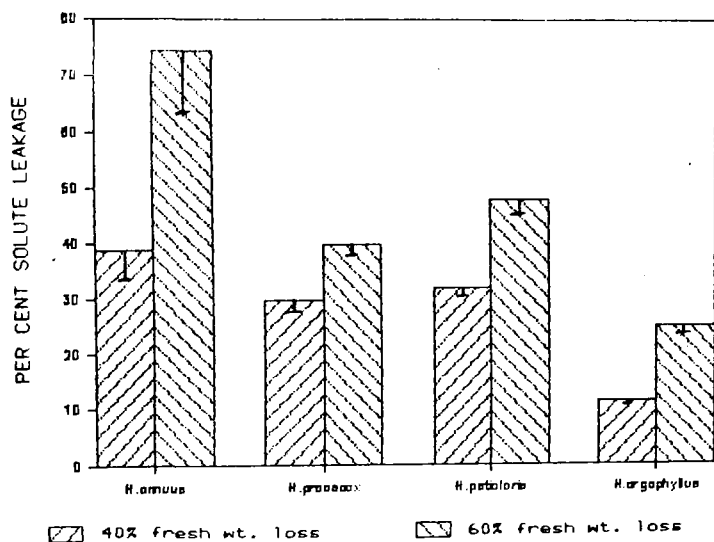


Fig. 16 Per cent solute leakage from the leaf tissues of *Helianthus* species under live wilting stress.

species, *H. annuus* and *H. procerus* which lost 1.593 and 1.449 ml water/100 cm²/leaf area/3 hr respectively. The differences in rate of water loss between these two species was negligible (Table 18a;Fig.14).

c) Maintenance of membrane integrity:

The amount of solutes leached into the bathing media (distilled water) from the leaf tissues previously subjected to live wilting stress was measured as a reflection of the maintenance of membrane integrity.

At 60 % loss of fresh weight, BSH-1 showed the highest percentage leakage (78.86) while Acc. No 188 showed the least (59.97). However, the contrasting genotypes selected under early and late stress did not differ significantly in the maintenance of membrane integrity (Table 17b;Fig.15).

The loss of membrane integrity in the wild species was assessed at 40 and 60 per cent loss of fresh weight. (Table 18b;Fig.16). Among the wild species, *H. argophyllus* showed the least membrane leakage at both 40 and 60 per cent fresh weight loss(11.4 and 25.1% respectively). *H. annuus* had the highest leakage of solutes under both the conditions(38.8 and 74.4% at 40 and 60% fresh weight loss respectively). However, *H. argophyllus* alone differed statistically from other species in maintenance of membrane integrity under both the conditions.

DISCUSSION

V-DISCUSSION

The primary objective of the present study was to screen sunflower germplasm for drought resistance/tolerance under simulated moisture stress situations. Though sunflower crop experiences characteristic intermittent spells of moisture stress during kharif, it might not be valid to screen the germplasm under these conditions, because of the lack of control on the stage and the degree of moisture stress that the crop will be subjected to.

Rather, a valid technique might be to conduct field evaluation of the growth and yield performance of the germplasm when subjected to defined periods of moisture stress. Such a method would facilitate a meaningful comparison of the relative performance among the germplasm and with their corresponding irrigated control performance.

Accordingly in this study, the germplasm was subjected to moisture stress at two stages, namely, at early vegetative phase (40-71 DAS; hereafter referred to as 'early stress') and at late vegetative phase/early reproductive phase (58-93 DAS; hereafter referred to as 'late stress'). The growth and yield performances of the genotypes under each of these stresses was compared with

that of their respective control grown under completely irrigated conditions.

Apart from its influence on individual characters per se, moisture stress may alter the nature of inter-relationship among them. In this regard, simple correlation and path co-efficient analysis were conducted to understand the inter-relationships of the various characters and their contribution to seed yield and kernel oil per cent under the different stress treatments.

The effect of intermittent moisture stress on the growth and productivity may be overcome by a rapid recovery on alleviation of moisture stress. As an attempt to assess the genotypic variation in recovery, leaf area growth on alleviation of moisture stress was determined.

An important component of water relations in plants especially under rainfed situation, is their stomatal regulation with respect to the occurrence of dry and wet spells (Kramer 1983). A highly sensitive stomatal regulation tuned to the relative availability of soil moisture is desired. An attempt was made to study several water relation characters pertaining to cuticular and stomatal (transpirational) loss of water in a few sunflower genotypes contrasting in their growth and yield performance under imposed moisture stress.

Finally, the water relation characters of a few wild species namely Helianthus argophyllus, H. praecox and H. petiolaris was compared with H. annuus.

In the following section, we discuss the results obtained in each of the above mentioned aspects.

Growth, yield and oil characters as affected by moisture stress at early and late stages of crop growth

Several growth, yield and oil characters were studied in 24 germplasm including 7 commercial cultivars subjected to weekly irrigation (control) and moisture stress at early and late stages of crop growth. Under all the three treatments, significant genotypic differences in most characters was obtained. Under fully irrigated condition, the genotypes differed significantly in DFF, plant height, TDM, leaf area, kernel and seed oil content and head diameter; the genotypes did not differ significantly for HI, kernel/hull ratio, and filled seed weight (Table 4a). However the genotypes differed significantly in all the characters when subjected to stress at early vegetative phase (Table 4b.). Under late stress the genotypes differed in all characters except kernel/hull ratio and head diameter (Table 4c). Thus significant genotypic variation existed for most characters under moisture stress.

Moisture stress at the two stages significantly decreased the mean for most characters (Table 5; fig.3). Among the characters that were affected the most were filled seed weight, TDM, leaf area and test weight. DFF, days to maturity, kernel/hull ratio, seed and kernel oil content were least affected. These results indicate that irrespective of stage at which moisture stress is imposed, there occurs a considerable reduction in seed yield. The significant interaction between the stresses and genotypes indicated that there was a differential response of genotypes for moisture stress at both the stages (Table 5).

Similar effects of moisture stress on the sunflower growth and yield characters have been obtained earlier (Connor *et al.*, 1985, Dulay and Singh, 1983, Rawson and Turner, 1982, Fereres *et al.*, 1986, Talha and Osman, 1985, Sarkar and Bhattacharya, 1980, and Sheshagiri Rao, 1989).

