

**“SCREENING AND INHERITANCE STUDIES UNDER
SUPRA-OPTIMAL TEMPERATURE CONDITIONS AT
SEEDLING STAGE IN PEARL MILLET**

(*Pennisetum glaucum* (L.) R. BR.)”

BY

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in
Plant Breeding**



**COLLEGE OF AGRICULTURE
CCS HARYANA AGRICULTURAL UNIVERSITY
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2007

*Dedicated
To
My Reverent
Parents*

CERTIFICATE - I

This is to certify that this thesis entitled “**Screening and inheritance studies under supra-optimal temperature conditions at seedling stage in pearl millet (*Pennisetum glaucum* (L.) R. Br.)**”, submitted for the degree of **Doctor of Philosophy** in the subject of **Plant Breeding** to Chaudhary Charan Singh Haryana Agricultural University, Hisar, is a bonafide research work carried out by **Ashok Kumar** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CHAPTER-I

INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R.Br.) is one of the major cereal crops of the arid and semi-arid regions of Africa and Asia and provides staple food for millions of people in these regions. It is a multipurpose cereal grown for grain, stover and green fodder. It shall continue to play a prominent role in the integrated agricultural and livestock economy of the country particularly in rainfed areas due to its drought hardiness and tolerance to high temperature. It has the virtue of having exceptionally highest productivity per day both for grain as well as fodder. In the limiting environments, pearl millet is the only successful cereal and a major source of nutrition for the poor farming community. With its ability to adapt to diverse agro-ecological conditions, it may have unique position in the world agriculture. It also responds well to improved moisture and soil fertility conditions. In terms of annual production, pearl millet is the seventh most important cereal crop in the world, following wheat, rice, maize, barley, oat and sorghum (Qi *et al.*, 2004).

Pearl millet production in India is characterized by a higher degree of annual variation both in pre-green revolution and post-green revolution periods. Despite this instability in pearl millet production

there has been sustained growth of production in India during the past 25 years. The trend in production increased by 80,000 tonnes per annum from 1950 to 1964 and thereafter by 32,000 tonnes per annum.

India is a major pearl millet producing country with an area of around 9.30 million hectares and production of about 8.10 million tones (Anonymous, 2005a). Five states (Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana) account for nearly 95 percent of the pearl millet cultivated area (CMIE, 2004). Nearly 60 percent of the rural population of the North and Central India depend mainly on this crop as a staple food.

In Haryana, it is the main and indispensable summer crop with an area of 569 thousand hectares with a total grain production of 749 thousand tonnes and an average productivity of 1316.34 kg/ha (Anonymous, 2005b). Pearl millet provides an excellent nutritious food because of high biological value, more protein (11.6%), fat (5%) and mineral content (2.3%). It also contains adequate amount of essential amino acids such as tryptophane, threonine, arginine and lysine. Pearl millet is also high in lipids, calcium and low in crude fibre.

In pearl millet potential yield is known to be much more than the average yield. The difference between potential yield and average yield must be attributed to the factors that prohibit the genetic potential of the plant. There are different biological and physical factors which in adverse condition produce the differences. Fifteen per

cent losses are observed due to biological factors, remaining losses are due to physical factors.

The other constraints apart, the establishment of a satisfactory plant population is a major difficulty in the production of pearl millet. It has been seen that inhibition of seedling emergence is a common problem in pearl millet in semi-arid tropics (Soman *et al.*, 1987). The establishment of plant population depends mainly on satisfactory germination and seedling establishment. It is here the climatic-physical factor play the key role. The temperature is one of the key climatic factors and has profound effect on the growth and development of the pearl millet plant.

Pearl millet growing environments in these areas are characterized by low and erratic rainfall, high temperature and poor soil fertility. The soil temperatures in farmers' field in India and Africa commonly exceed 45° C and the temperatures as high as 60° C have occasionally been measured (Soman *et al.*, 1981; Singh, 1993). It is also true that several growth processes in pearl millet do require rather a high temperature. The rate of germination, coleoptiles elongation and rate of photosynthesis all reported to be maximizing up to temperature of about 35° C. The pearl millet in this sense could be said to have shown a good adaptation to the hot growing conditions of Sahel and Thar deserts of Africa and Asia. The temperatures in excess of 35° C on the other hand cause inhibition in the normal growth process.

In pearl millet, germination increases linearly with temperature from a base of 10°C to 12°C to optimum at 30°C to 34°C and declined to zero at about 45°C to 47°C (Ong and Monteith, 1982; Pearson, 1975; Soman and Peacock, 1985). The germination proceeds negatively after the temperature of 35°C and becomes zero at about 45°C (Peacock and Heinrich, 1984). Peacock *et al.* (1993) reported no effect of temperature on seedling 10 days after emergence. This was also indicated from the studies of Singh (1993).

Plant morphology, grain development and yield of pearl millet were markedly affected by temperature (Fussel *et al.*, 1980). High or supra-optimal temperature or heat stress affect the crop productivity by adversely influencing seed germination, tillering/plant, flowering, pollination, grain formation and grain development.

The supra-optimal temperatures are known to be the most important cause of poor crop stands in farmers field (Ong, 1983). The plant response to supra-optimal temperature includes inhibition of photosynthesis, protein synthesis, leakage of cell contents (stress injury) and disturbances in metabolic reactions. The rate of temperature change and the duration contribute to the intensity of heat stress. The most profound effect of high temperature has been well documented on early growth stages of pearl millet. The main stages are germination, coleoptiles elongation and early vegetative growth.

Heat stress produces direct or indirect stress injury. This complicated effect of elevated temperature is due to disturbances in metabolic reactions caused by slow vaporization of cellular water

content. The secondary heat injury includes drought injury whereas primary heat injury includes inhibition of growth, reduced nutrient supply, production of toxic compounds, protein break down and some biochemical lesion. The rate of temperature change and duration of high temperature contribute to the intensity of heat stress, where heat stress occurs it is important that crops possess a certain degree of heat tolerance to survive the stress period. Genetic variability for adaptation to high temperature exists in crop plants. Certain laboratory techniques are available for screening and identification of genotypes tolerant to high temperature such as electric conductivity test, chlorophyll stability index, germination, stress index, hydroponic seedling test and embryo protein synthesis, etc. A field screening technique which is supposed to be the most desirable has been reported by Peacock *et al.* (1990).

Heat may lead to the utilization of a greater amount of photosynthates than that produced by photosynthesis. Excessive heat results in protein denaturation and it affects the membrane composition and stability, which is a function of water, protein and the lipid components of the membrane as well as their interaction with each other. As the temperature rises, the lipids become increasingly liquid that affects the membrane functions and its structure.

As the temperature raises from optimum to the stress levels, there is a dramatic change in protein synthesis. A new set of proteins known as heat shock proteins (HSPs) are produced and normal protein synthesis is greatly reduced (Lin *et al.*, 1984). The ability of crop

plants to adapt to heat stress is potentially an important component of tolerance to heat stress under field conditions (Chen *et al.*, 1982).

Development of genotypes tolerant to heat stress using conventional breeding approaches is difficult mainly due to the lack of suitable field screening techniques required for screening both germplasm and segregating generations.

Many workers have demonstrated the ability and potential of gel electrophoresis of protein and isozymes for distinguishing crop varieties. Not only these are less influenced by environmental conditions, but also offer less laborious and rapid protocols. Electrophoresis of soluble seed proteins and isozymes has been reported to be useful for identification of hybrids and parental lines (Kapse and Nerkar, 1985; Agrawal *et al.*, 1988).

In recent years, protein markers are in routine usage and widely accepted as a reliable tool for the determination of genetic identity of crop varieties (Weir, 1990). Isozymes are polymorphic and more stable than morphological characters/traits (Tanksley and Orton, 1983; Di Renzo *et al.*, 1992). Therefore, these accurate and inexpensive biochemical markers have been used extensively to characterize populations (Perez de la Vega, 1993). Information generated from Isozyme is more accurate estimates of genetic diversity and of relationship within and among crop species and their wild relatives (Chan and Sun, 1997).

High temperature or heat being solely a climatic factor can not be controlled by any artificial means, which claims the modification

in the response of plants to high temperature tolerant pearl millet varieties. All this provide a good background work and knowledge to initiate programme of genetic studies and breeding for thermal tolerance.

Keeping the above factors in view, the present investigation entitled, “Screening and inheritance studies under supra-optimal temperature conditions at seeding stage in pearl millet (*Pennisetum glaucum* (L.) R.Br.)”, was undertaken with the following objectives:

- i) To screen the genotypes tolerant to high temperature stress
- ii) To estimate the genetic parameters and combining ability effects in the inheritance of heat tolerance and related traits.
- iii) To identify suitable genotypes for heat tolerance breeding.
- iv) To examine genotype $\times$ environment interaction and stability of the genotypes in temperature differing environments.
- v) To determine the correlations among the traits in different environments.

CHAPTER-II

REVIEW OF LITERATURE

The temperature has long been recognized as the main environmental stress on the development of the plants (Landsberg, 1975). In its real meaning it is different from other kind of environmental stresses in the sense that its artificial modification is not possible. A breeding frame work for temperature stress would therefore rest more on genotypic response of varieties than any other managerial measures.

2.1 Heat Tolerance

The temperature effect on germination, seedling establishment and early vegetative growth of pearl millet are well documented. The germination in pearl millet seeds linearly increased with the temperature from low up to optimal stage and declined with higher temperature was reported by Ong and Monteith (1982). Successful germination and seedling establishment under such conditions will depend mainly on the use of genetically heat tolerant genotypes and

appropriate management. Studies on four pearl millet landraces indicated that a high germination rate is an important trait (Mohamed, 1984).

Pearson (1975) also reported that percentage seedling is independent of temperature between 15°C and 33°C in the day time. Branching of roots was most prolific and production and expansion of new leaves were faster at high temperature. The dry weight accumulation was fastest at 35°C temperature. They also suggested that cool temperature depression of dry weight accumulation in pearl millet was due not only to lower rates of net photosynthesis but also to slower germination, slower and incomplete utilization of seed reserves, lower meristematic activity and top/root ratio and probably lower rates of carbohydrates translocation. Begg and Burton (1971) reported that rate of development to anthesis and leaf number was greater at the higher temperature, whereas dry weight was higher at the lower temperature. Most of the genotypes reached anthesis sooner at the higher temperature, and the variation between genotypes averaged over all photoperiods was greater at the lower temperature. The effect of photoperiod tended to be greater at the higher temperature, and the temperature effect was greatest at 14 hr. With the increase in photoperiod, there was also an increase in the number of tillers and the number of leaves on the main stem.

In the report of Launder (1971) it was stated that percentage of final emergence, rate of emergence, seedling survival and growth usually increase with temperature up to 33°C and decline at higher

ones. It has been established that inhibition of seedling emergence is a common problem in pearl millet in semi-arid tropics (Soman *et al.*, 1987). The high soil temperatures have also been found to be one of the principle causes of poor seedling emergence and establishment (Rai and Kumar, 1994).

Joshi *et al.* (1997) reported that germination behaviour and seedling growth of pearl millet parents and hybrids were studied in a range of temperatures from 10°C to 50°C under laboratory conditions. The optimum temperature for germination was found to be 30°C -35°C, while there was no germination at 10°C and 50°C. The seeds kept at 10°C for a week, when transferred to the optimum temperature resumed normal germination, thus exhibiting the chilling resistance. Hybrids performed better than the parents with respect to percent germination, germination index and seedling growth in terms of length and dry weight at most of the temperatures studied. The hybrid GHB-15 exhibited better parental heterosis at all the temperatures and the magnitude of mid parental heterosis was more at adverse temperatures than that at the optimum.

Soman (1981); Peacock and Heinrich (1984) also reported that soil temperature above 45°C inhibit the emergence in pearl millet.

The sensitivity of seeds to high temperature is likely to delay or prevent germination in many parts of the semi-arid tropics where pearl millet is grown. The very strong influence of timing of the period of high temperature suggested that seeds are most sensitive

when they are absorbing water. At some stage near the end of imbibition, seeds appear to develop a partial immunity to high temperature; alternatively, cellular repair mechanisms may allow affected seeds to germinate after a slight delay. Therefore, seeds should be sown in the evening for better germination. (Garcia-Huidobro *et al.*, 1985)

Peacock *et al.* (1993) reported genetic variation in seedling emergence and survival is largely due to tolerance of high temperatures rather than tolerance of soil moisture deficit. The broad sense heritability ($h^2 = 0.82$) of the thermo-tolerance index (TI) trait was high. The genetic variability for thermo-tolerance at seedling stage was identified by Singh (1993a) in a set of 38 genotypes, which included CMS lines, pollinators, inbreds, populations and hybrids. The hybrids HHB-67, HHB-68 and HHB-60 were identified among high tolerant types. The inbred lines H77/833-2, H90/4-5, and Togo-II also showed high tolerance traits. The hybrids and populations in general appeared more tolerant to drought stress than the CMS lines and pollinators. The rapid emergence and early vigour of hybrids could be the possible reason.

The studies of some other seedling characters for their effect and adaptation to high temperatures were undertaken. The investigation was extended to emergence rate, height of seedlings and number of leaves. A large magnitude of genotypic variability was noticed in respect of germination, thermo-tolerance index, emergence rate, seedling height and leaves/seedling. The criterion of

seed to seedling thermo-tolerance index (SSTI) was used by Singh (1993a) to evaluate the genotypes for tolerance to heat. This criterion takes into account the normal germination rate on the field as observed during monsoon.

Singh *et al.* (2003) reported that in combining ability analysis the mean squares due to both GCA and SCA were significant indicating the importance of both additive and non-additive type of gene action for the inheritance of seedling heat tolerance. However, the narrow sense heritability was low ($h^2 = 0.25$), suggesting that simple mass selection would not be effective in improving the heat tolerance. Rather, reciprocal recurrent selection might be expected to be more rewarding

Environment did not have major impact on the variability pattern of seedling emergence and seedling heat tolerance index and they have high heritability (broad sense) coupled with high genetic advance (Singh *et al.*, 2000). Shonnard and Gepts (1994) evaluated flower bud abortion and reduction in pod fill under high temperatures to study the genetics of heat tolerance during reproductive development in common bean. They reported significant additive genetic effects for both heat tolerant traits. They also indicated there were significant genotype $\times$ environment interactions. Their analysis demonstrated the presence of cytoplasmic effects, including interaction of cytoplasmic with nuclear genes. Porter *et al.* (1995) stated that highly significant GCA effect suggested that additive genetic effects can be exploited for

wheat germplasm improvement by selecting those genotypes with high levels of acquired high temperature tolerance that have significant positive GCA effects.

Peacock *et al.* (1993) suggested that the poor stand establishment of some pearl millet genotypes may be due to poor emergence rather than to subsequent seedling survival, and environmental conditions prior to emergence may be critical. They suggested that variation in emergence between genotypes could be reduced if all seeds were produced under similar conditions. Singh *et al.*, (2003) evaluated pearl millet hybrids and population lines for seedling establishment by having percent germination and thermo-tolerance index (TI) using ratio of seedlings surviving to total number of seedling emerged. The TI value was constantly higher in HHB-67 genotype in all the experiments. The results suggested that poor stand /seedling establishment of some pearl millet genotypes might be due to lower initial seedling emergence rather than subsequent seedling survival, thereby establishing the importance of environmental conditions before emergence. But in this context, seed to seedling thermo-tolerance index (SSTI) worked by Singh (1993a) assumes importance. This index takes into account the possible mortality of emerging seedling before they come above the soil.

Germination variation in seedling emergence of pearl millet and sorghum was observed by Soman and Peacock (1985). They reported genotypic variation in response of varieties to high

temperatures. They also reported that a temperature maximum of 45⁰C gave the best selection pressure and very few lines emerged at 50⁰C. The genetic differences among the lines from pearl millet and sorghum population measured at 45⁰C. High temperature affects germination and emergence in several ways. The soil temperature in the seed zone can inhibit germination itself and plumule extension can be halted at any time of germination. In these experiments, when the top soil in the clay pots was removed, many ungerminated seeds and seedlings with damaged plumules which had failed to emerge were observed.

Buckle and Grant (1974) recorded similar abnormalities with maize seedlings grown at an average soil temperature of 40⁰C. In addition differences in the rate of plumule extension were observed when sorghum was grown at a range of temperatures (Soman, 1981).

Gracia-Huidobro *et al.* (1982) stated that the rate of germination increased linearly with temperature from a base T_b to a sharply defined optimum T_o beyond which the rate decreased linearly with temperature, reaching zero at T_m . The linearity of the response both above and below T_o allowed time temperature to be combined in thermal time at which a specified fraction of the seeds germinated. They also reported that alternating temperature had a small but systematic effect on germination rate.

Khalifa and Ong (1990) also reported that the rate of germination of pearl millet cultivar increased linearly with increase in temperature from a base temperature (T_b) to an optimum value

(T_o). Above T_o , rate of germination decreased linearly to zero at a maximum temperature (T_m) of 46°C - 48°C depending on the genotype. They also reported that the short duration hybrids possessed a greater tolerance to high temperature than long duration hybrids. They indicated that faster germination rate of HHB-67 might have permitted it to escape the damaging effect of supra-optimal temperatures. The seeds which are slow to germinate are more sensitive to high temperature.

Other developmental and growth stages such as tiller development, leaf extension, spikelet initiation, grain development and grain yield are also reported to be markedly effected by temperature variations. Peacock *et al.* (1990) demonstrated that high temperatures (above 45°C) around the shoot meristem of sorghum seedlings inhibited seedling growth even when moisture was not limiting and that at 54°C seedlings died as a result of 'heat girdling' of the mesocotyle, which apparently caused the blockage of phloem and so prevented the flow of carbohydrates to the roots. Shoot carbohydrates increased while root carbohydrates declined, indicating that phloem transport from shoot to the root has been blocked or restricted.

Ong (1984) reported the major influence of the temperature on stem elongation and crop canopy in a stand of pearl millet. The decrease of tiller number with increasing temperature was also reported by Pearson (1975). Ong (1983) explained this relationship by a shortening of tillering phase and an inhibition of secondary

tillering with increasing temperature. The initial effect of high temperature was earlier tillering whereas at low temperature (19°C) tillering continued via basal tillers which produced secondary tillers, again at a rate which was closely related to the number of leaves present. Thus the plants at 19°C produced two to five times more tillers than those at or above 25°C. Fussell *et al.* (1980) reported even more prolific tillering for the same species: 7.8 times more at 21°C compared to 30°C.

The rate of leaf extension and spikelet initiation was also a linear function of the temperature up to 34°C so that time needed to form complete canopy decrease with increasing temperature up to that limit was the major finding of Ong and Monteith (1982). Fussell *et al.* (1980) published that plant morphology, grain development and yield of pearl millet were markedly affected by temperature during three stages of plant growth such as vegetative, stem elongation and grain developments. The same report indicated that high temperature during all three growth stages lowered the grain yield by reducing basal tillering, number of grains per inflorescence and grain weight. Inflorescence length, width and the density of spikelet also appeared to be determined by temperature regimes. The extremes of temperature before anthesis reduced the sites available for grain development and thus lowering the grain yield. There was no tillering response to different temperatures after the beginning of stem elongation, presumably because floral initiation had occurred before the start of the temperature treatments. After floral initiation,

competition for assimilates is high, resulting in little new development of tiller initials. Plant development and flowering in most genotypes are also accelerated by increasing temperature up to 33°C.

Effect of temperature on leaf canopy, stems and the panicles were investigated by Squire (1989) in a stand of pearl millet. He reported a marked effect of temperature range for growth processes in pearl millet.

The effect of high temperature stress is also well documented in respect of other agricultural crops. Poor crop establishment has also been described as a limiting factor for production of sorghum in temperature tracts. A temperature of 40°C to 48°C has been reported to be lethal for germination of sorghum seeds (Peacock, 1982). In maize it has been shown that aspects of embryo protein synthesis, including transcription and translation are disproportionately reduced at supra-optimal temperatures (Riley, 1981a, b & 1984). Effects of heat stress on yield and fruit set of bean, potato, soybean and tomato have been reported by Chen *et al.* (1982). It was said that heat killing time of leaf tissues was function of acclimating temperature. The authors also reported genetic variability to heat stress in these crops.

For wheat it has been reported that high temperature stress reduces productivity in many regions and limits response to cultural practices for high yield (Midmore *et al.*, 1984; Shipler and Blum, 1986). The stress is particularly detrimental during grain filling due

to curtailment of grain development when temperature rises (Al-khatib and Paulsen, 1984). The injury caused by heat stress varies significantly among growth stages with the highest heat injury occurring at the flowering stage as reported by Sapra and Anaele (1991). Susceptibility to heat injury decreased towards maturity. A positive and significant relationship between promptness index and germination stress index was found.

Heat stress not only affects the yield and its components but also to the isoenzyme composition of some crop plants (Iglesias, 1994). The response of crop plants to heat stress depends upon the nature of stress resistance and the phase of stress resistance in the plants.

2.2 Biological basis of thermo tolerance

2.2.1 Heat Shock Proteins (HSPs)

It has been shown that several species of higher plants including soybean, pea, tobacco, cotton, sorghum, maize and pearl millet respond to high temperature (39°C to 45°C) stress. A characteristic set of proteins known as heat shock proteins (HSPs) is synthesized as a result of sudden high temperature stress (Nover, 1984). Two major categories of HSPs are detected; one has a high molecular weight and other has low molecular weight. This phenomenon has been investigated in wide range of organisms both in animals and plants. According to Altschaler and Mascarenhas (1982), the similarity in response to heat shock in the range of 40°C

to 45°C suggested that there was fundamental role of HSPs in survival against high stress.

In cereals species, studies on HSPs have been carried out in maize (Cooper and Ho, 1983; Cooper *et al.*, 1984), sorghum (Howarth, 1989a), barley (Marmiroli *et al.*, 1986; Ada Neechi *et al.*, 1987) and wheat, rye and triticale (Ada Neechi *et al.*, 1987). In pearl millet investigation on heat shock proteins mechanism were studied (Howarth, 1989b) for genotypic and developmental variation during seed germination. It was observed that millet seedlings were competent to synthesize the complete spectrum of HSPs during a two hour's heat shock of 45°C. Further the investigation indicated that thermo-sensitivity of a genotype and HSPs synthesis was a complex response involving the transcriptional and translational control of RNA in the seed embryo.

Heat shock proteins (HSPs) induce thermo-tolerance in plants. In a study performed by Lin *et al.* (1984), it was observed that a prior treatment of soybean seedlings at 40°C for 2 h permitted higher levels of protein synthesis at the otherwise non-permissive heat shock temperature (i.e. above 42.5°C). When the heat shock is given to plant parts, the pre heat shock-proteins disappear and heat shock proteins appear. HSPs increase in concentration for a limited time following heat shock. Most HSPs decrease in concentration over time even if temperature remains high. So 40°C is considered the optimum temperature for induction of HSP synthesis in soybean seedlings. Under conditions where HSPs synthesis is not fully

developed, seedlings are not maximally protected. Only after HSP synthesis is well established, seedlings do show thermal protection. Heat-induced chromosomal puffing of *Drosophila melanogaster* was accompanied by the high level expression of a unique set of proteins called heat shock proteins (HSPs). There are six families of heat shock proteins i.e. HSP 110, HSP 90, HSP 70, HSP 60, HSP 20 and Ubiquitin.

In higher plants, the rate of synthesis of low molecular weight HSPs is correlated with acquired thermo-tolerance (Lin *et al.*, 1984). Accumulation of HSPs is important for protection from thermal killing but when the question comes whether quantity or quality of HSPs is important. Two cultivars which differ in thermo-tolerance normally do not differ in the quality of HSP induced at same temperature. Not only the HSP synthesis and acquired thermo-tolerance are highly coupled, but also the intra-specific differences in quality, quantity and the rate of accumulation of HSP are highly correlated with thermo-tolerance. Germinating pollen and early imbibing embryos (pre-torpedo stage) are not capable to synthesize HSPs in response of heat shock.

At cellular levels high temperature causes metabolic disturbances, depletion of respiratory substrates, reduction of photosynthetic activity, denaturation of proteins, inactivation of enzymes and damage to cellular structures. It is realized that a complex character like heat tolerance with respect to grain yield may not be linked to a single metabolic process. Plants have a multitude

of mechanisms which help them to survive and propagate under high temperature stresses. Zhang *et al.* (1997) suggested that there is an association between HSPs and heat tolerance, drought tolerance as under heat shock conditions certain HSPs (SH1 and SH2) were enhanced as revealed by SDS-PAGE analysis.

Viswanathan and Khanna (1996) studied the occurrence of heat shock proteins (HSP) in plants, with reference to their mechanism of protection from high temperature stress, regulation of HSP expression, the role of HSPs in thermo-tolerance of higher plants, the correlation between HSP expression and thermo-tolerance, cellular localization of HSP etc. in several crop species.

Heat-shock protein synthesis is cultivar dependent (Ronde *et al.*, 1993). The synthesis of heat related proteins was examined in six cotton cultivars using SDS-PAGE analysis. The protein profiles of heat stressed plants were highly cultivar specific. Heat related proteins did not result from protein degradation. Recovery to normal levels of protein synthesis occurred within an hour after the heat-stress was terminated.

Yen *et al.* (1993) reported that changes in protein synthesis occurred when asparagus was heat shocked at 34 to 37°C for 2-6 hr. as analyzed through SDS-PAGE. Most of the heat shock proteins were of low molecular weight (about 13-24 kDa). Wang *et al.* (1994) reported that more HSP types are induced in the summer variety than in spring variety i.e. the HSPs production is affected by different geographical groups.

Zahran *et al.* (1994) reported that lipopolysaccharides and protein profiles of rhizobia are altered by osmotic and heat stress as shown by SDS-PAGE. The stress induced changes in lipopolysaccharides were not associated with specific banding patterns of the lipopolysaccharides during incubation in medium containing elevated concentration of NaCl or sucrose, the protein patterns of rhizobia were also changed. A protein with relative mobility of 65 kDa appeared during temperature stress.

2.2.2 Membrane Thermo-stability

Heat tolerance usually improves membrane stability under heat stress which can be determined as lipid fluidity or electrolyte leakage. Osmo-regulators like proline and glycine - betaine may have a protective role in heat stress.

Martineau *et al.* (1979a) reported on the use of a technique to measure membrane thermo-stability in soybean leaf tissue and demonstrated consistent and reproducible cultivar differentials for heat tolerance with this technique. Martineau *et al.* (1979b) used this technique to screen segregating soybean population derived from crosses to heat tolerant and intolerant parents. Significant genetic variation for heat tolerance was observed in all populations in both years.

Sapra and Anaele (1990) screened the genotypes for heat tolerance in green house and field and the leaf samples taken at 2 weeks interval from vegetative to reproductive stages were assayed

for injury after treatment at 50°C and 25°C. Considerable variation between genotypes and years was observed for both traits. As reported by Titov *et al.* (1986), the speed of heat adaptation can also be used for estimating heat resistance of soybean cultivars. The tolerance differed in the hardened and non-hardened seedlings, as also depended on the speed of hardening. The speed of adaptation to heat was found negatively correlated with the heat tolerance.

Srinivasan *et al.* (1996) evaluated heat tolerance in food legume, by cell membrane thermo-stability and chlorophyll fluorescence techniques and ranked the legumes from heat tolerant to sensitive in the order: groundnut, soybean, pigeon pea and chickpea.

Chen *et al.* (1982) measured heat tolerance on the basis of 2,3,5-triphenyl tetrazolium chloride reduction and conductivity tests on leaf tissue. These methods were applied at early growth stages, following acclimatization at above 30°C for 12-24 hours.

Three screening techniques viz. (1) germinating seed in polyethylene glycol-600 (PEG) at -0.6 MPa osmotic pressure (2) subjecting seedlings to PEG-600 at -0.06 MPa osmotic pressure in hydroponic solution for 14 days and (3) a heat tolerance test based on cellular membrane thermo-stability were compared by Bouslama and Schapaugh (1984). They observed highly significant correlations between the hydroponic seedlings and heat tolerance tests indicating that both drought and heat tolerance were identified in the same cultivars. The hydroponic seedling test was found most reliable and

potentially useful for screening for drought tolerance in soybeans. Cellular membrane thermo-stability indicates the heat tolerance of different cultivars (Bousslama, 1983). Heat stress affects the physiological aspects e.g. membrane thermo-stability and chlorophyll fluorescence, regulation of compatible solutes as reported by Takeda *et al.* (1999). There was an accumulation of free proline in the leaves in response to high temperature.

Binelli *et al.* (1990) suggested that an electrolyte leakage assay reveals the sensitivity of the genotype to high temperature stress as compared to the high temperature tolerant genotypes. Higher the electrolyte leakage in shorter time less is the duration of heat killing. *Arabidopsis* seedlings are more sensitive and prone to damage as compared with the soybean seedlings at 42°C treatment for 2 h. HSP were synthesized in *Arabidopsis* at 42°C for 2 h. but their presence was not sufficient to recover from heat shock.

2.3 Screening methods for thermo-tolerance

Various techniques have been used to study the response of genotypes of cereals at high temperature. Screening methods are generally attempted at two levels; laboratory and field. Screening for heat tolerant genotypes can be done based on the characteristics like germination (percent germination under stress); growth during heat stress (yield, biomass); membrane stability (soluble leakage conductivity test); photosynthetic sensitivity (chlorophyll fluorescence at 685 nm), recovery after heat stress (yield, biomass

etc.); sensitivity of reproductive phase (flower/pod/fruit/seed production; pollen fertility).

2.3.1 Laboratory techniques

Certain laboratory techniques for screening and identification of genotypes tolerant to high temperatures such as electrolyte conductivity technique, chlorophyll stability technique, seed germination test, hydroponic seedling test and embryo protein synthesis etc. have been developed.

2.3.1.1 Electrical conductivity (EC)

Many laboratory techniques have been developed by various scientists. One bioassay often used in characterizing high temperature tolerance is electrolyte leakage of leaves subjected to heat stress (Shanahan *et al.*, 1990). These are electrical conductivity methods (Blum and Ebercon, 1981; and Nagarajan and Panda, 1980). Chlorophyll florescence method (Smillie, 1979; Smillie and Gibbons, 1981 and Moffat *et al.*, 1990) and embryo protein synthesis methods (Ougham and Staddart, 1985; Riley, 1981a, b, 1984 and Ougham *et al.*, 1988). Saadalla *et al.* (1990) suggested that the membrane thermo-stability test would be a suitable procedure for selecting heat tolerant winter wheat genotypes in a breeding programme.

Ibrahim and Quick (2001) found that the mean squares for general combining ability (GCA) was four times that of specific

combining ability (SCA), indicating the importance of additive gene effects in acquired thermal tolerance. They expressed the membrane thermal stability (MTS) in percent units as the reciprocal of the leakage: $MTS = (1 - T_1/T_2) \times 100$ where T_1 is the conductivity reading after heat treatment, and T_2 is the conductivity reading after autoclaving. Singh *et al.* (2004) studied the percent membrane injury in leaves under different planting conditions in chickpea genotypes. Membrane damage was more at later stages of crop growth as compared to early stages. There were significant differences in membrane injury at all the planting dates. Membrane injury was higher in delayed planting.

High temperature disrupts water, ion and organic solute movement across plant membranes, which interferes with photosynthesis and respiration (Christiansen, 1978). Damage to membrane may be assayed by the membrane thermal stability (MTS), which measures electrolyte leakage from leaves subjected to elevated temperatures (Sullivan, 1972). Although MTS is positively associated with yield performance under heat stressed conditions (Reynolds *et al.*, 1994).

The electrical conductivity method depends upon increased electrical conductance in leaf tissue under high temperature. A damage of cell membrane structure leads to increase permeability of ions. Also denaturation of protein takes place which increase the ion concentration of the cell. The technique is used as a direct conductivity method.

The chlorophyll fluorescence technique is based on process of photosynthesis. High temperature alters efficiency of photosynthesis and the relative amount of light energy that re-emitted as chlorophyll fluorescence. The variable fluorescence is not readily reversible. It is, therefore, a specially useful method to measure the heat induced injury.

The embryo protein synthesis technique is also based on its heat sensitivity which is known to limit the germination. The degree of correlation between temperature sensitivity for germination and EPS was very high. This correlation is likely to be applicable to most cereal crops during emergency at high temperature. It can be used as rapid laboratory technique for screening heat tolerant genotypes.

Some other laboratory tests such as germination under osmotic stress condition (GOS), heat shock test at seedling stage, water loss of excised leaves have also been applied for determining the variation in genotypic responses (Borghi *et al.*, 1990).

The minimum temperature at which movement of the protoplasm cease in all cells can be used as a measure of heat resistance (Zavadskaya *et al.*, 1981) and it increases under water stress in drought resistant varieties but do not change in susceptible ones. Further, it was found that chlorophyll breakdown under heat stress in drought susceptible variety was slower, as the temperature rose but in drought resistant variety, chlorophyll breakdown was not inhibited with the increase in temperature.

2.3.1.2 Electrophoresis of isozymes

Molecular markers are being extensively used in crop improvement programmes to (1) speed up selection efficiency of breeding methods and (2) construct saturated linkage maps. Molecular markers are better from morphological marker because alleles at most molecular markers loci are usually co-dominant and thus all possible genotypes (homozygotes and heterozygotes) can be distinguished in segregating populations, any plant tissue can be used for study and in most molecular loci, polymorphism occurs naturally.

Isozymes, the multiple molecular forms of the same enzyme with the same substrate specificity (Markert and Moller, 1959) usually detectable through electrophoresis due to differences in their net electrical charges. The differences in charge are because of the acidic and basic nature of different amino acids and the differences in electrophoretic mobility of enzymes are usually the result of changes in structural genes coding for polypeptide(s). Thus electrophoretic differences are the direct result of genetic differences. Detection of isozymes using electrophoretic techniques has been extensively used for the characterization and identification of species, inbred lines, isogenic lines and crosses in plant breeding studies. Hunter and Markert (1957) proposed the term “zymogram” to refer to the strips in which the enzyme location is demonstrated. Detection of isozyme using electrophoresis techniques has been extensively used for the characterization and identification of

species, inbred lines, isogenic lines, and crosses in plant breeding studies. The information obtained by the analysis of isozyme extracted from seed/seedling by electrophoresis has been well established to be very useful for estimating genetic variability, identification of cultivars and confirming hybridity (Cooke, 1995; Smith and Smith, 1992).

Isozymes patterns have been found useful for characterizing varieties of various crops such as wheat (Alexandrescu and Saulescu, 1982), rice (Santhy, 1994), maize (McDonald and Brewbacker, 1975), barley (Dai and Zhang, 1989), pearl millet (Varier, 1994; Chhabra, 1995, Chhabra *et al.* 2002), sorghum (Nagaraja, 1998) and mungbean (Eeswara and Pieris, 2001). Abdel *et al.* (1993) identified Egyptian cotton cultivars on the basis of electrophoretic profiles of esterase, glutamate oxaloacetate transaminase, peroxidase, catalase, leucine aminopeptidase and indophenoloxidase isozymes. Nerker and Rao (1993) compared Isozyme profiles of esterase (EST), malate dehydrogenase (MDH), alcoholdehydrogenase (ADH), peroxidase (POX), catalases (CAT) and acid phosphates (ACP) in twenty four cotton cultivars and hybrids. Of this esterase Isozyme revealed unique banding pattern for each genotype. MDH patterns were also useful in discriminating the different cultivars, though the patterns of hybrids resembled those in their respective male parents whereas other enzyme showed limited application. Varier *et al.* (1999) characterized four hybrids

and inbreds of castor on the basis of electrophoresis of Isozyme extracted from five days old seedlings. Sharma (2000) characterized hybrid and parental lines of cotton using esterase, peroxidase, alcohol dehydrogenase and superoxide dismutase isozymes.

Muehlbauer *et al.* (1989) used isoenzyme markers in gene mapping of near isogenic lines (NILs). The electrophoretic isoenzyme banding patterns of enzymes were examined where each NIL possessed an introgressed conventional gene. Linkage between the marker and the introgressed gene was indicated. Isozyme patterns have been found useful for characterizing varieties of various crops such as mungbean (Eeswara and Pieris, 2001), pearl millet (Chhabra, 1995). Esterase zymogram revealed a unique banding pattern for each genotype. Sharma (2000) characterized hybrid and parental lines of cotton using Esterase, peroxidase, alcohol dehydrogenase and superoxide dismutase isozymes. Several Isozymes like acid phosphatase, amylase, phosphoglucomutase and superoxide dismutase were found useful for varietal identification in soybean (Kadlac and Letal, 1996). Eeswara and Pieris (2001) characterized the mungbean varieties using isozymes, Esterase (EST) and Malate dehydrogenase (MDH) with seven polymorphic bands.

Cerna *et al.* (1997) performed an experiment to check whether molecular markers may be useful to select diverse parents for the expression of heterosis in soybean. Heterosis in yield may not be

associated with genetic diversity at molecular levels. It was suggested by the results of this study that in soybean, parent selection on the basis of RFLPs and Isozyme loci to exploit heterosis in seed yield may not be feasible. There was no association between genetic distance estimated by the RFLP analysis and seed yield heterosis, and in spite of the observed relationship between Isozyme loci and heterosis for yield, the practicality of using Isozyme markers to select parents may be limited because of the reduced number of assayable Isozyme loci in soybean.

Metz and Hymowitz (1993) used isozyme markers for the detection of hybridization in crosses between *Glycine tomentella* and *G. max*. Out of 19 isozymes used, particularly malate dehydrogenase, glucose-6-phosphate dehydrogenase and phosphoglucumutase were identified potentially useful markers as their banding pattern allowed the clear identification of hybrids.

Nainawatee (1971) reported three isozymes in diploid, tetraploid and hexaploid wheat showing no genetic variation. Mitra and Bhatia (1971) and Jaaska (1972) observed two broad zones of zymograms that were common to all rye and wheat species.

Peroxidase isoenzyme patterns have been used to indicate characteristic genetic make up of different species of plants like corn (Kadam *et al.*, 1973), *Desmodium* (Chow and Crowder, 1974), *Linum* (Tyson and Bloomberg, 1971), *Nicotiana spp* (Sheen, 1972) and *Oryza spp* (Palanichamy and Siddiq, 1977). In a few cases

attempts have been made to work out the location of genes for isoperoxidases and its relationship has been shown with height genes of plant in sorghum (Liang *et al.*, 1977). Also, Inter-and intra-specific polymorphism is exhibited by peroxidases. The matching of bands among species indicates a closer genetic relationship between them.

Paterson *et al.* (1990) observed peroxidase activity in the wheat seed development, which persisted beyond physiological maturity. They observed 12 (POX) isozymes bands in the embryo and more than 20 bands in the endosperm extracts from immature seeds, the number of which decreased as the seed matured. Nimbal *et al.* (2002) studied a set of back cross-inbred lines (BILS) of wheat using SOD, POX, MDH isozymes. Out of these peroxidase revealed maximum polymorphism.

The analysis of water-soluble seed esterases was found to be potentially useful which showed clear differences between the eight cultivars studies and good replication of protein patterns (but complex banding pattern) from within each cultivar. It has been shown (Varier *et al.*, 1992) that the expression of pearl millet esterases is unaffected by both, the site and season (year) of seed production in composite varieties. Shaista Halim (1997) reported that isozymes of esterase, glutamate oxaloacetate transminase and peroxidase were genotype-specific in pearl millet hybrids, restorers and male sterile lines. Gulati (1998) characterized 13 cytoplasmic-nuclear male sterile lines of pearl millet using isozymes profiles.

Balma *et al.* (1996) conducted isozyme studies on sixty landraces of pearl millet representing genetic variability of eight countries of West Africa. Seed samples produced more variability and number of bands than leaf samples. Feritar *et al.* (2002) used peroxidase (POX) isozyme for identification of 14 pearl millet accessions of African origin. Twelve isozyme systems viz., alcohol dehydrogenase (ADH), catalase (CAT), esterase (EST), glutamate dehydrogenase (GDH), glutamate oxaloacetate transaminase (GOT), lactate dehydrogenase (LDH), malate dehydrogenase (MDH), malic enzyme (ME), phosphoglucosomerase (PGI), 6-phosphogluconate dehydrogenase (6-PGD), Shikimate dehydrogenase (SKDH) and superoxide dismutase (SOD) were used to characterize NILs (near-isogenic lines) of pearl millet for height. Out of 12 enzyme systems 6 were identical for isolines of tall/dwarf near isogenic pairs and ADH (18 hours imbibed seed) & EST (18 hours imbibed seed) were most effective in determining within and between pairs variation (Chhabra *et al.* 1996). Recently, the role of isozymes in pearl millet improvement has been reviewed nicely by Chhabra *et al.* (2002).

2.3.1.2.1 Malate Dehydrogenase Isozyme (MDH)

Gulisano *et al.* (1980) reported that there are changes in the activity of malate dehydrogenase and glutamate dehydrogenase under double stress conditions (dry heat and feed deprivation). MDH activity increased significantly under double stress while under heat

stress it increased slightly after 24 hr and decreased significantly after 72 hr.