Compared to late stress, moisture stress at an early stage affected the growth and yield characters severely. Thus for characters like plant height, head diameter, filled seed weight, TDM, and test weight, there was nearly 5 to 25 per cent more reduction under early compared to late stress. This is reflected in the data on the per cent reduction of these characters over the control (Table 6) and average draught intensity. For

instance, the reduction in filled seed weight was 53.4 per cent under early stress compared to 41.75 per cent under late stress; the average drought intensity calculated on the basis of filled seed weight was 0.538 under early stress, compared to 0.399 under late stress. The TDM per plant reduced by 51.4 per cent under early stress while under late stress it reduced by 34.5 per cent. The average drought intensity calculated on the basis of TDM under early stress was nearly 65.7 per cent more than that under late stress. This confirms the results obtained by Dulay and Singh (1983) who reported that moisture stress at seedling stage results in higher reduction in seed yield than when the stress was imposed during the capitulum initiation and at anthesis. Similar results were reported by Shehagiri Rao (1989) in a study of 50 germplasm lines of sunflower. The greater reduction in the means of most characters under early stress could be due to the inhibition of growth processes such as leaf growth, accumulation of dry matter and inflorescence primordia development during the period of stress. Under late stress, because genotype accumulate considerable leaf area and TDM before the commencement of moisture stress, the per cent reduction in most characters is less. There was no difference between stress imposed at early and late stages of plant growth with respect to DFF. The seed and kernel oil content and kernel/hull ratio were marginally higher under early stress than under late.

Association studies:

a) Effect of moisture stress on the inter-relationship among the various characters.

One of the effects of moisture stress either at the vegetative or the reproductive stages or both, could be the alteration in the inter-relationship among the various growth and yield characters compared to that under irrigated condition. This might arise due to the differential effect of moisture stress on the various growth and yield characters.

The results on the correlation studies indicated that moisture stress at early and late stages of crop growth did not significantly alter the nature of association between most characters; they only altered the magnitude of the association (Table 9a, b, c).

The nature of correlation for kernel/hull ratio, seed and kernel oil content differed substantially across the various treatments. A detailed implications of such altered relation is discussed separately under the section on variation in the oil content.

Few workers have examined the correlations among the various growth and yield characters under moisture stress conditions in sunflower (Table 1). For instance, Deshmukh *et al.*, (1980) reported a significant positive correlation between plant height, stem diameter, stem

weight, and 100 seed weight with seed yield. Rawson and Turner(1982a, 1983) showed a positive relationship between leaf area and seed yield under control and stress conditions. A positive relationship for seed number per capitulum, and harvest index with seed yield was reported by Fereres *et al.*, (1986). In a more recent study, Sheshagiri Rao (1989) showed a positive relationship of TDM, leaf area, and test weight with seed yield.

In this study, similar relationship were obtained under irrigated, early and late stress conditions. The correlation between TDM per plant and filled seed weight was positive and significant under the all the treatments (Table 9a, b, c) indicating that despite the substantial reduction in TDM due to early and late stress the positive contribution of TDM to grain yield still persists. Yet another important yield component, namely, test weight was also highly positively correlated with seed yield. The consistent nature of correlation among most characters and particularly of few yield components with yield, irrespective of the moisture stress, can be explained considering that, both under early and late stress, the crops had substantial periods of recovery.

However, because of the differences in the magnitude of correlation between the various characters due to moisture stress, the seed yields might be affected differentially, as it is dependent upon a number of independent variables.

b) Path co-efficient analysis:

Simple correlation analysis do not offer information about the extent of contribution of the independent variables to seed yield. Independent variables might contribute to a dependent variable (here seed yield) either directly (by virtue of their intrinsic correlation) and indirectly (by virtue of their correlation with other characters influencing seed yield). In this regard, a modified regression analysis, known as path analysis was employed to estimate the relative direct and indirect contribution of a few important independent variables to seed yield.

Five independent variables, namely, DFF, head diameter, test weight, leaf area and TDM were chosen to examine their direct and indirect path co-efficients to seed yield under irrigated, early and late stress conditions separately. All these characters were positively and significantly correlated with filled seed weight under all the three treatments. Under control and early stress, TDM/plant contributed the highest direct effect to seed yield; under late stress the highest direct contribution was through test weight (Table 10a, b, c; Fig. 5a, b, c).

Though DFF was positively and significantly correlated with seed yield under both early and late

stress; its direct contribution to seed yield was low and negative. The same is true of leaf area whose direct effect was very low. This illustrates that despite a high positive correlation of the DFF and leaf area to seed yield, the contribution of these characters to seed yield is only indirectly through their correlation with other characters such as TDM. The direct contribution of test weight to seed yield was not substantial under early stress (Fig.5b).

Under late stress, the highest direct effect was obtained from test weight; the direct effect of TDM was negligible (Fig.5c). Again, this is in contrast to the correlation co-efficients of these characters to seed yield. Test weight, TDM and leaf area were highly positively correlated with seed yield. However, except test weight, the direct contributions of other characters to seed yield was negligible and indirect through test weight.

Under late stress, where the genotypes were stressed at a time when much of the TDM had been accumulated, seed yields were generally limited by mobilisation of resources during the grain filling period. Thus seed yield under late stress was determined more by test weight than TDM or leaf area.

The direct and indirect contribution of several independent variables to seed yield under stressed

condition in sunflower has been reported earlier (Table 2). For instance, Naskar *et al.*, (1982,1988) showed that the direct contribution to seed yield was highest from plant height followed by 100 seed weight and capitulum size. Veikov (1980), Lakshmaniah (1978) and Lakshmana Rao (1983) reported that head diameter contributed the highest direct effect to seed yield. In a study comprising 50 genotypes of sunflower subjected to moisture stress at early and late growth stages, Sheshagiri Rao (1989) found that the test weight contributed the highest positive direct effect under control and late stress condition, while the head diameter contributed the highest positive direct effect under early stress. These results are partly confirmed by our study.

One of the reasons for the lack of complete correspondence between the various studies might be the choice of various independent variables for conducting the path analysis, and also the nature and magnitude of correlation among the variables. The above results suggest that, different selection criteria need to be evolved for screening genotypes under control and early stress on one hand and under late stress on the other.

Effect of duration on the performance of genotypes under moisture stress

The genotypes in the study ranged in their days taken to fifty per cent flowering from 55 to 75 days

after sowing. One of the major drawbacks in assessing genotypes of such heterogeneous duration group is the lack of control on the precise developmental stage at which the moisture stress is imposed. Thus, although the genotypes are subjected to defined periods of moisture stress, the critical stages of crop growth affected might vary. For instance, it is likely that when the late varieties are still in their vegetative phase, the early varieties might be close to anthesis or in early grain filling period. In such situation, stress at an early stage would be more detrimental to the early than the late duration genotypes. To assess the performance of genotypes belonging to different duration classes, a duration-wise analysis of the various growth and yield characters was made (Table 13).

The performance of genotypes with respect to few important characters like filled seed weight, TDM, test weight and leaf area was found to be positively and significantly correlated with days taken to 50 per cent flowering under control, early and late stress based on their absolute values. This indicates that the pattern of relation of these characters with duration remains unaltered under moisture stress condition.

A duration-wise analysis of various growth and yield characters (Table 13) showed that under all the three treatments, the mean for characters such as plant

height, filled seed weight, test weight, TDM increased from the early to late duration genotypes (see Fig. 9a, b, c, d, e). For instance, under control conditions, the filled seed weight increased from 28 g per plant in the early genotypes to 47.7 g in the late genotypes. Similar pattern of increase was observed between the duration group under early and late stress conditions. The late genotypes yielded 2.13 and 1.89 times that of early genotypes under early and late stress respectively. Similar relationship between TDM, filled seed weight, leaf area and duration was obtained on re-analysing the data of Sheshagiri Rao (1989) on 50 genotypes subjected to early and late stress (data not shown).

The increase in the filled seed weight with the duration category (Fig. 7a) may be a reflection of the increase in leaf area and the TDM per plant from the early to late duration genotypes under all the treatments. For example, the TDM per plant in the late genotypes was 77.7, 72.2 and 74.9 per cent more than in early genotypes under control, early and late stress conditions respectively (Fig. 7c)

The per cent seed oil and kernel/hull ratio was negatively correlated to the duration under all the three treatments (Table 9a, b, c). The per cent kernel oil was negatively related to duration under fully irrigated and early stress; it was positively correlated to duration under late stress condition. However, on analysing the

mean of genotypes belonging to different duration group, there appears to be no predictable pattern for the kernel/hull ratio, per cent seed and oil. The per cent reduction of seed and kernel oil under the early and later stress was negligible. Interestingly under early stress, the kernel/hull ratio increased in the first three duration category, ranging from 25 to 60 per cent more than the control. Such increased kernel/hull ratio may be indicative of a greater resource mobilisation in to the seeds subsequent to the alleviation of moisture stress at the vegetative stage. In fact, alleviation of moisture stress before anthesis and grain filling has been reported to increase the mobilisation of dry matter to seeds (Rawson and Turner, 1982a).

Fischer and Maurer (1978) suggested the use of a drought susceptibility index (DSI) to assess the performance of genotypes subjected to moisture stress. In this method the performance of the genotypes under moisture stress relative to its maximum potential under complete irrigation is normalised by the average reduction in the performance of all genotypes in the study.

Considering filled seed weight, the DSI in the study ranged from 0.44 to 1.63 under early stress and from 0.00 to 1.76 under late stress indicating wide variability among the genotypes. The genotypes also

exhibited wide variability for DSI when the TOM was considered (Table 16).

The DSI generally tended to be negatively correlated with the duration; the correlation was significant for DSI calculated on the basis of filled seed weight under early stress (Fig. 10c).

There was no relation between DSI (considering filled seed weight) with the yield potential under completely irrigated conditions. This is in contrast to that observed in maize and wheat (IRRI, 1982). However, Fereres *et al.*, (1986) did find such correlation in a study comprising sunflower genotypes.

Earlier workers have recognised the role of mid to late duration varieties in obtaining higher productivity under moisture stress conditions (Rowson and Turner 1982a, 1983). Particularly, studies by Rowson and Turner (1982a) have shown that whenever irrigation was available higher seed yield can be obtained from late maturing cultivars. They argued that, such is possible, simply due to features associated with greater duration and not due to differences in the genetic potential of the genotypes. Giménez and Fereres (1986) also showed that late maturing genotypes of sunflower performed better than early because of their ability to extract soil moisture from the greater depths.

Turner and Begg (1981) suggested and later provided evidence in small grain cereals to show that earliness is usually advantageous under dryland condition. However, studies of Rawson and Turner (1982a) on sunflower grown under stored moisture, invalidates this claim. Results of our study, also do not support the above contention. Early duration cultivar not only had lower absolute values for filled seed weight, TDM, leaf area etc., but also showed consistently higher per cent reduction in these characters when subjected to early and late stress.

Leaf Recovery Growth

In sunflower, the seed yields are closely related to the maximum leaf area (Rawson and Turner, 1982a; Rawson et al 1980; Muriel and Downes, 1974). Under moisture stress where virtually no new leaf growth occurs (Rawson and Turner, 1982b) the seed yields are drastically affected. The productivity of the crop under moisture stress depends upon (a) the extent of leaf area production at the commencement of stress and (b) on the rate and extent of leaf area recovery on alleviation of moisture stress.

Sunflower has a remarkable ability to renew its leaf area growth on alleviation of moisture stress (Rawson and Turner 1982b). In this study, the leaf area per plant increased with the duration of genotype

($r=0.534$, $P<0.01$) under irrigated condition. The late genotypes had nearly 62% more leaf area than the early genotypes on the 71st day under control. Under early stress, the late genotypes had 38% more leaf area than the early duration genotypes. During the period of stress (between 41 and 71 DAS) there was almost no additional leaf growth in genotypes of all duration classes. Rather all the genotypes showed nearly 10-15% reduction in leaf area due to senescence of leaf during stress (Table 14; Fig. 8a).