Schrader *et al.* (2004) reported that photosynthesis is inhibited by high temperatures because of increased thylakoid membrane ionic conductance and ribulose-1,5-bisphosphate carboxylase / oxygenase (Rubisco) deactivation. To confirm the findings, a proxy for NADPH and stromal redox status the activation state of NADP-malate dehydrogenase (NADP-MDH) was measured and it was observed that sustained heating caused a decline in Rubisco activation and also oxidized the stroma by NADP-MDH activation and this was hypothesized to result from increased cyclic photophosphorylation, explaining the maintenance of ATP content in the face of increased thylakoid membrane ion leakage.

Eeswara and Peiris (2001) characterized the mungbean varieties using isozymes. Esterase (EST) and malate dehydrogenase (MDH) were the most polymorphic. Variety specific isozymic banding pattern were observed for diaphorase, esterase and malate dehydrogenase.

Brewer *et al.* (1969) reported two MDH isozymes in thirty-eight wheat strains, each nullisomic for one chromosome and tetrasomic for a homologous are thus showing no significant electrophoretic variation.

Alonso-Blanco *et al.* (1994) developed cytogenetic maps involving chromosome 1R, 3R, 4R and 6R of rye. They observed the MDH-R₁, the isozyme forms of MDH were located in chromosome

1R and the other for MDH-R₂ was located in chromosome 3R. Miller and Reader (1987) reported the presence of gene for isozymic forms, Mdh-1 of MDH on the long arm of Homeologous chromosome-1.

MDH was studied by Tostain and Riandey (1985) and Lavergne *et al.* (1986) and ADH was the first enzyme system whose genetics has been worked out in Pearl millet (Banuett-Bourillon and Hague, 1979; Banuett-Bourillon, 1982a, b). Another enzyme system subjected to a detailed study is that of EST (Sandmeier *et al.*, 1981; Tostain and Riandey, 1984; Subba Rao *et al.*, 1989).

2.3.1.2.2 Superoxide dismutase enzyme (SOD)

Khanna-Chopra and Sabarinath (2004) reported that superoxide dismutase enzyme (SOD) is ubiquitous, being widely distributed among O₂- consuming organisms and is the first line of defence against oxidative stress. The leaf protein extracts, thylakoidal and stromal fractions were subjected to elevated temperatures ranging from 50°C to boiling and it was observed that out of six SOD isoforms, SOD V showed stability even after boiling. A new SOD band with higher electrophoretic mobility appeared under high temperature treatment (>60°C). The inhibitor studies and sub-cellular analysis revealed that the SOD V isoform was a chloroplastic Cu/Zn SOD.

Several isozymes like acid phosphatase, amylase, phosphoglucosmutase and superoxide dismutase were found useful for varietal identification in soybean (Kadlac and Letal, 1996).

Rivero *et al.* (2004) studied the oxidative metabolism in tomato plants subjected to heat stress. The leaf concentrations of the antioxidant compounds (ASA) and activity of enzyme superoxide dismutase (SOD) were determined. High temperature stress caused (1) decreased shoot weight (2) accumulation of H_2O_2 (3) increased SOD activity and (4) increased level of an antioxidant compounds. Heat stress occurred in tomato plants at $35^{\circ}C$ and this temperature may have initially inhibited the ascorbate/glutathione cycle and then provoked an oxidative burst as indicated by foliar H_2O_2 accumulation.

Eyidogan *et al.* (2003) studied the superoxide dismutase activity of hexaploid and tetraploid wheat cultivars subjected to heat and chilling stress. Shoot and root extracts were subjected to native PAGE and the presence of Mn and Cu/Zn isozymes of SOD was revealed. Heat stress caused a significant increase in SOD activity. Under cold stress no significant change in SOD activity was observed in shoot tissues while in roots of hexaploid cultivars activity was significantly enhanced while a decrease was observed in roots of tetraploid cultivar. Thus it was suggested that enhanced SOD activity might be one of the reasons of relatively greater stress tolerance of bread wheat cultivars over durum cultivars under heat and chilling stress conditions.

The temperature determines the gas exchange and chlorophyll fluorescence, as well as antioxidant response as expressed by SOD (Camejo *et al.*, 2002) physiological and biochemical variables changed depending on the genotype and stress exposure time.

Elongation of the radicle in the heat-sensitive cultivars was significantly inhibited by high temperature, while the radicle of heat tolerant cultivar grew normally. Low membrane permeability, high proline content and high SOD activity were observed in the heat tolerant cultivars both under normal and high temperature.

Zhang and Han (1997) reported that stress treatment of leaves in soybean caused an increased SOD and POD activity. High temperature (45°C for 2-4 hrs) and drought treatment were given to Bainong 6 and Jilin 27 genotypes and increase in the SOD and POD activities of intact leaves in two soybean cultivars was recorded as a result of high temperature / drought stress.

Melakeselam and Zhou (1999) reported that freezing stress increase the activity of superoxide dismutase (SOD) while heat stress significantly decreased in rape. Both the freezing and heat stressed plants had higher endogenous free proline content, rate of electrolyte leakage, and the level of lipid peroxidation. Heat and freezing induced changes in fatty acid composition, loss of antioxidant enzyme activities, membrane integrity and chlorophyll degradation.

2.3.1.3 Electrophoresis of proteins

Proteins, primary product of structural genes are mostly used for electrophoretic studies now a days because hidden variability in the genotypes for various traits can be exploited with their help. Polymorphism in banding pattern is depending on the pH of the buffer which fringes from 3.1 - 10.2 (McLellan, 1982). The most common system of electrophoresis appears to be the Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) developed by Laemmli (1970).

Nowak and Colborne (1989) reported that heat stress significantly reduced tuberization in potato. The high temperatures reduced the accumulation of patatin and 22 kDa protein in all cultivars kennebec showing the great and LT2 the least reduction. So it suggested that microtuber production and SDS-PAGE of proteins produced *in vitro* under heat stress could be used to screen germplasm for hot climates. Wang *et al.* (1990) evaluated 73 accessions of *G. herbaceum* by electrophoretic analysis of water soluble seed proteins. They divided accessions into 18 groups according to the pattern of their electrophoretic bands.

2.3.2 Laboratory cum field screening technique

Genotypic response to temperature is difficult to study in the field because soil temperature varies with the moisture status of the soil and the system becomes even more complex if a crust develops on the soil (Soman *et al.*, 1984). Laboratory techniques representing

near-field condition have also been developed and used for sorghum and pearl millet.

Scheuring *et al.* (1978) recorded germination of the sorghum in wet sand in a warm water bath at a constant temperature for 72 hours. The seeds were thus exposed to a continuous high temperature (maximum of 40°C). Wilson *et al.* (1982) varied soil temperature using two different surface colourants, charcoal and kaolin in small pots. Though the temperature regime obtained with their technique was adequate for screening for emergence, the water status of the soil could not be controlled. Similarly Buckle and Grant (1974) grew maize seedling in soil in dark incubators. Mustain (1981) observed an effect of differing moisture levels on germination at high temperatures.

Soman and Peacock (1985) used clay pots filled with sieved top soil for germination of sorghum and pearl millet seedling, placed in a steel water tank so that only the top 7 cm of the pots was above the water level. The soil surface was 2 cm below the mouth of the pot. The surface of the water was covered with floating white plastic balls to reduce evaporation. The soil in pots was heated with infra red lamps (240-250 V, 250 W, Phillips, Type IRR) fitted to frame above the tank in two rows. The temperature of the soil surface could be altered by varying the height of the frame of infra red lamps above the soil surface, to obtain the temperatures of 35°C, 40°C, 45°C and 50°C measured at 2 cm below the soil surface. Water was added to the tank daily to maintain a constant level, ensuring

that the wet soil column (25 cm long) in the pots provided a steady water supply for the seedlings while allowing them to be affected by the temperature of the soil. The soil water content in the pots was measured gravimetrically. The experiment showed that a temperature of 45°C gave the best selection pressure and very few lines emerged at 50°C.

2.3.3 Field screening technique

Measurements of germination in constant temperature incubators are not necessarily relevant to the field where soil temperatures vary diurnally. Observations with selected sorghum lines have shown that material which fails to germinate in the incubators at 40°C germinated and emerged when sown in soil of the same mean temperature (Soman and Peacock 1985). Results of germination studies made at constant temperature do not necessarily reflect field germination where soil temperature at seed depth may fluctuate widely during the day (Singh *et al.*, 2003)

Latest in the row is a simple and effective field screening technique for pearl millet genotypes. The technique standardized by Peacock *et al.* (1993) was used for pearl millet seedlings experiment conducted in Rajasthan during 1989, 1990. The experiments were conducted during high temperature season of April and May. Environmental measurements were taken in respect of air temperature, soil surface temperature and soil moisture. A condition was created where the drought did not occur in the field. Recording

of seedling emergence commenced immediately the first seedlings were seen and continued daily at 1700 local time until there was no further emergence. The number of live seedlings was counted daily and dead seedlings were marked with wooden sticks. This method provided a check against loss of seedlings by any other means, for example removal by birds or rodents.

A thermo-tolerance index (TI) was calculated as the ratio of seedling which survived to the total number of seedling which emerged. The results of the experiment done with the above technique showed considerable genotypic variation in the thermo-tolerance index which allow the grouping of genotypes into categories of high and low thermo-tolerance. The technique is repeatable and allows a large number of genotypes to be screened at the same time.

Singh, (1993a) using the same technique argued in favour of use of seed to seedling thermo-tolerance index (SSTI) which proceeds on the basis of both, pre and post-emergence mortalities. The pre-emergence mortality was estimated as difference in germination under stress and normal conditions. This provides a good background work and knowledge to initiate programme of genetic studies and breeding for thermo-tolerance.

The same technique of Peacock *et al.* (1993) and Singh, (1993a) has been used in our investigation.

CHAPTER-III

MATERIALS AND METHODS

The material for the experiment have been chosen and generated in accordance with the objectives of the experiment. The focal objective was to have an understanding of phenotypic and genotypic response of cultivars of pearl millet to the high temperature stress. It involved the steps of identification of heat tolerant genotypes and then investigates into their genetic variance. A field screening technique (Peacock *et al.*, 1993) was thought appropriate and applied to the material. Since the technique was applicable to the very young seedlings of pearl millet, it was also of concern to see the association of seedling thermo-tolerance to other characteristics of seedlings help to develop an idea of phenotypic identification of qualifying genotypes. Since the field screening technique had not been much in use, its conformation through a laboratory technique was also required. The test of electrolyte leakage was, therefore, conducted on the same seedlings. All this turned out to be a virtual set of experimentation before entering into the scheme of genetic investigation and analysis.

The experiment which was conducted at the research area of department of Plant Breeding, CCS Haryana Agricultural University,

Hisar was carried out in two sets during 2004 and 2005 (table 1).

Experimental set – I (2004) consisted of:

1. Field screening of genotypes and development of thermo-tolerance indices.
2. Test of electrolyte leakage and membrane thermo stability.
3. Observations on seedling traits and their associations with thermo-tolerance indices.
4. Selection of parents and their mating in diallel design.

Experimental set – II (2005) – The mating experiment.

1. Raising of experimental material i.e. ten parents and 45 hybrids (one set of diallel) in three environments and recording of observations.
2. Analysis of genetic variance
3. Analysis of genotype $\times$ environment interactions

3.1 Experimental set – I (2004)

Screening of initial material for thermo-tolerance

Forty six genotypes of pearl millet which included advanced inbred lines, elite pollinators, populations and hybrids (table 2) were selected for testing their reaction to higher natural temperature. The screening was done by applying a field screening technique (Peacock *et al.*,

Table 1: Details of the experiments conducted

Year	Experiment	Sowing Date	Material	Design	Replications	Environment condition
2004	I	10/5/2004	46 genotypes	R.B.D.	3	E ₁ (High temp.)
2004	I	31/5/2004	46 genotypes	R.B.D.	3	E ₂ (High temp.)
2005	II	21/5/2005	10×10 Diallel	R.B.D.	3	E ₁ (High temp.)
2005	II	13/6/2005	10×10 Diallel	R.B.D.	3	E ₂ (High temp.)
2005	II	17/7/2005	10×10 Diallel	R.B.D.	3	E ₃ (Normal temp.)

R.B.D. : Randomized Block Design

Temp. : Temperature

Location : Research farm, Department of Plant Breeding, CCS Haryana Agricultural University, Hisar.

Table 2: List of genotypes used for screening heat tolerance

Sr. no.	Genotypes		Sr. no.	Genotypes
1.	CSSC-46-2		24	99HS-18
2.	G73-107		25	Togo-II
3.	H77/29-2		26	HTP-88
4.	78/711		27	ICR-161
5	96AC-93		28	77/245
6	HTP-94/54		29	77/371
7	ICMR-01004		30	CVJ-2-5-3-1-3
8	ICMR-01007		31	99/57-1
9	H90/4-5		32	77/273
10	(G73-107×BSECT CP-1)		33	841B×90/4-5
11	INB 87/74-3-20		34	7B
12	VCF ₄ -2359		35	18B
13	MRC		36	36B
14	72-2-2-98K-1		37	94222B
15	1448-98K-1		38	HHB-67-1
16	(77/371× BSECT CP-1)		39	HHB-67-2
17	1250		40	HHB-94
18	HTP-31		41	HHB-117
19	77/667		42	HHB-146
20	1305		43	HHB-162
21	HTP-92/80		44	HHB-176
22	96AC-82		45	HHB-181
23	S-97/120		46	H77/833-2

1993) and also through laboratory techniques (Membrane Thermo-Stability). The genotypes were put to screening under high temperatures conditions during May, 2004 (May 10 and May 31). The seedlings taken from the same field set were also simultaneously subjected to the test of membrane thermo-stability in the laboratory.

The lines have been primarily categorized on the basis of their response to high natural temperature as shown by an experiment conducted in May 10, 2004 and May 31, 2004.

Methodology

Ten genotypes were selected (table 3) from a set of 46 genotypes including advanced inbred lines, elite pollinators, populations and hybrids of pearl millet through a field screening technique under high temperature condition during May, 2004. These 46 genotypes grown in three replications in Randomized Block Design on May 10, 2004 and May 31, 2004. Each genotype was raised in three-rows each of 1.5 m length spaced 30 cm apart from the other. Fifteen seeds were sown in each row at a distance of 10 cm each. The field was given medium light irrigation and precisely levelled before sowing. The seeds were sown in the absence of a mechanized planter. Marked wooden sticks were used to ensure the placement of seed at uniform depth (figure 1). The stick was inserted into the soil up to 4 cm mark, tilted to one side cutting an angle of about 30°, making space for the seed. The seed (one) was dropped along the body of stick. The seed would settle in the bottom on gentle pull-out of the stick. We have had

a good bit of rehearsal on this method in a small, side-by plot.

Table 3: List of different selected parents of pearl millet and their response to supra-optimal temperature

Sr. no.	Genotypes	Response to supra-optimal temperature
1.	H77/833-2	Tolerant
2.	H77/29-2	Susceptible
3.	G73-107	Tolerant
4.	77/245	Susceptible
5.	CVJ-2-5-3-1-3	Tolerant
6.	1305	Susceptible
7.	77/371× BSECT CP-1	Tolerant
8.	96AC-93	Tolerant
9.	Togo-II	Tolerant
10.	99HS-18	Tolerant

The emphasis of observation centred on germination, survival and mortality of the seedlings. The seedlings were inspected every day in the morning. The seedlings which had died due to heat desiccation were spotted in each genotype on everyday basis. Such seedlings were marked by fixing a small wooden stick along their side as a check against the loss of dead seedlings. Process was continued up to a date till the surviving seedlings were established and there was no more mortality.

Counts

- a) Mortality count = The number of wooden stick fixed in place of dried up seedlings in each genotype.

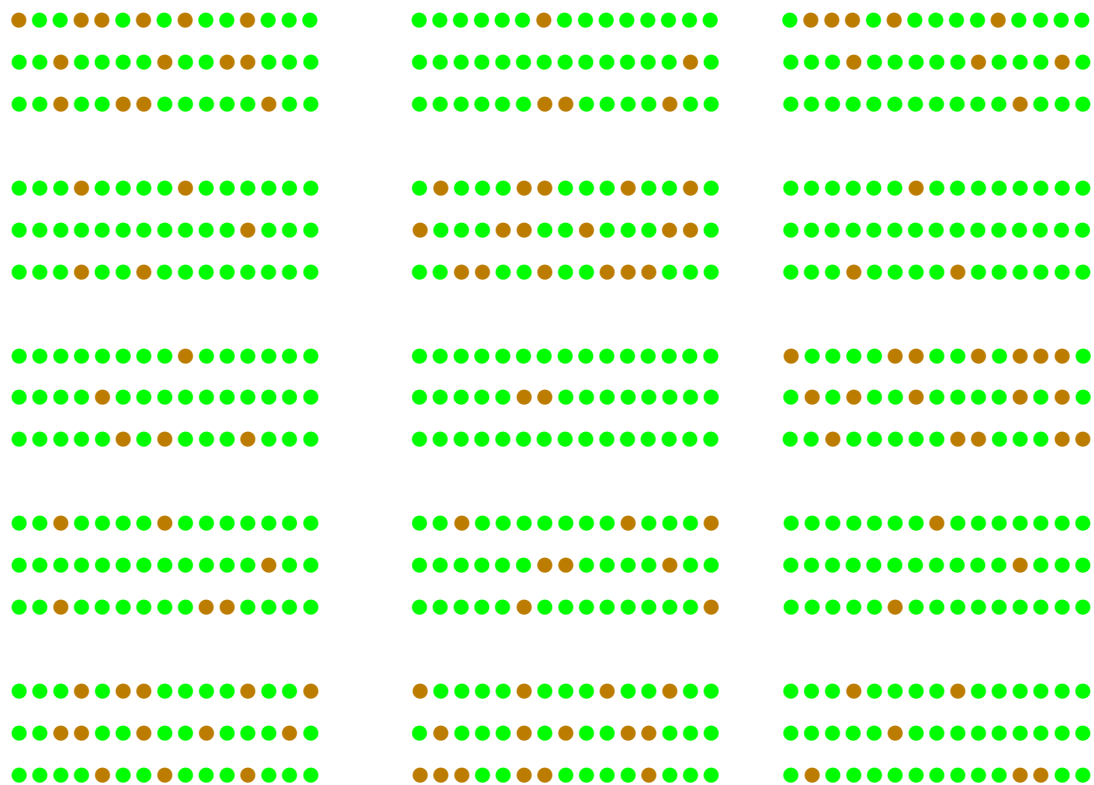


Fig. 1: Field layout and every day count for germination and mortality

Spacing – Row = 30 cm
 Plant = 10 cm
 Seed depth = 5 cm

- b) Survival count = The number of established seedlings at stoppage of mortality
- c) Germination count = a + b

Calculation for Seedling Thermo-tolerance Index (STI)

$$\text{STI} = \frac{\text{Number of seedlings survived}}{\text{Number of seedlings emerged}} \times 100$$

Monitoring

(a) Soil moisture:

A condition of no-drought was maintained in order to determine the exclusive effect of temperature. This was maintained by measuring the moisture status of the soil by gravimetric method on alternate days. The soil samples were taken from a depth of 5 cm, 10 cm and 20 cm.

(b) Soil surface temperature:

The soil surface temperature was measured by a soil thermometer at surface between 2:00 pm and 2:30 pm daily.

(c) Temperature 5 cm above the soil surface

Temperature 5 cm above the soil surface was recorded between 2:00 pm and 2:30 pm daily.

(d) Air temperature:

Daily maximum and minimum temperature observed by the device of maximum – minimum thermometers mounted in the field at 1m above the soil surface.

3.2 Laboratory screening

3.2.1 Membrane thermo-stability (MTS) test

The young leaves of the 21 days old seedlings of each genotype were used for membrane thermo-stability test. A middle portion of 10 cm from each leaf was taken and the midrib was removed and two equal halves of the 10 cm each were made. Each half were taken to provide replications. Each leaf portion was cut into pieces and thoroughly washed with and rinsed with distilled water two times to remove the electrolytes adhering to the plant tissue, as well as electrolyte released from the cutting of plant tissue and put them into test tubes. After final rinsing tubes were drained, maintaining sufficient water to prevent desiccation of plant material during heat treatment. These test tubes were covered with Aluminium foil and incubated in water bath at 55°C for 15 minutes for giving heat treatment. After the heat treatment period, 10 ml of distilled water was added to the test tubes. Then all the test tubes held at 10°C for overnight to allow diffusion of electrolytes from plant material. Test tubes were brought out of refrigerator and shaken well to mix the contents. An initial electrical conductivity (EC) of both the replications of each treatment (T_1) was determined with electrical conductivity meter. Then these test tubes were autoclaved at 15 psi for 2 minutes for complete electrolyte leakage from the leaf samples. These test tubes were then cooled at room temperature, contents mixed and final EC was taken for all the treatments (T_2). According to Ibrahim and Quick (2001) membrane

thermo-stability was expressed as MTS from the following calculations:

$$MTS = (1 - T_1/T_2) \times 100$$

Where,

T_1 – conductivity reading after heat treatment

T_2 – conductivity reading after autoclaving.

Basis of selection of the parents

The parents were selected on the basis of Seedling Thermo-tolerance index (STI). Ten parents were selected on the basis of most tolerant (7) and most susceptible (3). These selected parents are given in table 3.

Calculation of Seed to Seedling Thermo-tolerance Index (SSTI)

The SSTI was calculated as an extension of STI by taking expected germination into account. It was necessary to correct the effect of under soil mortality (USM). The laboratory germination of the same lot of spare seed was taken as expected germination.

$$SSTI = \frac{\text{Number of seedlings survived}}{\text{Number of seedlings expected to emerge}} \times 100$$

Other seedling traits and their association

The observations were also recorded on other seedling traits at two weeks stage where the mortality is expected to stop. These traits were:

1. Germination %

2. Emergence rate (ER)
3. Number of leaves / seedling
4. Height of seedling
5. Fresh weight (g) / seedling
6. Dry weight (g) / seedling

The methods of observation are described in the next pages. The pooled correlation of these traits was calculated *vis a vis* the STI and SSTI.

Crossing programme

A crossing block of the selected ten parents was grown in July 2004. The crossing was attempted in the month of August. The parents were crossed in all possible combinations. Thus 45 single crosses were obtained which do not include reciprocals (table 4).

3.2 Main experiment (Experimental set – II, 2005)

The analysis of genetic variance and $G \times E$ interaction

The main experiment was conducted on ten parents and 45 single crosses generated from diallel mating of 10 parents. The material was grown in R.B.D. with three replications. The experiment was conducted under three environments created through dates of sowing so as to conduct the experiment under different range of temperatures.

Environment 1 (E_1) = Middle of May / End of May, 2005

Environment 2 (E_2) = Early June, 2005

Environment 3 (E_3) = Mid July, 2005 (Monsoon period 2005)

The manner of raising the seedlings i.e. field preparation,

Table 4: List of hybrids developed in 10 × 10 half-diallel

Sr. no.	Hybrids		Sr. no.	Hybrids
1.	H77/833-2 × H77/29-2		24	G73-107 × 99HS-18
2.	H77/833-2 × G73-107		25	77/245 × CVJ-2-5-3-1-3
3.	H77/833-2 × 77/245		26	77/245 × 1305
4.	H77/833-2 × CVJ-2-5-3-1-3		27	77/245 × (77/371 × BSECT CP-1)
5	H77/833-2 × 1305		28	77/245 × 96AC-93
6	H77/833-2 × (77/371 × BSECT CP-1)		29	77/245 × Togo-II
7	H77/833-2 × 96AC-93		30	77/245 × 99HS-18
8	H77/833-2 × Togo-II		31	CVJ-2-5-3-1-3 × 1305
9	H77/833-2 × 99HS-18		32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)
10	H77/29-2 × G73-107		33	CVJ-2-5-3-1-3 × 96AC-93
11	H77/29-2 × 77/245		34	CVJ-2-5-3-1-3 × Togo-II
12	H77/29-2 × CVJ-2-5-3-1-3		35	CVJ-2-5-3-1-3 × 99HS-18
13	H77/29-2 × 1305		36	1305 × (77/371 × BSECT CP-1)
14	H77/29-2 × (77/371 × BSECT CP-1)		37	1305 × 96AC-93
15	H77/29-2 × 96AC-93		38	1305 × Togo-II
16	H77/29-2 × Togo-II		39	1305 × 99HS-18
17	H77/29-2 × 99HS-18		40	(77/371 × BSECT CP-1) × 96AC-93
18	G73-107 × 77/245		41	(77/371 × BSECT CP-1) × Togo-II
19	G73-107 × CVJ-2-5-3-1-3		42	(77/371 × BSECT CP-1) × 99HS-18
20	G73-107 × 1305		43	96AC-93 × Togo-II
21	G73-107 × (77/371 × BSECT CP-1)		44	96AC-93 × 99HS-18
22	G73-107 × 96AC-93		45	Togo-II × 99HS-18
23	G73-107 × Togo-II			

method of sowing, spacing, monitoring of soil moisture, soil temperature, air temperature etc. was the same as described in the method of screening. No fertilizer and chemical was given.

3.2.1 Observations recorded

1. Seedling thermo-tolerance index (STI)

The ratio of seedling survival to the number of seedling emergence, expressed in percentage.

$$\text{STI} = \frac{\text{Number of seedlings survived}}{\text{Number of seedlings emerged}} \times 100$$

2. Seed to seedling thermo-tolerance index (SSTI)

The ratio of seedling survival to the number of seedling expected to emerge, expressed in percentage.

$$\text{SSTI} = \frac{\text{Number of seedlings survived}}{\text{Number of seedlings expected to emerge}} \times 100$$

Note: Expected germination of seeds is based on the germination under monsoon environment in this experiment.

3. Germination (%): The Germination (%) was calculated by counting the number of seedlings germinated in each genotype to the number of seeds sown and expressed in percentage.

$$\text{Germination (\%)} = \frac{\text{Number of seedlings germinated}}{\text{Number of seeds sown}} \times 100$$

4. Rate of emergence of seedlings:

Rate of emergence of the seedlings was calculated by counting the seedlings germinated on daily basis from third day of sowing to the day when the seedling emergence was completely stopped.

$$\text{Emergence Rate (ER)} = \frac{\text{No. of normal seedlings}}{\text{Days to first count}} + \text{-----} + \frac{\text{No. of normal seedlings}}{\text{Days to final count}}$$

5. Number of leaves per seedling (two week stage)

6. Seedling height (cm)

Height of the seedlings was measured from base to top of the plant at two week stage.

Note: The data for seedling height and number of leaves per seedling was recorded on 10 random seedlings per replication.

7. Fresh weight (g) per seedling

After four week stage uprooting five random plants per genotype were weighed freshly.

8. Dry weight (g) per seedling

After four week stage uprooting five random plants per genotype oven dried and was weighed separately.

9. Panicle emergence (days)

The date on which the 50% spikes emerged was recorded and the number of days was calculated from the date of sowing.

10. Effective tillers/plant

The number of ear bearing tillers per plant was counted at maturity of

the crop.

11. Plant height (cm)

Plant height at maturity was measured from base of the plant to the tip of the ear of the main tiller.

12. Ear length (cm)

Length of the ear of the main tiller was measured at maturity from the first basal spikelet to the apical tip of the peduncle.

13. Ear weight (g) per plant

All ears of each plant were sun dried and weighed separately.

14. Dry fodder yield (g) per plant

After clipping the ears of the harvested plants, the fodder was weighed after sun drying.

15. Grain yield (g) per plant

All the ears of a plant were sun dried, threshed and grain yield per plant was recorded.

16. Total biological yield (g) per plant

The total biological yield per plant excluding the roots was recorded and expressed in grams.

3.3 Statistical procedure and analysis

Statistical procedure and analysis for the present study can be classified under following headings:

i) Analysis of variance for CRD:

Analysis of variance for Completely Block Design (CRD) was conducted only for laboratory test i.e. Membrane Thermo-Stability

(MTS) test under each environment on mean basis to detect variation among the genotypes.

ANOVA					
Source of Variation	d.f.	S.S.	M.S.	Expected Mean Sq.	'F' value
Genotype	t-1	T_rSS	$M_G = T_rSS/t-1$	$\sigma_e^2 + r\sigma_g^2$	M_G/M_e
Error	N-t	ESS	$M_e = ESS/N-t$	σ_e^2	
Total	N-1	TSS			

Where,

t = Number of genotypes

N = Total number of observations

M_G = Mean square due to genotype

M_e = Mean square due to error

The significance of M_G was tested against M_e by 'F' test at P = 0.05 and P = 0.01 level of significance.

ii) Analysis of variance for RBD:

An analysis of variance for Randomized Block Design (RBD) was conducted for every character under each environment on mean basis to detect variation among the genotypes. The model and procedure given by Panse and Sukhatme (1967).

$$Y_{ij} = \mu + g_i + b_j + e_{ij}$$

Where,

- Y_{ij} = Mean values of i^{th} genotype in the j^{th} block
 μ = General mean
 g_i = Effect of i^{th} genotype
 b_j = Effect of j^{th} block
 e_{ij} = Random error associated with i^{th} genotype and j^{th} block

ANOVA

Source of Variation	d.f.	S.S.	M.S.	Expected Mean Sq.	'F' value
Replication	r-1	RSS	$M_R = \text{RSS}/r-1$	$\sigma_e^2 + r\sigma_g^2$	M_R/M_e
Genotype	t-1	$T_r\text{SS}$	$M_G = T_r\text{SS}/t-1$	$\sigma_e^2 + r\sigma_g^2$	M_G/M_e
Error	$(r-1)(t-1)$	ESS	$M_e = \text{ESS}/(r-1)(t-1)$	σ_e^2	
Total	rt-1	TSS			

Where,

- t = Number of genotypes
 r = Number of replications

The significance of M_R and M_G was tested against M_e by 'F' test at $P = 0.05$ and $P = 0.01$ level of significance.

Parameters of variability

1. Mean

A seedling thermo-tolerance index (STI) and seed to seedling thermo-tolerance index (SSTI) were determined on the basis of phenotypic means in each environment and on pool basis. Similarly, the mean performance of crosses was used to explain the dynamism of other characters. The mean value of each character was worked out by dividing the total by corresponding number of observations.

$$\bar{X} = \frac{\sum x_{ij}}{N}$$

Where,

N = Total number of observations

$\sum x_{ij}$ = Any observation in i^{th} genotype and j^{th} replication.

2. Range

It is the difference between the lowest and the highest values present in the observations included in a sample.

3. Standard error

It was calculated with the help of error mean square from the analysis of variance as:

$$\text{Standard error (SE)} = \sqrt{\frac{2 (\text{EMS})}{r}}$$

Where,

EMS = Error mean sum of squares

r = Number of replications

4. Variance

Genotypic and phenotypic variances were computed as follows:

$$\sigma^2_g = \frac{M_G - M_e}{r}$$

$$\sigma^2_p = \sigma^2_g + \sigma^2_e$$

Where,

M_G = Mean square due to genotype

M_e = Mean square due to error

σ^2_g = Genotypic variance

σ^2_p = Phenotypic variance

σ^2_e = Environmental variance or M_e

The genotypic component was further partitioned into parents, crosses and parents vs. crosses. The data for different characters were statistically analysed on the basis of the model described as under:

The assumptions of the model are:

- i) The observations are independent.
- ii) Errors in the model are normally and independently distributed with mean and variance (σ^2).
- iii) The different effects in the model are additive.

5. Critical difference

Critical difference was calculated with the help of SE for testing the difference of two means.

CD = SE $\times$ t at 5% level of significance.

Where, SE = Standard error

6. Correlation coefficients analysis

Correlations among the various characters studied were calculated to establish the nature and magnitude of associations among the traits. These were calculated separately for different environments using the formula of Al-Jibouri *et al.* (1958) as follows.

$$r_{pxy} = \frac{\sigma_{pxy}}{\sqrt{\sigma^2_{px} \cdot \sigma^2_{py}}}$$

Where,

r_{pxy} = Phenotypic correlation coefficient between x and y variable

σ_{pxy} = Covariance of x and y

σ^2_{px} = Phenotypic variance of x variable

σ^2_{py} = Phenotypic variance of y variable

The phenotypic correlation coefficients were tested against standardized tabulated values of r with (n-2) degree of freedom as given by Fisher and Yates (1963).

Diallel Analysis

The genetic parameters were estimated using the following approaches of diallel analysis:

a) Combining ability analysis

Griffing's (1956a) Method 2, Model 1 was considered to be the most appropriate for this analysis. Method 2 was adopted in the present

situation as parents and one set of F_1^s were included not the reciprocals. Model 1 assumes both the genotype and block effects are fixed (constant) and the environment effect (error) is a random variable such that $e_{ij} \sim \text{IN}(0, \sigma^2)$ (Eisenhart, 1947). Under these assumptions the experimental material is regarded as the reference population as also the inference population. The present experimental material is derived from highly selected inbred lines and thus constitutes the population about which inferences are to be drawn. However, the block effects could well be considered as random variables and hence Mixed Model B would perhaps appear to be better suited than Model 1 as it assumes that the genotype effects are fixed and block effects are random variables. But, for the use of mixed model B, somewhat arbitrary and inconsistent assumptions have to be made with regard to the mixed elements (Griffing, 1956b). Moreover, if Mixed Model B is used, the combining ability analyses are essentially the same as determined from Model 1 analyses. Hence, the use of Model 1 for this present investigation.

The crosses taken up in the experiment were 45 single crosses developed from 10 genotypes crossed in diallel fashion without reciprocals. It was thus possible to carry out a combining ability analysis to test the variance due to general combining ability (gca) and specific combining ability (sca) and then to calculate gca effects of parents and sca effects of crosses.

The skeleton of the analysis is given as under:

ANOVA					
Source of Variation	d.f.	S.S.	M.S.	Expected Mean Sq.	'F' value
Replication	r-1	S ₁	S ₁ /r-1 = M _R	$\sigma_e^2 + r\sigma_r^2$	M _R /M _e
Genotype	t-1	S ₂	S ₂ /t-1 = M _G	$\sigma_e^2 + t\sigma_g^2$	M _G /M _e
Parents	(p-1)	S ₃	S ₃ /p-1 = M _P		M _P /M _e
Crosses	(c-1)	S ₄	S ₄ /c-1 = M _C		M _C /M _e
Parents vs. Crosses	1	S ₅	S ₅ /1 = M _{P×C}		M _{P×C} /M _e
Error	(r-1)(t-1)	S ₆	S ₆ /(r-1)(t-1) = M _e	σ_e^2	
Total	Rt-1	S ₇			

Where,

r = Number of replications

t = Number of genotypes

p = Number of parents

c = Number of crosses

M_R = Mean squares due to replications

M_G = Mean squares due to genotypes

M_P = Mean squares due to parents

M_C = Mean squares due to crosses

M_{P×C} = Mean squares due to parents vs. crosses

M_e = Mean squares due to error

The significance of M_R , M_G , M_P , M_C , and $M_{P \times C}$ was tested against M_e by 'F' test at $P = 0.05$ and $P = 0.01$ level of significance.

The combining ability analysis in Method 2 Model 1 is based on the following statistical model:

$$X_{ij} = \mu + g_i + g_j + S_{ij} + \frac{1}{bc} \sum_{k=1}^r \sum_{l=1}^c e_{ijkl}$$

i, j = 1, 2 p,

k = 1, 2 r,

l = 1, 2 c

Where,

P = Number of parents,

R = Number of blocks,

C = Number of observations in each of the plots,

μ = Population mean,

g_i = General combining ability effects of the i^{th} parent,

g_j = General combining ability effects of the j^{th} parent,

S_{ij} = The specific combining ability effects of the ij^{th} cross such that $S_{ij} = S_{ji}$

e_{ijkl} = The experimental effect pertaining to the ijk^{th} observation.

The restrictions $\sum_i g_i = 0$ and $\sum_j S_{ij} + S_{ii} = 0$ (for each i) are imposed.

The sum of squares were calculated as follows:

$$S_g = \frac{1}{p+2} \left(\sum_i (X_{i\cdot} + X_{ii})^2 - \frac{4}{p} X^2_{\cdot\cdot} \right)$$

$$S_s = \sum_i \sum_{j \leq i} X^2_{ij} - \frac{1}{p+2} \sum_i (X_{i\cdot} + X_{ii})^2 \frac{2}{(p+1)(p+2)} X^2_{\cdot\cdot}$$

Where,

S_g = Sum of squares due to general combining ability,

S_s = Sum of squares due to specific combining ability,

p = Number of parents,

$X_{i\cdot}$ = Total of the array of the i^{th} parent,

$X_{\cdot\cdot}$ = Grand total of the $p(p-1)/2$ progenies and p parental values,

X_{ij} = Progeny mean value,

X_{ii} = Parental mean value of the i^{th} parent in the diallel table.

The analysis of variance table for combining ability giving expectations of mean squares takes the following form:

ANOVA				
Source of Variation	d.f.	Sum of Squares	Mean Squares	Expected Mean Sq.
gca	$p-1$	S_g	M_g	$\sigma^2 + (p+2) \left(\frac{1}{p+1} \right) \sum g_i^2$
sca	$p(p-1)/2$	S_s	M_s	$\sigma^2 + 2 \sum_i \sum_j S_{ij}^2 / p(p-1)$
Error	m	S_e	M'_e	σ^2

Where,

$$M'_e = M_e / bc$$

Where,

$$M_e = \text{Error mean square for the RBD,}$$

$$r = \text{Number of replications.}$$

The following F ratios may be used to test for gca and sca effects. To test for differences among gca effects use:

$$F_{[(p-1), m]} = M_g / M'_e$$

and to test for differences among sca effects use:

$$F_{[p(p-1)/2, m]} = M_s / M'_e$$

The estimates of general and specific combining ability effects:

The various effects were estimated as follows:

$$\hat{\mu} = \frac{2}{p(p+1)} X_{..}$$

$$\hat{g}_i = \frac{1}{p+2} [X_{i.} + x_{ii} - \frac{2}{p} X_{..}]$$

$$\hat{S}_{ij} = x_{ij} - \frac{1}{p+2} [X_{i.} + x_{ii} + X_{j.} + x_{jj}] - \frac{2}{(p+1)(p+2)} X_{..}$$

gca / sca ratio

It was calculated as

$$\text{gca / sca ratio} = \sigma_g^2 / \sigma_g^2$$

Where,

$\hat{g}_i$ is the general combining ability effect of the i^{th} parent and $\hat{S}_{ij}$ is the specific combining ability effect of ij^{th} cross. P , $X_{i.}$, X_{ii} , and $X_{..}$ are same as explained as above.

Standard error of the estimates

Standard error of an estimate was calculated as the square root of the variance of the estimate. The variances of the estimates were calculated as follows:

The variance of any parent of F_1 mean value is:

$$\text{Variance } (x_{ij}) = \hat{\sigma}^2 = M_e'$$

and the variance of the difference between any two mean values is

$$\text{Variance } (x_{ij} - x_{kl}) = 2 \hat{\sigma}^2$$

Variances of effects and differences between effects may be estimated as follow:

$$\text{Variance } (\hat{\mu}) = \frac{2}{p(p+1)} \hat{\sigma}^2$$

$$\text{Variance } (\hat{g}_i) = \frac{p-1}{p(p+2)} \hat{\sigma}^2$$

$$\text{Variance } (\hat{S}_{ii}) = \frac{p(p-1)}{(P+1)(p+2)} \hat{\sigma}^2$$

$$\text{Variance } (\hat{S}_{ij}) = \frac{p^2 + p + 2}{(p+1)(p+2)} \hat{\sigma}^2 \quad (i \neq j)$$

$$\text{Variance } (\hat{g}_i - \hat{g}_j) = \frac{2}{(p+2)} \hat{\sigma}^2 \quad (i \neq j)$$

$$\text{Variance } (\hat{S}_{ii} - \hat{S}_{jj}) = \frac{2(p-2)}{(p+2)} \hat{\sigma}^2 \quad (i \neq j)$$

$$\text{Variance } (\hat{S}_{ij} - \hat{S}_{ik}) = \frac{2(p+1)}{(p+2)} \hat{\sigma}^2 \quad (i \neq j, k; j \neq k)$$

$$\text{Variance } (\hat{S}_{ij} - \hat{S}_{kl}) = \frac{2p}{(p+2)} \hat{\sigma}^2 \quad (i \neq j, k, l; j \neq k, l; k \neq l)$$

Estimation of variance components

Based on the expectation given above, we develop these components as below:

$$\hat{\sigma}_g^2 = \frac{(M_g - M_s)}{(p+2)}$$

$$\hat{\sigma}_s^2 = M_s - M_e$$

$$\hat{\sigma}_e^2 = M_e$$

Hence,

$$V_A \text{ (Additive variance)} = 2 \hat{\sigma}_g^2$$

$$V_D \text{ (Dominance variance)} = \hat{\sigma}_s^2$$

Component analysis (Hayman, 1954)

Numerical analysis

The component analysis of the diallel cross was carried out by the method of Hayman (1954). The analysis is based on the following assumptions:

- i) Homozygous parents
- ii) Diploid segregation
- iii) No reciprocal differences
- iv) No multiple alleles
- v) No genotype-environment interaction
- vi) No epistasis (i.e., no non-allelic gene interaction)
- vii) Uncorrelated gene distribution.

The following genetic components of variation were computed following the method given by Hayman (1954).

$$D = V_{OLO} - E$$

$$F = 2V_{OLO} - W_{OLO1} - 2(n-2) E / n$$

$$H_1 = V_{OLO} - 4 W_{OLO1} + 4 V_{1L1} - (3n-2) E / n$$

$$H_2 = 4 V_{1L1} - 4 V_{OL1} - 2 E$$

$$h^2 = 4 (M_{L1} - 4 M_{LO})^2 - 4 (n-1) E / n^2$$

The statistics in the above formulae may be explained as follows:

$$V_{OLO} = \text{Variance of the parents}$$

$$V_r = \text{Variance of the } r^{\text{th}} \text{ array}$$

W_r	=	The covariance between the parents and their off-springs in the r^{th} array
V_1L_I	=	Mean covariance of the array
V_OL_I	=	The variance of the means of arrays
W_{OLO1}	=	The mean covariance between the parents and their offspring in the r^{th} array
$(M_{L1}-M_{LO})$	=	The difference between the mean of the parents and the mean of their n^2 progenies
E	=	The environmental component of variance which is observed from analysis of variance for design.
n	=	Number of parents

The remaining genetic components were calculated according to the diallel analysis proposed by Hayman (1954). These are:

D	=	Component of variance due to the additive effects of the genes
H_1	=	Component of variance due to the dominance effects of the genes
H_2	=	$(H_1 (1 - u - v))^2$ where,
u	=	Proportion of positive genes in the parents
v	=	Proportion of negative genes in the parents
h^2	=	Net dominance effect (as the algebraic sum over all the loci in heterozygous phase in all the crosses)

F = It indicates the relative frequency of dominant and recessive alleles in parents

$$(M_{L1} - M_{LO}) = 1/n [GT/n - PT]$$

Proportions of genetic components

The different proportions of the genetic components were worked out according to the procedures given below:

i) Degree of dominance

The mean degree of dominance was calculated as proposed by Hayman (1954).

$$\begin{aligned} \text{Mean degree of dominance} &= (H_1 / D)^{1/2} \\ \text{If } (H_1 / D)^{1/2} &= 0 &= \text{no dominance} \\ &= 1 &= \text{Complete dominance} \\ &> 1 &= \text{Over dominance} \\ &< 1 > 0 &= \text{Partial dominance} \end{aligned}$$

ii) Proportion of genes

Proportion of genes with positive and negative effects in the parents was estimated as follows:

$$\text{Proportion of genes} = H_2 / 4H_1$$

When u and v are symmetrically distributed ($u = v = 0.5$), the ratio will give the value of 0.25.

iii) Proportion of dominant and recessive genes in the parents

$$= \frac{(4DH_1)^{1/2} + F}{(4DH_1)^{1/2} - F}$$

If,

The ratio = 1, (equality of dominant and recessive genes),
 > 1, (excess of dominant genes),
 < 1, (excess of recessive genes).

iv) Number of gene groups that control the character and exhibit dominance

It was calculated by h^2 / H_2 .

It is an approximate measure only of the sets of genes exhibiting dominance and detectable by biometrical genetic analysis.

v) Heritability in narrow sense

Heritability in narrow sense was calculated as under:

$$h^2_{NS} = \frac{1/4 D}{1/4 D + 1/4 H_1 + E - 1/4 F}$$

(Crumpacker and Allard, 1962)

vi) Correlation coefficient (r) between the parental measurement (Y_r) and the parental order of dominance ($W_r + V_r$)

It was calculated as:

$$r(Y_r, W_r + V_r) = \frac{\text{Cov.}(Y_r, W_r + V_r)}{\sqrt{\text{Var. } Y_r} \sqrt{\text{Var. } W_r + V_r}}$$

When r is near to unity, the recessive genes must be mostly positive.

When r is approximately -1, the dominant genes are positive, and

when it is small, equal proportion of dominant genes having positive and negative effects is indicated.

Graphical analysis (Hayman, 1954)

The graphical analysis was done as proposed by Hayman (1954). For each character, V_r , W_r graphs were prepared. V_r is the variance of all the offspring of each array and W_r is the covariance of each array.

Regression analysis

In this analysis the W_r values are regressed on the corresponding V_r estimates.

Where,

V_r = Variance of the r^{th} array

W_r = The covariance between the parents and their off-springs in the r^{th} array

The presence of gene interactions can easily be detected and interpreted by the observed regression coefficient

$$b_{W_r/V_r} = \frac{SP (W_r : V_r)}{SS (V_r)}$$

The standard error of regression coefficient was calculated by the following formula (Smith, 1954):

$$S_b = \sqrt{(y - \bar{y})^2 - b (x - \bar{x}) (y - \bar{y}) / (n - 2) (x - \bar{x})^2}$$

Where,

$$\begin{aligned} x &= V_r \\ y &= W_r \end{aligned}$$

The test of significance for the slope b_{W_r/V_r} was carried out for its deviation from zero as well as from unity by using ‘t’ value of $(b_{W_r/V_r}-0) / S_b$ and $(1-b_{W_r/V_r}) / S_b$ with n-2 degree of freedom. The interpretation of these tests has been given in experimental results.

Similarly the presence of mean dominance can easily be detected and interpreted by estimating the value of Y-intercept “a” of the best fitting regression line.

$$a = W_{OLO1} - b_{W_r/V_r} \times V_1L_1$$

Where,

$$\begin{aligned} V_1L_1 &= \text{Mean variance of the arrays} \\ W_{OLO1} &= \text{The mean covariance between the parents} \\ &\quad \text{and the arrays} \end{aligned}$$

Stability analysis

The stability parameters of the parents and the hybrids in diallel cross were computed using the analysis approach of Freeman and Perkins (1971). The statistical model has been used to describe the performance of a genotype/hybrid over a series of environments. Freeman and Perkins (1971) proposed independent estimate of environmental index by dividing the replications into groups, so that the one group may be used for measuring the average performance of

varieties in various environments and the other group, averaging over the varieties is used for estimating the environmental index.

For describing Y_{ijk} , i.e., performance in k^{th} replicate of i^{th} genotype in the j^{th} environment, Freeman and Perkins proposed the following model:

$$Y_{ijk} = m + d_i + e_j + g_{ij} + e_{ijk}$$

Where,

- m = general mean,
- d_i = additive genetic effect of the i^{th} genotype,
- e_j = additive environmental effect,
- g_{ij} = genotype-environment interaction effect,
- e_{ijk} = the error associated with k^{th} observation.

The analysis of variance in this model has the following form (table 5):

Test of significance

If environment residual (1) S.S. is significant, environmental index is adequately the index of additive environmental effect. The following tests of significance were performed:

- a) Heterogeneity of regression is tested against residual S.S. (2),
- b) Residual interaction ($G \times E$) S.S. against error S.S.
- c) Environment (residual) S.S. against error S.S.
- d) Environment (combined) S.S. against environmental (residual) S.S. (1)

Estimation of environmental index (Z_j)

$$Z_j = Y_{\cdot j} - \bar{Y}_{\cdot \cdot}$$

Table 5: Skelton for Analysis of variance for $G \times E$ interactions

Source of Variation	d.f.	S.S.	M.S.
Genotypes (G)	t-1	$(1/rs)(\sum_j Y_{i..}^2) - (1/rst)(Y^2 \dots)$	M_1
Environments (E)	s-1	$(1/rt)(\sum_j Y_{.j.}^2) - (1/rst)(Y^2 \dots)$	M_2
Combined Regression	1	$(\sum_j Y_{.j} Z_j)^2 / (rt \sum_j Z_j^2)$	M_3
Residual (1)	s-2	S.S. Environment – S.S. Combined regression	M_4
Interaction (G×E)	(s-1)(t-1)	$(1/r)(\sum_i \sum_j Y_{ij.}^2) - (1/rs)(\sum_i Y_{i..}^2) - (1/rt)(\sum_j Y_{.j.}^2) + (1/rst)(Y^2 \dots)$	M_5
Heterogeneity of Reg.	(t-1)	$[(\sum_j Y_{ij.} Z_j)^2 / (r \sum_j Z_j^2)] - [(\sum_j Y_{.j.} Z_j)^2 / (rt \sum_j Z_j^2)]$	M_6
Residual (2)	(s-2)(t-1)	S.S. _{G×E} – S.S. heterogeneity	M_7
Error between Rep.	St(r-1)	$\sum_i \sum_j \sum_k Y_{ijk}^2 - (1/r)(\sum_i \sum_j Y_{ij.}^2)$	M_8

Where,

$Y_{.j}$ = the total over all the varieties under jth environment

$$\bar{Y}.. = \sum_i \sum_j Y_{ij} / \text{Total number of observations}$$

Estimation of regression coefficient (b_i)

$$b_i = \frac{\sum_j \sum_k Y_{ij} Z_j}{\sum_j \sum_k Z_j^2}$$

Calculation of

$$\overline{S}_{di}^2 = \left[\sum_j \delta_{ij}^2 / (s-2) \right] - (S_e^2 / r)$$

Where,

$$\sum_j \delta_{ij}^2 = \sigma_{v_i}^2 - b \sum_j Y_{ij} Z_j$$

and S_e^2 = Error mean square.

Test of significance

$$SE_b = \sqrt{\frac{\text{Residual M.S.}}{\text{Environmental index S.S.}}}$$

$$t = (b_i / SE_b) \quad \text{at 1 d.f.}$$

CHAPTER-IV

EXPERIMENTAL RESULTS

The experiment is consisted of two major portions. One was related to the screening of the genotypes for heat tolerance. This was necessary because status of the most of the genotypes in relation to heat tolerance was not already known. The screening methods for heat tolerance have not been adequately applied in pearl millet research. It was therefore important to conduct screening of important genotypes before an investigation of its genetic makeup. The screening aspect of the research programme was therefore, considered as one full set of experiment. Another set related to inheritance studies by using diallel analysis of Griffing (1956b) and Hayman (1954) and also the genotypes into environmental interactions. The results for each set of experiment have separately been presented.

4.1 Screening of genotypes

The genotypes included in this programme were the advanced inbred lines, elite pollinators, populations, male sterile lines and hybrids. The screening was not limited only to seedling thermo-tolerance index (STI). Certain other characters known to be important for heat

tolerance mechanism were also included. These characters were related to germination, early vigour and plant development such as germination (%), emergence rate (ER), number of leaves/seedling, seedling height (cm), seedling fresh weight (g), seedling dry weight (g).

Field screening technique and laboratory screening technique were simultaneously used. The heat tolerance was measured as seedling thermo-tolerance index (STI) through the field screening technique of Peacock *et al.* (1993). Whereas, membrane thermo-stability (MTS) was taken as index for heat tolerance in the laboratory technique. Another index known as seed to seedling thermo-tolerance index (SSTI) was also calculated as an improvement and extension of seedling thermo-tolerance index (STI).

4.1.1 Environmental ambience

Before the results of screening methods are presented, it is important to know environmental background in which the genotypes were subjected to screening.

- i) Temperatures
 - a) Soil surface temperature
 - b) Temperature 5 cm above the soil surface
 - c) Air temperature at 1 m height
- ii) Soil moisture
- iii) Rainfall / irrigation

4.1.1.1 Environmental measurements

The screening experiment was conducted in two environments with different dates of sowing 10th May, 2004 and 31st May, 2004 for environment–I (E₁) and environment–II (E₂), respectively.

i) Temperatures

a) Soil surface temperature

The soil surface temperature was recorded up to a maximum of 63.5°C in environment–I and 62.9°C in environment–II as shown in figure 2. A dip in temperature was seen on 8th, 9th, and 10th days after sowing. This had happened due to cloudy weather on these days.

b) Temperature 5 cm above the soil surface

The temperature 5 cm above the soil surface ranged between 42.0°C and 49.8°C in environment–I and 34.7°C and 47.6°C in environment–II as shown in figure 3 . A dip was recorded in temperature on 8th, 9th, and 10th days after sowing. This had happened due to cloudy weather on these days.

c) Air temperature at 1 m height

The air temperature was recorded up to a maximum of 44.2°C in environment–I and 43.2°C in environment–II as shown in figure 4. A dip in temperature was seen on 8th, 9th, 10th and 11th days after sowing. This had happened due to cloudy weather on these days.

ii) Soil moisture

Measure of soil moisture was maintained throughout in order to check the reduction of soil moisture to the drought level. The mortality have stopped well before the moisture reduced to 8.1 per cent in environment – I and 8.8 per cent in environment–II which was well above the permanent wilting point (6%). The initial soil moisture contents in environment–I and environment–II were 16.8 per cent and 15.6 per cent, respectively. The dynamic status of soil moisture is shown in figure 5.

iii) Rainfall / irrigation

During screening in both the environments (environment–I and environment–II) there was no rain up to 15th day after sowing. In environment–I when the mortality of the seedlings stopped and the soil moisture reduced to 8.1 per cent the field was irrigated to avoid the drought condition. But in environment–II on 16th and 18th days after sowing there was rain 23.2 mm and 9.7 mm, respectively (figure 6).

4.1.2 Field screening

Forty six genotypes were grown in randomised block design (RBD) with three replications in two environments. The related data is presented for different characters.

4.1.2.1 Analysis of variance

A simple randomised block design (RBD) analysis was carried out separately for both the environments in respect of all the eight

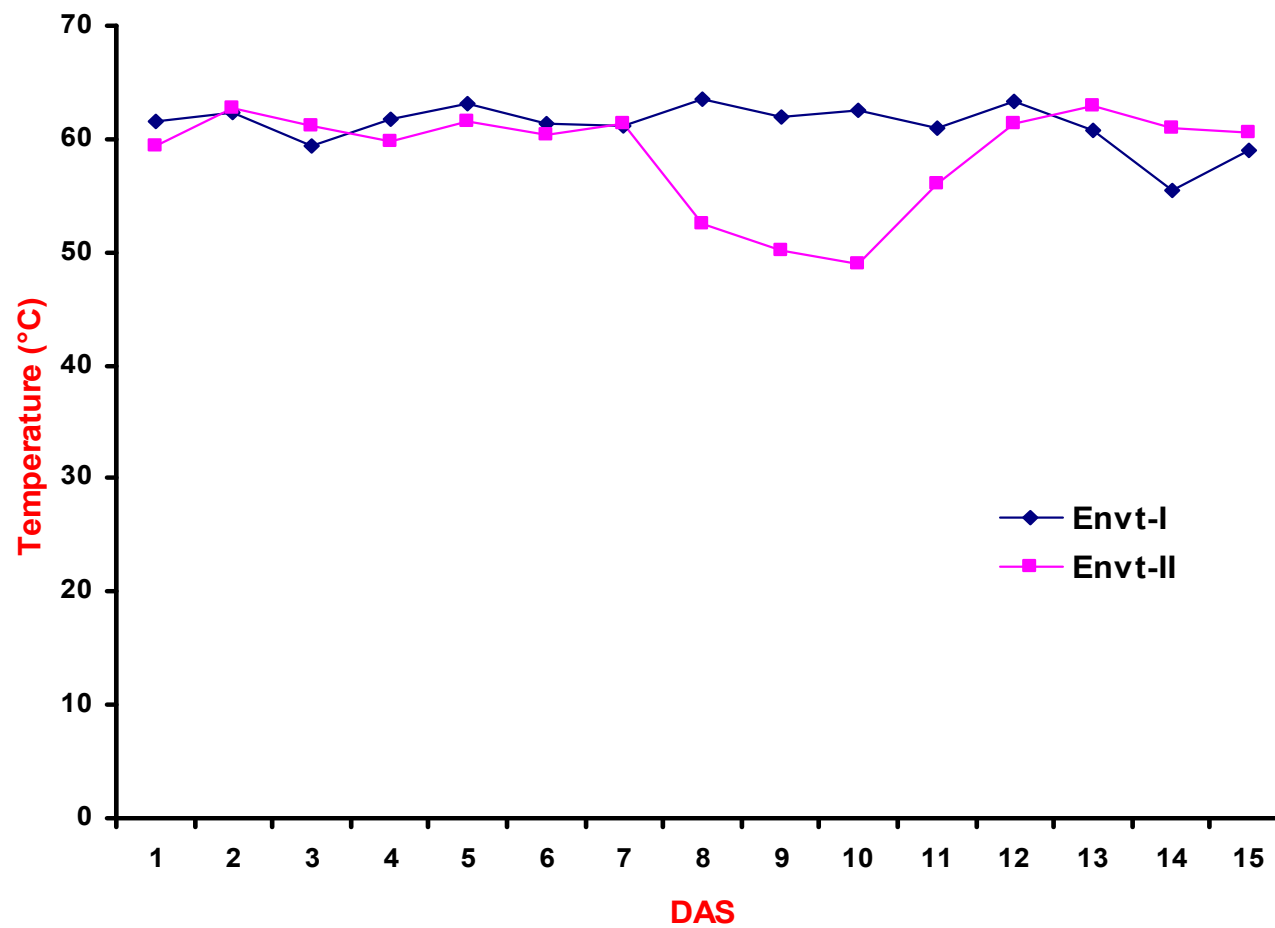


Figure 2: Soil surface temperature in two environments during screening experiment

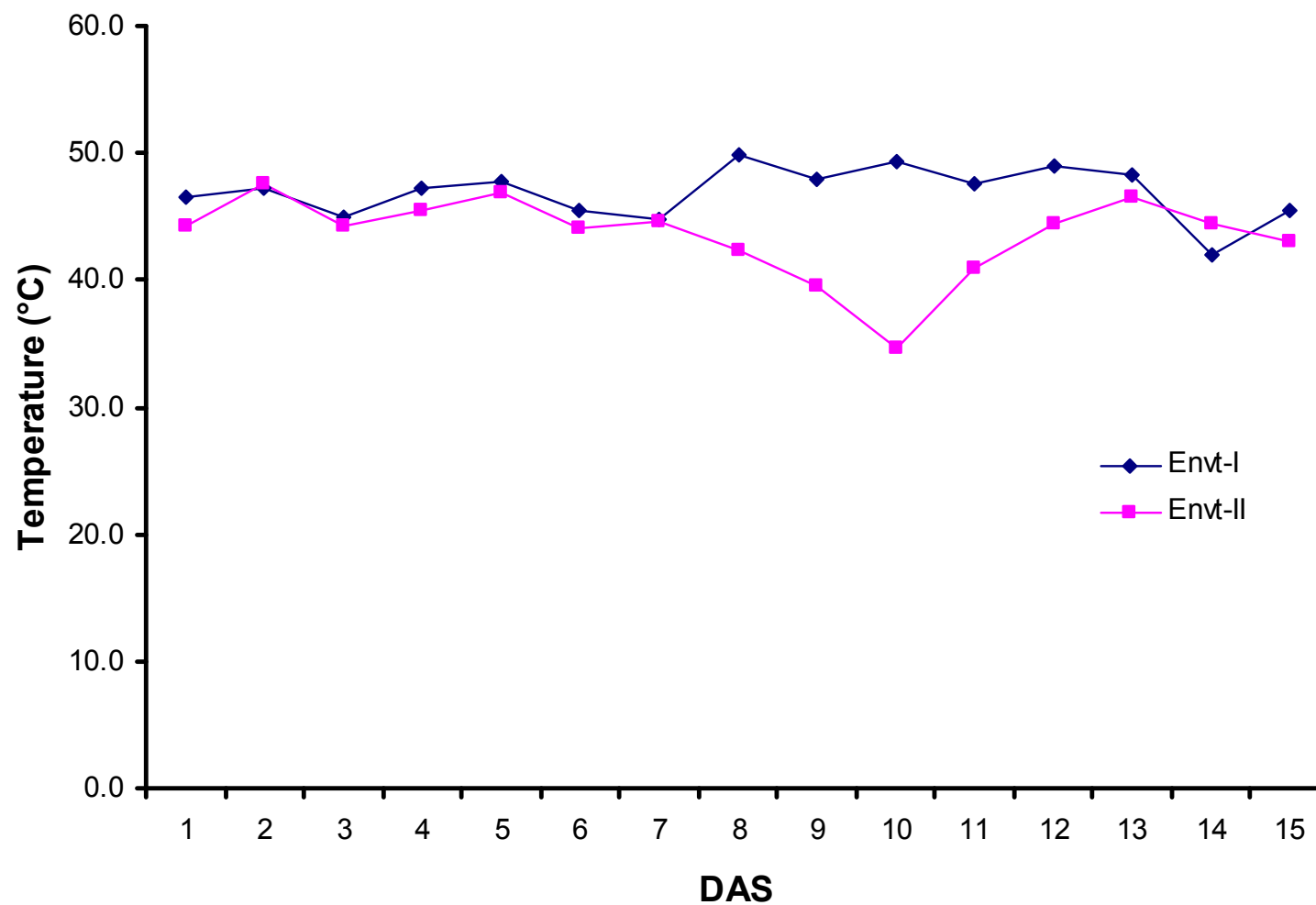


Figure 3: Temperature 5 cm above the soil surface in two environments during screening experiment

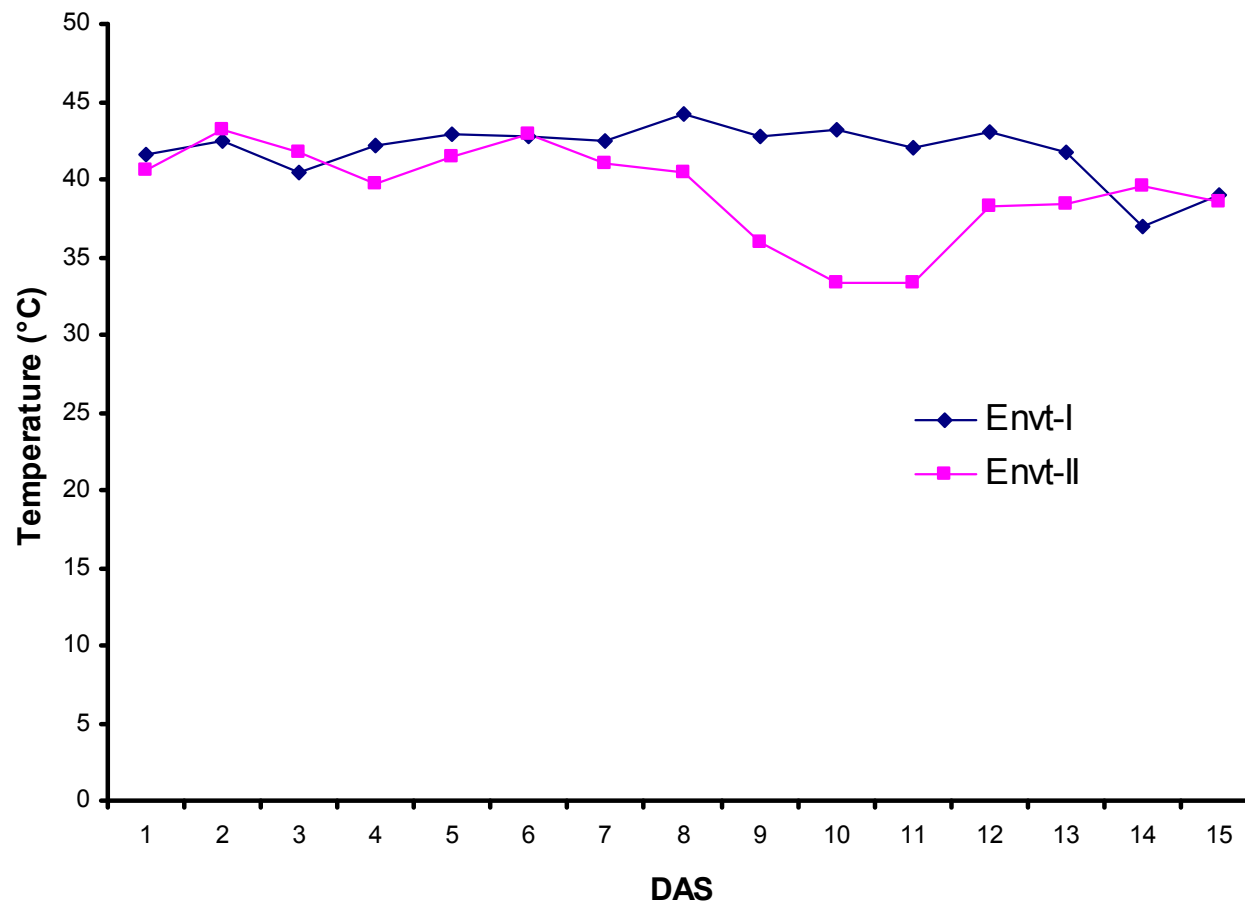


Figure 4: Air temperature in two environments during screening experiment

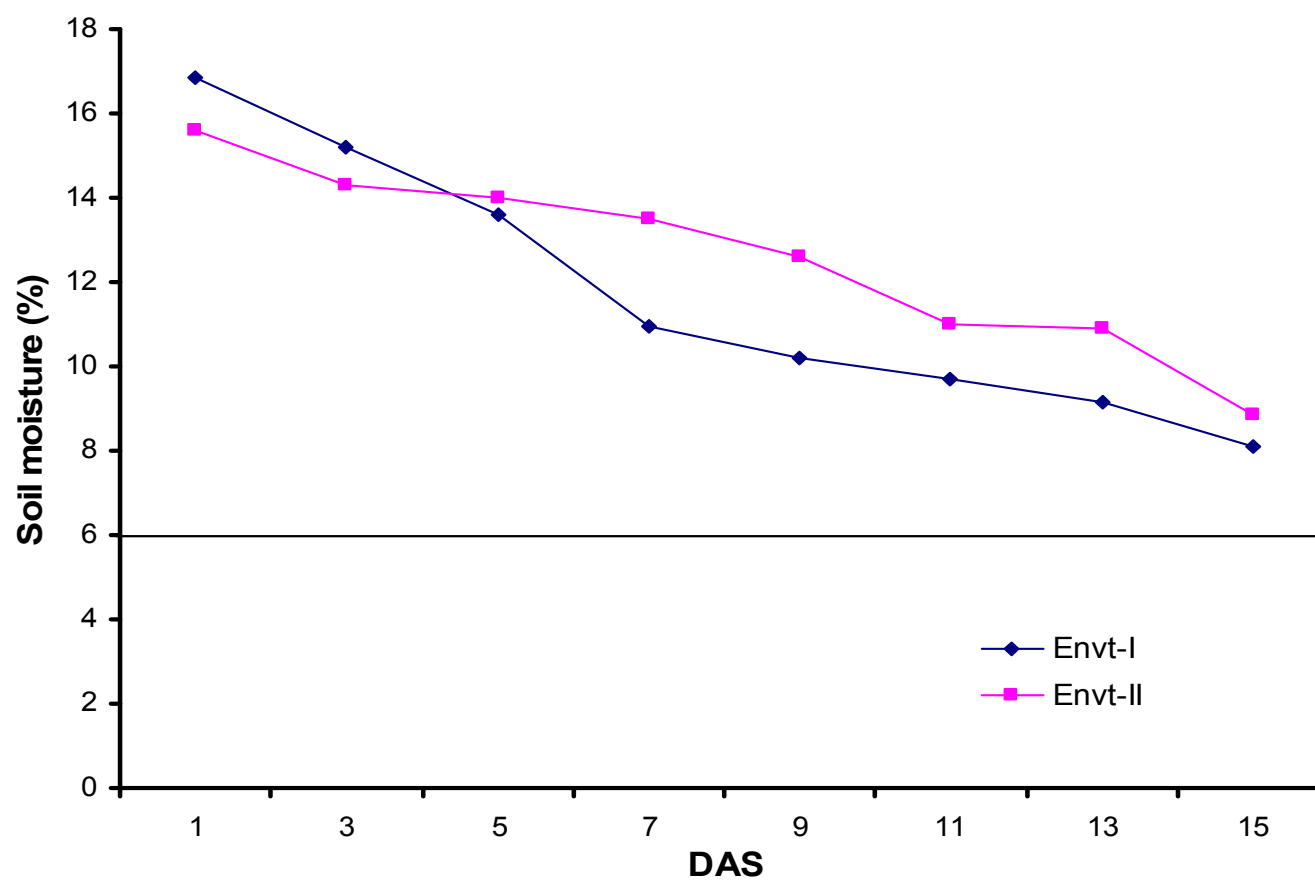


Figure 5: Soil moisture status in two environments during screening experiment

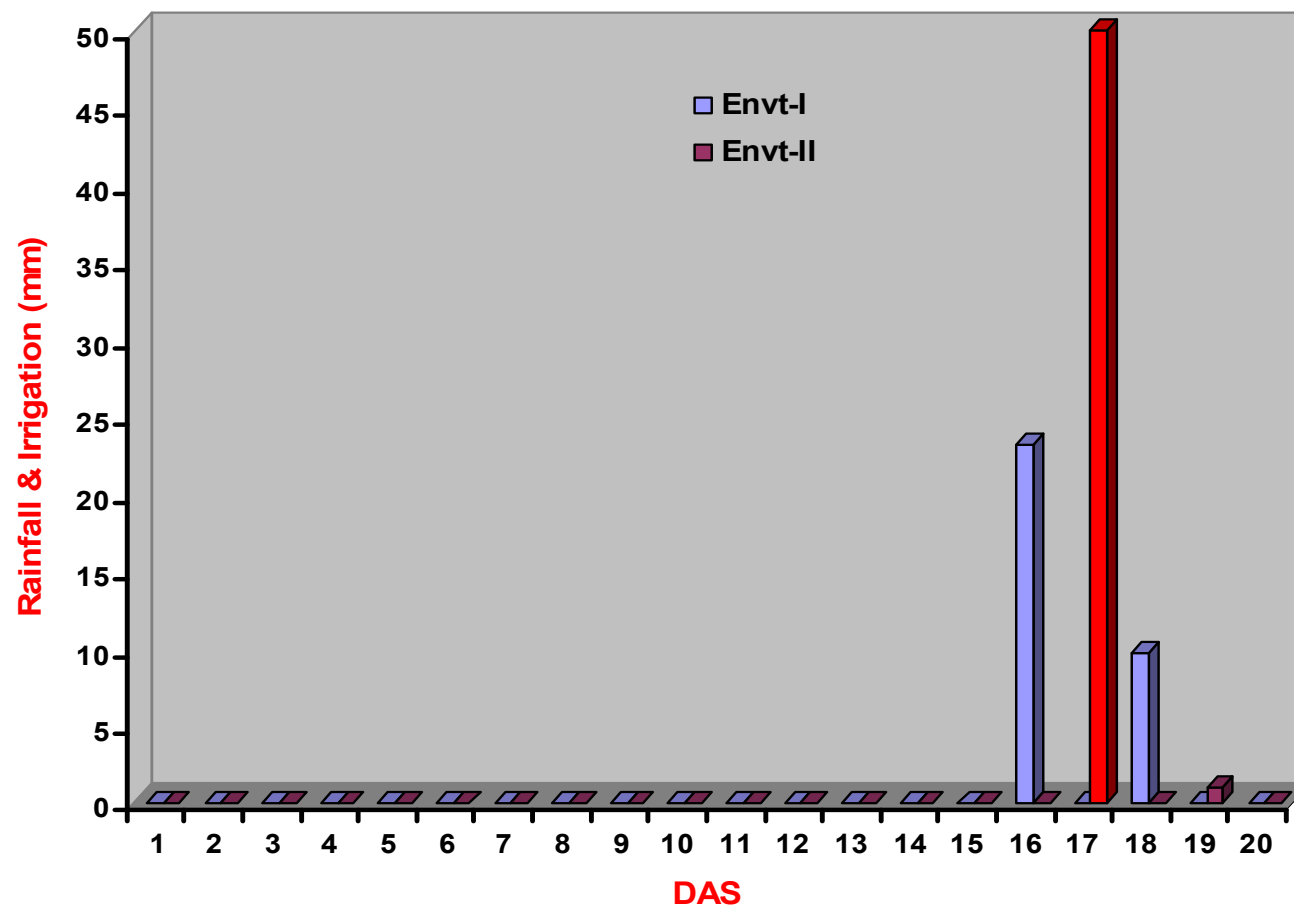


Figure 6: Rainfall and irrigation in two environments during screening experiment

characters are presented in table 6. The F-ratio and mean squares due to genotypes were highly significant indicating enough genetic variability present for all the characters in each environment, which justified further analysis of the data.

4.1.2.2 Genotypic responses

The genotypes were evaluated on the basis of mean performance. The mean performance of all the genotypes for various characters in each environment is given in tables 7. The data for seedling thermo-tolerance index (STI), seed to seedling thermo-tolerance index (SSTI), germination, and emergence rate (ER) are the transformed data.

i) Seedling thermo-tolerance index (STI)

As evident from table 7, the seedling thermo-tolerance index (STI) was also lower in environment-I (E_1). On the pooled basis its value ranged from 41.09 to 77.84 with an average of 56.92. The genotype H77/833-2 was the best scorer followed by 99HS-18, CVJ-2-5-3-1-3, (77/371 × BSECT CP-1), 96AC-93, Togo-II and G73-107 as close runners up. These seven genotypes were selected as the tolerant for heat stress. The genotype 1305, 77/245 and H77/833-2 were selected as the susceptible to heat stress.

ii) Seed to seedling thermo-tolerance index (SSTI)

The values for seed to seedling thermo-tolerance index (SSTI) were much lower than that of the STI as the SSTI also covers/includes the under surface mortality (USM). Environment-I had lower SSTI values in comparison to the environment-II, as the high initial air

Table 6: Analysis of variance for screening experiment

Environ ment	Source of Variation	D.F	Mean Sum of Squares							
			STI (%)	SSTI (%)	Germination (%)	Rate of emergence	No. of leaves/ seedling	Seedling height (cm)	Fresh weight (g) /seedling	Dry weight (g) /seedling
E₁	Replication	2	5.765	7.02	12.36	41.99	0.155	0.185	0.36	0.03
	Treatment	45	250.53**	208.98**	88.24**	154.51**	5.44**	13.29**	30.75**	1.33**
	Error	90	7.18	7.78	3.67	11.19	0.75	3.29	1.44	0.07
E₂	Replication	2	1.61	19.86	12.98	263.18	0.84	8.56	1.57	0.05
	Treatment	45	315.04**	260.78**	94.08**	65.33**	4.98**	16.64**	39.51**	1.53**
	Error	90	6.63	7.38	4.83	20.83	0.87	2.92	2.35	0.11

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Table 7: Mean performance of the genotypes during screening for different characters

Sr. no.	Inbreds/genotypes	STI %*				SSTI %*		
		E ₁	E ₂	Mean		E ₁	E ₂	Mean
1.	CSSC-46-2	64.73	71.04	67.89		52.88	64.60	58.74
2.	G73-107	64.72	71.23	67.97		54.97	65.82	60.39
3.	H77/29-2	44.21	44.52	44.36		31.60	36.34	33.97
4.	78/711	47.84	53.99	50.91		38.21	46.92	42.56
5	96AC-93	70.84	72.73	71.78		63.01	66.56	64.79
6	HTP-94/54	54.62	51.58	53.10		48.39	39.77	44.08
7	ICMR-01004	50.83	54.37	52.60		39.13	47.54	43.34
8	ICMR-01007	55.38	59.60	57.49		49.49	53.25	51.37
9	H90/4-5	54.59	59.63	57.11		49.65	53.49	51.57
10	(G73-107×BSECT CP-1)	59.10	54.17	56.64		49.51	38.75	44.13
11	INB 87/74-3-20	51.44	58.09	54.77		41.70	47.90	44.80
12	VCF ₄ -2359	46.04	47.33	46.69		38.02	40.96	39.49
13	MRC	47.54	45.06	46.30		40.39	39.09	39.74
14	72-2-2-98K-1	50.29	59.51	54.90		36.70	47.58	42.14
15	1448-98K-1	54.02	52.54	53.28		40.72	45.35	43.04
16	(77/371× BSECT CP-1)	70.31	74.04	72.18		55.54	69.19	62.36
17	1250	52.32	56.88	54.60		36.34	47.82	42.08
18	HTP-31	51.06	56.78	53.92		36.05	44.83	40.44
19	77/667	44.41	48.70	46.56		38.18	39.21	38.70
20	1305	40.33	41.85	41.09		27.84	35.10	31.47
21	HTP-92/80	49.63	53.64	51.63		33.44	46.57	40.01
22	96AC-82	48.81	52.38	50.59		34.86	38.72	36.79
23	S-97/120	50.21	52.52	51.36		34.73	43.05	38.89
24	99HS-18	78.56	76.26	77.41		57.94	63.26	60.60
25	Togo-II	71.00	72.29	71.64		52.23	58.27	55.25

Sr. no.	Inbreds/genotypes	STI %*				SSTI %*		
		E ₁	E ₂	Mean		E ₁	E ₂	Mean
26	HTP-88	55.37	59.84	57.61		40.23	50.92	45.57
27	ICR-161	43.72	49.69	46.70		32.75	38.48	35.61
28	77/245	42.31	44.12	43.22		29.36	38.37	33.87
29	77/371	53.24	60.34	56.79		42.55	54.29	48.42
30	CVJ-2-5-3-1-3	69.80	78.76	74.28		55.71	60.55	58.13
31	99/57-1	49.20	56.14	52.67		39.29	43.59	41.44
32	77/273	55.22	60.78	58.00		38.38	50.11	44.25
33	841B×90/4-5	47.76	44.83	46.29		35.55	34.86	35.21
34	7B	53.32	48.47	50.89		37.66	45.67	41.66
35	18B	47.85	42.49	45.17		34.80	33.96	34.38
36	36B	49.92	57.86	53.89		35.10	35.75	35.43
37	94222B	49.79	56.19	52.99		38.04	45.08	41.56
38	HHB-67-1	56.49	59.13	57.81		44.93	47.32	46.12
39	HHB-67-2	68.29	67.81	68.05		48.56	56.03	52.30
40	HHB-94	62.21	65.87	64.04		50.28	52.05	51.17
41	HHB-117	59.88	68.90	64.39		43.85	49.00	46.43
42	HHB-146	61.26	66.50	63.88		48.75	56.99	52.87
43	HHB-162	57.40	58.28	57.84		45.37	47.07	46.22
44	HHB-176	58.33	60.59	59.46		45.25	45.56	45.40
45	HHB-181	61.74	66.07	63.90		46.15	47.49	46.82
46	H77/833-2	75.24	80.45	77.84		56.32	62.83	59.58
	Mean	55.46	58.39	56.92		42.84	48.17	45.50
	CD	4.355	4.184	—		4.531	4.414	—
	SE (d)	2.188	2.102	—		2.277	2.218	—
	SE (m)	1.547	1.487	—		1.610	1.568	—
	CV	4.833	4.410	—		6.510	5.639	—

* Values are transformed values

Contd...

Contd... table 7

Sr. no.	Inbreds/genotypes	Germination (%)*				Emergence rate (ER)		
		E ₁	E ₂	Mean		E ₁	E ₂	Mean
1.	CSSC-46-2	42.53	44.75	43.64		48.92	41.25	45.09
2.	G73-107	48.32	52.76	50.54		50.81	40.50	45.66
3.	H77/29-2	42.40	47.95	45.18		38.09	37.77	37.93
4.	78/711	40.53	46.48	43.50		33.76	37.01	35.39
5	96AC-93	55.99	49.82	52.90		40.03	37.83	38.93
6	HTP-94/54	42.01	32.95	37.48		34.05	35.04	34.55
7	ICMR-01004	42.17	48.40	45.28		47.77	40.23	44.00
8	ICMR-01007	58.52	59.10	58.81		41.83	39.52	40.68
9	H90/4-5	54.31	54.06	54.19		48.84	42.81	45.82
10	(G73-107×BSECT CP-1)	45.75	38.74	42.24		40.29	46.52	43.40
11	INB 87/74-3-20	45.56	47.15	46.35		38.45	41.17	39.81
12	VCF ₄ -2359	40.97	42.95	41.96		38.82	37.11	37.96
13	MRC	44.31	42.00	43.15		45.87	36.81	41.34
14	72-2-2-98K-1	40.29	46.10	43.19		39.67	40.98	40.32
15	1448-98K-1	36.99	42.21	39.60		47.70	34.36	41.03
16	(77/371× BSECT CP-1)	47.97	55.54	51.76		40.11	39.47	39.79
17	1250	42.14	54.66	48.40		53.40	35.74	44.57
18	HTP-31	41.15	51.20	46.17		49.13	42.27	45.70
19	77/667	28.60	38.09	33.34		42.77	28.19	35.48
20	1305	44.64	50.88	47.76		47.75	39.43	43.59
21	HTP-92/80	39.44	52.26	45.85		38.40	38.41	38.41
22	96AC-82	43.26	45.40	44.33		39.59	36.14	37.87
23	S-97/120	41.69	50.54	46.11		40.39	35.14	37.77
24	99HS-18	48.34	50.11	49.23		47.99	34.13	41.06
25	Togo-II	47.09	48.39	47.74		55.13	36.20	45.66

Sr. no.	Inbreds/genotypes	Germination (%) [*]				Emergence rate (ER)		
		E ₁	E ₂	Mean		E ₁	E ₂	Mean
26	HTP-88	46.93	58.13	52.53		47.90	39.78	43.84
27	ICR-161	41.03	50.88	45.95		47.37	30.89	39.13
28	77/245	44.22	47.53	45.87		52.44	36.63	44.54
29	77/371	46.70	53.61	50.16		54.98	39.87	47.42
30	CVJ-2-5-3-1-3	48.43	49.15	48.79		44.39	38.44	41.41
31	99/57-1	43.26	42.86	43.06		31.59	41.86	36.72
32	77/273	39.05	47.11	43.08		46.79	32.69	39.74
33	841B×90/4-5	43.11	44.83	43.97		33.55	38.85	36.20
34	7B	40.69	54.96	47.82		46.41	34.85	40.63
35	18B	38.78	42.30	40.54		35.50	32.46	33.98
36	36B	41.98	37.92	39.95		30.56	28.20	29.38
37	94222B	39.85	42.63	41.24		29.55	34.80	32.18
38	HHB-67-1	48.55	49.33	48.94		41.33	44.46	42.89
39	HHB-67-2	51.90	54.28	53.09		45.71	44.34	45.03
40	HHB-94	54.44	53.84	54.14		40.60	40.09	40.35
41	HHB-117	48.28	49.09	48.68		38.16	41.72	39.94
42	HHB-146	48.59	53.18	50.89		43.38	43.21	43.29
43	HHB-162	49.15	50.54	49.84		34.41	45.89	40.15
44	HHB-176	44.37	43.49	43.93		28.08	44.04	36.06
45	HHB-181	49.95	48.95	49.45		34.37	39.11	36.74
46	H77/833-2	39.75	43.20	41.47		56.35	52.33	54.34
	Mean	44.65	48.05	46.35		42.46	38.66	40.56
	CD	3.115	3.570	—		5.436	7.416	—
	SE (d)	1.565	1.794	—		2.732	3.727	—
	SE (m)	1.107	1.268	—		1.931	2.635	—
	CV	4.293	4.572	—		7.880	11.805	—

* Values are transformed values

Contd...