The extent of recovery of leaf growth on alleviation of moisture stress was significantly different among the genotypes belonging to the various duration groups. Early genotypes (55-60 and 61-65 DFF) did not show any recovery; in contrast there was nearly 10.6 and 34.8% recovery of leaf growth in the genotypes of 65-70 and 71-75 DFF duration category respectively (Table 14; Fig. 8b).

Rawson and Turner (1982b) maintained that the extent of recovery depends upon the number of days available for growth before the anthesis. Our studies however, indicate that irrespective of the number of days available before anthesis, late duration genotypes have on an average higher leaf growth per unit time, and hence a better recovery. This might be facilitated as Rawson and Turner (1982b, 1983) acknowledge, by virtue of the

late genotypes having larger number of young leaves and primordia at the time of cessation of stress. Thus, both the intrinsic ability of rapid leaf growth and the total time available after alleviation, facilitates long duration genotypes to counteract the effect of intermittent moisture stress better than the early duration genotypes.

In summary, the above discussion on the effect of duration on the performance of genotypes, suggests that under intermittent moisture stress condition, mid to late duration genotypes might be preferable. These genotypes not only exhibit high absolute values of TDM and filled seed weight but are also less affected by moisture stress at any given crop growth stage. Recovery performance of these genotypes are also better than early types. However, it must be borne in mind, that the performance of these genotypes, need not necessarily be based on intrinsic genetic potentiality but might be due to several duration related growth features as outlined above.

Relationship between the absolute growth and yield performance under irrigated with that under early and late stress conditions.

The above association studies examined the nature of of inter-relationships among the various characters under control, early and late stress separately. However

In this section, an attempt is made to understand if the absolute performance of genotypes under early and late stress are related to their performance under fully irrigated condition. Correlation analysis was conducted on various characters between the fully irrigated (control) and the stress treatments (Table 7a; Fig. 4a, 4b).

Significant positive correlation existed between the early and late stress with that of control for filled seed weight, TDM, kernel/hull ratio, test weight, leaf area, kernel and seed oil content (Table 7a; Fig. 4a and 4b). Under late stress condition, the characters, filled seed weight, kernel oil content and kernel/hull ratio were not correlated with that of the control. In other words, except for these characters under late stress, the performance of genotypes under early and late stress condition is reflected reasonably by their performance under irrigated condition.

The above correlations might be explained due to several reasons. First, it could be due to the genotype-duration related performance, the pattern of which remains unaltered under the early and late stress. For example, given a) that the absolute performance of genotype for traits such as filled seed weight, TDM, leaf area etc., increased with the duration and b) the per cent reduction of these traits under early and late stress is similar for the various duration group, the

correlation between the control performance with that under early and late stress will be maintained. Indeed, data exists from the present study and others (Rowson and Turner, 1982a; Rowson and Turner, 1983) to show that both of the above conditions are met.

Though elaborate discussion on the effect of duration on response of genotype to moisture stress is presented elsewhere, it might be stated here that, there exists either poor or no correlation at all, between the per cent reduction of leaf area, TDM, test weight and filled seed weight under early and late stress with the absolute performance under control conditions.

Second, the correlation could also be explained due to the intrinsically higher rate of recovery in genotypes of long duration which are characterised by a greater number of young leaves and primordia (Rowson and Turner, 1982b). They reported a higher recovery growth in the late variety, Manchurian, compared to the early variety Suncross 150, on alleviation of moisture stress. Their data also suggested that the late varieties might have an intrinsically higher leaf expansion rate than the early. As will be discussed elsewhere the leaf growth rates in this study also, were found to be higher for late compared to early genotypes.

The above reasons attributed to explain the performance between control, and early and late stress

do not however reflect the genetic potentialities of the genotypes. The correlations are primarily due to duration related features. To explain the correlation on intrinsic genetic potentialities one might have to consider genotypes of the same duration in the analysis.

Table. 7b gives the correlation between the control and early and late stress condition for filled seed weight, test weight, TDM and leaf area of genotypes belonging to 61-65 DFF duration category. No significant correlation was noticed for the various characters except test weight ($r=0.467$ between control and late stress). This reaffirms the earlier view that the variation in the absolute growth and yield performance under moisture stress among the genotypes is controlled by virtue of their duration.

The per cent reduction of the various characters under the stress treatments were not correlated with the absolute performance of the corresponding characters under control (Table 8a, b).

Seed and kernel oil per cent - Genotypic variation and influence of moisture stress.

Significant variation existed for seed oil percentage under control, early and late stress (Table 5). The kernel oil percentage differed significantly among the genotypes under control and early stress only.

The variation in the seed and kernel oil percentage among the 24 genotypes ranged from 27.8 to 41 and 43.3 to 53.7% respectively under control condition (Table 4a). Similar variation has been realised earlier by Thompson *et al.*, (1981) in a study of 305 collection of sunflower including 28 species.

Analysing the influence of several environmental and management factors on seed oil percentage from the annual reports of AICRP on sunflower, it was found that except season no other factors adversely affected seed oil percentage. It was also noticed that environmental temperature during anthesis and grain filling period is critical for build up of seed oil.

There are conflicting reports regarding the influence of moisture stress on the per cent seed oil content. Prunty(1981) and Rawson and Turner(1982a, 1983) found that seed oil content did not decrease in sunflower when subjected to rainfed conditions of growth. But several other workers such as, Hall *et al.*, (1989) and Talha and Osman (1975) reported significant decrease in the seed oil percentage. It is important to note that such divergent results might be influenced by intensity of stress as well as the developmental stage at which the stress was imposed.

In our study, though the differences in the seed oil and kernel oil percentage between control, early and

late stress was significant, there was in fact no reduction due to moisture stress; rather there was a marginal increase in the seed and kernel oil percentage (Table 5). These results support the findings of Prunty (1981), Rowson and Turner (1982a,1983) and more recently of Sheshagiri Rao(1989) who also reported no reduction in seed and kernel oil content in 50 sunflower genotypes subjected to moisture stress at early and late stages of crop growth.

The apparent stability of seed and kernel oil percentage under moisture stress is despite the substantial reduction in the yield and yield components. Though, there is no evidence to suggest that there is a proportional mobilisation of fatty acids vis-a-vis the carbohydrates to the developing seeds, our studies and that of Prunty(1981),Rowson and Turner(1982a, 1983) and Sheshagiri Rao (1989) suggest such a possibility. The adaptive function of such a strategy is intriguing.