Contd... table 7

Sr. no.	Inbreds/genotypes	No. of leaves/seedling				Seedling height (cm)		
		E ₁	E ₂	Mean		E ₁	E ₂	Mean
1.	CSSC-46-2	6.20	6.53	6.37		10.00	11.87	10.93
2.	G73-107	6.30	6.90	6.60		11.63	12.43	12.03
3.	H77/29-2	3.14	3.80	3.47		11.37	12.70	12.03
4.	78/711	4.34	5.09	4.72		11.20	12.10	11.65
5.	96AC-93	6.60	6.70	6.65		12.90	13.60	13.25
6.	HTP-94/54	3.39	4.07	3.73		13.43	12.00	12.72
7.	ICMR-01004	5.28	5.87	5.58		7.47	9.40	8.43
8.	ICMR-01007	2.59	3.16	2.88		8.33	10.10	9.22
9.	H90/4-5	5.77	5.51	5.64		7.33	7.67	7.50
10.	(G73-107×BSECT CP-1)	5.73	6.07	5.90		11.50	10.23	10.87
11.	INB 87/74-3-20	5.78	5.57	5.67		9.63	9.07	9.35
12.	VCF ₄ -2359	5.97	6.43	6.20		12.30	12.03	12.17
13.	MRC	5.40	5.73	5.57		9.43	10.53	9.98
14.	72-2-2-98K-1	5.87	5.98	5.93		9.73	10.83	10.28
15.	1448-98K-1	4.53	4.83	4.68		10.13	10.80	10.47
16.	(77/371× BSECT CP-1)	5.80	5.37	5.58		13.80	15.17	14.48
17.	1250	4.73	4.77	4.75		9.17	8.50	8.83
18.	HTP-31	3.02	3.29	3.16		7.97	7.67	7.82
19.	77/667	3.63	3.47	3.55		8.20	8.13	8.17
20.	1305	2.97	3.59	3.28		8.53	10.60	9.57
21.	HTP-92/80	5.02	5.13	5.08		12.37	14.47	13.42
22.	96AC-82	4.60	5.27	4.93		6.57	9.03	7.80
23.	S-97/120	4.97	5.57	5.27		8.07	9.97	9.02
24.	99HS-18	6.83	6.99	6.91		12.37	14.07	13.22
25.	Togo-II	6.95	7.11	7.03		10.97	13.43	12.20

Sr. no.	Inbreds/genotypes	No. of leaves/seedling				Seedling height (cm)		
		E ₁	E ₂	Mean		E ₁	E ₂	Mean
26	HTP-88	4.30	5.11	4.71		13.93	15.67	14.80
27	ICR-161	5.63	5.93	5.78		9.77	11.20	10.48
28	77/245	4.03	4.90	4.47		13.57	15.37	14.47
29	77/371	4.81	5.24	5.02		7.62	6.77	7.19
30	CVJ-2-5-3-1-3	7.63	7.80	7.72		11.87	13.37	12.62
31	99/57-1	5.17	5.31	5.24		9.20	8.23	8.72
32	77/273	5.37	5.70	5.54		8.23	7.83	8.03
33	841B×90/4-5	5.08	5.65	5.36		10.10	11.50	10.80
34	7B	4.47	5.44	4.95		12.17	13.50	12.83
35	18B	3.24	3.52	3.38		7.53	9.33	8.43
36	36B	5.55	6.47	6.01		8.77	8.43	8.60
37	94222B	5.11	5.87	5.49		9.43	11.10	10.27
38	HHB-67-1	8.10	8.21	8.16		12.53	14.03	13.28
39	HHB-67-2	8.23	8.37	8.30		12.17	14.00	13.08
40	HHB-94	5.38	5.77	5.57		10.33	12.07	11.20
41	HHB-117	6.56	6.97	6.76		10.10	9.77	9.93
42	HHB-146	7.31	8.37	7.84		12.83	13.07	12.95
43	HHB-162	6.51	6.67	6.59		14.10	14.20	14.15
44	HHB-176	5.88	6.25	6.07		12.50	12.23	12.37
45	HHB-181	6.43	6.40	6.42		13.13	13.70	13.42
46	H77/833-2	6.46	6.84	6.65		8.60	9.47	9.03
	Mean	5.36	5.73	5.55		10.50	11.33	10.91
	CD	1.406	1.512	—		2.947	2.776	—
	SE (d)	0.707	0.760	—		1.481	1.395	—
	SE (m)	0.500	0.537	—		1.047	0.986	—
	CV	16.143	16.246	—		17.277	15.077	—

Contd...

Contd... table 7

Sr. no.	Inbreds/genotypes	Fresh weight (g)/seedling				Dry weight (g)/seedling		
		E ₁	E ₂	Mean		E ₁	E ₂	Mean
1.	CSSC-46-2	10.47	15.25	11.42		1.88	2.85	2.37
2.	G73-107	9.67	12.22	10.18		2.98	3.64	3.31
3.	H77/29-2	3.37	5.68	3.83		1.03	1.67	1.35
4.	78/711	6.76	7.44	6.90		1.32	1.54	1.43
5.	96AC-93	10.33	13.10	10.89		2.41	2.77	2.59
6.	HTP-94/54	10.78	12.40	11.10		2.06	2.21	2.14
7.	ICMR-01004	6.19	9.75	6.90		1.63	2.41	2.02
8.	ICMR-01007	3.62	4.35	3.77		1.09	1.30	1.20
9.	H90/4-5	4.08	4.41	4.14		1.43	1.49	1.46
10.	(G73-107×BSECT CP-1)	6.64	8.81	7.08		1.60	2.24	1.92
11.	INB 87/74-3-20	5.61	5.65	5.62		1.22	1.15	1.19
12.	VCF ₄ -2359	13.27	16.40	13.89		2.38	3.25	2.82
13.	MRC	6.00	8.83	6.57		1.02	1.66	1.34
14.	72-2-2-98K-1	6.37	7.65	6.62		1.26	1.31	1.29
15.	1448-98K-1	9.07	11.53	9.56		1.75	2.25	2.00
16.	(77/371× BSECT CP-1)	9.57	13.55	10.36		2.07	2.81	2.44
17.	1250	6.38	8.71	6.84		1.26	1.81	1.53
18.	HTP-31	4.89	5.68	5.04		1.20	1.47	1.34
19.	77/667	6.73	9.51	7.29		1.37	2.06	1.72
20.	1305	5.51	8.67	6.14		1.11	1.82	1.46
21.	HTP-92/80	3.10	5.75	3.63		0.84	1.45	1.14
22.	96AC-82	4.09	5.04	4.28		1.17	1.32	1.24
23.	S-97/120	2.94	5.74	3.50		1.04	1.81	1.42
24.	99HS-18	14.36	17.59	15.00		3.02	3.26	3.14
25.	Togo-II	9.38	12.85	10.07		2.02	2.67	2.35

Sr. no.	Inbreds/genotypes	Fresh weight (g)/seedling				Dry weight (g)/seedling		
		E ₁	E ₂	Mean		E ₁	E ₂	Mean
26	HTP-88	9.92	12.43	10.42		1.74	2.35	2.05
27	ICR-161	7.27	7.63	7.34		1.71	1.63	1.67
28	77/245	5.93	7.59	6.26		1.43	1.78	1.60
29	77/371	6.61	9.17	7.12		1.42	1.75	1.58
30	CVJ-2-5-3-1-3	11.12	14.67	11.83		3.01	3.74	3.38
31	99/57-1	3.40	4.63	3.65		0.85	1.16	1.00
32	77/273	8.32	10.68	8.79		1.54	2.04	1.79
33	841B×90/4-5	9.59	13.60	10.39		1.88	2.50	2.19
34	7B	5.50	5.56	5.51		1.36	1.31	1.33
35	18B	6.27	7.55	6.52		1.42	1.55	1.48
36	36B	12.24	12.70	12.34		2.37	2.34	2.36
37	94222B	7.90	11.23	8.57		1.67	2.34	2.00
38	HHB-67-1	12.17	15.38	12.81		1.94	2.69	2.31
39	HHB-67-2	13.03	15.55	13.54		3.11	3.51	3.31
40	HHB-94	10.11	11.17	10.32		1.94	2.09	2.02
41	HHB-117	12.50	12.50	12.50		2.20	2.43	2.31
42	HHB-146	9.93	11.43	10.23		1.90	2.11	2.00
43	HHB-162	14.23	14.57	14.30		2.52	2.64	2.58
44	HHB-176	9.59	10.58	9.79		1.73	1.99	1.86
45	HHB-181	12.72	14.36	13.05		3.69	3.74	3.72
46	H77/833-2	9.02	10.59	9.33		2.65	2.89	2.77
	Mean	8.19	10.22	8.59		1.79	2.19	1.99
	CD	1.948	2.492	—		0.444	0.542	—
	SE (d)	0.979	1.252	—		0.223	0.272	—
	SE (m)	0.692	0.886	—		0.158	0.193	—
	CV	14.648	15.008	—		15.295	15.222	—

temperature and soil surface temperature were of considerable influence on SSTI as seen from the table. The genotype 96AC-93 had the highest worth for SSTI on pooled basis followed by (77/371× BSECT CP-1), 99HS-18, G73-107, H77/833-2, CVJ-2-5-3-1-3 and Togo-II. The genotype 1305 had the lowest value followed by two genotypes 77/245 and H77/29-2. The values of SSTI ranged from 31.47 to 64.79 with an average of 45.50 (figure 7).

iii) Germination (%)

The germination was lower in environment–I than in environment–II. This period has the highest range of temperature with a high average. Genotype-wise, highest germination (58.81) recorded for the genotype ICMR–01007 over both the environments 58.52 and 59.10 respectively while the genotype 77/667 had the lowest germination (33.34). In stress environments the germination ranged from 33.34 to 58.81 with an average of 46.35. Thus, the genotype ICMR–01007 gives a preliminary indication of resistant to heat.

iv) Emergence rate (ER)

The various genotypes showed a variable performance in respect of emergence rate. On pooled basis the genotype H77/833-2 was adjudged as the genotype with fastest emergence of seedlings. The genotype 36B showed the lowest emergence rate of the seedlings. The emergence rate ranged from 29.38 to 54.34 with an average of 40.56.

v) Number of leaves/seedling

This trait is an attribute of initial vigour and growth of the plant. The mean values in both the environments is given in table 7. On the

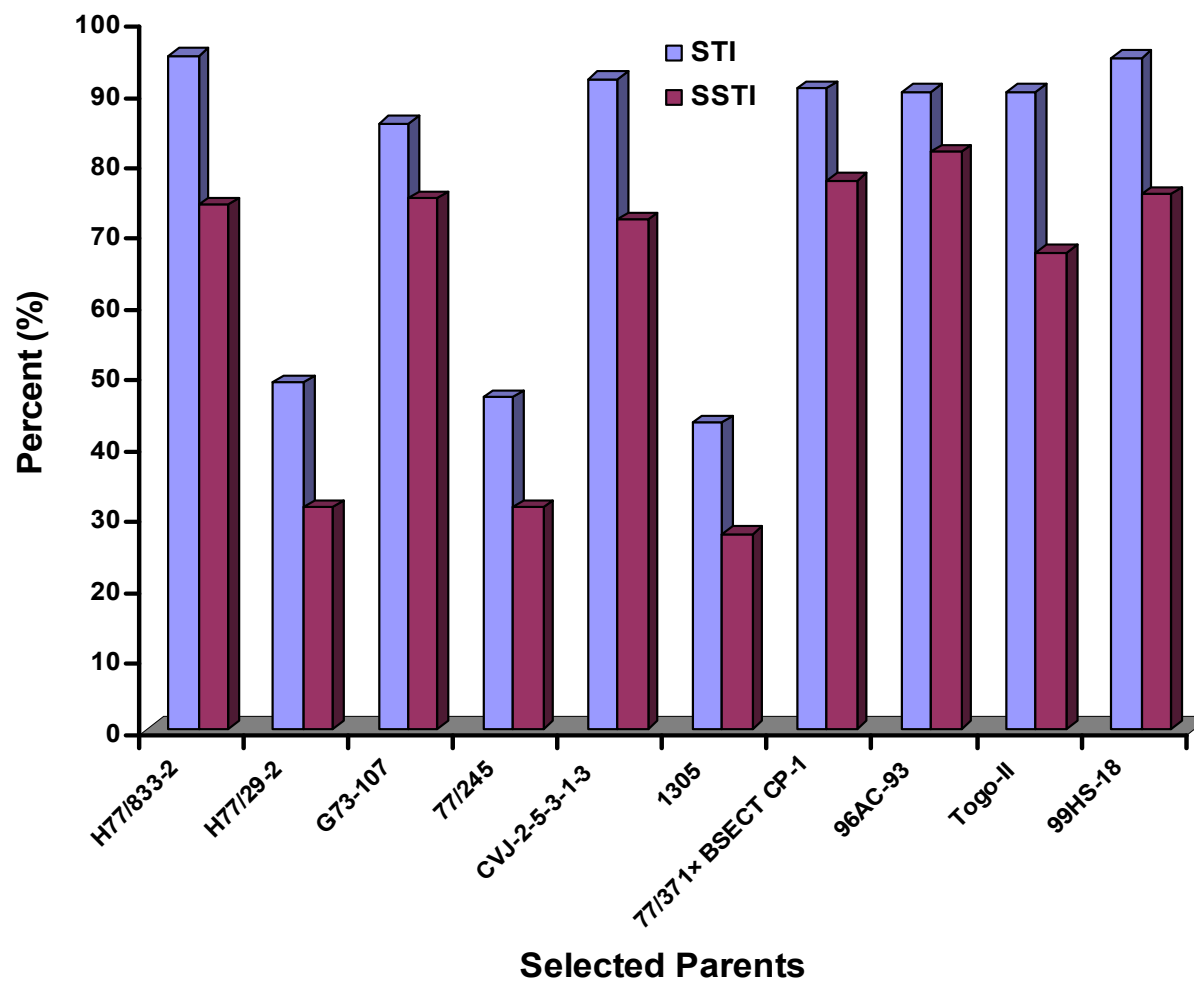


Figure 7: Values for STI and SSTI during screening experiment

pooled basis the number of leaves/seedling ranged from 2.88 to 8.30 with an average of 5.55. The genotype HHB-67-2 had the highest Number of leaves/seedling while the genotype ICMR- 01007 had the lowest value. The plants showing high vigour are expected to be tolerant to heat, perhaps due to the fact that of seedlings are able to fully utilise the nutritional resources of the seed.

vi) Seedling height (cm)

This observation is an indication of vigour and speed of growth of seedling at an early stage. The genotype HTP – 88 was the fastest growing genotype and 77/371 was identified as the slowest growing genotype as indicated by pooled mean. The seedling height ranged from 7.19 to 14.80 with an average of 10.91.

vii) Fresh weight (g) / seedling

This trait is an attribute of growth and development of the seedling at an early stage. Environment-I (E_1) had the lower seedling fresh weight (g) than environment-II (E_2) indicating the effect of more heat stress. On the pooled basis the seedling fresh weight (g) ranged from 3.50 to 15.00 with an average of 8.59. The genotype 99HS-18 had the highest fresh weight/seedling while the genotype S-97/120 had the lowest fresh weight/seedling.

viii) Dry weight (g) / seedling

The mean performance in both the heat stress environments is given in table 7. Environment-I had the lower dry weight/seedling than environment-II indicating the more heat stress during the environment-I. The genotype HHB-181 had the highest seedling dry

weight (g) while the genotype 99/57-1 had the lowest dry weight/seedling. On the pooled basis the seedling dry weight (g) ranged from 1.00 to 3.72 g with an average of 1.99 g.

4.1.3 Correlations among the characters

The correlations among the traits were calculated with a view to find whether there was any association of these traits with tolerance indices. It was seen that all these traits were important for heat tolerance in pearl millet as seen from the correlations.

i) Environment-I (E_1):

The correlation matrix for different characters is given in table 8a. Seedling thermo-tolerance index (STI) had a significant positive association with seed to seedling thermo-tolerance index (SSTI), germination (%), , number of leaves/seedling, seedling height (cm), seedling fresh weight (g) and seedling dry weight (g). Seed to seedling thermo-tolerance index (SSTI), in addition, was also positively correlated with germination, seedling thermo-tolerance index (STI), number of leaves/seedling, seedling height (cm), seedling fresh weight (g) and seedling dry weight (g). Germination (%) is positively correlated with number of leaves/seedling and seedling dry weight (g).

Number of leaves/seedling had a significant correlation with seedling height, seedling fresh weight (g) and seedling dry weight (g) while the seedling fresh weight (g) and seedling dry weight were highly correlated.

Table 8a: Correlation coefficients among various characters in second environment (E-I) during screening experiment

Characters	STI	SSTI	Germination	Rate of emergence	No. of leaves/ seedling	Seedling height	Fresh weight /seedling	Dry weight /seedling	Membrane thermo-stability
STI	1.000	0.915**	0.498**	0.245	0.655**	0.357*	0.564**	0.692**	0.807**
SSTI		1.000	0.582**	0.165	0.581**	0.337*	0.504**	0.622**	0.727**
Germination			1.000	0.050	0.371*	0.286	0.262	0.357*	0.362*
Rate of emergence				1.000	0.056	-0.176	-0.103	0.021	0.045
No. of leaves/ seedling					1.000	0.368*	0.635**	0.652**	0.576**
Seedling height						1.000	0.550**	0.474**	0.149
Fresh weight /seedling							1.000	0.859**	0.436**
Dry weight /seedling								1.000	0.568**
Membrane thermo stability									1.000

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Table 8b: Correlation coefficients among various characters in first environment (E-II) during screening experiment

Characters	STI	SSTI	Germination	Rate of emergence	No. of leaves/ seedling	Seedling height	Fresh weight /seedling	Dry weight /seedling	Membrane thermo-stability
STI	1.000	0.897**	0.312*	0.421**	0.636**	0.242	0.485**	0.583**	0.874**
SSTI		1.000	0.465**	0.363*	0.493**	0.297*	0.402*	0.504**	0.848**
Germination			1.000	0.232	0.091	0.283	-0.093	0.001	0.255
Rate of emergence				1.000	0.360*	0.126	0.073	0.167	0.241
No. of leaves/ seedling					1.000	0.377**	0.627**	0.627**	0.557**
Seedling height						1.000	0.481**	0.460**	0.266
Fresh weight /seedling							1.000	0.881**	0.472**
Dry weight /seedling								1.000	0.541**
Membrane thermo stability									1.000

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Table 8c: Pooled correlation coefficients among various characters in two environments during screening experiment

Characters	STI	SSTI	Germination	Rate of emergence	No. of leaves/ seedling	Seedling height	Fresh weight /seedling	Dry weight /seedling	Membrane thermo-stability
STI	1.000	0.931**	0.446**	0.410**	0.663**	0.312*	0.546**	0.666**	0.872**
SSTI		1.000	0.496**	0.444**	0.563**	0.314*	0.465**	0.584**	0.836**
Germination			1.000	0.399**	0.260	0.295*	0.076	0.180	0.365*
Rate of emergence				1.000	0.234	-0.014	0.002	0.139	0.198
No. of leaves/ seedling					1.000	0.382**	0.647**	0.657**	0.584**
Seedling height						1.000	0.520**	0.478**	0.230
Fresh weight /seedling							1.000	0.871**	0.464**
Dry weight /seedling								1.000	0.569**
Membrane thermo stability									1.000

* Significant at $P = 0.05$

** Significant at $P = 0.01$

ii) Environment–II (E_2):

The correlations among the characters had the same pattern of association as in environment–I (E_1) except that in case, seedling thermo-tolerance index (STI) and seed to seedling thermo-tolerance index (SSTI) showed a significant correlation with emergence rate (ER) too. Germination (%) did not show any correlation with number of leaves as well as seedling dry weight. Seedling thermo-tolerance index (STI) was also not correlated with seedling height (cm) as shown in table 8b.

iii) Pooled correlation among the characters:

The correlations among the characters are given in table 8c. This table showed that all the correlations among the characters are same as in environment–I (E_1) except that germination (%) showed correlation with rate of emergence as well as seedling height (cm).

4.1.4 Laboratory screening

4.1.4.1 Membrane thermo-stability (MTS)

This is one of the most popular techniques used to access the tolerance of plants to heat at an early stage. It was used in this experiment just to know whether any similarity of the results is seen with the field screening technique. It was seen from the results that both the techniques had given almost similar results, thus, offering validity and adequacy to each other.

4.1.4.2 Analysis of variance for membrane thermo-stability (MTS)

A simple completely randomised design (CRD) analysis was carried out separately for both the environments for membrane thermo-stability (MTS) is presented in table 9. The mean sum of squares due to genotypes were highly significant indicating that enough genetic variability was present for membrane thermo-stability (MTS) in each environment, which justified further analysis of the data.

4.1.4.3 Mean performance for membrane thermo-stability (MTS)

Genotypes were evaluated for membrane thermo stability (MTS). The values (mean performance) is given in the table 10. Environment-I (E_1) mean over the genotypes was also equal to that of the environment-II (E_2) mean performance. On pooled basis the membrane thermo-stability (MTS) values ranged from 52.35 to 75.05 with an average of 65.10. The genotype CVJ-2-5-3-1-3 showed highest value for membrane thermo-stability (MTS) followed by 99HS-18, Togo-II, H77/833-2, (77/371 $\times$ BSECT CP-1), G73-107 and 96AC-93. These genotypes were selected as the tolerant genotypes for heat stress. The genotype 1305 showed lowest value for membrane thermo-stability (MTS) followed by 77/245 and H77/29-2 and these genotypes were selected as the susceptible for heat stress (figure 8).

Table 9: Analysis of variance for Membrane Thermo stability of screening experiment

Environment	Source of Variation	D.F.	Sum of Squares	Mean Sum of Squares	F-Cal
	Treatment	45	2693.84	59.86**	11.70
E ₁	Error	46	235.33	5.12	
	Total	91	2929.18		
	Treatment	45	3518.27	78.18**	18.33
E ₂	Error	46	196.18	4.26	
	Total	91	3714.45		

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Table 10: Mean performance of the genotypes during screening for Membrane Thermo stability in two environments.

Sr. no	Genotypes	Membrane Thermo stability*			Sr. no	Genotypes	Membrane Thermo stability*		
		E ₁	E ₂	Mean			E ₁	E ₂	Mean
1.	CSSC-46-2	70.35	76.25	73.30	27	ICR-161	56.99	55.52	56.26
2.	G73-107	71.78	73.59	72.69	28	77/245	53.30	54.73	54.02
3.	H77/29-2	54.51	56.03	55.27	29	77/371	64.00	64.89	64.44
4.	78/711	61.95	62.91	62.43	30	CVJ-2-5-3-1-3	74.60	75.49	75.05
5	96AC-93	70.80	72.87	71.83	31	99/57-1	63.00	64.47	63.73
6	HTP-94/54	59.62	61.66	60.64	32	77/273	67.92	65.44	66.68
7	ICMR-01004	61.13	61.39	61.26	33	841B×90/4-5	62.35	59.57	60.96
8	ICMR-01007	66.68	67.99	67.33	34	7B	70.33	69.84	70.08
9	H90/4-5	66.03	66.49	66.26	35	18B	66.61	64.61	65.61
10	(G73-107×BSECT CP-1)	61.50	62.67	62.08	36	36B	66.37	65.38	65.88
11	INB 87/74-3-20	64.83	66.92	65.87	37	94222B	69.48	66.61	68.05
12	VCF ₄ -2359	57.63	61.16	59.39	38	HHB-67-1	63.12	64.98	64.05
13	MRC	57.97	58.32	58.14	39	HHB-67-2	71.62	70.27	70.95
14	72-2-2-98K-1	65.52	65.37	65.45	40	HHB-94	68.86	69.58	69.22
15	1448-98K-1	61.00	60.32	60.66	41	HHB-117	68.64	70.55	69.59
16	(77/371× BSECT CP-1)	70.81	75.43	73.12	42	HHB-146	68.24	70.65	69.44
17	1250	58.97	62.78	60.87	43	HHB-162	65.09	63.63	64.36
18	HTP-31	58.31	58.39	58.35	44	HHB-176	63.03	59.34	61.19
19	77/667	62.82	60.46	61.64	45	HHB-181	68.42	70.23	69.33
20	1305	52.08	52.62	52.35	46	H77/833-2	71.75	75.42	73.58
21	HTP-92/80	63.53	62.76	63.14		Mean	64.81	65.38	65.10
22	96AC-82	65.66	62.69	64.18		CD	4.57	4.17	—
23	S-97/120	61.39	57.99	59.69		SE (d)	2.26	2.07	—
24	99HS-18	72.88	77.05	74.97		SE (m)	1.60	1.46	—
25	Togo-II	72.65	75.51	74.08		CV	3.49	3.16	—
26	HTP-88	67.06	66.86	66.96					

- Values are transformed values

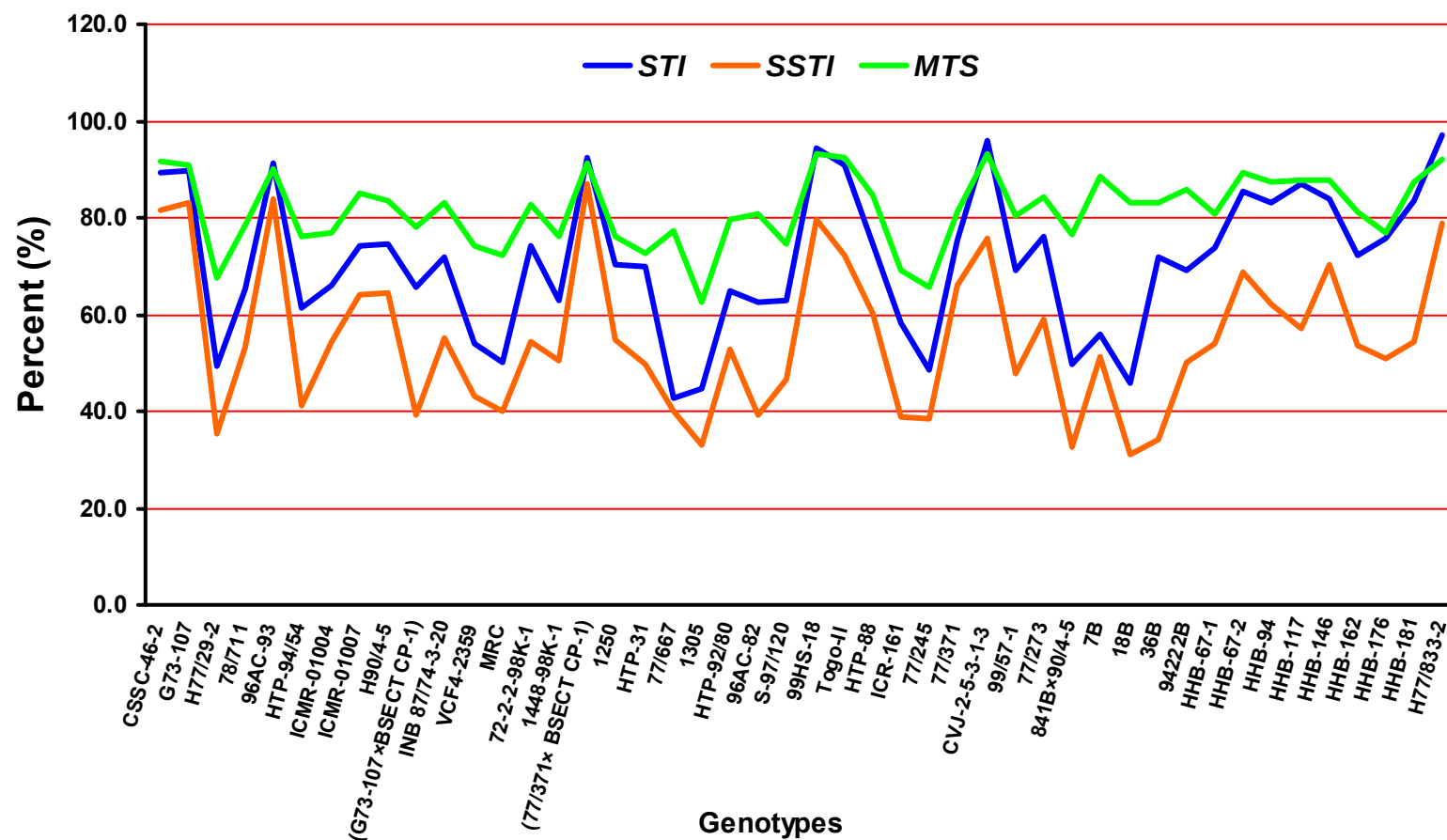


Fig. 8- Values of STI, SSTI and Membrane thermo-stability during screening experiment

4.1.5 Correlation of membrane thermo-stability (MTS) with other field screening characters

In environment-I (E_1) the correlation matrix for different characters is given in table 8a. It showed that membrane thermo-stability (MTS) had a significant positive correlation with germination (%), seedling thermo-tolerance index (STI), seed to seedling thermo-tolerance index (SSTI), number of leaves/seedling, seedling fresh weight (g) and seedling dry weight (g).

In environment-II (E_2) membrane thermo-stability (MTS) showed the same pattern of association except that the germination did not show significant correlation with membrane thermo-stability (MTS) (Table 8b).

On pooled basis the correlation of membrane thermo-stability (MTS) with other field characters showed the same pattern of association as shown in environment-I (E_1) (Table 8c).

4.2 Main experiment

The screening procedure in the field and the laboratory applied on 46 genotypes (table 2) led to the selection of ten genotypes (table 3) for inheritance studies. These ten genotypes were mated in a diallel fashion (excluding reciprocals). The criterion of inclusion of genotypes in the inheritance analysis was based on their mean values of their heat tolerance such as tolerant and susceptible.

Forty five hybrids and ten parents were grown in randomised block design (RBD) with three replications in three environments

during 2005. The traits for inheritance studies were some seedling traits and also some agronomic traits.

This experiment began in the same way as that for screening during 2004. The entire material was exposed to high summer field temperatures to study the heat tolerance reaction and other traits related to seedling survival. The results of the experiment are given below in the following manner:

1. Environmental measurements
2. Heat tolerance indices
3. Diallel analysis
 - a) Combining ability analysis
 - b) Graphical analysis
4. Genotype $\times$ environment interaction and stability analysis

4.2.1 Environmental measurements

The environmental background in this set of experiment was the same as was observed for the screening of the material during 2004. These included soil surface temperature (figure 9), Temperature 5 cm above the soil surface (figure 10) and air temperature at 1 m height (figure 11). The soil moisture (figure 12) was also measured and maintained in the same way as during screening.

The results indicated that maximum temperature went up to 63.0 °C in environment–II. This temperature was about 18°C higher than the normal atmospheric temperature measured at 1 m above the soil surface. This excessive amount of heat perhaps was responsible

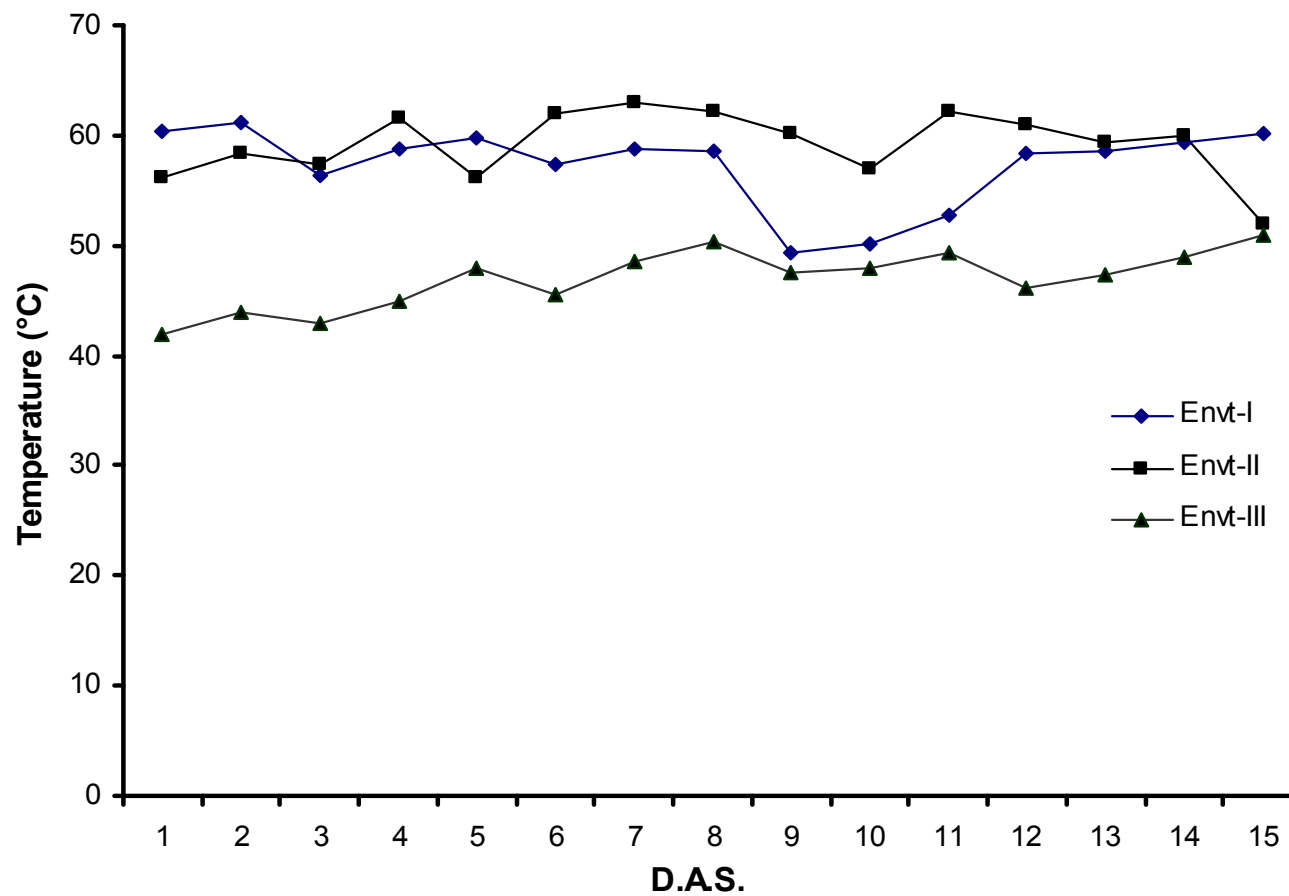


Figure 9: Soil surface temperature in different environments

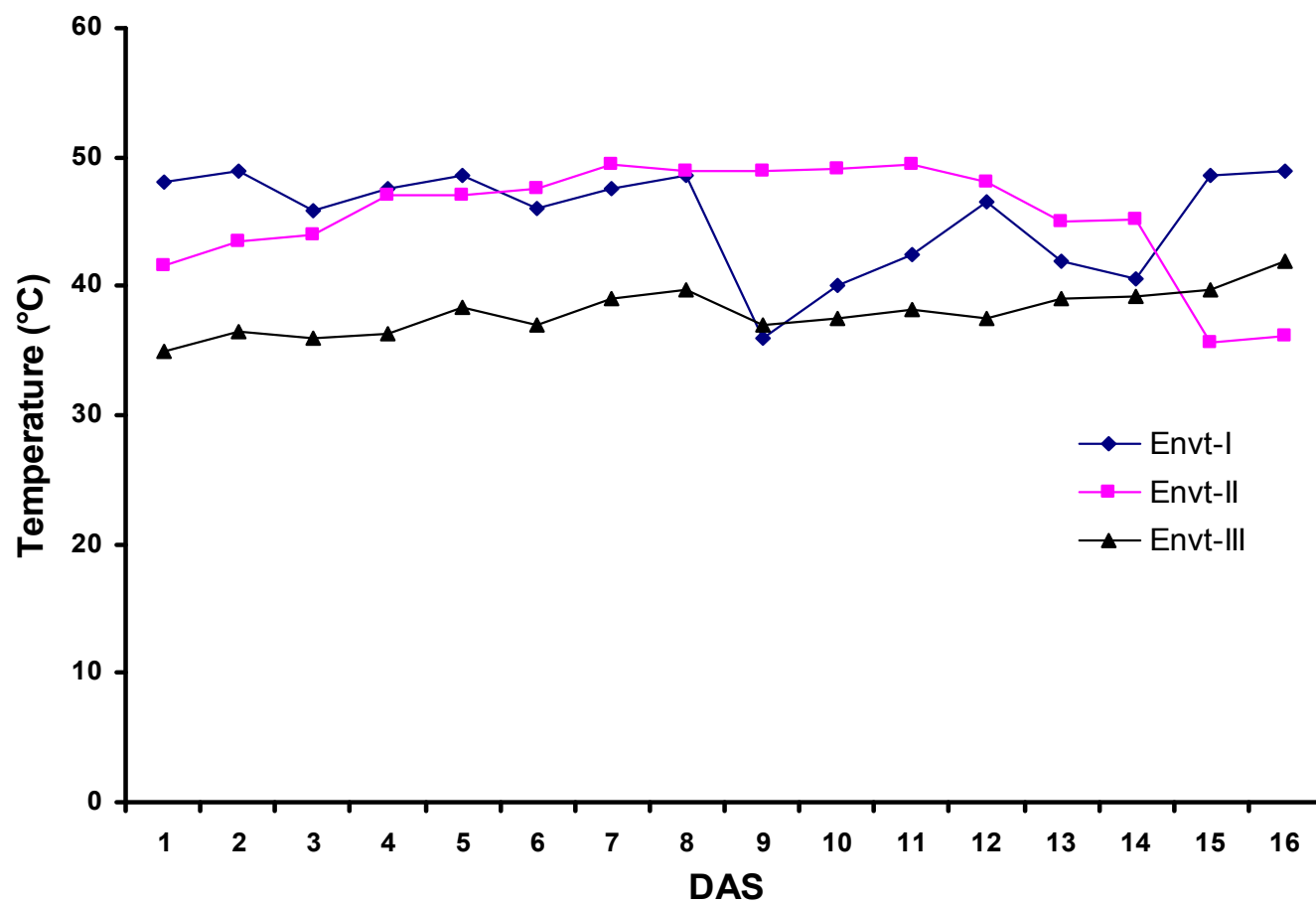


Figure 10: Temperature 5 cm above the soil surface in different environments

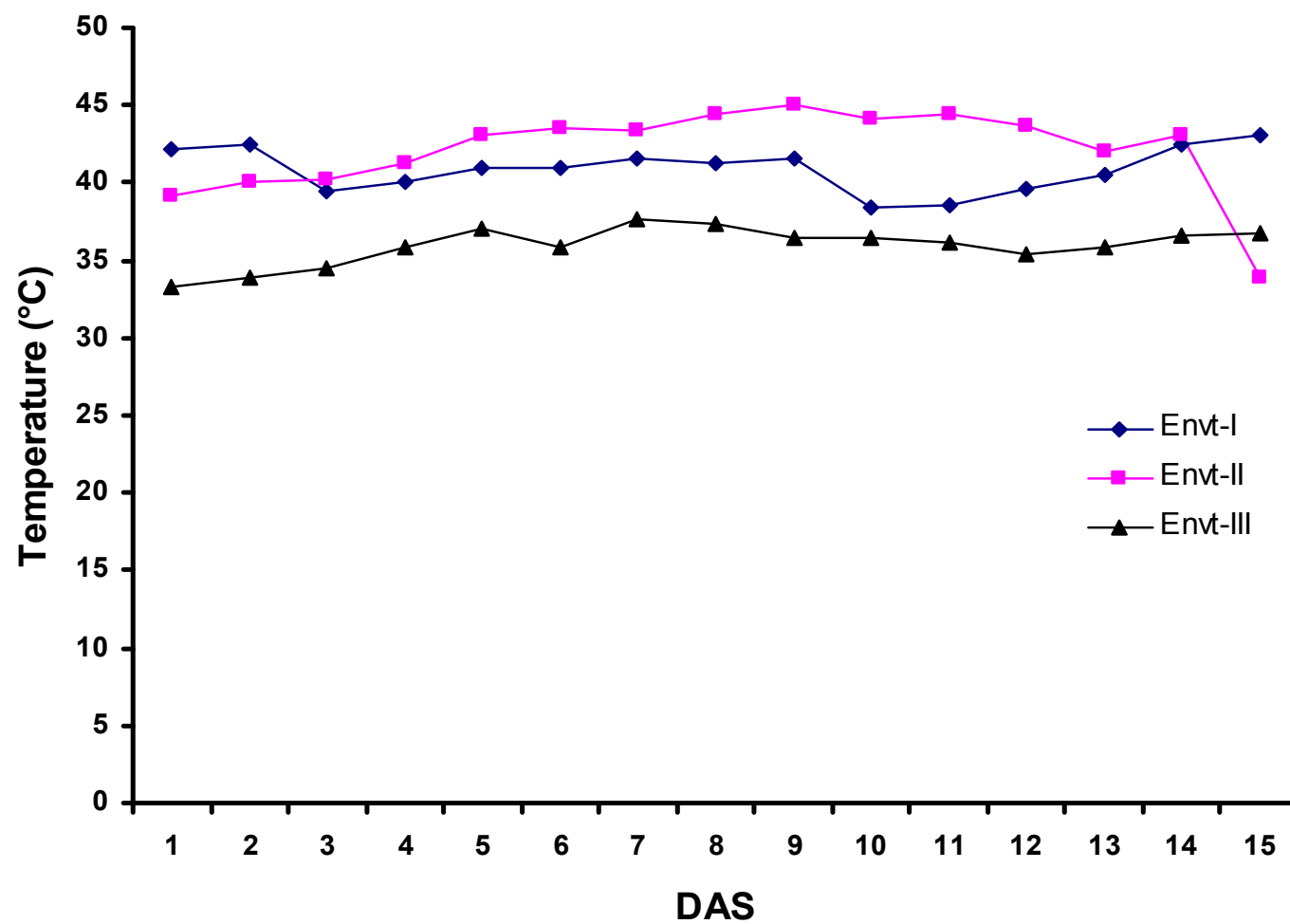


Figure 11: Air temperature in different environments

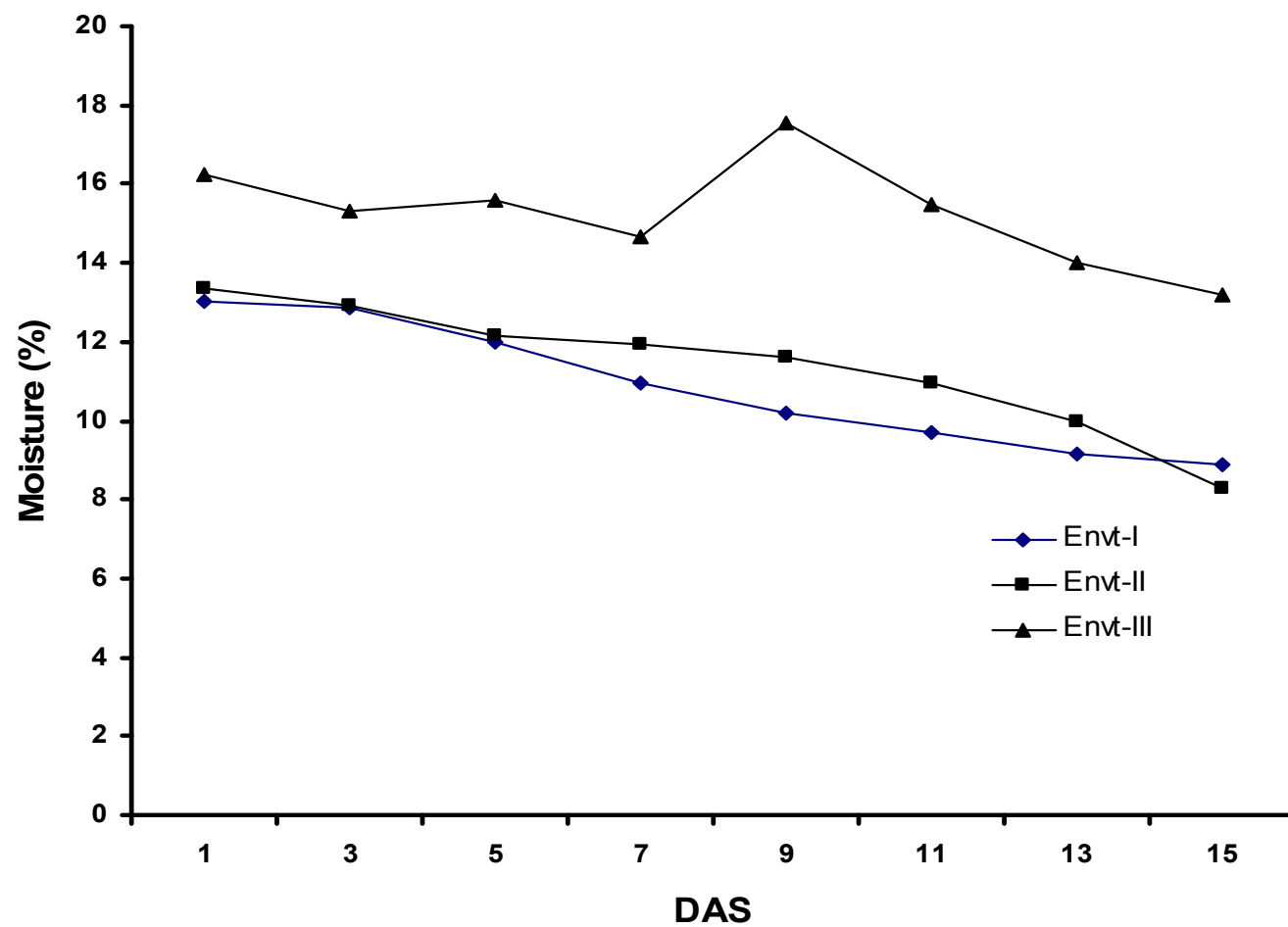


Figure 12: Soil moisture status in different environments

for mortality of seedling. Many a seedlings were found desiccated at the point of contact besides the desiccation at the tips. The temperature around the tip level i.e. 5 cm above the soil surface also reached up to an extent of 50°C. It could therefore be concluded that the seedlings had to survive in a really high temperature i.e. 50 °C (at tip level) and 63°C at contact level. An index of survival could therefore be validly considered as an adequate index for heat tolerance. The fact remains that the moisture level remained above the permanent wilting point. The drought effect was therefore not in the play.

4.2.2 Heat tolerance indices

The 45 hybrids were evaluated for their heat tolerance as per TI of Peacock *et al.* (1993) hither to referred as seedling thermo-tolerance index (STI) and also seed to seedling thermo-tolerance index (SSTI) and membrane thermo stability (MTS). The results of the three indices are given below.

4.2.2.1 Seedling thermo-tolerance index (STI)

The seedling thermo-tolerance index (STI) of the hybrids recorded values as low as 53 and as high as 82. The ten hybrids which recorded highest values for tolerance are listed in table 11. Among the hybrids H77/29-2 × 77/245 and H77/833-2 × 96AC-93 were the highly tolerant genotypes.

Table11: Mean performance of the parents and the crosses for different characters

[illegible]

Sr. no	Genotypes	Germination (%)					Rate of emergence			
		E ₁	E ₂	E ₃	Mean		E ₁	E ₂	E ₃	Mean
20	G73-107 × 1305	48.81	45.61	75.97	56.80		47.17	47.91	47.75	47.61
21	G73-107 × (77/371 × BSECT CP-1)	56.36	55.19	62.83	58.12		49.86	52.19	52.03	51.36
22	G73-107 × 96AC-93	57.40	45.10	64.15	55.55		51.29	49.82	51.95	51.02
23	G73-107 × Togo-II	44.60	43.57	60.44	49.53		43.96	51.38	49.51	48.29
24	G73-107 × 99HS-18	54.73	43.56	63.74	54.01		51.02	49.55	50.55	50.37
25	77/245 × CVJ-2-5-3-1-3	47.66	46.66	59.21	51.17		51.70	49.18	49.00	49.96
26	77/245 × 1305	45.75	40.60	60.52	48.95		51.28	52.97	52.03	52.10
27	77/245 × (77/371 × BSECT CP-1)	50.17	49.29	60.22	53.22		51.08	54.73	52.74	52.85
28	77/245 × 96AC-93	54.72	47.05	62.21	54.66		51.35	51.97	50.06	51.13
29	77/245 × Togo-II	52.52	44.92	58.89	52.11		51.88	48.61	50.74	50.41
30	77/245 × 99HS-18	57.40	40.99	68.72	55.70		52.49	48.98	52.58	51.35
31	CVJ-2-5-3-1-3 × 1305	43.64	39.44	57.00	46.69		49.74	45.17	46.50	47.14
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	43.45	38.08	67.74	49.76		52.72	49.96	50.35	51.01
33	CVJ-2-5-3-1-3 × 96AC-93	48.62	41.97	57.43	49.34		48.84	49.80	50.58	49.74
34	CVJ-2-5-3-1-3 × Togo-II	46.70	43.43	62.33	50.82		43.99	48.13	46.31	46.14
35	CVJ-2-5-3-1-3 × 99HS-18	54.93	50.80	72.73	59.49		52.76	49.84	51.62	51.41
36	1305 × (77/371 × BSECT CP-1)	46.13	45.39	57.17	49.56		49.86	49.55	50.80	50.07
37	1305 × 96AC-93	54.73	51.77	68.30	58.27		52.24	47.79	49.19	49.74
38	1305 × Togo-II	42.30	34.20	52.62	43.04		43.09	45.61	44.45	44.38
39	1305 × 99HS-18	54.33	45.07	69.47	56.29		52.25	47.53	49.91	49.89
40	(77/371 × BSECT CP-1) × 96AC-93	55.95	44.29	74.61	58.28		52.16	49.55	51.21	50.97
41	(77/371 × BSECT CP-1) × Togo-II	52.52	47.28	61.06	53.62		54.92	48.08	51.32	51.44
42	(77/371 × BSECT CP-1) × 99HS-18	55.95	42.98	62.95	53.96		47.29	48.87	50.31	48.83
43	96AC-93 × Togo-II	50.17	39.77	64.86	51.60		50.19	51.95	52.37	51.50
44	96AC-93 × 99HS-18	55.95	48.12	69.24	57.77		50.36	53.85	52.05	52.09
45	Togo-II × 99HS-18	46.70	44.97	72.93	54.87		47.18	43.19	47.96	46.11
	Mean	50.43	44.82	62.71	52.65		47.92	49.81	49.23	48.99
	CD	2.718	2.965	4.535	—		5.970	5.368	5.340	—
	SE (d)	1.369	1.494	2.285	—		3.008	2.704	2.690	—
	SE (m)	0.968	1.056	1.615	—		2.127	1.912	1.902	—
	CV	3.325	4.082	4.462	—		7.687	6.650	6.692	—

Sr. no	Genotypes	STI %					SSTI%			
		E ₁	E ₂	E ₃	Mean		E ₁	E ₂	E ₃	Mean
20	G73-107 × 1305	67.04	63.80	90.00	73.61		45.56	41.15	90.00	58.90
21	G73-107 × (77/371 × BSECT CP-1)	79.90	62.03	90.00	77.31		66.20	54.36	90.00	70.19
22	G73-107 × 96AC-93	69.78	55.56	90.00	71.78		61.56	40.19	90.00	63.92
23	G73-107 × Togo-II	52.79	48.35	90.00	63.71		40.18	36.03	90.00	55.40
24	G73-107 × 99HS-18	64.60	51.97	90.00	68.86		55.34	37.04	90.00	60.79
25	77/245 × CVJ-2-5-3-1-3	59.28	58.59	90.00	69.29		47.85	46.13	90.00	61.33
26	77/245 × 1305	51.02	49.90	90.00	63.64		39.79	34.64	90.00	54.81
27	77/245 × (77/371 × BSECT CP-1)	53.08	50.44	90.00	64.51		44.98	41.91	90.00	58.96
28	77/245 × 96AC-93	52.47	48.43	90.00	63.63		47.08	37.84	90.00	58.31
29	77/245 × Togo-II	48.85	42.63	90.00	60.49		44.21	33.79	90.00	56.00
30	77/245 × 99HS-18	56.28	46.16	90.00	64.15		48.63	30.14	90.00	56.26
31	CVJ-2-5-3-1-3 × 1305	60.97	55.79	90.00	68.92		45.94	38.42	90.00	58.12
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	66.50	57.66	90.00	71.39		42.88	33.81	90.00	55.56
33	CVJ-2-5-3-1-3 × 96AC-93	74.77	67.60	90.00	77.45		59.57	47.09	90.00	65.55
34	CVJ-2-5-3-1-3 × Togo-II	58.06	66.14	90.00	71.40		44.22	44.79	90.00	59.67
35	CVJ-2-5-3-1-3 × 99HS-18	73.22	65.90	90.00	76.37		55.34	47.66	90.00	64.33
36	1305 × (77/371 × BSECT CP-1)	51.37	48.70	90.00	63.36		42.10	39.36	90.00	57.15
37	1305 × 96AC-93	71.17	69.65	90.00	76.94		56.40	52.20	90.00	66.20
38	1305 × Togo-II	57.81	43.73	90.00	63.85		45.75	28.87	90.00	54.87
39	1305 × 99HS-18	72.87	69.68	90.00	77.52		55.76	44.79	90.00	63.52
40	(77/371 × BSECT CP-1) × 96AC-93	70.87	63.68	90.00	74.85		54.32	40.38	90.00	61.57
41	(77/371 × BSECT CP-1) × Togo-II	80.25	75.05	90.00	81.77		63.10	54.13	90.00	69.08
42	(77/371 × BSECT CP-1) × 99HS-18	73.66	69.45	90.00	77.70		63.12	45.56	90.00	66.23
43	96AC-93 × Togo-II	59.22	54.86	90.00	68.03		46.89	34.84	90.00	57.24
44	96AC-93 × 99HS-18	74.11	53.78	90.00	72.63		58.73	39.79	90.00	62.84
45	Togo-II × 99HS-18	56.88	54.31	90.00	67.06		39.80	36.65	90.00	55.48
	Mean	63.77	58.41	90.00	70.72		50.79	41.90	90.00	60.90
	CD	5.552	5.251	—	—		4.209	4.086	—	—
	SE (d)	2.797	2.645	—	—		2.120	2.058	—	—
	SE (m)	1.978	1.870	—	—		1.499	1.456	—	—
	CV	5.372	5.547	—	—		5.113	6.016	—	—

Sr. no	Genotypes	No. of leaves/seedling					Seedling height (cm)			
		E ₁	E ₂	E ₃	Mean		E ₁	E ₂	E ₃	Mean
20	G73-107 × 1305	11.40	8.82	16.57	12.26		12.17	15.07	28.32	18.52
21	G73-107 × (77/371 × BSECT CP-1)	9.77	7.03	13.95	10.25		18.55	19.46	27.30	21.77
22	G73-107 × 96AC-93	10.77	8.60	12.64	10.67		17.18	18.40	28.61	21.40
23	G73-107 × Togo-II	9.06	8.81	11.89	9.92		16.80	18.08	30.87	21.92
24	G73-107 × 99HS-18	11.71	7.66	16.35	11.91		13.98	16.75	33.70	21.48
25	77/245 × CVJ-2-5-3-1-3	9.84	9.20	11.94	10.33		15.00	17.28	22.03	18.10
26	77/245 × 1305	12.79	8.23	15.50	12.17		14.38	15.77	20.80	16.98
27	77/245 × (77/371 × BSECT CP-1)	8.33	5.88	9.39	7.87		15.05	16.97	28.46	20.16
28	77/245 × 96AC-93	7.95	6.62	10.58	8.38		16.53	17.97	21.17	18.56
29	77/245 × Togo-II	9.77	7.51	12.43	9.90		17.23	17.18	31.63	22.01
30	77/245 × 99HS-18	10.45	8.63	11.84	10.31		20.16	19.70	28.54	22.80
31	CVJ-2-5-3-1-3 × 1305	9.36	8.48	14.03	10.63		13.58	14.22	21.79	16.53
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	8.00	7.12	10.13	8.41		13.35	17.42	24.00	18.26
33	CVJ-2-5-3-1-3 × 96AC-93	9.33	7.38	14.78	10.50		15.52	16.80	32.60	21.64
34	CVJ-2-5-3-1-3 × Togo-II	9.63	8.55	11.80	9.99		14.22	16.07	26.38	18.89
35	CVJ-2-5-3-1-3 × 99HS-18	9.98	8.07	13.38	10.47		14.35	16.00	27.00	19.12
36	1305 × (77/371 × BSECT CP-1)	8.63	6.30	9.13	8.02		14.99	17.67	20.58	17.74
37	1305 × 96AC-93	8.75	6.94	14.76	10.15		16.78	16.05	27.57	20.14
38	1305 × Togo-II	6.37	5.66	7.94	6.66		11.77	16.80	22.49	17.02
39	1305 × 99HS-18	11.15	8.18	14.10	11.14		17.74	17.67	27.66	21.02
40	(77/371 × BSECT CP-1) × 96AC-93	9.55	7.53	14.62	10.57		17.48	17.95	31.71	22.38
41	(77/371 × BSECT CP-1) × Togo-II	8.59	6.93	9.90	8.48		19.65	20.07	26.53	22.08
42	(77/371 × BSECT CP-1) × 99HS-18	9.03	6.22	11.25	8.83		15.01	16.87	27.05	19.64
43	96AC-93 × Togo-II	10.07	7.28	11.67	9.67		17.59	16.18	21.23	18.34
44	96AC-93 × 99HS-18	10.13	6.52	13.34	10.00		13.53	16.18	29.25	19.66
45	Togo-II × 99HS-18	9.39	6.53	14.62	10.18		11.17	12.78	25.82	16.59
	Mean	8.98	7.01	11.68	9.22		15.13	16.18	24.92	18.74
	CD	1.026	1.333	1.916	—		2.837	2.054	2.766	—
	SE (d)	0.517	0.672	0.965	—		1.429	1.035	1.394	—
	SE (m)	0.366	0.475	0.683	—		1.011	0.732	0.985	—
	CV	7.048	11.740	10.123	—		11.567	7.831	6.849	—

Sr. no	Genotypes	Fresh weight (g)/seedling					Dry weight (g)/seedling			
		E ₁	E ₂	E ₃	Mean		E ₁	E ₂	E ₃	Mean
20	G73-107 × 1305	17.77	51.89	111.49	60.38		2.89	5.88	11.97	6.91
21	G73-107 × (77/371 × BSECT CP-1)	18.01	34.82	104.15	52.33		2.39	2.77	7.53	4.23
22	G73-107 × 96AC-93	13.45	93.33	146.69	84.49		2.97	8.45	12.78	8.07
23	G73-107 × Togo-II	11.12	46.78	93.19	50.36		1.86	4.73	9.85	5.48
24	G73-107 × 99HS-18	27.53	86.72	119.18	77.81		3.62	6.91	9.81	6.78
25	77/245 × CVJ-2-5-3-1-3	22.82	46.79	114.92	61.51		3.28	4.24	11.16	6.23
26	77/245 × 1305	9.49	104.39	120.53	78.14		1.21	9.15	9.92	6.76
27	77/245 × (77/371 × BSECT CP-1)	32.22	85.18	126.21	81.20		4.69	8.27	11.41	8.12
28	77/245 × 96AC-93	19.34	60.56	115.43	65.11		3.52	5.63	9.11	6.08
29	77/245 × Togo-II	17.49	82.50	154.43	84.81		2.29	8.06	14.12	8.16
30	77/245 × 99HS-18	32.17	130.27	35.31	65.91		3.95	9.65	2.85	5.49
31	CVJ-2-5-3-1-3 × 1305	12.54	28.03	101.94	47.50		1.78	2.54	8.01	4.11
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	9.22	52.26	128.06	63.18		2.36	4.58	10.54	5.83
33	CVJ-2-5-3-1-3 × 96AC-93	16.67	100.94	119.41	79.01		2.50	9.74	11.15	7.79
34	CVJ-2-5-3-1-3 × Togo-II	10.12	41.63	110.61	54.12		2.61	3.77	8.91	5.10
35	CVJ-2-5-3-1-3 × 99HS-18	30.56	32.37	70.89	44.61		4.49	3.01	6.58	4.69
36	1305 × (77/371 × BSECT CP-1)	18.82	46.65	79.20	48.22		3.56	4.26	7.24	5.02
37	1305 × 96AC-93	15.16	100.37	119.60	78.38		3.11	11.38	12.84	9.11
38	1305 × Togo-II	9.02	46.76	93.88	49.89		2.41	4.56	7.95	4.97
39	1305 × 99HS-18	21.45	46.28	106.18	57.97		3.01	4.47	9.91	5.80
40	(77/371 × BSECT CP-1) × 96AC-93	15.37	125.86	143.79	95.01		2.11	11.04	11.83	8.33
41	(77/371 × BSECT CP-1) × Togo-II	21.36	56.01	95.03	57.47		3.15	6.35	10.01	6.50
42	(77/371 × BSECT CP-1) × 99HS-18	19.35	72.53	118.06	69.98		3.14	7.04	10.67	6.95
43	96AC-93 × Togo-II	15.39	103.47	122.12	80.33		3.25	9.07	10.90	7.74
44	96AC-93 × 99HS-18	35.32	72.23	119.50	75.69		4.40	6.54	10.24	7.06
45	Togo-II × 99HS-18	34.48	67.64	119.10	73.74		4.77	7.67	12.07	8.17
	Mean	16.56	57.73	98.54	57.61		2.72	5.38	8.85	5.65
	CD	2.214	4.272	8.905	—		0.381	0.404	0.794	—
	SE (d)	1.115	2.152	4.486	—		0.192	0.203	0.400	—
	SE (m)	0.789	1.522	3.172	—		0.136	0.144	0.283	—
	CV	8.242	4.566	5.576	—		8.647	0.627	5.533	—

Sr. no	Genotypes	Panicle emergence (days)				Effective tillers/plant			
		E ₁	E ₂	E ₃	Mean	E ₁	E ₂	E ₃	Mean
20	G73-107 × 1305	67.33	50.00	42.33	53.22	2.86	2.10	3.12	2.69
21	G73-107 × (77/371 × BSECT CP-1)	55.00	44.67	34.33	44.67	2.43	1.97	2.73	2.38
22	G73-107 × 96AC-93	56.00	50.33	46.33	50.89	2.70	2.43	3.00	2.71
23	G73-107 × Togo-II	60.33	47.67	42.00	50.00	2.10	2.09	2.31	2.17
24	G73-107 × 99HS-18	56.67	46.00	35.00	45.89	1.70	2.47	2.70	2.29
25	77/245 × CVJ-2-5-3-1-3	60.00	43.33	42.00	48.44	3.00	2.31	3.70	3.00
26	77/245 × 1305	57.67	48.00	35.00	46.89	1.68	2.46	3.16	2.44
27	77/245 × (77/371 × BSECT CP-1)	54.00	43.67	38.33	45.33	1.96	2.25	2.42	2.21
28	77/245 × 96AC-93	53.33	42.67	38.33	44.78	1.86	1.69	1.98	1.84
29	77/245 × Togo-II	59.67	47.00	40.67	49.11	1.74	2.45	2.98	2.39
30	77/245 × 99HS-18	57.33	44.67	38.33	46.78	1.48	2.28	2.09	1.95
31	CVJ-2-5-3-1-3 × 1305	60.33	44.67	33.67	46.22	3.12	1.93	3.30	2.78
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	56.33	44.33	36.00	45.56	3.21	3.15	2.59	2.98
33	CVJ-2-5-3-1-3 × 96AC-93	55.33	45.33	44.67	48.44	1.70	2.02	3.17	2.30
34	CVJ-2-5-3-1-3 × Togo-II	61.67	49.67	45.33	52.22	2.07	2.25	3.25	2.52
35	CVJ-2-5-3-1-3 × 99HS-18	57.00	44.67	38.00	46.56	1.48	1.78	2.25	1.83
36	1305 × (77/371 × BSECT CP-1)	56.67	42.67	38.00	45.78	2.71	2.42	3.05	2.73
37	1305 × 96AC-93	56.00	40.67	34.00	43.56	1.82	2.76	2.51	2.36
38	1305 × Togo-II	65.33	55.33	47.33	56.00	2.14	2.66	2.96	2.59
39	1305 × 99HS-18	59.33	45.00	37.33	47.22	1.28	1.42	1.80	1.50
40	(77/371 × BSECT CP-1) × 96AC-93	54.67	44.00	34.67	44.44	1.27	2.01	2.26	1.85
41	(77/371 × BSECT CP-1) × Togo-II	55.33	48.33	41.00	48.22	2.13	2.41	2.86	2.47
42	(77/371 × BSECT CP-1) × 99HS-18	54.67	44.33	51.33	50.11	1.77	1.67	1.75	1.73
43	96AC-93 × Togo-II	59.00	45.00	39.67	47.89	2.14	2.69	3.39	2.74
44	96AC-93 × 99HS-18	56.00	49.00	45.33	50.11	1.49	1.75	2.06	1.77
45	Togo-II × 99HS-18	60.00	51.33	43.33	51.56	1.83	2.03	2.16	2.01
	Mean	58.68	46.53	41.16	48.79	2.18	2.33	2.68	2.40
	CD	3.507	3.651	4.279	—	0.359	0.391	0.455	—
	SE (d)	1.767	1.840	2.156	—	0.181	0.197	0.229	—
	SE (m)	1.249	1.301	1.524	—	0.128	0.139	0.162	—
	CV	3.687	4.842	6.414	—	10.181	10.343	10.476	—

Sr. no	Genotypes	Plant height (cm)					Earhead length (cm)			
		E ₁	E ₂	E ₃	Mean		E ₁	E ₂	E ₃	Mean
20	G73-107 × 1305	207.88	199.28	170.67	192.61		22.28	24.33	25.83	24.15
21	G73-107 × (77/371 × BSECT CP-1)	238.17	202.63	174.25	205.02		19.43	21.28	22.20	20.97
22	G73-107 × 96AC-93	285.37	214.61	168.75	222.91		21.18	22.18	23.17	22.17
23	G73-107 × Togo-II	248.64	246.09	216.25	236.99		22.37	23.65	27.33	24.45
24	G73-107 × 99HS-18	246.77	205.67	178.55	210.33		20.25	20.81	23.22	21.43
25	77/245 × CVJ-2-5-3-1-3	212.57	204.97	177.25	198.26		21.09	23.60	26.75	23.81
26	77/245 × 1305	197.89	177.90	155.17	176.99		19.19	21.00	21.97	20.72
27	77/245 × (77/371 × BSECT CP-1)	209.28	194.85	171.92	192.02		18.51	19.35	20.20	19.36
28	77/245 × 96AC-93	220.03	190.54	167.67	192.75		17.29	17.80	21.33	18.81
29	77/245 × Togo-II	220.75	235.03	198.75	218.18		23.00	25.08	26.58	24.89
30	77/245 × 99HS-18	221.27	214.62	169.00	201.63		19.82	20.19	22.23	20.75
31	CVJ-2-5-3-1-3 × 1305	222.69	195.47	172.50	196.89		24.06	25.53	30.67	26.75
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	221.04	195.24	170.87	195.72		21.42	21.73	22.38	21.84
33	CVJ-2-5-3-1-3 × 96AC-93	239.21	233.17	193.33	221.90		23.50	24.77	26.00	24.76
34	CVJ-2-5-3-1-3 × Togo-II	235.90	228.60	202.78	222.43		20.93	26.66	29.89	25.83
35	CVJ-2-5-3-1-3 × 99HS-18	224.44	202.40	169.67	198.84		20.28	23.11	23.86	22.42
36	1305 × (77/371 × BSECT CP-1)	220.11	192.95	164.17	192.41		20.05	21.73	22.10	21.29
37	1305 × 96AC-93	239.65	196.25	158.00	197.97		18.22	20.03	20.47	19.57
38	1305 × Togo-II	218.94	202.17	192.22	204.44		25.45	25.83	26.44	25.91
39	1305 × 99HS-18	227.57	194.13	169.67	197.12		20.70	24.08	25.93	23.57
40	(77/371 × BSECT CP-1) × 96AC-93	232.94	210.89	178.58	207.47		20.56	21.15	21.57	21.09
41	(77/371 × BSECT CP-1) × Togo-II	226.62	220.94	176.67	208.08		18.68	22.53	24.50	21.90
42	(77/371 × BSECT CP-1) × 99HS-18	223.05	192.77	163.92	193.25		19.95	20.26	22.09	20.77
43	96AC-93 × Togo-II	232.52	215.54	168.75	205.60		19.53	20.27	25.11	21.64
44	96AC-93 × 99HS-18	244.94	206.98	181.11	211.01		19.52	20.21	22.42	20.72
45	Togo-II × 99HS-18	176.83	155.41	143.33	158.53		19.32	20.08	26.58	21.99
	Mean	212.97	195.47	165.29	191.24		19.82	21.46	23.01	21.43
	CD	9.848	11.726	12.105	—		2.429	1.981	2.451	—
	SE (d)	4.961	5.907	6.098	—		1.224	0.998	1.235	—
	SE (m)	3.508	4.177	4.312	—		0.865	0.706	0.873	—
	CV	2.853	3.701	4.519	—		7.560	5.696	6.572	—

Sr. no	Genotypes	Earhead weight (g)/plant					Dry fodder yield (g)/plant			
		E ₁	E ₂	E ₃	Mean		E ₁	E ₂	E ₃	Mean
20	G73-107 × 1305	63.40	57.94	63.73	61.69		124.90	101.58	119.61	115.36
21	G73-107 × (77/371 × BSECT CP-1)	39.36	39.80	57.70	45.62		116.97	98.58	103.03	106.19
22	G73-107 × 96AC-93	42.70	58.43	62.01	54.38		103.19	98.72	101.59	101.17
23	G73-107 × Togo-II	57.36	51.75	68.22	59.11		120.98	108.08	129.96	119.67
24	G73-107 × 99HS-18	35.58	42.29	66.12	48.00		123.50	96.85	115.16	111.84
25	77/245 × CVJ-2-5-3-1-3	67.60	65.58	72.99	68.72		152.25	118.61	141.62	137.49
26	77/245 × 1305	57.00	51.42	53.47	53.97		116.87	105.65	107.37	109.96
27	77/245 × (77/371 × BSECT CP-1)	25.77	24.60	28.38	26.25		69.89	47.78	46.36	54.68
28	77/245 × 96AC-93	55.41	50.58	57.48	54.49		119.52	81.74	95.26	98.84
29	77/245 × Togo-II	30.67	54.31	59.63	48.20		117.37	110.21	121.64	116.41
30	77/245 × 99HS-18	38.46	31.19	42.25	37.30		74.93	67.20	64.76	68.96
31	CVJ-2-5-3-1-3 × 1305	41.78	47.96	62.81	50.85		138.22	114.25	122.52	125.00
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	45.22	52.35	56.40	51.32		116.73	96.58	102.48	105.26
33	CVJ-2-5-3-1-3 × 96AC-93	46.76	42.80	60.90	50.15		119.75	98.32	108.68	108.91
34	CVJ-2-5-3-1-3 × Togo-II	40.58	37.27	51.90	43.25		125.88	107.17	112.17	115.07
35	CVJ-2-5-3-1-3 × 99HS-18	32.87	25.13	53.56	37.19		100.55	97.33	103.64	100.51
36	1305 × (77/371 × BSECT CP-1)	35.69	46.92	51.40	44.67		116.52	98.26	100.41	105.07
37	1305 × 96AC-93	51.15	40.23	48.13	46.50		99.65	76.75	75.71	84.04
38	1305 × Togo-II	68.85	72.83	67.95	69.87		122.65	114.10	125.83	120.86
39	1305 × 99HS-18	52.19	43.32	48.00	47.84		109.29	76.77	89.68	91.92
40	(77/371 × BSECT CP-1) × 96AC-93	31.58	44.63	47.17	41.13		91.66	75.40	81.00	82.68
41	(77/371 × BSECT CP-1) × Togo-II	44.22	64.58	70.38	59.73		141.53	123.69	137.97	134.39
42	(77/371 × BSECT CP-1) × 99HS-18	27.20	29.09	35.43	30.57		73.92	46.92	50.23	57.02
43	96AC-93 × Togo-II	59.72	43.91	71.26	58.30		155.37	139.27	144.32	146.32
44	96AC-93 × 99HS-18	34.65	27.58	44.96	35.73		59.59	51.86	60.94	57.46
45	Togo-II × 99HS-18	53.81	49.95	54.36	52.70		102.99	88.76	92.44	94.73
	Mean	39.63	41.23	48.36	43.07		94.98	80.87	86.63	87.49
	CD	6.705	5.009	6.258	—		9.586	7.502	8.223	—
	SE (d)	3.378	2.523	3.153	—		4.829	3.779	4.143	—
	SE (m)	2.388	1.784	2.229	—		3.415	2.672	2.929	—
	CV	10.440	7.496	7.984	—		6.227	5.723	5.857	—

Sr. no	Genotypes	Grain yield (g)/plant				Total biological yield(g)/plant			
		E ₁	E ₂	E ₃	Mean	E ₁	E ₂	E ₃	Mean
20	G73-107 × 1305	41.99	41.99	50.18	44.72	188.30	159.52	183.34	177.06
21	G73-107 × (77/371 × BSECT CP-1)	18.74	23.69	41.81	28.08	156.33	138.39	160.73	151.82
22	G73-107 × 96AC-93	27.03	44.60	43.79	38.47	145.89	157.15	163.59	155.55
23	G73-107 × Togo-II	39.84	36.70	53.72	43.42	178.35	159.82	198.18	178.78
24	G73-107 × 99HS-18	21.96	27.82	50.09	33.29	159.08	139.14	181.29	159.83
25	77/245 × CVJ-2-5-3-1-3	42.25	47.52	58.39	49.39	219.85	184.18	214.61	206.21
26	77/245 × 1305	43.18	39.56	42.44	41.73	173.86	157.08	160.85	163.93
27	77/245 × (77/371 × BSECT CP-1)	16.31	16.62	19.99	17.64	95.66	72.38	74.74	80.93
28	77/245 × 96AC-93	36.46	35.87	40.71	37.68	174.93	132.32	152.74	153.33
29	77/245 × Togo-II	15.98	40.53	47.70	34.74	148.05	164.52	181.26	164.61
30	77/245 × 99HS-18	32.05	25.78	26.43	28.09	113.39	98.39	107.01	106.26
31	CVJ-2-5-3-1-3 × 1305	24.72	32.41	49.07	35.40	180.00	162.22	185.32	175.85
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	26.14	37.66	41.78	35.19	161.95	148.93	158.88	156.59
33	CVJ-2-5-3-1-3 × 96AC-93	30.97	29.31	44.45	34.91	166.51	141.11	169.58	159.07
34	CVJ-2-5-3-1-3 × Togo-II	27.42	25.70	41.85	31.66	166.45	144.43	164.07	158.32
35	CVJ-2-5-3-1-3 × 99HS-18	20.04	15.81	42.51	26.12	133.42	122.46	157.20	137.69
36	1305 × (77/371 × BSECT CP-1)	20.05	36.65	41.79	32.83	152.21	145.18	151.82	149.74
37	1305 × 96AC-93	34.56	26.47	31.55	30.86	150.80	116.98	123.84	130.54
38	1305 × Togo-II	45.00	61.20	53.50	53.23	191.50	186.93	193.78	190.74
39	1305 × 99HS-18	39.24	33.32	38.40	36.99	161.49	120.09	137.69	139.76
40	(77/371 × BSECT CP-1) × 96AC-93	18.80	35.42	33.47	29.23	123.24	120.03	128.17	123.81
41	(77/371 × BSECT CP-1) × Togo-II	22.91	46.46	55.86	41.74	185.75	188.27	208.35	194.12
42	(77/371 × BSECT CP-1) × 99HS-18	17.66	21.87	21.47	20.33	101.12	76.01	85.66	87.60
43	96AC-93 × Togo-II	37.80	25.38	56.55	39.91	215.10	183.18	215.58	204.62
44	96AC-93 × 99HS-18	27.07	21.54	24.09	24.23	94.24	79.44	105.90	93.19
45	Togo-II × 99HS-18	39.86	38.42	36.68	38.32	156.80	138.71	146.80	147.43
	Mean	25.10	29.14	35.13	29.79	134.60	122.10	134.99	130.56
	CD	4.234	3.485	3.437	—	11.546	9.273	11.673	—
	SE (d)	2.133	1.756	1.731	—	5.817	4.672	5.881	—
	SE (m)	1.508	1.241	1.224	—	4.113	3.303	4.158	—
	CV	10.408	7.379	6.036	—	5.293	4.686	5.336	—

4.2.2.2 Seed to seedling thermo-tolerance index (SSTI)

Seed to seedling thermo-tolerance index (SSTI) which is expected to be more regressive index changed the values of the STI based on the variation in germination in normal environment (E_3). The reductions in values were not in strict proportion of the STI. Here the values ranged between 46 and 73. A list of ten hybrids led by H77/833-2 $\times$ 96AC-93 is given in table 11. It was interesting to find that eight of the hybrids were common in list of best ten for STI and SSTI. Thus, both the indices appear validating each other.

4.2.2.3 Membrane thermo stability (MTS)

Membrane Thermo Stability (MTS) has long been recognised as a parameter of heat tolerance. All the hybrids were put to membrane thermo stability test in the laboratory under standard protocol. A Completely Randomised Design (CRD) analysis was carried out for Membrane Thermo-Stability (MTS) is presented in table 12. The mean sum of squares due to genotypes were highly significant indicating that enough genetic variability was present for Membrane Thermo Stability (MTS) in each environment, which justified further analysis of the data. The values of top ten hybrids selected through this method (table 13). The range of values laid between 50.73 and 77.42. Among the hybrids H77/29-2 $\times$ CVJ-2-5-3-1-3, CVJ-2-5-3-1-3 $\times$ 96AC-93 and (77/371 $\times$ BSECT CP-1) $\times$ Togo-II were the highly tolerant genotypes.

Table 12: Analysis of variance for Membrane Thermo stability of main experiment

Environment	Source of Variation	D.F.	Sum of Squares	Mean Sum of Squares	F-Cal
	Treatment	54	6910.71	127.98**	50.48
E ₁	Error	55	139.45	2.54	
	Total	109	7050.16		
	Treatment	54	6497.42	120.32**	37.46
E ₂	Error	55	176.67	3.21	
	Total	109	6674.09		

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Table 13: Mean performance of the genotypes for Membrane Thermo stability in two environments.