The seed and kernel oil per cent are influenced by several independent attributes in the plant. Under control and early stress, seed oil was negatively correlated to DFF, filled seed weight, TDM and test weight (Table 9a and 9b). Under late stress seed oil was positively correlated to filled seed weight and kernel/hull ratio. The kernel oil percentage was not correlated to any character, except DFF and kernel/hull

ratio under control and early stress. It was positively correlated to DFF, TDM and filled seed weight under late stress (Table 9c). The relationship of seed oil with other characters could be resolved by considering the kernel/hull ratio as a primary determinant of seed oil percentage.

To determine the contribution of various independent variables to kernel oil, a path co-efficient analysis was conducted (Table 11a,b,c). The filled seed weight and kernel/hull ratio were found to contribute the highest positive direct effect to kernel oil under control and late stress condition (Fig.6a and 6c). The contribution of TDM was high and negative. In contrast, under early stress, test weight and kernel to hull ratio contributed positively, while filled seed weight contributed negatively (Fig.6b). However, these path co-efficients are relative and do not seem to explain the complete contribution to kernel oil, as the residual co-efficient in all the three treatments was high.

Earlier workers (Giriraj *et al.*, 1979; Shabana 1975; Zali *et al.*, 1977; Lakshmanaiah 1978;) had reported the correlation of seed oil with several characters such as seed yield, head diameter, leaf number, hull weight(only) and with plant height, seed yield and test weight(all +vely). The path analysis studies of Lakshmanaiah(1978) and Sheshagiri Rao (1989) showed that there was no single major contributor to kernel oil. In

their studies also the residual co-efficients were very high. It is likely that kernel oil percentage is determined more by several metabolic processes during anthesis than by such gross determinants of growth as considered here.

Standardised normal distribution of genotypes based on
a) their absolute total dry matter and seed weight and
b) their drought susceptibility index.

The association analysis presented in the previous section showed a positive relationship between TDM and filled seed weight under all the three treatments. Based on these two characters, a standardised normal distribution (Z distribution) was plotted to categorise each of the genotypes with respect to TDM and filled seed weight under the early and late stress conditions separately (Fig.9). A distribution of this sort, facilitates comparison of genotypes on a two dimensional scale.

Under early stress, most of the genotypes grouped into the I and III quadrant. The I quadrant is characterised by those having high TDM with high filled seed weight, while the III is characterised by genotypes having low TDM and low filled seed weight. Only two genotypes grouped in the IV quadrant characterised by low TDM and high filled seed weight. Based on the dispersion of the genotypes, selection could be made from among the genotypes in the I quadrant.

Accordingly, irrespective of the duration, genotype no. 13 and 12 were found to be the best performers with respect to their TDM and filled seed weight. Within a duration group also (considering the II duration group of 61-65 DFF containing 12 genotypes) the dispersion pattern is similar; in this group genotype no 24 was found to be the best (Fig.9).

Under late stress, the genotypes were found to be distributed in all the four quadrants, though predominantly in I and III. Disregarding the duration group, genotype no.12 and 14 were found to be the best. Within the II duration (61-65 DFF) group, the best performer was genotype no.3. Thus disregarding the duration group it appears that, the genotype no .12 and 14 have the highest TDM and filled seed weight under both the stress conditions. These belong to the late duration (71-75 DFF) group. Their performance might be related to their avoidance of moisture stress due to either a good establishment or better recovery on alleviation of moisture stress. The variation in the performance of genotypes belonging to 61-65 DFF category might be related to several intrinsic genetic differences among the genotypes. Selection of genotypes based on the above screening methods though empirical, appears to be valid as these have been made on the absolute values rather than their per cent reduction. Such field evaluation of

genotypes needs to be supported from laboratory investigations by monitoring the physiological processes or characters that predispose them to perform better under rainfed environments.

Following Fischer and Maurer (1978) drought susceptibility index for genotypes based on their filled seed weight and TDM was computed. A standardised normal distribution based on these characters were developed for genotypes under early and late stress separately (Table 16; Fig. 10a). The distribution of genotypes in this method depends upon their intrinsic ability to withstand stress and sustain relatively less reduction in TDM and filled seed weight. There appears to be no definite association between the duration of genotypes and the quadrants they occupy. A similar pattern was seen with regard to distribution of genotypes in the four quadrants under late stress. Considering the distribution of genotypes within II duration category (61-65 DFF), under early stress, most genotypes occupied I and III quadrant; genotypes in the III quadrant are those with low susceptibility indices for TDM and filled seed weight. It is interesting to note that genotype no. 24 which was the best performer in previous analysis also was best in this grouping (Fig. 10b).

A large number of genotypes that had low TDM and low filled seed weight on the absolute scale, were also characterised by high DSI for TDM and filled seed

weight. The distribution of genotypes under late stress was also concentrated in the I and III quadrant. There was a large degree of correspondence between this analysis and the previous based on the absolute TDM and filled seed weight.

Rate of fresh weight loss, maintenance of membrane integrity and transpirational loss of water under live wilting stress in few selected sunflower genotypes and species.

Thompson et al., (1981) reported a wide spread occurrence of Helianthus ranging from swamps to deserts. Accordingly it was expected that the genus would exhibit wide variation for drought resistance/tolerance to moisture stress. Ixoras and Voinescue (1981) demonstrated the usefulness of H. argophyllus as a source of drought tolerance in sunflower.

We examined simple water relation characters in four species namely H. annuus (acc. no.188) , H. argophyllus, H. petiolaris, and H. praecox . Under live wilting stress the cultivated species H. annuus showed the highest rate of fresh weight loss followed by H. praecox, H. petiolaris and H. argophyllus (Fig.12). This pattern however was not reflected in the transpirational water loss. H. argophyllus exhibited the highest rate of water loss followed by H. petiolaris , H. annuus and H. praecox (Table 18a; Fig.14). These differences may be attributed to the fact that while live wilting stress is

predominantly due to non-stomatal water loss, the transpirational loss is due to stomatal regulation. Further, since the transpirational loss is allowed to proceed under water non-limiting condition, the necessary regulatory mechanism to conserve water loss in the species, particularly, H. argophyllus may not be triggered. As an index of the ability of species to withstand live wilting stress, the loss of membrane integrity was estimated. At both 40 and 60% loss fresh weight, H. argophyllus showed the least loss of membrane integrity, while H. annuus showed the highest (Table 18b; Fig. 16). These results suggest that, at least, under excised leaf condition, H. argophyllus possesses a higher ability to withstand moisture stress.

This confirms the results of Jxoras and Volnesue (1984) who attributed the relative drought tolerant of H. argophyllus to its thick leaf pubescence. Hybrids between H. annuus and H. argophyllus were found to be relatively drought tolerant.

Similar assessment of the rate of loss of fresh weight, transpirational loss of water and maintenance of membrane integrity was made on contrasting genotypes of H. annuus obtained under early and late stress conditions. Genotype BSH-1 which was selected as a poor performer under early stress lost its fresh weight significantly faster than Acc. No. 188, which was

selected as a good performer (Fig.11). There was no differences in these genotypes with respect to transpirational water loss (Table 17a;Fig.13). However, BSH-1 associated with its rapid loss of fresh weight also showed the highest loss of cell solutes while the good performer, Acc. No. 188, showed the least leakage (Fig.15).

Contrasting genotypes selected from under late stress, namely Acc. Nos. 66 and 88 did not show differences in fresh weight loss, transpirational loss of water and maintenance of membrane integrity. These results indicate that the differences in the field performance of genotype might not be due to their intrinsic differences in drought tolerance mechanisms. Rather, it might be due to several drought resistant mechanisms such as better root proliferation resulting in efficient water extraction, stomatal regulation under moisture stress etc.,

SUMMARY

SUMMARY

VI-SUMMARY

Sunflower is mainly grown in the kharif season and generally experiences intermittent moisture stress due to uneven distribution of rainfall. These stresses reduce the crop growth and thereby the productivity. In this study, it was envisaged to screen sunflower germplasm for drought resistance/tolerance under simulated moisture stress situations. Twenty four germplasms including 7 commercial cultivars were subjected to moisture stress during summer 1989, at two stages namely, early vegetative (41-71 DAS; early stress) and at late vegetative or early reproductive phase (58-93 DAS; late stress). The performance of genotypes under these stress treatments was compared with their performance under irrigated condition.

Under all the three treatments, significant genotypic differences in most of the growth, yield and oil characters was obtained. Moisture stress at the two stages of growth reduced the mean of most of the characters. The characters such as filled seed weight, TDM, test weight and leaf area were affected severely by moisture stress, while DFF, days to maturity, per cent seed and kernel oil were least affected. The per cent reduction was more under early stress compared to moisture stress at late stages of growth. The greater reduction under early stress could be due to the stress

induced restriction of growth process like leaf area development, accumulation of dry matter etc.,

Moisture stress at both stages of crop growth did not alter the nature of association between most of the growth and yield characters; however, the magnitude of correlation was substantially altered. The nature of correlation of kernel/hull ratio, seed and kernel oil content with other characters differed across the treatments.

Path analysis was conducted to estimate the contribution of a few important characters such as DFF, head diameter, TDM, test weight and leaf area to filled seed weight. Under control and early stress condition, TDM contributed the highest direct effect while under late stress the highest direct contribution was through test weight. Under late stress condition, moisture stress was imposed at a time when all the genotypes had accumulated considerable amount of dry matter. In this conditions seed yields are generally limited by mobilisation of resources to the developing sinks. Thus test weight had more bearing on final seed yields under the late stress condition.

A duration-wise analysis of various growth, yield and oil characters showed that under all three treatments, the mean plant height, filled seed weight, leaf area, TDM and test weight increased from early to

late duration genotypes. The leaf area recovery growth rates after alleviation of moisture stress was higher in the late duration compared to early duration genotypes. This might be due to features such as higher leaf area growth rate, dry matter accumulation in long duration genotypes and not due to differences in the genetic potential among the genotypes.

The per cent seed and kernel oil differed significantly among the treatments. However, moisture stress did not appreciably altered the seed and kernel oil content; there was infact either no or slight increase in the seed and kernel oil content under early and late stress. Thus there was a relative stability in the per cent seed and kernel oil content. Path analysis conducted for the kernel oil content showed that there was no single major contributor to kernel oil because of very high residual factor co-effecient under all the treatments.

Based on the standardised normal distribution considering the absolute filled seed weight and TOM and also the drought susceptibility index based on these characters, the genotype Acc. No.188 and 88 were selected as good performers under early and late stress respectively. Genotypes BSH-1 and Acc.No. 66 were selected as poor performers under early and late stress respectively. These contrasting genotypes were studied for their water relation characters using excised leaf

systems. BSH-1 which was selected as a poor performer under early stress showed a higher rate of fresh weight loss and higher per cent solute leakage from cells under live wilting stress than the corresponding good performing line Acc. No. 188. The contrasting genotypes selected under late stress did not differ significantly for both the parameters studied.

Four species of Helianthus, namely, H. annuus, H. argophyllus, H. petiolaris and H. praecox were examined for several water relation parameters. Under live wilting stress, in the laboratory, the cultivated species, H. annuus showed the highest rate of fresh weight loss followed by H. praecox, H. petiolaris and H. argophyllus. As an index of the ability of the species to withstand live wilting stress, the loss of membrane integrity was studied. At both 40 and 60 per cent loss of fresh weight, H. argophyllus, showed the least loss of membrane integrity, while H. annuus showed the highest. These results suggest that at least under excised leaf conditions, H. argophyllus possesses a higher ability to withstand moisture stress.

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*Original not seen

APPENDICES

Appendix 1. Soil characteristics of the experimental field.