Sr. no	Genotypes	Membrane Thermo stability*			Sr. no	Genotypes	Membrane Thermo stability*		
		E ₁	E ₂	Mean			E ₁	E ₂	Mean
1.	H77/833-2	74.74	73.73	74.23	21	G73-107 × (77/371 × BSECT CP-1)	71.30	68.94	70.12
2.	H77/29-2	53.37	55.42	54.39	22	G73-107 × 96AC-93	67.22	70.09	68.65
3.	G73-107	79.44	72.37	75.91	23	G73-107 × Togo-II	57.49	55.41	56.45
4.	77/245	54.15	54.42	54.28	24	G73-107 × 99HS-18	67.95	70.11	69.03
5	CVJ-2-5-3-1-3	75.74	76.81	76.27	25	77/245 × CVJ-2-5-3-1-3	60.21	59.45	59.83
6	1305	52.28	51.69	51.99	26	77/245 × 1305	54.23	53.99	54.11
7	77/371 × BSECT CP-1	74.21	73.58	73.90	27	77/245 × (77/371 × BSECT CP-1)	52.24	52.17	52.20
8	96AC-93	72.22	75.63	73.92	28	77/245 × 96AC-93	56.39	54.24	55.31
9	Togo-II	74.35	75.98	75.16	29	77/245 × Togo-II	49.96	51.50	50.73
10	99HS-18	76.39	74.65	75.52	30	77/245 × 99HS-18	59.70	62.19	60.95
1.	H77/833-2 × H77/29-2	72.11	68.66	70.39	31	CVJ-2-5-3-1-3 × 1305	61.91	64.31	63.11
2.	H77/833-2 × G73-107	75.29	70.72	73.00	32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	68.08	64.11	66.09
3.	H77/833-2 × 77/245	66.70	67.42	67.06	33	CVJ-2-5-3-1-3 × 96AC-93	78.13	76.33	77.23
4.	H77/833-2 × CVJ-2-5-3-1-3	74.03	71.78	72.90	34	CVJ-2-5-3-1-3 × Togo-II	67.38	68.01	67.69
5	H77/833-2 × 1305	51.21	51.71	51.46	35	CVJ-2-5-3-1-3 × 99HS-18	74.53	73.63	74.08
6	H77/833-2 × (77/371 × BSECT CP-1)	73.58	72.34	72.96	36	1305 × (77/371 × BSECT CP-1)	64.88	64.47	64.68
7	H77/833-2 × 96AC-93	75.87	75.85	75.86	37	1305 × 96AC-93	76.12	74.90	75.51
8	H77/833-2 × Togo-II	67.57	67.08	67.33	38	1305 × Togo-II	69.11	71.12	70.12
9	H77/833-2 × 99HS-18	65.96	66.02	65.99	39	1305 × 99HS-18	76.80	75.07	75.94
10	H77/29-2 × G73-107	68.67	66.01	67.34	40	(77/371 × BSECT CP-1) × 96AC-93	75.79	74.62	75.21
11	H77/29-2 × 77/245	61.53	64.02	62.77	41	(77/371 × BSECT CP-1) × Togo-II	76.06	78.73	77.40
12	H77/29-2 × CVJ-2-5-3-1-3	75.98	78.86	77.42	42	(77/371 × BSECT CP-1) × 99HS-18	75.06	74.70	74.88
13	H77/29-2 × 1305	68.73	68.92	68.82	43	96AC-93 × Togo-II	68.81	66.15	67.48
14	H77/29-2 × (77/371 × BSECT CP-1)	66.20	65.18	65.69	44	96AC-93 × 99HS-18	73.68	69.27	71.47
15	H77/29-2 × 96AC-93	59.90	58.30	59.10	45	Togo-II × 99HS-18	65.60	63.08	64.34
16	H77/29-2 × Togo-II	70.06	68.21	69.13		Mean	67.78	67.30	67.54
17	H77/29-2 × 99HS-18	67.38	65.07	66.22		CD	3.20	3.60	—
18	G73-107 × 77/245	73.36	70.89	72.12		SE (d)	1.59	1.79	—
19	G73-107 × CVJ-2-5-3-1-3	68.37	69.60	68.99		SE (m)	1.13	1.27	—
20	G73-107 × 1305	70.09	74.30	72.19		CV	2.35	2.66	—

* Values are transformed values

Taken all the three test together, it was observed that among the tolerant hybrids seven hybrids were common qualifiers. This test also holds validity for screening along with STI and SSTI.

4.2.3 Correlations among the characters (Main experiment)

The phenotypic correlations were computed among the characters in all the three environments separately during the main experiment. The significant correlations among the characters are discussed as under:

Environment-I:

The correlation matrix for different characters is given in table 14a. None of the character was found to be positively correlated with panicle emergence but the characters like, emergence rate (ER), seed to seedling thermo-tolerance index (SSTI), number of leaves/seedling, seedling height, fresh weight (g)/seedling, dry weight (g)/seedling and plant height were negatively correlated.

Also, none of the characters was found to be positively correlated with number of effective tillers/plant but germination and fresh weight (g)/seedling were negatively correlated. Plant height showed a significant positive correlation with germination, emergence rate (ER), seed to seedling thermo-tolerance index (SSTI), number of leaves/seedling, seedling height, fresh weight (g)/seedling, dry weight (g)/seedling, ear length, ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant but panicle emergence had negatively correlated with plant height.

Ear length had significant positive correlation with emergence rate (ER), number of leaves/seedling, plant height, ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant. Ear weight (g)/plant was positively associated with emergence rate (ER), number of leaves/seedling, dry weight (g)/seedling, plant height, ear length, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant.

Dry fodder yield (g)/plant was positively correlated with emergence rate (ER), number of leaves/seedling, seedling height, dry weight (g)/seedling, plant height, ear length, ear weight (g)/plant, grain yield (g)/plant and total biological yield (g)/plant.

Grain yield (g)/plant had a significant positive correlation with number of leaves/seedling, fresh weight (g)/seedling, dry weight (g)/seedling, plant height, ear length, ear weight (g)/plant, dry fodder yield (g)/plant and total biological yield (g)/plant but negatively correlated with germination (%).

Total biological yield (g)/plant was found to be associated with emergence rate (ER), number of leaves/seedling, seedling height, dry weight (g)/seedling, plant height, ear length, ear weight (g)/plant, dry fodder yield (g)/plant and grain yield (g)/plant.

Environment-II:

The correlations among the characters had almost the same pattern of associations as in environment-I except that in case, number of effective tillers/plant did not show any significant correlation with fresh weight (g)/seedling and panicle emergence with

Table 14a: Correlation coefficients among various characters in first environment (E-I)

Characters	Panicle emergence	Effective tillers/ plant	Plant height	Ear length	Ear weight /plant	Dry fodder yield/plant	Grain yield/plant	Total biological yield/plant
STI	-0.253	-0.140	0.162	-0.036	-0.078	-0.103	-0.143	-0.100
SSTI	-0.367**	-0.265	0.342*	-0.042	-0.126	-0.105	-0.175	-0.117
Germination	-0.250	-0.458**	0.440**	-0.091	-0.153	-0.157	-0.127*	-0.165
Rate of emergence	-0.551**	-0.049	0.509**	0.278*	0.322*	0.439**	0.292	0.425**
No. of leaves/ seedling	-0.278*	-0.101	0.577**	0.411**	0.537**	0.575**	0.528**	0.594**
Seedling height	-0.513**	-0.228	0.594**	0.104	0.261	0.443**	0.196	0.407**
Fresh weight /seedling	-0.373**	-0.329*	0.350**	0.111	0.229	0.239	0.280*	0.249
Dry weight /seedling	-0.383**	-0.138	0.363**	0.150	0.364**	0.423**	0.368**	0.427**
Panicle emergence	1.000	0.170	-0.279*	0.236	0.000	-0.190	0.046	-0.138
Effective tillers/plant		1.000	-0.122	0.095	0.234	0.143	0.132	0.181
Plant height			1.000	0.547**	0.485**	0.554**	0.482**	0.562**
Ear length				1.000	0.528**	0.558**	0.512**	0.578**
Ear weight/plant					1.000	0.765**	0.958**	0.884**
Dry fodder yield/plant						1.000	0.654**	0.978**
Grain yield/plant							1.000	0.789**
Total biological yield/plant								1.000

* Significant at P = 0.05

** Significant at P = 0.01

Note: The correlations are shown only with the post seedling traits.

Table 14b: Correlation coefficients among various characters in second environment (E-II)

Characters	Panicle emergence	Effective tillers/ plant	Plant height	Ear length	Ear weight /plant	Dry fodder yield/plant	Grain yield/plant	Total biological yield/plant
STI	-0.215	-0.203	-0.040	0.049	-0.042	-0.108	-0.104	-0.090
SSTI	-0.292*	-0.165	0.082	0.060	-0.076	-0.140	-0.146	-0.124
Germination	-0.165	-0.215	0.214	-0.036	-0.179	-0.231	-0.209	-0.222
Rate of emergence	-0.327*	0.101	0.436**	0.035	0.059	0.074	0.045	0.072
No. of leaves/ seedling	-0.361**	0.206	0.553**	0.576**	0.584**	0.630**	0.541**	0.638**
Seedling height	-0.394**	0.151	0.714**	0.478**	0.585**	0.576**	0.581**	0.601**
Fresh weight /seedling	-0.326*	0.152	0.541**	0.221	0.411**	0.408**	0.435**	0.424**
Dry weight /seedling	-0.354**	0.170	0.553**	0.243	0.461**	0.417**	0.480**	0.447**
Panicle emergence	1.000	-0.165	-0.216	-0.020	-0.168	-0.211	-0.120	-0.204
Effective tillers/plant		1.000	0.159	0.133	0.338*	0.356**	0.278*	0.363**
Plant height			1.000	0.635**	0.534**	0.581**	0.541**	0.587**
Ear length				1.000	0.551**	0.640**	0.554**	0.634**
Ear weight/plant					1.000	0.840**	0.974**	0.926**
Dry fodder yield/plant						1.000	0.840**	0.974**
Grain yield/plant							1.000	0.879**
Total biological yield/plant								1.000

* Significant at P = 0.05

** Significant at P = 0.01

Note: The correlations are shown only with the post seedling traits.

Table 14c: Correlation coefficients among various characters in third environment (E-III)

Characters	Panicle emergence	Effective tillers/ plant	Plant height	Ear length	Ear weight /plant	Dry fodder yield/plant	Grain yield/plant	Total biological yield/plant
STI	—	—	—	—	—	—	—	—
SSTI	—	—	—	—	—	—	—	—
Germination	0.147	−0.397**	0.207	0.002	0.006	−0.096	−0.074	−0.063
Rate of emergence	−0.405**	0.029	0.364**	0.173	0.466**	0.342*	0.369**	0.386**
No. of leaves/ seedling	−0.543**	0.154	0.481**	0.415**	0.604**	0.524**	0.548**	0.556**
Seedling height	−0.333*	−0.082	0.565**	0.262	0.468**	0.382**	0.424**	0.414**
Fresh weight /seedling	−0.300*	−0.031	0.560**	0.336*	0.542**	0.446**	0.479**	0.482**
Dry weight /seedling	−0.284*	−0.018	0.522**	0.325*	0.528**	0.431**	0.466**	0.467**
Panicle emergence	1.000	−0.257	−0.219	−0.107	−0.425**	−0.385**	−0.406**	−0.402**
Effective tillers/plant		1.000	0.050	0.258	0.432**	0.533**	0.495**	0.504**
Plant height			1.000	0.673**	0.627**	0.607**	0.617**	0.620**
Ear length				1.000	0.633**	0.698**	0.673**	0.683**
Ear weight/plant					1.000	0.956**	0.974**	0.980**
Dry fodder yield/plant						1.000	0.993**	0.995**
Grain yield/plant							1.000	0.997**
Total biological yield/plant								1.000

* Significant at P = 0.05

** Significant at P = 0.01

Note: The correlations are shown only with the post seedling traits.

Table 14d: Pooled correlation coefficients among various characters in all the three environments

Characters	Panicle emergence	Effective tillers/ plant	Plant height	Ear length	Ear weight /plant	Dry fodder yield/plant	Grain yield/plant	Total biological yield/plant
STI	-0.215	-0.211	0.030	-0.007	-0.043	-0.101	-0.111	-0.084
SSTI	-0.247	-0.268*	0.184	-0.017	-0.066	-0.129	-0.144	-0.112
Germination	-0.135	-0.478**	0.326*	-0.069	-0.104	-0.190	-0.145	-0.167
Rate of emergence	-0.593**	0.032	0.517**	0.217	0.388**	0.361**	0.348**	0.377**
No. of leaves/ seedling	-0.474**	0.109	0.576**	0.496**	0.641**	0.607**	0.630**	0.630**
Seedling height	-0.493**	-0.115	0.735**	0.360**	0.526**	0.520**	0.515**	0.532**
Fresh weight /seedling	0.425**	-0.082	0.661**	0.351**	0.581**	0.496**	0.576**	0.533**
Dry weight /seedling	-0.428**	-0.016	0.634**	0.354**	0.620**	0.509**	0.614**	0.554**
Panicle emergence	1.000	-0.150	-0.269*	0.022	-0.329*	-0.337*	-0.280*	-0.341*
Effective tillers/plant		1.000	-0.012	0.170	0.366**	0.405**	0.323*	0.401**
Plant height			1.000	0.650**	0.603**	0.596**	0.619**	0.610**
Ear length				1.000	0.608**	0.671**	0.648**	0.664**
Ear weight/plant					1.000	0.910**	0.984**	0.957**
Dry fodder yield/plant						1.000	0.907**	0.991**
Grain yield/plant							1.000	0.950**
Total biological yield/plant								1.000

* Significant at P = 0.05

** Significant at P = 0.01

Note: The correlations are shown only with the post seedling traits.

plant height. Whereas, number of effective tillers/plant also showed significant positive correlation with ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant (table 14b).

Environment–III:

The correlation coefficients for different characters in environment–III are given in table 14c. The correlation coefficients among the characters had the same pattern of associations as in environment–I and II, except that panicle emergence had significant negative correlation with ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant.

Pooled correlation:

The pooled correlations among the characters are given in table 14d. All the correlations among the characters were same as in environment–I, II and III. While evaluating the diallel progenies it was seen that the heat tolerance indices STI and SSTI were not showing any perceptible pooled correlation with either the developmental traits or the maturity characters. Since experiment proceeded without any stress after the establishment of seedling, the pearl millet plants show great resilience and recovery. Hence the early heat effects could have no impact on its later growth and development. The association of grain yield/plant and total biological yield was almost parallel with all the other traits. The most important character was dry fodder yield in both the cases. The other important

characters were ear weight, ear length and plant height. The character of early vigour of seedling also contributed for good grain yield.

4.2.4 Diallel analysis

4.2.4.1 Analysis of variance

The analysis of variance for sixteen different characters in three different environments (two stress and one normal) was carried out for testing the significance of genotypic differences and the results are presented in table 15. It is noteworthy from the ANOVA table that no variability was observed for seedling thermo-tolerance index (STI) and seed to seedling thermo-tolerance index (SSTI) in the environment-III (E_3). In this environment no seedling mortality was observed and the germination was taken as standard. The values for STI and SSTI were therefore equal and highest for all the genotypes in this environment and hence no variation was observed. These two characters i.e. seedling thermo-tolerance index (STI) and seed to seedling thermo-tolerance index (SSTI) were not subjected to any further analysis in environment-III (E_3) only.

The genotypic variance was also partitioned into its appropriate orthogonal components *viz.* parents, hybrids and parents vs. hybrids. Significant genotypic differences were observed for all the characters in all the three environments. Significance of the mean squares associated with parents vs. hybrids indicated presence of average heterosis for all the characters.

Table 15: Analysis of variance for 10×10 half-diallel for different characters in three environments

Envi- ronment	Source of Variation	D.F	Mean Sum of Squares					
			Germination (%)	Rate of emergence	STI (%)	SSTI (%)	No. of leaves/ seedling	Seedling height (cm)
	Replicates	2	6.52731	5.96768	7.83393	20.70093	0.18674	3.37641
	Treatments	54	109.70255**	81.81153**	308.63092**	206.80900**	11.00708**	21.06317**
E ₁	Parents	9	51.18163**	142.89925**	591.14816**	188.80254**	10.84227**	10.87906**
	Hybrids	44	114.23573**	33.98933**	256.97199**	206.33716**	4.72874**	13.91526**
	Parents Vs. Hybrids	1	436.93104**	1636.19916**	38.96838	389.62793**	288.73741**	427.22798**
	Error	108	2.81184	13.56832	11.73684	6.74337	0.40104	3.06462
	Replicates	2	5.83819	37.07389*	15.96635	1.98738	0.34925	4.48213
	Treatments	54	99.97443**	28.25177**	353.78177**	190.74306**	6.65284**	17.64081**
E ₂	Parents	9	65.07784**	37.18879**	698.66289**	179.85404**	7.05379**	14.08518**
	Hybrids	44	105.69731**	21.27302**	291.02537**	194.29240**	3.29256**	7.00003**
	Parents Vs. Hybrids	1	162.23710**	254.88361**	11.13326	132.57362**	150.89673**	517.83569**
	Error	108	3.34760	10.97039	10.49505	6.35570	0.67641	1.60576
	Replicates	2	8.94398	48.08815*	—	—	0.51076	0.95989
	Treatments	54	126.15600**	48.42216**	—	—	28.11077**	59.47316**
E ₃	Parents	9	71.35735**	109.76388**	—	—	14.68699**	11.12764**
	Hybrids	44	132.17740**	13.79360	—	—	15.54071**	45.81632**
	Parents Vs. Hybrids	1	354.40180**	1020.00335**	—	—	702.00767**	1095.48362**
	Error	108	7.82907	10.85444	—	—	1.39771	2.91325

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Contd...

Contd... table 15

Envi- ro- nment	Source of Variation	D.F	Mean Sum of Squares				
			Fresh weight (g) /seedling	Dry weight (g) /seedling	Panicle emergence (days)	Effective tillers/plant	Plant height (cm)
	Replicates	2	0.33999	0.02590	31.86061**	4.16348**	167.29472*
	Treatments	54	9308.29527**	3.19767**	41.52368**	0.85657**	3267.06089**
E ₁	Parents	9	225.61719**	0.42162**	45.11481**	0.18538**	1408.07476**
	Hybrids	44	6741.23518**	2.61839**	32.01347**	1.00797**	1103.95657**
	Parents Vs. Hybrids	1	2341.44289**	53.67022**	427.65286**	0.23609*	115174.52616**
	Error	108	201.51619	0.05535	4.68159	0.04907	36.92099
	Replicates	2	8.99529	0.07177	6.56364	0.02556	615.75565**
	Treatments	54	2576.94570**	21.77519**	29.99618**	0.69822**	2689.98723**
E ₂	Parents	9	106.12519**	0.77429**	26.30000**	0.48079**	1655.55405**
	Hybrids	44	1860.26552**	14.83428**	25.33165**	0.73449**	961.62857**
	Parents Vs. Hybrids	1	56348.25791**	516.18348**	268.50135**	1.05929**	88047.66697**
	Error	108	6.94613	0.06206	5.07598	0.05829	52.34122
	Replicates	2	37.68421	0.30220	0.29697	0.21161	94.59847
	Treatments	54	3870.84450**	34.45076**	80.45499**	0.94511**	1924.20108**
E ₃	Parents	9	1360.81650**	13.07836**	80.10741**	0.94166**	1160.37343**
	Hybrids	44	2520.84767**	23.78032**	62.54377**	0.95514**	737.81513**
	Parents Vs. Hybrids	1	85860.95705**	696.30188**	871.67710**	0.53496*	60999.63199**
	Error	108	30.19169	0.24004	6.96981	0.07883	55.78505

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Contd...

Contd... table 15

Envi- ro- nment	Source of Variation	D.F	Mean Sum of Squares				
			Ear length (cm)	Ear weight (g)/plant	Dry fodder yield (g)/plant	Grain yield (g)/plant	Total biological yield(g)/plant
	Replicates	2	1.70641	10.77192	96.34539	3.92777	115.54459
	Treatments	54	16.02572**	617.70406**	3041.13204**	342.85030**	5756.17582**
E ₁	Parents	9	22.40093**	116.53959**	270.14155**	38.58650**	613.21919**
	Hybrids	44	10.10497**	402.96671**	1712.71411**	241.36880**	3029.99650**
	Parents Vs. Hybrids	1	219.16167**	14576.62749**	86430.43524**	7546.41053**	171994.67546**
	Error	108	2.24610	17.11430	34.98126	6.82350	50.75268
	Replicates	2	8.28842**	5.89094	22.68506	2.60877	15.07116
	Treatments	54	24.36886**	605.92784**	2472.59877**	419.20073**	5134.83489**
E ₂	Parents	9	38.71874**	141.22393**	195.43682**	31.32426**	572.30706**
	Hybrids	44	14.63359**	354.95366**	1547.59288**	262.62465**	2934.92304**
	Parents Vs. Hybrids	1	323.57161**	15831.12746**	63667.31560**	10799.43646**	142993.70699**
	Error	108	1.49406	9.55133	21.42411	4.62311	32.73886
	Replicates	2	1.43746	9.85141	46.80064	9.26334	33.45160
	Treatments	54	32.79225**	720.49211**	2989.53021**	550.61308**	6517.32994**
E ₃	Parents	9	37.02185**	163.05190**	232.36440**	45.53893**	714.84982**
	Hybrids	44	21.88348**	318.13193**	1902.63916**	315.72179**	3686.89934**
	Parents Vs. Hybrids	1	474.71212**	23441.30203**	75627.22861**	15431.49707**	183278.59719**
	Error	108	2.28608	14.91014	25.74223	4.49588	51.87705

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Table 16: Analysis of variance for combining ability for different characters in three environments

Enviro- nment	Source of Variation	D.F	Mean Sum of Squares							
			Germination (%)	Rate of emergence	STI (%)	SSTI (%)	No. of leaves/ seedling	Seedling height (cm)	Fresh weight (g) /seedling	Dry weight (g) /seedling
	GCA	9	93.47938**	38.80636**	272.96211**	158.89527**	3.92042**	5.87873**	84.35379**	0.76474**
E ₁	SCA	45	25.18515**	24.96334**	68.85995**	50.94455**	3.61875**	7.24952**	52.07958**	1.12612**
	Error	108	0.93728	4.52277	3.91228	2.24779	0.13368	1.02154	0.62196	0.01845
	GCA	9	61.46085**	11.18124**	237.87074**	108.75022**	2.81219**	4.45254**	598.23740**	4.71792**
E ₂	SCA	45	27.69760**	9.06446**	93.93856**	54.54718**	2.09870**	6.16581**	911.13080**	7.76649**
	Error	108	1.11587	3.65680	3.49835	2.11857	0.22547	0.53525	2.31538	0.02069
	GCA	9	83.81618**	23.37207**	—	—	8.40467**	7.33537**	1011.32146**	10.93737**
E ₃	SCA	45	33.69916**	14.69445**	—	—	9.56338**	22.32219**	1346.07351**	11.59283**
	Error	108	2.60969	3.61815	—	—	0.46590	0.97108	10.06390	0.08001

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Contd...

Contd... table 16

Enviro -nment	Source of Variation	D.F	Mean Sum of Squares							
			Panicle emergence (days)	Effective tillers/plant	Plant height (cm)	Ear length (cm)	Ear weight (g)/plant	Dry fodder yield (g)/plant	Grain yield (g)/plant	Total biological yield(g)/plant
	GCA	9	46.76995**	0.39947**	796.67170**	15.72605**	238.15130**	1065.45556**	159.64521**	2000.02574**
E ₁	SCA	45	7.25548**	0.26274**	1147.49002**	3.26508**	199.45136**	1003.36170**	105.21108**	1902.46518**
	Error	108	1.56053	0.01636	12.30700	0.74870	5.70477	11.66042	2.27450	16.91756
	GCA	9	19.68561**	0.39714**	692.32969**	28.64345**	148.93609**	989.35207**	98.59735**	1859.92473**
E ₂	SCA	45	8.06135**	0.19986**	937.52895**	4.01885**	212.58392**	791.16910**	147.96082**	1681.94901**
	Error	108	1.69199	0.01943	17.44707	0.49802	3.18378	7.14137	1.54104	10.91295
	GCA	9	32.20536**	0.44598**	534.66901**	38.10638**	178.53641**	1188.75231**	185.30200**	2222.15728**
E ₃	SCA	45	25.74093**	0.28885**	662.74663**	5.49563**	252.48956**	958.06162**	183.18483**	2162.50052**
	Error	108	2.32327	0.02628	8.59502	0.76203	4.97005	8.58074	1.49863	17.29235

* Significant at P = 0.05

** Significant at P = 0.01

4.2.4.2 Analysis of variance for combining ability

Mean squares obtained from the analysis of variance for general combining ability (gca) and specific combining ability (sca) for all the sixteen characters studied in a 10×10 diallel set in three environments are shown in table 16. It was evident from the analysis of variance table for combining ability that gca and sca 'F' values for the mean squares were highly significant for all the characters in all the three environments except STI and SSTI in environment-III (E_3). No variability was observed for these two characters only in environment-III (E_3). Any seedling mortality was not observed in this environment and the germination in this environment was taken as standard for the calculation of SSTI. Therefore STI and SSTI were equal and highest for all the genotypes in this environment and hence no variation. These two characters i.e. seedling thermo-tolerance index (STI) and seed to seedling thermo-tolerance index (SSTI) were not further analysed. Further analysis for all those characters which showed significant variation was carried out. These results exhibited the importance of additive and non-additive type of variance in the inheritance of all the characters studied.

The relative importance of additive and non-additive components was determined by studying the components of variance g_i^2 and s_{ij}^2 , gca/sca ratio, heritability in broad sense (h_{bs}^2) and narrow sense (h_{ns}^2) and general predictability ratio (all derived from equivalent component variances).

4.2.4.3 Griffings numerical approach

4.2.4.3.1 Combining ability effects

The estimates of specific combining ability effects for 45 F_1 crosses/hybrids in respect of 16 characters under three environments are presented in table 17-32.

i) Seedling thermo-tolerance index (STI)

The combining ability analysis for seedling thermo-tolerance index (STI) could be conducted only in two environments (E_1 and E_2). In environment–III the values did not show any variation (table 17a-b). The parent CVJ-2-5-3-1-3 qualified as the best general combiner for STI in both the stress environments. This was followed by four other parents, namely, H77/833-2, ($77/371 \times$ BSECT CP-1), 96AC-93 and 99HS-18 which also showed positive and significant gca effects in both environments (E_1 and E_2). These parents were also those which showed high tolerance to heat effect; The parent G73-107 also showed significant and positive gca value only in environment–I . The parents 77/245 and 1305 were the poor combiners in both the environments (E_1 and E_2) while the parents H77/29-2 and Togo-II also showed significant but negative gca effects (figure 13a-b).

The magnitude of sca effects, of course differed for specific crosses in different environment but the direction (+ve or –ve) generally remained the same. Ten cross combinations, namely, $H77/833-2 \times H77/29-2$, $H77/833-2 \times 77/245$, $H77/833-2 \times 96AC-93$, $H77/29-2 \times CVJ-2-5-3-1-3$, $H77/29-2 \times 1305$, $G73-107 \times 77/245$,

Table 17a: Estimates of gca and sca effects for seedling thermo-tolerance index (STI %) (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		3.846*	3.185	7.752**	-0.316	-22.071**	-1.003	8.201**	-3.673	-12.396**
H77/29-2			-1.826	3.070	10.902**	10.090**	-1.175	-8.141**	5.922**	-2.745
G73-107				12.472**	-3.625	8.576**	10.020**	0.582	-11.853**	-4.869*
77/245					-0.105	3.153	-6.193**	-6.118**	-5.183*	-2.586
CVJ-2-5-3-1-3						0.705	-5.181*	3.770*	-8.377**	1.953
1305							-8.779**	11.702**	2.894	13.131**
77/371× BSECT CP-1								-0.020	13.925**	2.509
96AC-93									-6.420**	3.637
Togo-II										-9.031**
99HS-18										
gca effects	3.145**	-2.723**	2.214**	-8.392**	4.012**	-7.516**	3.900**	3.215**	-1.340*	3.486**
Parental Means	78.297	48.350	61.867	43.853	71.930	39.037	69.517	66.603	71.987	75.940

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 17b: Estimates of gca and sca effects for seedling thermo-tolerance index (STI %) (Environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		3.646*	6.073**	8.297**	-3.142	-23.617**	-1.109	14.116**	-6.322**	-13.375**
H77/29-2			-1.845	2.566	17.187**	19.245**	-0.853	-10.416**	-2.853	-3.313
G73-107				11.226**	-2.562	12.069**	0.634	-3.649*	-8.436**	-7.599**
77/245					2.475	5.856**	-3.276	-3.095	-6.482**	-5.732**
CVJ-2-5-3-1-3						-2.649	-10.447**	1.677	2.629	-0.387
1305							-7.340**	15.798**	-7.703**	15.464**
77/371× BSECT CP-1								0.166	13.949**	5.566**
96AC-93									-4.050*	-7.910**
Togo-II										-4.964*
99HS-18										
gca effects	3.875**	-0.888	-0.661	-8.342**	6.057**	-6.018**	3.647**	1.459*	-0.956	1.827**
Parental Means	73.873	44.950	54.130	35.807	68.130	32.810	67.057	60.007	68.610	73.187

* Significant at $P = 0.05$

** Significant at $P = 0.01$



Fig. 13a: Estimates of gca effects for STI in environment-I

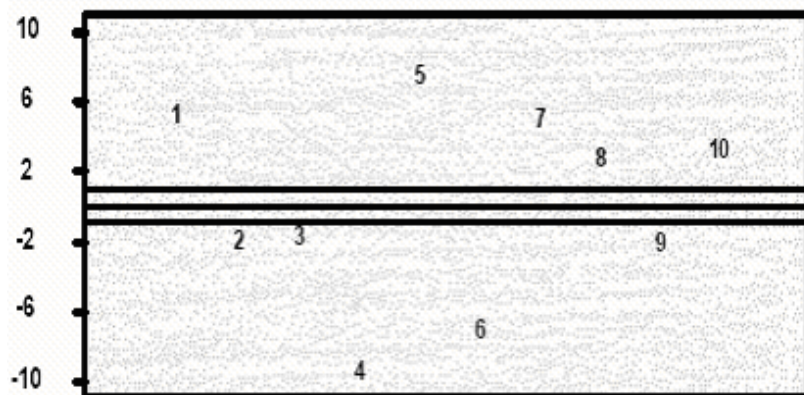


Fig. 13b: Estimates of gca effects for STI in environment-II

List of parents	
Sr. no.	Genotypes
1.	H77/833-2
2.	H77/29-2
3.	G73-107
4.	77/245
5	CVJ-2-5-3-1-3
6	1305
7	77/371× BSECT CP-1
8	96AC-93
9	Togo-II
10	99HS-18

G73-107 $\times$ 1305, 1305 $\times$ 96AC-93, 1305 $\times$ 99HS-18 and (77/371 $\times$ BSECT CP-1) $\times$ Togo-II showed consistency for positive significant sca values in both the stress environments (E_1 and E_2). Similarly, ten other crosses carried negatively significant values in both environments (E_1 and E_2), namely, H77/833-2 $\times$ 1305, H77/833-2 $\times$ 99HS-18, H77/29-2 $\times$ 96AC-93, G73-107 $\times$ Togo-II, G73-107 $\times$ 99HS-18, 77/245 $\times$ Togo-II, CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1), 1305 $\times$ (77/371 $\times$ BSECT CP-1), 96AC-93 $\times$ Togo-II and Togo-II $\times$ 99HS-18. The sca effects for STI were thus seemed to be more associated with genotypes than the environment.

Other than ten cross combinations mentioned above three crosses, namely, H77/29-2 $\times$ Togo-II, G73-107 $\times$ (77/371 $\times$ BSECT CP-1) and CVJ-2-5-3-1-3 $\times$ 96AC-93 in environment-I and three crosses, namely, H77/833-2 $\times$ H77/29-2, 77/245 $\times$ 1305 and (77/371 $\times$ BSECT CP-1) $\times$ 99HS-18 in environment-II also showed significant and positive gca values.

The cross H77/29-2 $\times$ 1305 was the best specific combination (19.245) for STI in environment-I but in environment-II the cross (77/371 $\times$ BSECT CP-1) $\times$ Togo-II showed the highest sca value (13.925) while the cross combination H77/833-2 $\times$ 1305 was identified as the poorest specific cross combination for STI in both the stress environments (E_1 and E_2). It was a matter of enormous importance that the best specific cross had resulted from the two susceptible parents. That would mean the genes for heat tolerance are

distributed across the parents. In such a situation the estimation of gca and sca assume added significance.

ii) Seed to seedling thermo-tolerance index (SSTI)

The analysis of combining ability for SSTI was also conducted on two environments (E_1 and E_2). This trait though, had shown a very close relationship with STI in the observations during screening. The picture of gca of parents, however, was at variance. At least the good combiners exhibited a change of order. In the environment – I, three parents ($77/371 \times$ BSECT CP-1), G73-107 and 96AC-93 were found as best general combiners (figure 14a-b). The parent 96AC-93, however, did not stand the test in environment – II. In environment – II, CVJ-2-5-3-1-3 performed as best general combiner, whereas, it lost significance for environment – I. The poorest combiners in both the environments were parents 1305 and 77/245. These parents per se also had poor tolerance to heat stress. The overall result, however, maintained the trend that good per se performer were also the good combiner for this trait and reverse was also true.

Table 18a-b showed the estimates of sca for SSTI in two environments. As regards the sca effects the results were almost similar to STI. In both the environments (E_1 and E_2) ten cross combinations i.e. $H77/833-2 \times H77/29-2$, $H77/833-2 \times (77/371 \times \text{BSECT CP-1})$, $H77/833-2 \times 96AC-93$, $H77/29-2 \times \text{CVJ-2-5-3-1-3}$, $H77/29-2 \times \text{Togo-II}$, $G73-107 \times 77/245$, $G73-107 \times (77/371 \times \text{BSECT CP-1})$, $1305 \times 96AC-93$, $1305 \times 99HS-18$ and $(77/371 \times$

Table 18a: Estimates of gca and sca effects for seed to seedling thermo-tolerance index (SSTI %) (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		6.220**	5.133**	0.248	3.878*	-16.004**	6.924**	11.088**	1.142	-4.496**
H77/29-2			0.923	2.555	9.238**	-1.163	2.485	-8.621**	6.832**	-3.942*
G73-107				7.582**	-1.965	-0.717	9.041**	3.995*	-13.431**	-0.236
77/245					1.377	1.539	-4.154**	-2.453	-1.369	1.086
CVJ-2-5-3-1-3						2.458	-11.494**	4.793**	-6.603**	2.559
1305							-4.045**	9.859**	3.155*	11.204**
77/371× BSECT CP-1								-3.117*	9.620**	7.682**
96AC-93									-6.989**	2.876*
Togo-II										-12.097**
99HS-18										
gca effects	0.632	0.442	3.252**	-4.774**	0.460	-7.765**	3.120**	3.526**	-0.427	1.534**
Parental Means	44.983	44.407	52.127	38.033	49.587	32.113	50.557	52.123	59.803	51.537

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Table 18b: Estimates of gca and sca effects for seed to seedling thermo-tolerance index (SSTI %) (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		6.577**	0.326	0.641	-0.813	-17.495**	9.818**	18.303**	-8.784**	-0.792
H77/29-2			-0.363	4.179**	10.125**	7.639**	-4.224**	-7.766**	4.794**	-4.410**
G73-107				6.191**	-0.047	3.141*	7.365**	-4.084**	-6.157**	-5.088**
77/245					4.479**	2.130	0.410	-0.932	-2.902*	-6.500**
CVJ-2-5-3-1-3						-1.488	-15.094**	0.911	0.694	3.630*
1305							-0.400	15.162**	-6.082**	9.894**
77/371× BSECT CP-1								-5.645	10.185**	1.671
96AC-93									-6.377**	-1.374
Togo-II										-2.431
99HS-18										
gca effects	1.658**	1.197*	1.668**	-3.827**	3.574**	-5.567**	3.423**	0.698	-1.382**	-1.441**
Parental Means	41.330	36.023	44.600	30.403	47.853	24.520	46.707	39.200	47.670	41.723

* Significant at $P = 0.05$

** Significant at $P = 0.01$

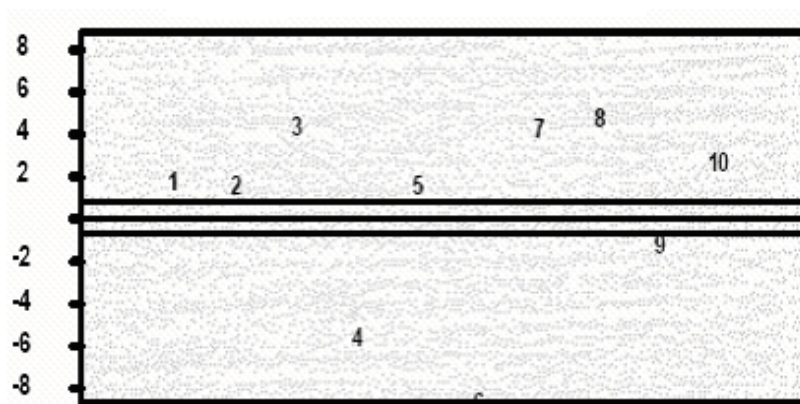


Fig. 14a: Estimates of gca effects for SSTI in environment-I

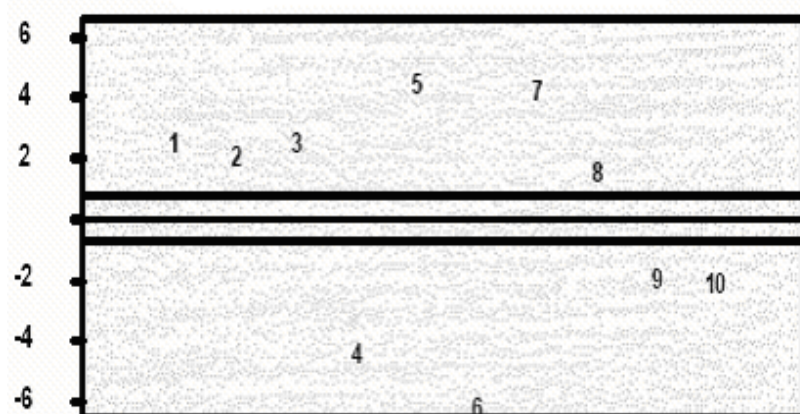


Fig. 14b: Estimates of gca effects for SSTI in environment-II

List of parents	
Sr. no.	Genotypes
1.	H77/833-2
2.	H77/29-2
3.	G73-107
4.	77/245
5	CVJ-2-5-3-1-3
6	1305
7	77/371× BSECT CP-1
8	96AC-93
9	Togo-II
10	99HS-18

BSECT CP-1) $\times$ Togo-II were identified as the crosses having the positive significant sca values. While, the six crosses, namely, H77/833-2 $\times$ 1305, H77/29-2 $\times$ 96AC-93, H77/29-2 $\times$ 99HS-18, G73-107 $\times$ Togo-II, CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1) and 96AC-93 $\times$ Togo-II showed the significant but negative sca effects in both the environments. Other seven crosses, namely, H77/833-2 $\times$ G73-107, H77/833-2 $\times$ CVJ-2-5-3-1-3, G73-107 $\times$ 96AC-93, CVJ-2-5-3-1-3 $\times$ 96AC-93, 1305 $\times$ Togo-II, (77/371 $\times$ BSECT CP-1) $\times$ 99HS-18 and 96AC-93 $\times$ 99HS-18 in environment-I and five cross combinations, namely, H77/29-2 $\times$ 77/245, H77/29-2 $\times$ 1305, G73-107 $\times$ 1305, 77/245 $\times$ CVJ-2-5-3-1-3 and CVJ-2-5-3-1-3 $\times$ 99HS-18 in environment-II also showed the significant sca effects.

The cross 1305 $\times$ 99HS-18 was the best specific combination (11.204) with the cross H77/833-2 $\times$ 96AC-93 as close runner up with a value (11.088) in environment-I but in environment-II the cross H77/833-2 $\times$ 96AC-93 showed the highest sca value (18.303) with the cross 1305 $\times$ 96AC-93 as close runner up with a value 15.162. While the cross H77/833-2 $\times$ 1305 was identified as the poorest specific cross combination for SSTI in both the environments (E_1 and E_2). The best specific cross 1305 $\times$ 99HS-18 involves one tolerant parent and susceptible parent (1305). This parent also gave best specific cross for STI. It is a re-assertion of the fact the heat tolerant genes are also contributed by parents with poor performance per se. this indicates a complex nature of gene distribution and the control system for the trait.

iii) Germination (%)

The estimate of general combining ability (gca) effects in respect of germination (table 19a-c) indicated that inbreds/parents H77/29-2 and (77/371 × BSECT CP-1) exhibited significant positive gca effects in all the three environments. The parent G73-107 showed positive gca effect in both the stress environments (environment-I and environment-II) while the parents 96AC-93 and 99HS-18 showed positive gca effect in environment-I and III. Except this, parent CVJ-2-5-3-1-3 showed high positive effect in environment-III (figure 15a-c).

On the other hand parents H77/833-2, CVJ-2-5-3-1-3, 1305 and Togo-II exhibited significant but negative gca effects in environment-I while the parents H77/833-2, 1305, Togo-II and 99HS-18 in environment-II and parents H77/833-2, 77/245, 1305 and Togo-II showed significant negative gca effects in environment-III (normal environment).