Soil characteristics	Soil depth(cm)	
	0-15	15-30
A.Mechanical composition (% oven dry basis)		
1.Coarse sand	34.85	26.12
2.Fine sand	33.33	28.15
3.Silt	8.20	8.20
4.Clay	21.50	35.38
Textural class	Sandy clay loam	
B. Single value physical constants		
1.Field capacity(%)	14.80	15.70
2.Permanent wilting point(%) at 15 bar	6.50	9.30
3.Bulk density(g/cc)	1.59	1.54

Appendix 2. Climatological data for the experimental period(Jan-May 1989)

WEEK	RH	Rain fall (mm)	Temperature(C)		Sunshine hours	Evaporation mm for 24 hrs
			Max.	Min.		
Jan 1-7	62	0	26.0	13.6	9.2	5.3
8-14	59	0	26.3	11.9	8.5	5.0
15-21	61	0	26.6	13.0	7.3	4.7
22-28	59	0	26.0	12.0	8.0	5.2
29-4	54	0	28.3	12.1	10.1	5.3
Feb 5-11	50	0	30.6	11.0	10.8	5.6
12-18	47	0	31.2	13.6	11.1	6.2
19-25	53	0	31.0	14.9	10.8	6.5
26-4	54	0	30.9	13.9	10.8	6.4
Mar 5-11	61	0	30.8	15.8	10.9	5.8
12-18	54	0	30.9	16.9	8.8	6.2
19-25	47	0	33.0	18.8	11.1	6.6
26-1	49	5.2	31.6	18.0	9.2	6.3
Apr 2-8	56	0.4	34.7	19.1	10.0	6.9
9-15	55	0	34.3	20.1	10.4	7.4
16-22	60	0	32.1	20.7	8.0	7.1
23-29	60	1.2	33.4	20.4	7.9	6.5
30-6	57	6.5	34.6	21.4	10.3	6.6

Appendix 3. The mean of various growth, yield and oil characters for 24 genotypes under irrigated control condition.

Genotype NO.	1	2	3	4	5	6	7	8	9	10	11	12	13
1	61	133.6	14.50	44.94	41.50	38.50	5.59	98.50	48.50	41.30	1.760	109.04	2905
2	63	153.9	15.40	52.25	44.70	34.00	6.72	100.50	45.30	43.25	1.420	122.25	2857
3	64	161.4	16.00	48.10	42.15	39.75	6.14	101.00	47.30	36.33	2.760	131.45	3345
4	73	186.0	15.50	59.15	54.95	38.05	6.15	106.50	49.30	38.10	2.095	154.40	3075
5	60	145.6	12.10	24.70	19.80	34.95	4.51	97.00	44.40	31.58	1.555	78.00	1930
6	62	157.8	12.85	33.50	28.70	35.55	4.94	101.00	48.25	35.61	1.935	93.70	2574
7	63	152.2	14.20	48.00	44.50	37.15	6.52	102.00	47.85	38.58	1.585	121.10	3637
8	67	158.1	12.85	32.55	28.90	37.95	5.60	105.50	47.80	31.27	1.415	103.25	3065
9	63	144.9	10.15	20.25	16.85	39.85	4.07	97.50	43.85	24.47	2.060	82.85	2068
10	63	164.3	16.30	49.55	44.00	34.45	6.20	97.00	47.25	35.54	1.485	139.45	3456
11	67	180.8	14.85	49.35	44.10	33.80	6.17	100.00	47.70	40.13	1.485	123.95	3279
12	72	215.6	13.40	57.05	47.65	27.85	6.28	101.50	46.30	35.05	1.140	163.45	3013
13	71	217.3	12.20	69.25	53.65	29.50	6.62	104.00	43.35	41.67	0.965	161.00	5399
14	71	185.4	14.20	39.55	34.85	29.20	5.83	100.50	43.65	31.39	1.230	124.75	2842
15	62	161.0	12.65	39.30	37.30	40.75	5.14	96.50	50.35	39.86	1.870	98.50	2630
16	63	136.1	14.00	42.55	37.55	32.25	4.82	96.50	43.50	35.95	1.295	119.40	3228
17	59	155.7	15.05	41.75	34.55	39.55	7.26	102.50	48.20	37.45	1.825	111.65	2342
18	61	148.1	14.00	36.85	34.45	33.00	6.68	96.50	47.30	35.58	1.700	103.55	2996
19	70	172.8	15.65	50.30	37.75	40.70	5.70	101.00	48.95	36.42	2.320	135.25	3512
20	67	153.7	14.90	44.75	41.55	41.05	4.47	97.50	53.90	39.61	1.240	112.50	2627
21	59	92.4	9.85	27.05	23.45	39.55	4.53	96.00	45.80	43.80	1.140	61.70	2107
22	60	110.7	11.15	39.25	34.20	36.65	5.69	99.50	48.80	44.44	1.460	88.25	2448
23	61	144.4	12.95	30.61	30.05	37.75	6.14	89.00	48.65	36.92	1.305	82.91	2608
24	62	180.4	13.30	57.50	51.05	37.55	5.74	100.00	48.65	44.26	1.535	128.80	3275

1. DFF 2. Plant height (cm) 3. Head diameter (cm) 4. Seed yield (g) 5. Filled seed weight (g)
6. Seed oil (%) 7. Test weight (g) 8. Days to maturity 9. Kernel oil (%) 10. Harvest index
11. Kernel/hull ratio 12. TDM (g) 13. Leaf area (cm²)

Appendix 4. The mean of various growth, yield and oil characters for 24 genotypes under early stress condition.

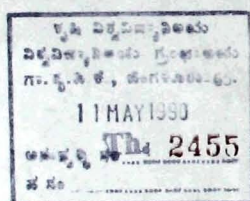
Genotype NO.	1	2	3	4	5	6	7	8	9	10	11	12	13
1	61	109.1	7.85	17.05	14.20	43.05	3.78	102.50	51.85	33.54	2.540	49.50	798
2	63	112.1	8.93	18.91	15.05	41.10	3.70	99.00	49.10	38.81	2.360	49.01	1019
3	63	121.3	10.25	21.85	19.55	42.40	3.45	107.50	50.55	37.70	2.770	57.80	1031
4	69	110.8	9.50	30.60	27.45	38.15	3.94	107.50	49.55	45.12	2.235	65.45	1049
5	62	110.7	7.70	12.25	8.70	41.95	3.65	97.00	51.70	29.94	2.140	40.50	505
6	62	120.7	8.35	15.75	13.63	38.50	3.07	100.50	47.80	37.54	1.975	41.90	712
7	63	100.8	9.00	13.60	12.40	39.10	2.55	104.50	50.45	34.14	3.115	39.55	849
8	67	112.9	9.80	24.05	23.35	38.55	4.05	107.00	49.90	41.39	2.365	56.40	1076
9	67	107.6	5.75	6.35	4.30	40.00	2.28	102.00	45.00	26.94	2.325	23.50	489
10	65	107.3	7.85	13.50	5.45	40.15	2.50	98.50	48.55	27.42	2.700	48.10	683
11	69	136.5	10.50	16.00	15.20	34.80	3.66	102.00	48.65	34.20	1.480	46.55	756
12	75	145.3	12.20	33.85	28.35	27.95	4.89	106.00	41.05	41.45	0.800	81.70	1478
13	68	155.6	12.50	54.16	39.75	31.15	5.26	106.50	46.45	43.74	0.950	124.01	1770
14	71	142.6	12.25	30.50	26.65	30.25	5.00	102.50	46.25	42.62	1.240	71.45	824
15	62	115.7	9.80	15.40	13.35	44.30	3.79	103.00	51.95	30.70	2.335	50.25	939
16	63	109.7	8.35	12.65	11.80	34.75	2.84	99.50	47.65	33.74	2.955	37.75	751
17	60	109.5	9.95	28.15	23.40	42.80	5.02	105.50	53.70	42.07	2.950	66.25	1394
18	61	109.2	7.50	11.20	9.15	33.80	3.18	98.50	47.65	32.47	2.170	34.65	751
19	63	124.2	10.70	26.70	23.95	43.80	3.94	100.50	53.05	39.65	1.975	67.75	1542
20	69	108.5	10.85	26.55	21.65	41.55	3.69	111.00	50.05	39.90	2.310	66.05	1157
21	64	67.4	8.40	10.05	6.36	41.45	3.09	99.50	52.20	28.28	2.060	34.70	880
22	59	106.5	10.15	21.80	19.95	40.65	4.65	101.50	49.45	37.97	2.360	57.50	901
23	61	112.6	9.20	20.35	18.35	42.15	4.19	97.50	52.35	37.05	1.865	52.85	1035
24	64	128.8	11.75	28.15	23.15	40.60	3.93	103.00	50.45	37.97	2.525	73.90	1408

1. DFF 2. Plant height (cm) 3. Head diameter (cm) 4. Seed yield (g) 5. Filled seed weight (g)
 6. Seed oil (%) 7. Test weight (g) 8. Days to maturity 9. Kernel oil (%) 10. Harvest index
 11. Kernel/hull ratio 12. TDM (g) 13. Leaf area (cm²)

Appendix 5. The mean of various growth, yield and oil characters for 24 genotypes under late stress condition.

Genotype No.	1	2	3	4	5	6	7	8	9	10	11	12	13
1	60	137.3	9.75	23.50	21.50	34.25	4.27	93.50	42.25	31.85	1.545	72.65	2453
2	66	127.8	13.30	21.40	20.05	34.25	3.95	103.00	46.75	35.56	0.710	59.95	1994
3	61	150.3	12.20	30.50	24.80	37.90	4.71	98.00	47.45	33.40	1.790	94.15	2353
4	72	154.5	12.20	32.30	30.00	38.35	4.73	101.50	53.10	32.54	1.995	99.25	3078
5	63	153.2	12.00	21.00	18.13	34.25	3.67	100.50	43.40	29.40	1.400	71.15	2911
6	62	147.7	10.40	18.65	14.95	34.05	3.33	93.00	46.40	33.95	1.325	55.25	2406
7	63	144.1	10.95	26.05	22.40	36.95	3.80	95.00	46.70	36.61	1.885	71.65	2280
8	67	147.9	11.25	32.50	29.35	36.60	4.30	102.00	50.25	39.72	1.980	77.35	2325
9	67	138.0	7.60	7.35	5.50	32.50	2.01	97.50	45.40	21.45	1.990	34.25	1570
10	62	141.1	11.00	23.45	14.70	30.35	3.18	94.50	40.50	36.39	1.490	64.10	3376
11	64	151.9	11.55	26.75	18.94	32.20	4.27	94.50	47.35	31.32	1.165	85.35	2776
12	74	193.6	14.65	53.15	34.85	32.40	5.80	110.00	47.10	38.39	1.080	139.30	4649
13	74	155.8	10.50	33.45	29.45	32.75	5.45	104.00	48.10	33.78	1.150	96.00	3009
14	74	210.9	13.45	53.65	47.30	32.25	5.97	107.50	46.60	46.74	1.335	112.80	5115
15	60	142.5	9.95	17.80	11.21	34.50	3.50	98.50	48.70	27.42	1.935	65.25	2038
16	61	132.1	9.10	21.55	15.05	32.70	2.81	90.50	46.00	30.87	1.490	69.50	2849
17	60	131.4	10.20	21.70	19.85	32.65	4.61	93.00	45.80	36.17	1.860	59.95	2063
18	60	135.3	10.65	22.40	19.01	33.15	4.01	93.00	43.95	37.50	1.810	59.50	2109
19	64	149.4	11.90	35.85	32.55	40.05	4.16	100.00	49.35	44.96	1.225	78.55	2905
20	67	146.4	11.25	24.85	20.85	37.55	3.26	98.00	51.55	38.89	2.125	61.65	2924
21	65	91.9	8.90	20.75	14.65	35.50	3.24	100.00	45.00	43.90	0.830	47.20	2142
22	61	130.2	10.40	28.30	22.40	34.75	4.15	96.00	48.10	36.73	1.600	77.35	2742
23	60	136.0	12.20	30.65	26.49	36.75	4.95	93.00	42.30	41.93	1.390	72.25	2798
24	61	162.5	12.50	18.75	15.10	33.60	3.59	110.00	44.15	23.79	1.225	78.35	2615

1. DFF 2. Plant height (cm) 3. Head diameter (cm) 4. Seed yield (g) 5. Filled seed weight (g)
6. Seed oil (%) 7. Test weight (g) 8. Days to maturity 9. Kernel oil (%) 10. Harvest index
11. Kernel/hull ratio 12. TDM (g) 13. Leaf area (cm²)



Th. 2455