A consideration of specific combining ability (sca) effects reveals that out of 45 cross combinations only five crosses, namely, H77/833-2 × H77/29-2, H77/29-2 × Togo-II, CVJ-2-5-3-1-3 × 99HS-18, 1305 × 96AC-93 and 1305 × 99HS-18 exhibited significant positive sca effects in all the three environments (two heat stress and one normal). The crosses H77/833-2 × (77/371 × BSECT CP-1), H77/833-2 × 96AC-93, H77/29-2 × CVJ-2-5-3-1-3, G73-107 × (77/371 × BSECT CP-1) and (77/371 × BSECT CP-1) × Togo-II

Table 19a: Estimates of gca and sca effects for germination % (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		6.061**	5.286**	-6.494**	2.312*	-9.572**	6.959**	7.362**	2.635**	-3.576**
H77/29-2			-0.200	0.557	1.900*	-11.414**	7.376**	-3.620**	5.360**	1.176
G73-107				-0.649	0.681	1.737	2.418*	3.014**	-5.932**	0.863
77/245					-0.815	0.854	-1.582	2.521*	4.168**	5.720**
CVJ-2-5-3-1-3						-0.119	-7.169**	-2.449*	-0.516	4.384**
1305							-0.910	7.237**	-1.333	7.363**
77/371× BSECT CP-1								1.601	2.024*	2.123*
96AC-93									-0.776	1.673
Togo-II										-3.717**
99HS-18										
gca Effects	-2.767**	4.149**	1.774**	-0.409	-1.539**	-5.121**	1.735**	2.184**	-1.669**	1.662**
Parental Means	39.407	55.127	50.367	47.470	48.243	43.263	47.477	46.513	46.133	45.747

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Table 19b: Estimates of gca and sca effects for germination % (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		6.583**	-0.788	-6.096**	-0.413	-11.097**	10.617**	12.070**	-6.147**	2.157*
H77/29-2			-0.893	2.929**	2.275*	-6.185**	-1.842	-2.062*	9.708**	-1.195
G73-107				-0.845	1.384	2.571*	6.277**	-2.132*	-1.260	-2.612*
77/245					0.896	-0.643	2.173*	1.623	1.896	-3.387**
CVJ-2-5-3-1-3						-2.061*	-9.288**	-3.708**	0.148	6.176**
1305							2.539*	10.613**	-4.558**	4.963**
77/371× BSECT CP-1								-2.741*	2.652*	-2.998**
96AC-93									-3.168**	3.833**
Togo-II										3.072**
99HS-18										
gca effects	-2.001**	3.547**	2.144**	0.346	0.600	-3.921**	1.950**	0.263	-2.137**	-0.791*
Parental Means	37.373	47.253	48.257	46.237	48.313	38.907	45.023	38.180	39.373	38.233

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 19c: Estimates of gca and sca effects for germination % (environment–III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		5.179**	3.938*	–1.936	–1.974	–10.897**	1.455	2.567	–0.086	–9.050**
H77/29-2			–3.305*	–0.096	–1.097	–6.914**	7.078**	0.307	3.417*	9.740**
G73-107				0.163	–0.148	15.982**	–2.182	–0.520	–0.623	–3.661*
77/245					–2.076	3.661*	–1.654	0.675	0.969	4.451**
CVJ-2-5-3-1-3						–3.406*	2.312	–7.659**	0.858	4.917**
1305							–3.828*	7.641**	–4.429**	6.081**
77/371× BSECT CP-1								8.930**	–1.003	–5.464**
96AC-93									3.132*	1.175
Togo-II										8.468**
99HS-18										
gca effects	–3.241**	2.679**	0.643	–2.492**	1.062*	–3.365**	1.653**	1.314*	–2.299**	4.045**
Parental Means	61.633	60.917	59.177	55.650	68.973	54.037	63.197	57.217	52.763	62.473

* *Significant at P* = 0.05

** *Significant at P* = 0.01

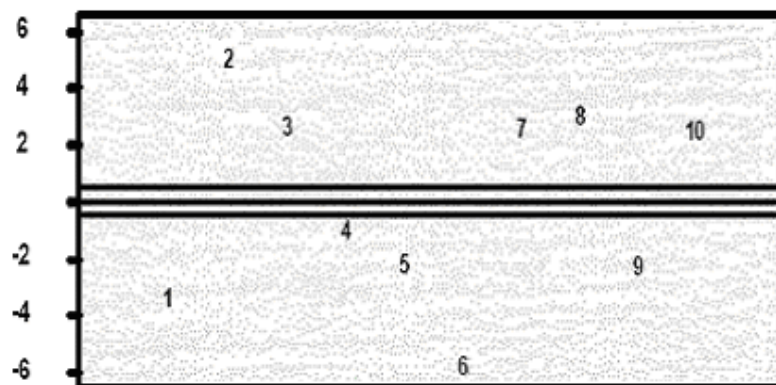


Fig. 15a: Estimates of gca effects for germination (%) in environment-I

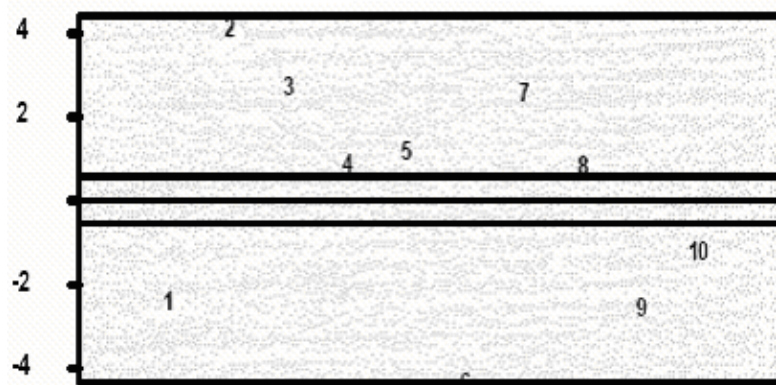


Fig. 15b: Estimates of gca effects for germination (%) in environment-II

List of parents	
Sr. no.	Genotypes
1.	H77/833-2
2.	H77/29-2
3.	G73-107
4.	77/245
5	CVJ-2-5-3-1-3
6	1305
7	77/371× BSECT CP-1
8	96AC-93
9	Togo-II
10	99HS-18

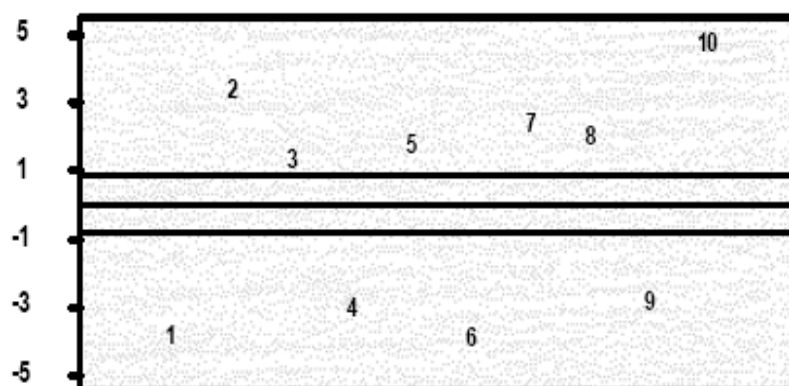


Fig. 15c: Estimates of gca effects for germination (%) in environment-III

showed significant and positive sca effects in stress environments (environment-I and environment-II) while the crosses H77/833-2 $\times$ G73-107, H77/29-2 $\times$ (77/371 $\times$ BSECT CP-1) and 77/245 $\times$ 99HS-18 in environment-I and environment-III and the crosses G73-107 $\times$ 1305 and Togo-II $\times$ 99HS-18 in environment-II and environment-III showed significant positive sca effects.

The six cross combinations, namely, H77/833-2 $\times$ CVJ-2-5-3-1-3, H77/833-2 $\times$ Togo-II, G73-107 $\times$ 96AC-93, 77/245 $\times$ 96AC-93, 77/245 $\times$ Togo-II and (77/371 $\times$ BSECT CP-1) $\times$ 99HS-18 in environment-I and five crosses, namely, H77/833-2 $\times$ 99HS-18, H77/29-2 $\times$ 77/245, 77/245 $\times$ (77/371 $\times$ BSECT CP-1), 1305 $\times$ (77/371 $\times$ BSECT CP-1) and 96AC-93 $\times$ 99HS-18 in environment-II and four cross combinations, namely, H77/29-2 $\times$ 99HS-18, (77/371 $\times$ BSECT CP-1) $\times$ 96AC-93 and 96AC-93 $\times$ Togo-II also showed significant and positive sca effects for germination (%).

iv) Emergence rate (ER)

The parent (77/371 $\times$ BSECT CP-1) was found to be the best general combiner for this character since it had significant and positive gca effects in environment-I and environment-III. While the parent CVJ-2-5-3-1-3 in environment-I and H77/29-2 in environment-II also showed positive and significant gca values showing that they were good general combiners. Similarly, the parent H77/29-2 and 1305 were found to be the poorest combiners in environment-I and

environment–III and the parent Togo-II in environment–II showed significant but negative gca effects (table 20a-c and figure 16a-c).

Significant positive sca effects in all the three environments for this trait were exhibited by only one cross combination, namely, H77/29-2 $\times$ G73-107. However, four crosses, namely, H77/833-2 $\times$ 1305, H77/29-2 $\times$ Togo-II and 77/245 $\times$ 1305 in environment–I and III and H77/833-2 $\times$ G73-107 in environment–I and II showed consistency for positive significant values in two environments. The five cross combinations viz., H77/833-2 $\times$ H77/29-2, 77/245 $\times$ Togo-II, 1305 $\times$ 96AC-93, 1305 $\times$ 99HS-18 and (77/371 $\times$ BSECT CP-1) $\times$ Togo-II in environment–I, two crosses, namely, H77/833-2 $\times$ 77/245 and 96AC-93 $\times$ 99HS-18 in environment–II and the cross G73-107 $\times$ 77/245 in environment–III exhibited significant positive sca effects indicating that these cross combinations were identified as the fast emerging crosses.

v) **Number of leaves/seedling**

Positive and significant gca effects were recorded for the parents G73-107 and CVJ-2-5-3-1-3 in all the three environments (E_1 , E_2 and E_3) for this character. These parents could, therefore be termed as overall best combiners. The two parents Togo-II and 99HS-18 also showed positive significant gca values in two environments (E_1 and E_3) and the parent 96AC-93 exhibited the significant positive gca effect in the environment–III only. While the parents H77/29-2, 77/245 and (77/371 $\times$ BSECT CP-1) exhibited the significant but negative gca

Table 20a: Estimates of gca and sca effects for emergence rate (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		5.366*	5.456*	3.626	−1.140	4.863*	−5.175*	−0.888	2.688	1.288
H77/29-2			5.337*	3.041	2.414	−5.796**	2.540	0.383	7.183**	3.490
G73-107				0.610	−1.376	0.664	−0.824	1.783	−4.327*	1.283
77/245					1.804	5.254*	0.883	2.326	4.076*	3.240
CVJ-2-5-3-1-3						2.494	1.306	−1.407	−5.030*	2.286
1305							2.306	5.866**	−2.064	5.646*
77/371× BSECT CP-1								1.619	5.592*	−3.485
96AC-93									2.045	0.759
Togo-II										−1.205
99HS-18										
gca effects	0.245	−3.893**	0.861	0.378	1.597*	−2.272**	1.902**	0.725	−0.495	0.952
Parental Means	40.370	28.157	45.340	36.247	50.440	33.760	49.343	43.127	42.453	43.173

* *Significant at P* = *0.05*

** *Significant at P* = *0.01*

Table 20b: Estimates of gca and sca effects for rate of emergence (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-0.677	4.782*	4.430*	0.333	0.857	1.792	1.660	0.172	2.361
H77/29-2			4.033*	-1.599	2.050	-2.855	1.236	0.865	2.793	-0.021
G73-107				1.896	3.445	-0.797	1.301	-0.880	2.774	0.671
77/245					-1.130	3.671	3.249	0.685	-0.581	-0.488
CVJ-2-5-3-1-3						-3.329	-0.715	-0.686	-0.265	1.175
1305							-0.113	-1.688	-1.777	-0.120
77/371× BSECT CP-1								-2.110	-1.482	-0.959
96AC-93									2.573	4.203*
Togo-II										-4.369*
99HS-18										
gca effects	-0.433	1.449*	0.061	0.649	-0.150	-1.161	1.018	0.825	-1.262*	-0.996
Parental Means	41.090	49.797	41.320	46.043	49.070	50.563	50.747	49.150	47.367	46.593

* *Significant at P* = *0.05*

** *Significant at P* = *0.01*

Table 20c: Estimates of gca and sca effects for rate of emergence (environment–III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		2.692	2.281	2.821	−0.336	5.897**	−0.868	0.438	−0.048	0.091
H77/29-2			3.627*	2.801	2.193	−0.537	3.532	2.797	5.635**	2.324
G73-107				4.109*	1.516	0.432	0.191	0.809	−0.473	−0.251
77/245					−0.748	5.262**	1.434	−0.537	1.294	2.323
CVJ-2-5-3-1-3						−0.175	−0.849	0.082	−3.036	1.462
1305							2.581	1.669	−1.920	2.726
77/371× BSECT CP-1								−0.842	0.422	−1.399
96AC-93									2.174	1.043
Togo-II										−1.899
99HS-18										
gca effects	0.021	−2.062**	0.850	0.309	0.210	−2.770**	1.761**	1.056	−0.095	0.719
Parental Means	42.790	32.577	44.810	40.470	49.597	35.723	50.653	47.527	47.967	47.460

* *Significant at P* = 0.05

** *Significant at P* = 0.01

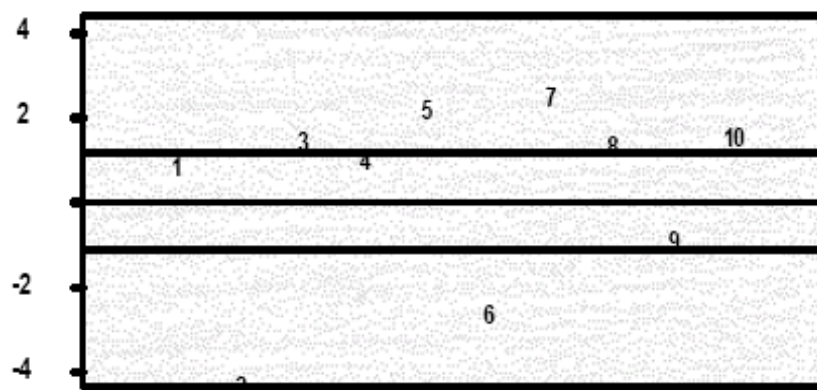


Fig. 16a: Estimates of gca effects for emergence rate (ER) in environment-I

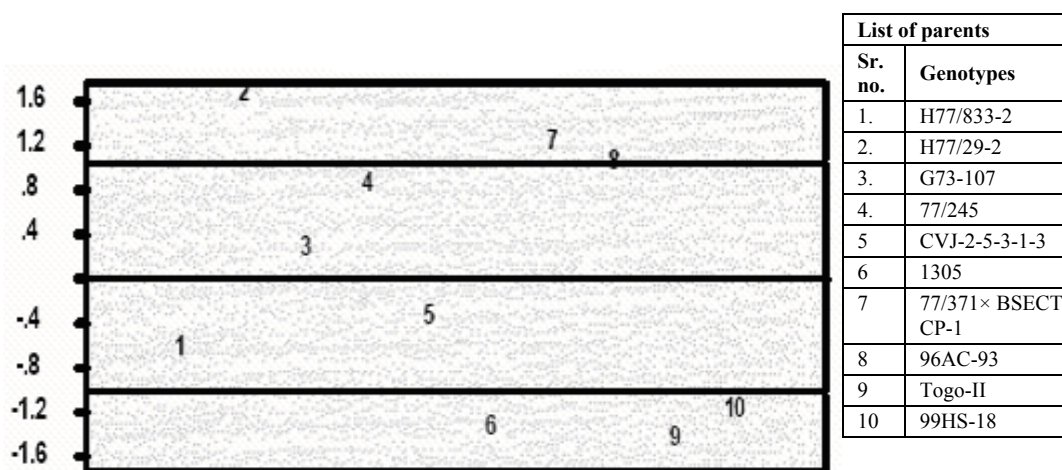


Fig. 16b: Estimates of gca effects for emergence rate (ER) in environment-II

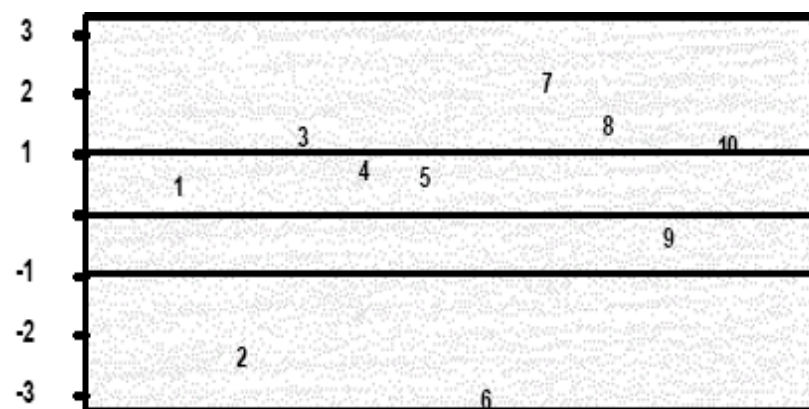


Fig. 16c: Estimates of gca effects for emergence rate (ER) in environment-III

Table 21a: Estimates of gca and sca effects for number of leaves/seedling (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-1.200	0.817*	-1.221**	0.579	2.998**	0.360	1.865**	1.001**	0.026
H77/29-2			0.725*	1.084**	1.325**	1.251**	2.055**	0.160	0.860*	1.275**
G73-107				0.621	0.028	1.510**	0.175	0.597	-0.697*	0.988**
77/245					1.040**	4.466**	0.307	-0.664	1.585**	1.297**
CVJ-2-5-3-1-3						0.270	-0.802*	-0.054	0.672*	0.047
1305							0.310	-0.158	-2.109**	1.696**
77/371× BSECT CP-1								0.940*	0.402	-0.123
96AC-93									1.298**	0.393
Togo-II										0.068
99HS-18										
gca effects	0.119	-0.794**	1.087**	-0.479**	0.294*	-0.185	-0.480**	0.105	-0.317*	0.651**
Parental Means	6.610	3.630	8.777	3.770	8.020	3.497	6.213	7.007	6.810	7.453

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 21b: Estimates of gca and sca effects for number of leaves/seedling (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-0.489	-0.634	-1.214*	1.051*	2.570**	0.747	1.685**	-0.303	0.345
H77/29-2			0.076	0.289	2.081**	1.040*	0.754	0.301	0.741	0.872
G73-107				0.643	0.046	1.261*	-0.276	0.762	1.011*	-0.121
77/245					1.836**	1.887**	-0.209	0.006	0.928*	2.069
CVJ-2-5-3-1-3						0.813	-0.293	-0.562	0.641	0.178
1305							-0.085	0.023	-1.221*	1.317**
77/371× BSECT CP-1								0.870	0.309	-0.389
96AC-93									0.121	-0.622
Togo-II										-0.566
99HS-18										
gca effects	-0.055	-0.615**	0.737**	-0.483**	0.845**	-0.180	-0.437**	0.095	0.056	0.038
Parental Means	5.017	2.943	7.097	2.923	5.800	2.843	5.417	5.903	6.287	5.540

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 21c: Estimates of gca and sca effects for number of leaves/seedling (environment–III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		–3.103**	0.830	–0.365	0.714	4.369**	4.447**	–0.111	0.481	–1.043
H77/29-2			1.260	–0.841	2.844**	3.549**	3.201**	2.126**	0.018	3.804**
G73-107				1.435*	–0.786	3.479**	1.681*	–0.864	–0.156	2.487**
77/245					1.159	4.960**	–0.325	–0.373	2.936**	0.528
CVJ-2-5-3-1-3						1.646*	–1.439*	1.973**	0.452	0.220
1305							–2.197**	2.198**	–3.167**	1.185
77/371× BSECT CP-1								2.880**	–0.382	–0.850
96AC-93									0.143	0.005
Togo-II										2.744**
99HS-18										
gca effects	–0.286	–0.489*	1.177**	–1.374**	0.474*	0.235	–0.586*	0.652**	–0.807**	1.004**
Parental Means	7.997	4.270	9.350	4.373	9.233	4.137	6.997	8.993	8.530	9.147

* *Significant at P* = 0.05

** *Significant at P* = 0.01

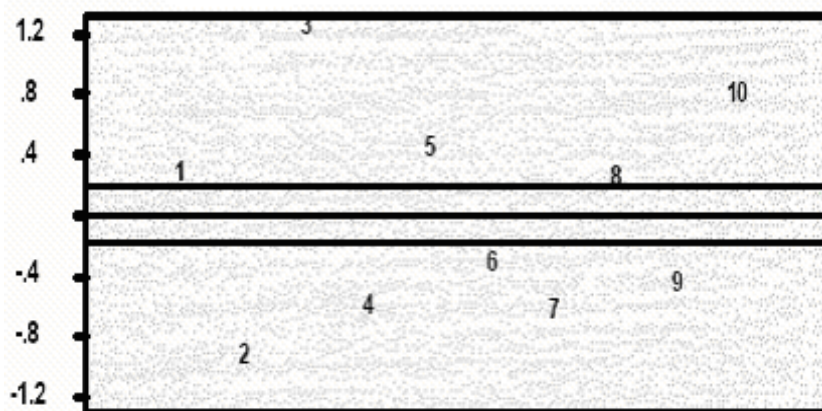


Fig. 17a: Estimates of gca effects for number of leaves in environment-I

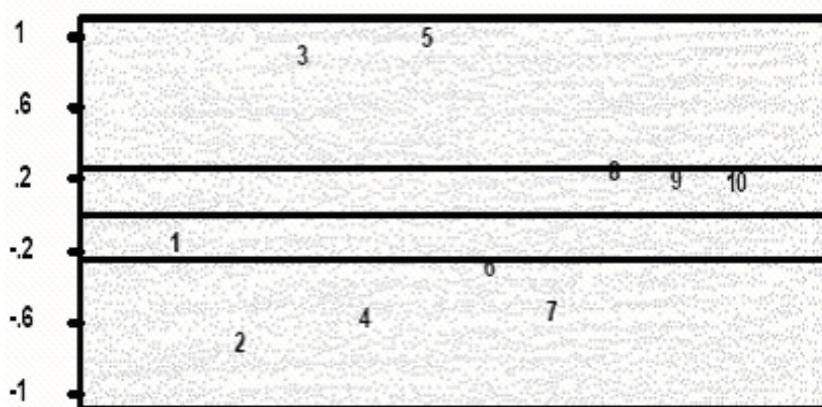


Fig. 17b: Estimates of gca effects for number of leaves in environment-II

List of parents	
Sr. no.	Genotypes
1.	H77/833-2
2.	H77/29-2
3.	G73-107
4.	77/245
5	CVJ-2-5-3-1-3
6	1305
7	77/371× BSECT CP-1
8	96AC-93
9	Togo-II
10	99HS-18

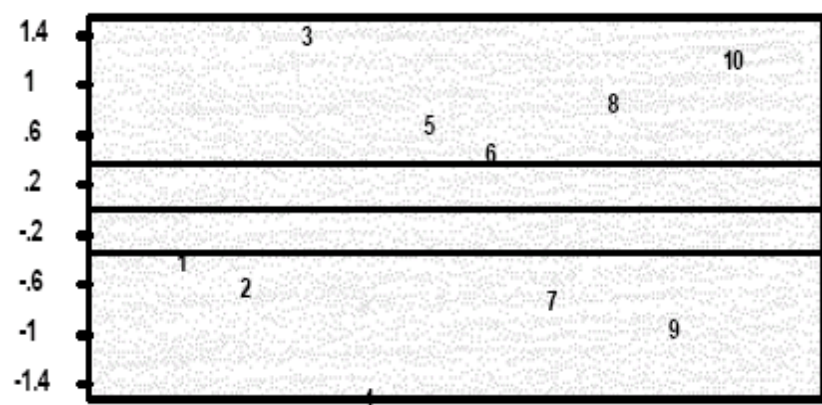


Fig. 17c: Estimates of gca effects for number of leaves in environment-III

effects consistently over all the three environments (table 21 a-c and figure 17a-c).

Significant and positive sca effects in all the three environments (E_1 , E_2 and E_3) for this trait were exhibited by six cross combinations, namely, $H77/833-2 \times 1305$, $H77/29-2 \times CVJ-2-5-3-1-3$, $H77/29-2 \times 1305$, $G73-107 \times 1305$, $77/245 \times 1305$ and $77/245 \times Togo-II$. Three crosses, namely, $H77/833-2 \times 96AC-93$, $77/245 \times CVJ-2-5-3-1-3$ and $1305 \times 99HS-18$ in stress environments-I and II. Four cross combinations viz., $H77/29-2 \times (77/371 \times BSECT\ CP-1)$, $H77/29-2 \times 99HS-18$, $G73-107 \times 99HS-18$ and $(77/371 \times BSECT\ CP-1) \times 96AC-93$ in environment-I and III showed consistency for positive significant sca values in two environments.

There were other hybrids which were important only for one or the other environment. These were, namely, $H77/833-2 \times G73-107$, $H77/833-2 \times Togo-II$, $H77/29-2 \times G73-107$, $H77/29-2 \times 77/245$, $H77/29-2 \times Togo-II$, $77/245 \times 99HS-18$, $CVJ-2-5-3-1-3 \times Togo-II$ and $96AC-93 \times Togo-II$ in environment-I, two crosses viz., $H77/833-2 \times CVJ-2-5-3-1-3$ and $G73-107 \times Togo-II$ in environment-II and eight cross combinations, namely, $H77/833-2 \times (77/371 \times BSECT\ CP-1)$, $H77/29-2 \times 96AC-93$, $G73-107 \times 77/245$, $G73-107 \times (77/371 \times BSECT\ CP-1)$, $CVJ-2-5-3-1-3 \times 1305$, $CVJ-2-5-3-1-3 \times 96AC-93$, $1305 \times 96AC-93$ and $Togo-II \times 99HS-18$ in environment-III also showed the positive significant sca effects. While, only the cross combination $1305 \times Togo-II$ was identified as the consistently poor specific combination in all the three environments.

vi) Seedling height (cm)

The gca effects for seedling height showed tremendous variation in different environments. Only one parent i.e. (77/371 × BSECT CP-1) showed the consistency for significant positive gca effects for seedling height and hence was the best combiner for this trait. Other than this the two parents 77/245 and 96AC-93 in environment-I, one parent i.e. G73-107 in environment-II and 99HS-18 in environment-III also showed the significant and positive gca effects. While the two parents i.e. H77/833-2 and 1305 exhibited the significant but negative gca effects in environment-II and III (figure 18a-c).

The sca effects of crosses for seedling height are presented in table 22a-c. The seven cross combinations, namely, H77/833-2 × 1305, H77/29-2 × CVJ-2-5-3-1-3, H77/29-2 × (77/371 × BSECT CP-1), H77/29-2 × 99HS-18, G73-107 × Togo-II, 77/245 × 99HS-18 and 1305 × 99HS-18 showed significant positive sca effects consistently over all the three environments. The four crosses, namely, H77/833-2 × CVJ-2-5-3-1-3, H77/833-2 × 96AC-93, G73-107 × (77/371 × BSECT CP-1) and (77/371 × BSECT CP-1) × Togo-II in environment-I and II, while, the cross 1305 × 96AC-93 in environment-I and III and only one cross G73-107 × 96AC-93 showed the consistency over the two environments for the positive significant sca values.

In addition, two crosses i.e. G73-107 × 77/245 and 96AC-93 × Togo-II in environment-I, four cross combination, namely, H77/833-2

Table 22a: Estimates of gca and sca effects for seedling height (cm) (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-0.792	1.709	-0.062	3.338**	3.513**	-1.195	2.753**	1.191	0.946
H77/29-2			-0.415	-0.590	3.540**	-0.561	3.527**	-0.809	0.410	4.071**
G73-107				2.468*	0.342	-1.570	2.565*	1.330	2.095*	-1.257
77/245					-0.626	-0.164	-1.736	-0.118	1.730	4.122**
CVJ-2-5-3-1-3						0.310	-2.166*	0.132	-0.019	-0.421
1305							0.553	2.481*	-1.388	4.051**
77/371× BSECT CP-1								0.939	4.254**	-0.921
96AC-93									2.325*	-2.267*
Togo-II										-3.485**
99HS-18										
gca effects	-0.177	0.152	0.080	0.878*	-0.389	-1.471**	0.771*	0.640*	-0.509	0.026
Parental Means	9.080	11.247	11.660	14.377	12.140	8.580	13.767	13.030	10.560	12.767

* *Significant at P* = *0.05*

** *Significant at P* = *0.01*

Table 22b: Estimates of gca and sca effects for seedling height (cm) (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-0.101	0.672	-0.122	2.139**	3.902**	-0.947	2.599**	0.830	3.304**
H77/29-2			-1.085	-1.062	3.816**	1.162	1.680*	0.849	1.494*	2.081**
G73-107				1.104	0.569	-1.139	1.669*	1.482*	1.593*	0.364
77/245					0.505	-0.099	-0.481	1.388*	1.026	3.654**
CVJ-2-5-3-1-3						-1.737*	-0.119	0.133	-0.172	-0.135
1305							1.043	0.295	1.473*	2.451**
77/371× BSECT CP-1								0.613	3.158**	0.062
96AC-93									0.144	0.248
Togo-II										-2.724**
99HS-18										
gca effects	-1.096**	-0.007	0.594*	0.254	0.343	-0.570*	1.012**	0.144	-0.285	-0.389
Parental Means	7.850	11.750	14.753	13.733	14.367	11.367	14.867	12.593	12.200	10.750

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 22c: Estimates of gca and sca effects for seedling height (cm) (environment-III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-1.888*	-2.188*	-0.613	-1.540	5.319**	6.246**	-0.309	0.773	-4.583**
H77/29-2			-4.644**	1.725	4.581**	6.737**	4.934**	2.046*	-3.796**	5.271**
G73-107				-2.323*	-0.307	4.053**	1.163	2.852**	5.460**	7.444**
77/245					-1.355	-2.478*	3.318**	-3.596**	7.212**	3.272**
CVJ-2-5-3-1-3						-1.442	-1.092	7.880**	2.015*	1.785
1305							-4.409**	2.956**	-1.772	2.548*
77/371× BSECT CP-1								5.226**	0.408	0.071
96AC-93									-4.520**	2.650**
Togo-II										-0.428
99HS-18										
gca effects	-0.932**	0.227	0.248	-0.744*	-0.793*	-0.897**	0.967**	0.595	0.240	1.090**
Parental Means	22.447	17.890	19.660	20.850	18.070	17.370	18.920	18.517	22.723	18.083

* *Significant at P* = 0.05

** *Significant at P* = 0.01

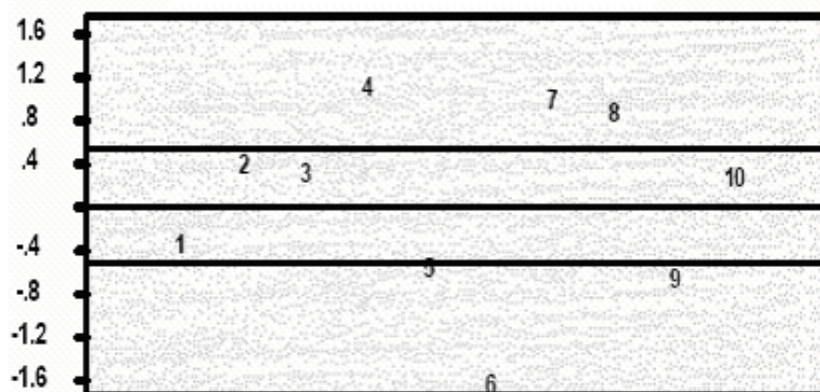


Fig. 18a: Estimates of gca effects for seedling height in environment-I

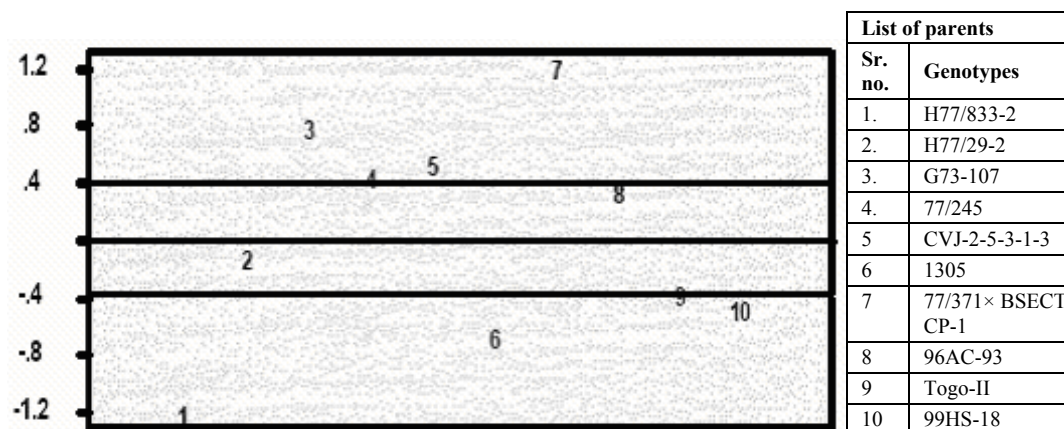


Fig. 18b: Estimates of gca effects for seedling height in environment-II

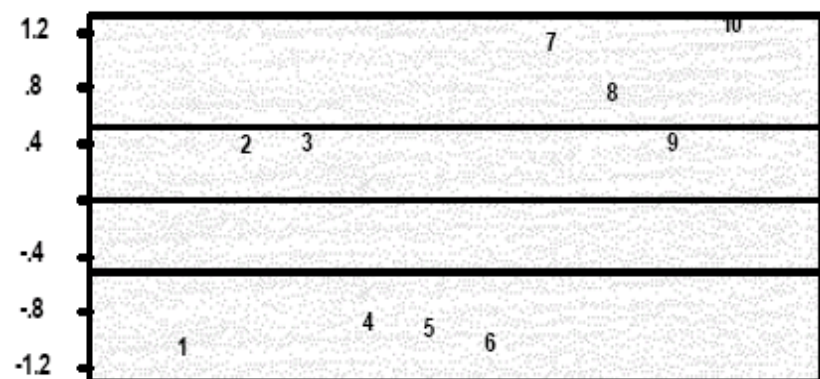


Fig. 18c: Estimates of gca effects for seedling height in environment-III

Table 23a: Estimates of gca and s.c.a. effects for fresh weight (g)/seedling (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		0.990	-0.874	-5.189**	6.185**	2.855**	-5.612**	9.157**	4.528**	-4.895**
H77/29-2			-3.981**	2.394**	2.148**	5.794**	-2.676**	10.170**	9.735**	-5.205**
G73-107				7.513**	0.480	5.293**	3.439**	-3.775**	-4.227**	5.857**
77/245					5.188**	-5.532**	15.104**	-0.430	-0.398	7.955**
CVJ-2-5-3-1-3						-0.735	-6.145**	-1.352	-5.384**	8.096**
1305							6.058**	-0.260	-4.518**	1.589*
77/371× BSECT CP-1								-2.137**	5.728**	-2.608**
96AC-93									-2.889**	10.718**
Togo-II										11.760**
99HS-18										
gca effects	-2.204**	-1.857**	-1.139**	1.402**	-0.349	-2.948**	-0.858**	1.797**	-0.082	6.238**
Parental Means	8.590	3.173	9.430	6.073	11.633	5.403	9.280	10.563	9.240	12.413

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 23b: Estimates of gca and sca effects for fresh weight (g)/seedling (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-2.301	-13.324**	10.195**	36.739**	18.218**	-0.960	4.279**	0.155	-4.085**
H77/29-2			-0.392	-8.110**	30.521**	21.840**	-7.285**	-24.656**	44.577**	3.557*
G73-107				20.753**	28.108**	2.217	-18.298**	25.511**	-6.393**	29.014**
77/245					-16.080**	41.015**	18.357**	-20.967**	15.622**	58.852**
CVJ-2-5-3-1-3						-19.763**	1.008	34.994**	-9.670**	-23.466**
1305							-5.096**	33.923**	-5.041**	-10.058**
77/371× BSECT CP-1								55.965**	0.757	12.741**
96AC-93									33.510**	-2.260
Togo-II										7.792**
99HS-18										
gca effects	-8.951**	-2.426**	-3.343**	10.362**	-5.216**	-4.715**	-1.266*	13.438**	-1.208*	3.325**
Parental Means	15.367	24.000	17.443	18.633	16.100	9.670	26.600	14.453	14.657	28.333

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 23c: Estimates of gca and sca effects for fresh weight (g)/seedling (environment–III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		–3.995	–19.981**	7.447*	–28.101**	7.170*	16.147**	58.632**	16.849**	54.301**
H77/29-2			–6.954*	–36.700**	53.746**	42.064**	41.717**	–2.751	47.619**	12.995**
G73-107				–5.856	6.110*	22.928**	11.618**	39.870**	–10.953**	28.849**
77/245					27.801**	30.095**	31.812**	6.734*	48.421**	–56.884**
CVJ-2-5-3-1-3						10.394**	32.544**	9.603**	3.480	–22.422**
1305							–19.628**	6.484*	–16.562**	9.556**
77/371× BSECT CP-1								26.697**	–19.382**	17.466**
96AC-93									–6.584*	4.618
Togo-II										6.892*
99HS-18										
gca effects	–12.531**	1.718	–8.139**	–6.270**	–5.152**	–1.840	2.127*	16.422**	13.741**	–0.077
Parental Means	19.243	28.107	49.447	59.567	41.660	48.610	33.300	59.733	91.133	70.700

* *Significant at P* = 0.05

** *Significant at P* = 0.01

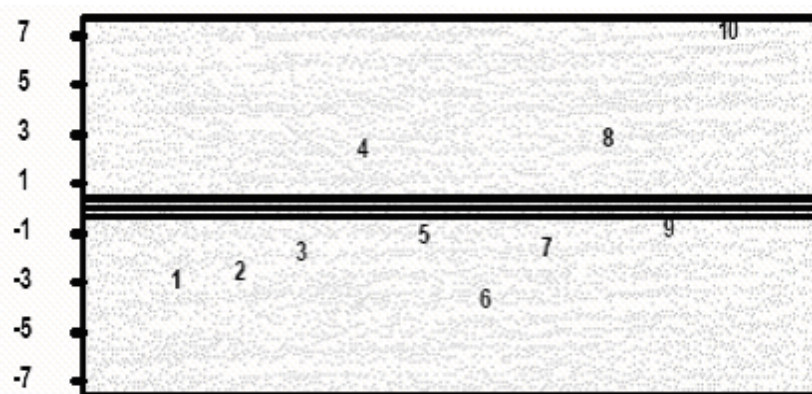
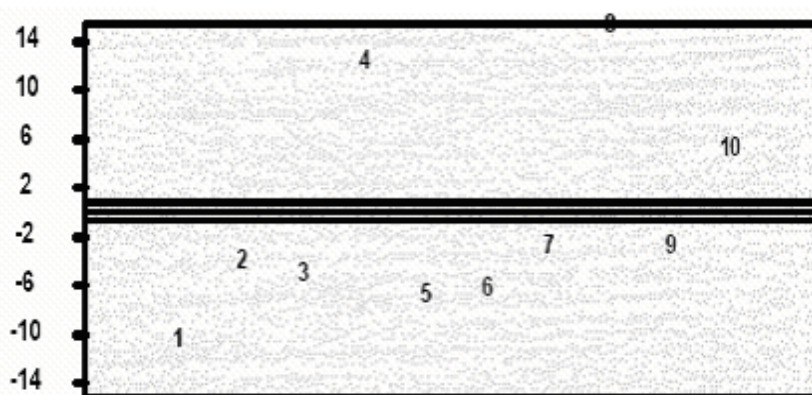


Fig. 19a: Estimates of gca effects for fresh weight (g)/seedling in environment-I



List of parents	
Sr. no.	Genotypes
1.	H77/833-2
2.	H77/29-2
3.	G73-107
4.	77/245
5	CVJ-2-5-3-1-3
6	1305
7	77/371× BSECT CP-1
8	96AC-93
9	Togo-II
10	99HS-18

Fig. 19b: Estimates of gca effects for fresh weight (g)/seedling in environment-II



Fig. 19c: Estimates of gca effects for fresh weight (g)/seedling in environment-III

× 99HS-18, H77/29-2 × Togo-II, 77/245 × 96AC-93 and 1305 × Togo-II in environment-II and ten crosses, namely, H77/833-2 × (77/371 × BSECT CP-1), H77/29-2 × 1305, H77/29-2 × 96AC-93, H77/29-2 × 1305, G73-107 × 99HS-18, 77/245 × (77/371 × BSECT CP-1), 77/245 × Togo-II, CVJ-2-5-3-1-3 × 96AC-93, CVJ-2-5-3-1-3 × Togo-II, (77/371 × BSECT CP-1) × 96AC-93 and 96AC-93 × 99HS-18 also showed the positive significant sca effects.

vii) Seedling fresh weight (g)

The parent 96AC-93 appeared to be good general combiner as indicated by significant positive gca effect in all the environments (E_1 , E_2 and E_3), while, the parents 77/245 and 99HS-18 in stress environments-I and II, parents (77/371 × BSECT CP-1) and Togo-II in environment-III showed the positive significant gca values for this character (table 23a-c).

The parents H77/833-2 and G73-107 were found to be consistently poor combiners in all the three environments (E_1 , E_2 and E_3). While, the parents H77/29-2, 1305 and (77/371 × BSECT CP-1) in environment-I and II and the parent CVJ-2-5-3-1-3 in environment-I and III showed consistency over two environments for significant negative gca effects. The parent 96AC-93 was identified as the best general combiner in environment-II and III, while, the parent 99HS-18 showed highest gca effect in environment-I for seedling fresh weight (g) (figure 19a-c).

A consideration of sca effect reveals that out of 45 cross combinations ten crosses, namely, H77/833-2 $\times$ 1305, H77/833-2 $\times$ 96AC-93, H77/29-2 $\times$ CVJ-2-5-3-1-3, H77/29-2 $\times$ 1305, H77/29-2 $\times$ Togo-II, G73-107 $\times$ 99HS-18, 77/245 $\times$ (77/371 $\times$ BSECT CP-1) and Togo-II $\times$ 99HS-18 exhibited significant positive sca effects in all the three environments. The crosses i.e., H77/833-2 $\times$ CVJ-2-5-3-1-3, G73-107 $\times$ 77/245 and 77/245 $\times$ 99HS-18 showed significant and positive sca effects in stress environments (E_1 and E_2) while, the five crosses, namely, H77/833-2 $\times$ Togo-II, G73-107 $\times$ 1305, G73-107 $\times$ (77/371 $\times$ BSECT CP-1), 77/245 $\times$ CVJ-2-5-3-1-3 and 1305 $\times$ 99HS-18 in environment-I and III. Ten crosses viz., H77/833-2 $\times$ 77/245, H77/29-2 $\times$ 99HS-18, G73-107 $\times$ CVJ-2-5-3-1-3, G73-107 $\times$ 96AC-93, 77/245 $\times$ 1305, 77/245 $\times$ Togo-II, CVJ-2-5-3-1-3 $\times$ 96AC-93, 1305 $\times$ 96AC-93, (77/371 $\times$ BSECT CP-1) $\times$ 96AC-93 and (77/371 $\times$ BSECT CP-1) $\times$ 99HS-18 showed significant positive sca effects.

Five cross combinations viz., H77/29-2 $\times$ 77/245, CVJ-2-5-3-1-3 $\times$ 99HS-18, 1305 $\times$ (77/371 $\times$ BSECT CP-1), (77/371 $\times$ BSECT CP-1) $\times$ Togo-II and 96AC-93 $\times$ 99HS-18 in environment-I, one cross 96AC-93 $\times$ Togo-II in environment-II and six crosses, namely, H77/29-2 $\times$ 77/245, H77/29-2 $\times$ 96AC-93, CVJ-2-5-3-1-3 $\times$ 99HS-18, 1305 $\times$ (77/371 $\times$ BSECT CP-1), (77/371 $\times$ BSECT CP-1) $\times$ Togo-II and 96AC-93 $\times$ 99HS-18 in environment-III also showed significant and positive sca effects for seedling fresh weight (g). Similarly, two cross combinations, viz., G73-107 $\times$ Togo-II and 1305 $\times$ Togo-II

showed consistency for the significant but negative sca effects in all the three environments and were the poorest specific combination.

viii) Seedling dry weight (g)

A perusal of table 24a-c revealed that out of ten parents, only one parent 96AC-93 was identified as the best general combiner over all the three environments having highest positive gca effect. Other than those mentioned above 99HS-18 in environment-I and II, Togo-II in environment-II and III and 77/245 in environment-II also exhibited positive and significant gca effects. While, the two parents i.e. H77/833-2 and G73-107 exhibited the significant but negative gca effects (figure 20a-c).

Significant positive sca effects in all the three environments for this trait were exhibited by eight cross combinations, namely, H77/833-2 $\times$ 96AC-93, H77/29-2 $\times$ 1305, H77/29-2 $\times$ Togo-II, G73-107 $\times$ 1305, G73-107 $\times$ 96AC-93, G73-107 $\times$ 99HS-18, 77/245 $\times$ (77/371 $\times$ BSECT CP-1) and Togo-II $\times$ 99HS-18. However, six crosses, namely, H77/833-2 $\times$ CVJ-2-5-3-1-3, H77/833-2 $\times$ 1305, G73-107 $\times$ 77/245, 77/245 $\times$ 99HS-18, (77/371 $\times$ BSECT CP-1) $\times$ Togo-II and 96AC-93 $\times$ Togo-II in environment-I and II (stress environments), two crosses, viz., H77/29-2 $\times$ 96AC-93 and 77/245 $\times$ CVJ-2-5-3-1-3 in environment-I and III and ten cross combinations, namely, H77/833-2 $\times$ 77/245, H77/833-2 $\times$ 99HS-18, H77/29-2 $\times$ CVJ-2-5-3-1-3, G73-107 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ 1305, 77/245 $\times$ Togo-II, CVJ-2-5-3-1-3 $\times$ 96AC-93, 1305 $\times$ 96AC-93, (77/371 $\times$

Table 24a: Estimates of gca and sca effects for dry weight (g)/seedling (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		−0.809**	−0.916**	−0.126	1.025**	3.156**	−0.403**	0.687**	0.378**	−1.141**
H77/29-2			−0.006	1.051**	0.189	0.703**	−0.019	0.810**	1.092**	−0.208
G73-107				0.918**	0.085	0.549**	0.090	0.367**	−0.518**	0.662**
77/245					0.559**	−1.534**	1.977**	0.494**	−0.505**	0.576**
CVJ-2-5-3-1-3						−0.809**	−0.205	−0.372*	−0.020	1.267**
1305							0.969**	0.212	−0.260*	−0.236
77/371× BSECT CP-1								−0.747**	0.518**	−0.082
96AC-93									0.315*	0.882**
Togo-II										1.480**
99HS-18										
gca effects	−0.127**	−0.194**	−0.337**	0.079	−0.079	−0.049	−0.084*	0.223**	−0.009	0.578**
Parental Means	1.540	0.930	1.430	1.173	1.703	1.247	1.503	1.843	1.463	2.277

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 24b: Estimates of gca and sca effects for dry weight (g)/seedling (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		0.596**	-1.064**	0.274*	3.609**	1.363**	-0.510**	0.393**	-0.143	0.586**
H77/29-2			-0.793**	-0.048	1.369**	1.507**	-0.442**	-1.526**	4.358**	0.787**
G73-107				0.866**	4.360**	1.241**	-2.028**	2.135**	-0.321*	1.844**
77/245					-1.215**	3.455**	2.403**	-1.754**	1.950**	3.522**
CVJ-2-5-3-1-3						-2.087**	-0.212	3.437**	-1.269**	-2.050**
1305							-0.772**	4.828**	-0.725**	-0.830**
77/371× BSECT CP-1								4.326**	0.899**	1.571**
96AC-93									2.116**	-0.439**
Togo-II										1.955**
99HS-18										
gca effects	-0.703**	-0.283**	-0.487**	0.571**	-0.500**	-0.257**	-0.091*	1.422**	0.155**	0.173**
Parental Means	1.427	1.913	1.290	1.800	1.413	0.880	2.583	1.470	1.283	2.257

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 24c: Estimates of gca and sca effects for dry weight (g)/seedling (environment-III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-0.094	-1.517**	0.733*	-2.410**	0.315	0.737*	5.176**	0.250	7.422**
H77/29-2			-1.334**	-2.853**	2.363**	3.502**	4.324**	1.563**	4.796**	0.506
G73-107				-1.053**	1.907**	4.072**	-0.400	3.153**	0.303	1.676**
77/245					3.800**	1.919**	3.374**	-0.627*	4.466**	-5.381**
CVJ-2-5-3-1-3						-0.078	2.424**	1.323**	-0.830**	-1.741**
1305							-1.517**	2.379**	-2.428**	0.948**
77/371× BSECT CP-1								1.344**	-0.403	1.676**
96AC-93									-1.214**	-0.451
Togo-II										1.455**
99HS-18										
gca effects	-0.975**	0.028	-0.892**	-0.789**	-0.702**	-0.064	-0.033	1.668**	1.588**	0.172
Parental Means	1.597	2.523	3.667	5.087	4.070	4.170	3.010	5.867	8.833	6.143

* *Significant at P* = 0.05

** *Significant at P* = 0.01

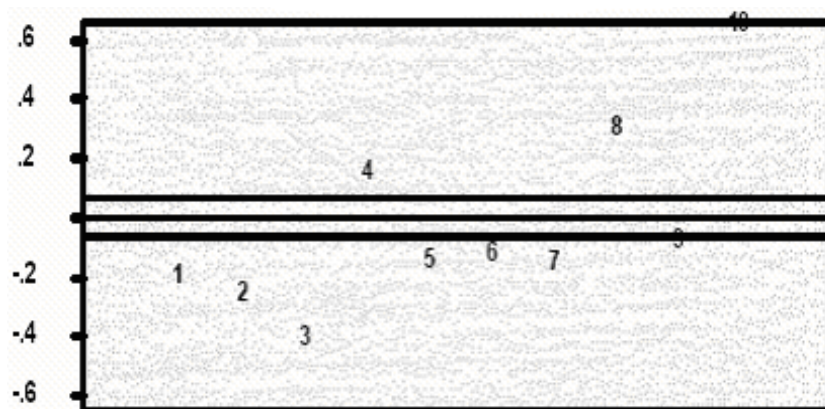


Fig. 20a: Estimates of gca effects for dry weight (g)/seedling in environment-I

List of parents	
Sr. no.	Genotypes
1.	H77/833-2
2.	H77/29-2
3.	G73-107
4.	77/245
5.	CVJ-2-5-3-1-3
6.	1305
7.	77/371× BSECT CP-1
8.	96AC-93
9.	Togo-II
10.	99HS-18

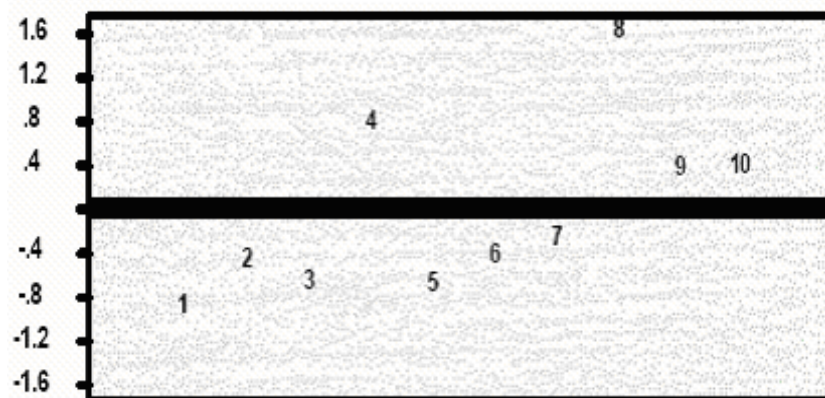


Fig. 20b: Estimates of gca effects for dry weight (g)/seedling in environment-II



Fig. 20c: Estimates of gca effects for dry weight (g)/seedling in environment-III

Table 25a: Estimates of gca and sca effects for panicle emergence (days) (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-2.152	-0.624	-3.374**	-2.902*	-1.902	-2.429*	0.015	-2.290	2.960*
H77/29-2			-1.124	-3.207*	1.598	-0.402	0.737	-1.818	-0.790	-0.207
G73-107				-3.679**	-1.874	4.793**	-2.402*	-1.290	-1.263	-3.346*
77/245					2.043	-1.957	-0.485	-1.040	0.987	0.237
CVJ-2-5-3-1-3						-1.485	-0.346	-1.235	0.793	-2.290
1305							-1.679	-2.235	2.793*	-1.624
77/371× BSECT CP-1								1.571	-2.068	-1.152
96AC-93									1.710	0.293
Togo-II										-0.013
99HS-18										
gca effects	-1.183**	2.317**	1.456**	-1.461**	0.733	2.400**	-2.739**	-2.850**	1.456**	-0.128
Parental Means	62.667	67.000	67.000	61.000	63.000	65.333	57.333	55.000	61.667	61.000

* *Significant at P* = *0.05*

** *Significant at P* = *0.01*

Table 25b: Estimates of gca and sca effects for panicle emergence (days) (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-2.061	0.634	1.717	-1.949	-2.811*	-1.561	-1.894	-1.061	0.328
H77/29-2			0.912	0.662	-1.005	-1.533	-0.949	-1.616	-2.116	-0.727
G73-107				-1.644	-4.644**	1.162	-1.922	2.745*	-2.088	-3.033*
77/245					-1.894	1.578	-0.505	-2.505*	-0.338	-1.949
CVJ-2-5-3-1-3						-1.422	0.495	0.495	2.662*	-1.616
1305							-2.366	-5.366**	7.134**	-2.477*
77/371× BSECT CP-1								0.217	2.384	-0.894
96AC-93									-1.949	2.773*
Togo-II										2.939*
99HS-18										
gca effects	-1.428**	1.294**	1.933**	-0.483	-0.817*	0.378	-1.872**	-0.872*	1.294**	0.572
Parental Means	48.000	53.333	54.333	48.000	49.333	50.333	45.333	48.333	45.333	50.000

* *Significant at P* = *0.05*

** *Significant at P* = *0.01*

Table 25c: Estimates of gca and sca effects for panicle emergence (days) (environment–III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		–2.674	–1.896	5.742**	–0.480	–3.785*	–4.869**	–0.563	3.215*	1.270
H77/29-2			3.742*	1.715	–0.174	–5.146**	–3.896*	0.076	–3.146*	–2.424
G73-107				–0.174	–8.063**	1.298	–7.119**	4.854**	–2.702	–7.646**
77/245					–0.091	–6.063**	–3.146*	–3.174*	–4.063*	–4.341**
CVJ-2-5-3-1-3						–5.285**	–3.369*	5.270**	2.715	–2.563
1305							–0.341	–4.369**	5.742**	–2.202
77/371× BSECT CP-1								–4.119**	–1.008	11.381**
96AC-93									–2.369	5.354**
Togo-II										0.131
99HS-18										
gca effects	–2.422**	1.939**	1.494**	1.522**	–0.589	–1.617**	–1.200**	–1.172**	2.050**	–0.006
Parental Means	38.333	51.000	53.000	51.000	46.000	48.000	47.000	38.333	46.000	41.667

* *Significant at P* = 0.05

** *Significant at P* = 0.01



Fig. 21a: Estimates of gca effects for panicle emergence (days) in environment-I

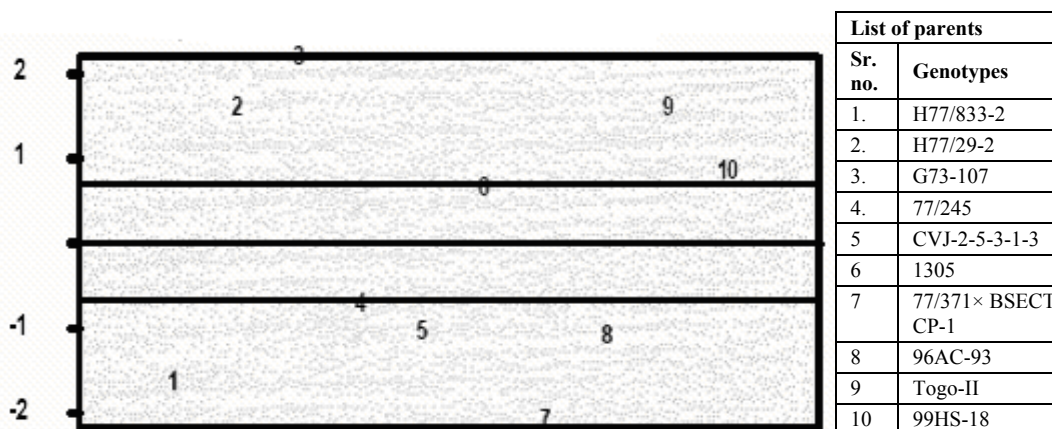


Fig. 21b: Estimates of gca effects for panicle emergence (days) in environment-II

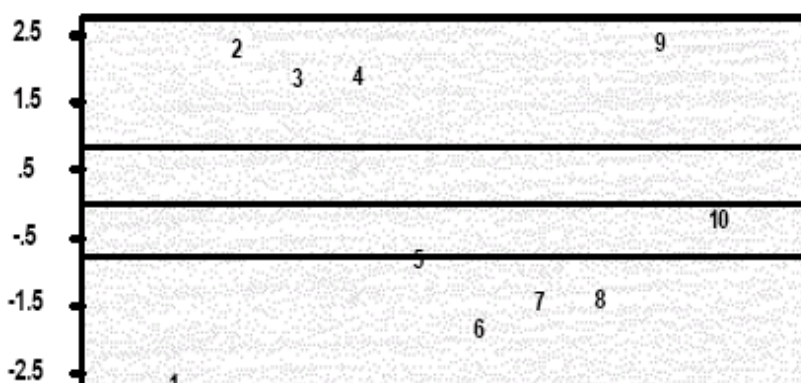


Fig. 21c: Estimates of gca effects for panicle emergence (days) in environment-III

BSECT CP-1) $\times$ 96AC-93 and (77/371 $\times$ BSECT CP-1) $\times$ 99HS-18 showed consistency for positive significant gca effects in two environments. However, six cross combinations H77/833-2 $\times$ Togo-II, H77/29-2 $\times$ 77/245, 77/245 $\times$ 96AC-93, CVJ-2-5-3-1-3 $\times$ 99HS-18, 1305 $\times$ (77/371 $\times$ BSECT CP-1) and 96AC-93 $\times$ 99HS-18 in environment-I, two crosses, viz., H77/833-2 $\times$ H77/29-2 and H77/29-2 $\times$ 99HS-18 in environment-II and three crosses, namely, H77/833-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/29-2 $\times$ (77/371 $\times$ BSECT CP-1) and CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1) in environment-III exhibited significant positive sca effects.

The best specific hybrid differed in order in the different environments indicating thereby the significance of effect of environment. Two crosses i.e. H77/833-2 $\times$ G73-107 and 1305 Togo-II were identified as consistently poor specific cross combinations in all the three environments.

ix) Panicle emergence

In this trait the negative values of gca are considered favourable as an indication of earliness. The parents H77/833-2, (77/371 $\times$ BSECT CP-1) and 96AC-93 in all the three environments had significant and negative gca effects and were, therefore, the best general combining parents. However, the parent 77/245 in environment-I, CVJ-2-5-3-1-3 in environment-II and 1305 in environment-III also exhibited significant but negative gca effects and thus, were considered as good general combiners for earliness.

Similarly, three parents i.e. H77/29-2, G73-107 and Togo-II showed significant positive gca effects in all the three environments, while the parent 1305 in environment-I and 77/245 in environment-III also showed significant positive gca effects and were good general combiners for lateness (figure 21a-c).

A perusal of table 25a-c revealed that out of 45 cross combinations only one cross i.e. G73-107 $\times$ 99HS-18 exhibited negative significant sca effects in all the three environments. The crosses H77/833-2 $\times$ (77/371 $\times$ BSECT CP-1) and G73-107 $\times$ (77/371 $\times$ BSECT CP-1) in environment-I and III and four crosses, namely, H77/833-2 $\times$ 1305, G73-107 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ 96AC-93 and 1305 $\times$ 96AC-93 in environment-II and III showed negative and significant sca effects while, the four cross combinations H77/833-2 $\times$ 77/245, H77/833-2 $\times$ CVJ-2-5-3-1-3, H77/29-2 $\times$ 77/245 and G73-107 $\times$ 77/245 in environment-I, and ten crosses, namely, H77/29-2 $\times$ 1305, H77/29-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/29-2 $\times$ Togo-II, 77/245 $\times$ 1305, 77/245 $\times$ (77/371 $\times$ BSECT CP-1), 77/245 $\times$ Togo-II, 77/245 $\times$ 99HS-18, CVJ-2-5-3-1-3 $\times$ 1305, CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1) and (77/371 $\times$ BSECT CP-1) $\times$ 96AC-93 in environment-III showed significant negative sca effects and thus, were good cross combinations for early flowering.

While, the cross 1305 $\times$ Togo-II only showed significant positive sca effect in all the three environments and as such was its sole best specific cross. The crosses G73-107 $\times$ 96AC-93 and 96AC-93 $\times$ 99HS-18 in environment-II and III, two crosses i.e. H77/833-2 $\times$

99HS-18 and G73-107 $\times$ 1305 in environment-I, the crosses CVJ-2-5-3-1-3 $\times$ Togo-II and Togo-II $\times$ 99HS-18 in environment-II and five cross combinations, namely, H77/833-2 $\times$ 77/245, H77/833-2 $\times$ Togo-II, H77/29-2 $\times$ G73-107, CVJ-2-5-3-1-3 $\times$ 96AC-93, (77/371 $\times$ BSECT CP-1) $\times$ 99HS-18 and 96AC-93 $\times$ 99HS-18 in environment-III exhibited the significant positive sca effects, indicating late flowering characteristics of these crosses.

x) Number of effective tillers/plant

Positive and significant gca effects were recorded for the parent 1305 in all the three environments. The parent H77/833-2 in environment-I and II (stress environments) and CVJ-2-5-3-1-3 in environment-I and III exhibited significant positive gca effects for two environments. Also, the parent G73-107 in environment-I was associated with significant and positive gca effect.

On the contrary, 99HS-18 in all the environments, Togo-II in environment-I and III, 77/245 and 96AC-93 in environment-I and H77/29-2 in environment-III had significant but negative gca effects, indicating that these were poor combiners for Number of effective tillers/plant (table 26a-c and figure 22a-c).

Only one cross combination i.e. H77/833-2 $\times$ 1305 exhibited significant and positive sca effects in all the three environments. However, three cross combinations H77/29-2 $\times$ G73-107, H77/29-2 $\times$ Togo-II and CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1) environment-I and II, two crosses, viz., H77/29-2 $\times$ 1305 and 77/245 $\times$ CVJ-2-5-3-1-

3 in environment-I and III and three crosses, namely, H77/833-2 $\times$ CVJ-2-5-3-1-3, G73-107 $\times$ 99HS-18 and 96AC-93 $\times$ Togo-II showed the positive and significant sca effects. Also, the cross combinations H77/833-2 $\times$ H77/29-2, H77/833-2 $\times$ 77/245, H77/833-2 $\times$ 99HS-18, G73-107 $\times$ 1305, G73-107 $\times$ 96AC-93, 77/245 $\times$ 1305 and CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1) in environment-I, four crosses, i.e. 77/245 $\times$ 99HS-18, CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1), 1305 $\times$ 96AC-93 and 1305 $\times$ Togo-II in environment-II and five crosses, namely, H77/29-2 $\times$ 77/245, G73-107 $\times$ 77/245, 77/245 $\times$ Togo-II, CVJ-2-5-3-1-3 $\times$ Togo-II and (77/371 $\times$ BSECT CP-1) $\times$ Togo-II in environment-III exhibited significant positive sca effects for number of effective tillers/plant.

However, three cross combinations, namely, H77/29-2 $\times$ CVJ-2-5-3-1-3, 1305 $\times$ 99HS-18 and (77/371 $\times$ BSECT CP-1) $\times$ 96AC-93 were identified as the poor specific cross combinations in all the three environments.

xi) Plant height (cm)

The parents H77/29-2, G73-107 and CVJ-2-5-3-1-3 had consistent and high significant positive gca effects over all the three environments. While, the parent Togo-II in environment-II and III and parent 96AC-93 in environment-I had significant and positive gca effect indicating good general combining abilities for tallness in pearl millet.

Table 26a: Estimates of gca and sca effects for effective tillers/plant (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		0.723**	0.054	0.473**	−0.833**	0.765**	−0.368**	0.139	−0.528**	0.530**
H77/29-2			0.668**	−0.703**	−0.549**	0.579**	−0.524**	0.146	0.356**	−0.126
G73-107				−0.239*	−0.118	0.259*	0.073	0.447**	−0.080	−0.342*
77/245					0.861**	−0.612**	−0.094	−0.090	−0.141	−0.256*
CVJ-2-5-3-1-3						0.606**	0.943**	−0.466**	−0.030	−0.479**
1305							0.287*	−0.502**	−0.110	−0.825**
77/371× BSECT CP-1								−0.815**	0.125	−0.104
96AC-93									0.235	−0.270*
Togo-II										0.132
99HS-18										
gca effects	0.212**	−0.018	0.181**	−0.128**	0.091*	0.244**	0.003	−0.101*	−0.173**	−0.311**
Parental Means	2.123	1.853	2.177	2.320	2.390	2.440	2.420	2.563	1.850	2.423

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 26b: Estimates of gca and sca effects for effective tillers/plant (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		0.198	0.200	−0.608**	0.568**	1.462**	0.176	−0.314*	−0.030	−0.075
H77/29-2			0.333*	0.069	−0.261*	0.169	−0.208	−0.397**	0.450**	0.129
G73-107				0.237	0.247	−0.393**	−0.383**	0.031	−0.232	0.457**
77/245					0.019	0.106	0.033	−0.573**	0.258	0.396**
CVJ-2-5-3-1-3						−0.534**	0.822**	−0.354*	−0.046	−0.218
1305							0.023	0.317*	0.291*	−0.638**
77/371× BSECT CP-1								−0.290*	0.184	−0.258
96AC-93									0.411**	−0.214
Togo-II										0.137
99HS-18										
gca effects	0.364**	0.004	0.056	−0.077	0.030	0.100*	−0.040	0.006	−0.068	−0.373**
Parental Means	2.273	2.100	2.197	2.210	2.273	2.133	2.203	3.037	1.487	1.730

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 26c: Estimates of gca and sca effects for effective tillers/plant (environment–III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		–0.135	–0.401*	–0.158	0.506**	1.455**	–0.012	–0.251	–0.424*	0.104
H77/29-2			–0.160	0.380*	–0.627**	0.765**	–0.068	0.230	–0.016	–0.245
G73-107				0.331*	0.215	0.126	0.110	0.261	–0.158	0.313*
77/245					0.715**	0.126	–0.230	–0.806**	0.471**	–0.337*
CVJ-2-5-3-1-3						0.063	–0.266	0.191	0.542**	–0.377*
1305							0.139	–0.527**	0.197	–0.882**
77/371× BSECT CP-1								–0.400*	0.478**	–0.551**
96AC-93									0.878**	–0.367*
Togo-II										0.007
99HS-18										
gca effects	0.075	–0.139*	0.009	0.050	0.249**	0.307**	–0.076	0.053	–0.225**	–0.302**
Parental Means	2.487	2.340	2.380	2.533	2.697	2.563	2.927	3.180	1.243	3.243

* *Significant at P* = 0.05

** *Significant at P* = 0.01

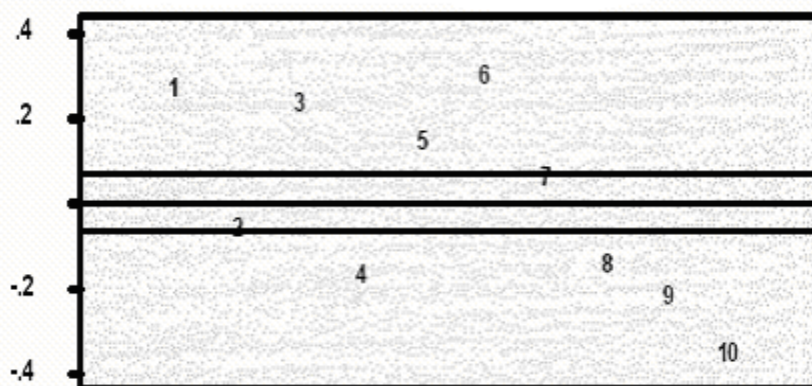
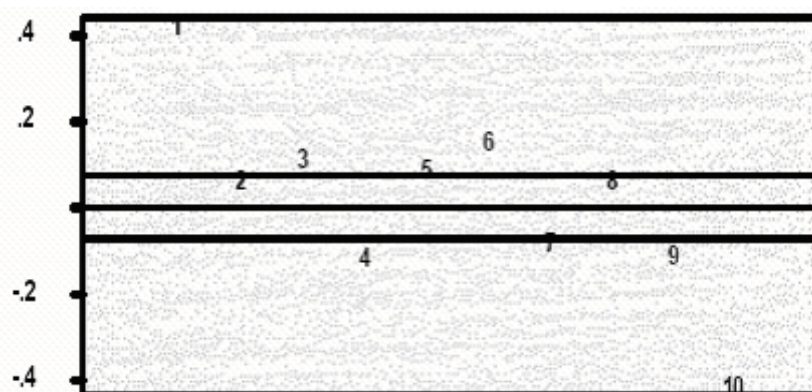


Fig. 22a: Estimates of gca effects for number of effective tillers/plant in environment-I



List of parents	
Sr. no.	Genotypes
1.	H77/833-2
2.	H77/29-2
3.	G73-107
4.	77/245
5	CVJ-2-5-3-1-3
6	1305
7	77/371× BSECT CP-1
8	96AC-93
9	Togo-II
10	99HS-18

Fig. 22b: Estimates of gca effects for number of effective tillers/plant in environment-II

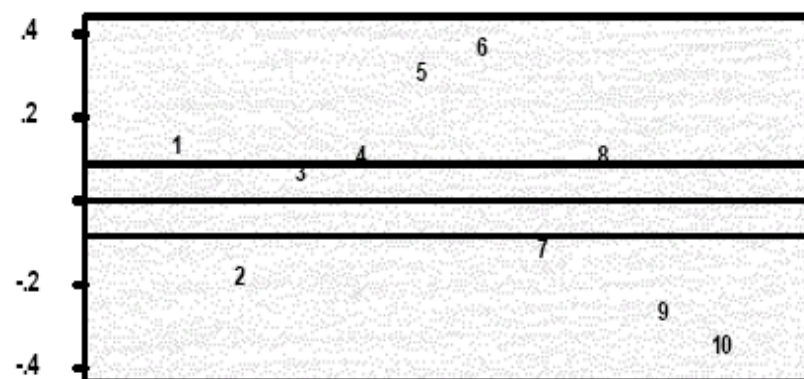


Fig. 22c: Estimates of gca effects for number of effective tillers/plant in environment-III

Table 27a: Estimates of gca and sca effects for plant height (cm) (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-5.395	0.474	15.551**	2.561	-1.440	2.403	7.484*	33.651**	31.822**
H77/29-2			8.957*	-9.436**	15.074**	1.559	16.736**	-11.310**	40.251**	28.555**
G73-107				-4.564	6.406	-3.785	21.738**	58.009**	28.956**	31.871**
77/245					4.990	6.429	13.045**	12.873**	21.263**	26.571**
CVJ-2-5-3-1-3						7.376*	0.952	8.193*	12.557**	5.882
1305							16.138**	24.752**	11.709**	25.127**
77/371× BSECT CP-1								13.265**	14.615**	15.833**
96AC-93									9.593**	26.801**
Togo-II										-33.635**
99HS-18										
gca effects	-6.490**	9.010**	5.572**	-14.625**	9.227**	-6.885**	-2.114*	8.811**	1.141	-3.647**
Parental Means	156.440	188.500	150.087	140.363	199.433	155.273	151.383	155.767	145.777	126.267

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 27b: Estimates of gca and sca effects for plant height (cm) (environment–II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		–23.232**	6.045	7.194	–2.330	8.734*	2.526	9.056*	37.704**	28.936**
H77/29-2			8.671**	–0.826	18.300**	–4.040	–1.361	9.023*	29.541**	24.616**
G73-107				–1.702	13.730**	7.027	7.226	12.783**	39.678**	17.246**
77/245					5.899	–3.827	9.975*	–0.761	39.153**	36.728**
CVJ-2-5-3-1-3						–1.385	–4.762	26.745**	17.593**	9.381*
1305							10.288*	7.165	8.509*	18.454**
77/371× BSECT CP-1								18.657**	24.128**	13.943**
96AC-93									12.302**	21.724**
Togo-II										–34.422**
99HS-18										
gca effects	–1.785	10.262**	4.765**	–5.764**	9.364**	–7.980**	–4.829**	1.598	6.176**	–11.809**
Parental Means	154.580	185.647	149.647	138.023	172.610	154.047	145.500	140.317	120.727	103.547

* *Significant at P* = *0.05*

** *Significant at P* = *0.01*

Table 27c: Estimates of gca and sca effects for plant height (cm) (environment–III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		–9.589*	–6.033	–1.912	–0.140	4.510	4.001	2.895	26.669**	25.687**
H77/29-2			–5.627	–13.840**	13.415**	6.022	19.457**	5.330	25.961**	11.896**
G73-107				–1.447	13.521**	6.404	5.146	5.886	40.624**	16.502**
77/245					7.726	1.025	12.934**	14.924**	33.245**	17.070**
CVJ-2-5-3-1-3						1.114	–5.361	23.346**	20.027**	0.491
1305							3.322	3.395	24.853**	15.874**
77/371× BSECT CP-1								19.137**	4.458	5.282
96AC-93									2.782	28.716**
Togo-II										–21.823**
99HS-18										
gca effects	–4.789**	7.555**	3.616*	–6.505**	10.740**	–4.643**	0.199	–6.042**	6.721**	–6.854**
Parental Means	132.667	153.887	135.033	117.417	149.700	122.743	131.500	100.000	100.333	101.733

* *Significant at P* = 0.05

** *Significant at P* = 0.01

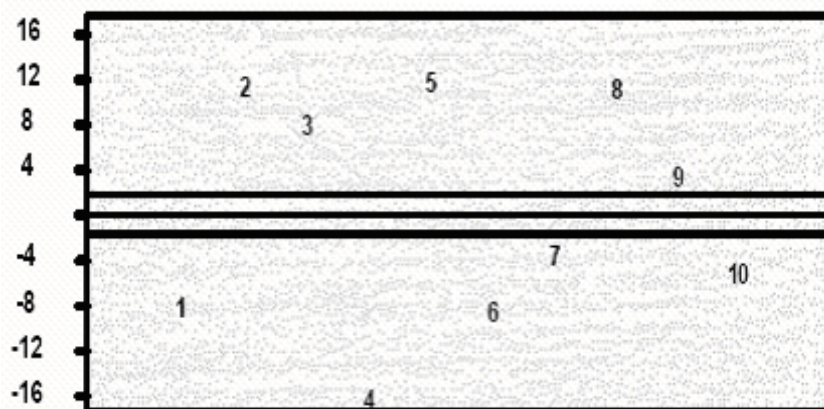


Fig. 23a: Estimates of gca effects for plant height (cm) in environment-I

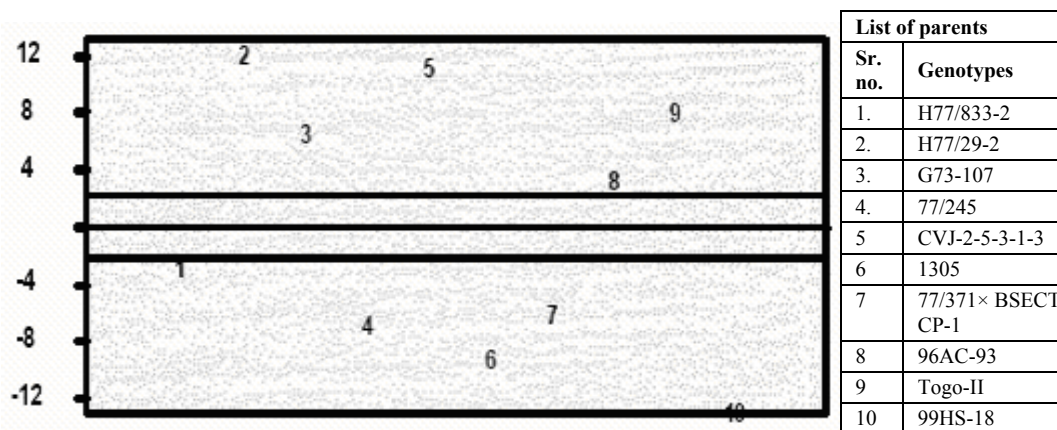


Fig. 23b: Estimates of gca effects for plant height (cm) in environment-II

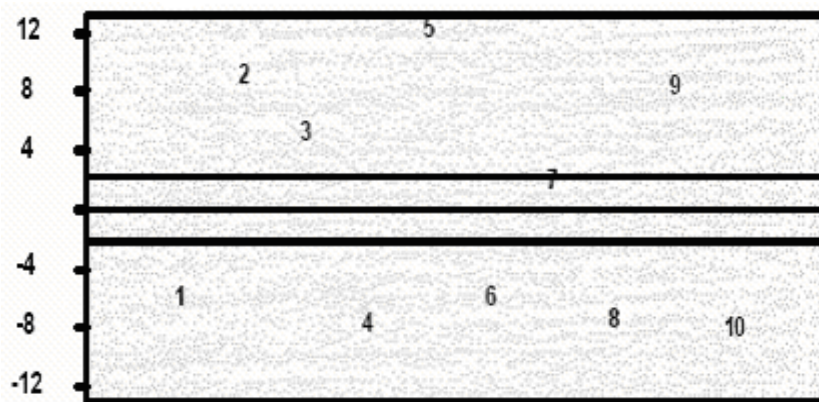


Fig. 23c: Estimates of gca effects for plant height (cm) in environment-III

Similarly, three parents, viz., 77/245, 1305 and 99HS-18 showed significant but negative gca effects in all the three environments. The parent H77/833-2 in environment-I and III and the parent (77/371 × BSECT CP-1) in environment-I and II exhibited significant negative gca effect indicating the good general combiners for dwarfness (table 27a-c and figure 23a-c).

The sca effects revealed that 16 cross combinations showed significant and positive sca effects in all the three environments. In stress environments (E_1 and E_2) five crosses, namely, H77/833-2 × 96AC-93, H77/29-2 × G73-107, G73-107 × 96AC-93, 1305 × (77/371 × BSECT CP-1) and (77/371 × BSECT CP-1) × 99HS-18, in environment-I and III two crosses i.e. H77/29-2 × (77/371 × BSECT CP-1) and 77/245 × 96AC-93, in environment-I only, six crosses, namely, H77/833-2 × 77/245, G73-107 × (77/371 × BSECT CP-1), CVJ-2-5-3-1-3 × 1305, 1305 × 96AC-93, (77/371 × BSECT CP-1) × Togo-II and 96AC-93 × Togo-II, in environment-II five crosses, viz., H77/833-2 × 1305, H77/29-2 × 96AC-93, CVJ-2-5-3-1-3 × 99HS-18, (77/371 × BSECT CP-1) × Togo-II and 96AC-93 × Togo-II exhibited significant and positive sca effects for tallness while, the one cross combination Togo-II × 99HS-18 showed negative significant sca effect in all the three environments indicating the specific cross combination for dwarfness.

xii) Ear length (cm)

The data for gca effects for each of the parents (table 28a-c) showed that the parents CVJ-2-5-3-1-3, 1305 and Togo-II were the most desirable parents in respect of the ear length since they possessed consistently high positive gca effects under all the environments. The parent G73-107 showed high and significant gca effect in environment-I and II. Whereas, parents H77/833-2, 77/245, (77/371 $\times$ BSECT CP-1), 96AC-93 and 99HS-18 were poor general combiners for ear length (figure 24a-c).

The magnitude of sca effects for Ear length revealed that only five crosses viz. H77/833-2 $\times$ 1305, 77/245 $\times$ Togo-II, (77/371 $\times$ BSECT CP-1) $\times$ 96AC-93, (77/371 $\times$ BSECT CP-1) $\times$ 99HS-18 and 96AC-93 $\times$ 99HS-18 exhibited significant positive sca effects in all the three environments. The crosses G73-107 $\times$ 96AC-93, CVJ-2-5-3-1-3 $\times$ 96AC-93 and 1305 $\times$ Togo-II in environment-I and II while, the four crosses H77/833-2 $\times$ Togo-II, H77/833-2 $\times$ 99HS-18, G73-107 $\times$ 77/245 and 1305 $\times$ 99HS-18 in environment-II and III tend to show high significant sca effects in two environments. Also, the cross 77/245 $\times$ 99HS-18 in environment-I, the crosses H77/29-2 $\times$ CVJ-2-5-3-1-3 and H77/29-2 $\times$ Togo-II in environment-II and the crosses H77/833-2 $\times$ CVJ-2-5-3-1-3, H77/833-2 $\times$ Togo-II, H77/29-2 $\times$ 1305, G73-107 $\times$ Togo-II, CVJ-2-5-3-1-3 $\times$ 1305 and Togo-II $\times$ 99HS-18 in environment-III were good specific cross combinations for ear length

Table 28a: Estimates of gca and sca effects for ear length (cm) (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		1.196	0.776	−0.273	0.758	1.932*	−0.392	−0.607	−0.655	1.175
H77/29-2			−0.733	0.024	0.353	1.007	0.432	1.583	0.925	0.219
G73-107				−1.027	0.439	0.616	−0.369	1.666*	0.928	0.499
77/245					0.250	−0.507	0.682	−0.253	3.529**	2.033*
CVJ-2-5-3-1-3						0.982	0.211	2.579**	−1.916*	−0.878
1305							−0.019	−1.567	3.738**	0.679
77/371× BSECT CP-1								2.645**	−1.160	1.797*
96AC-93									−0.028	1.656*
Togo-II										−0.476
99HS-18										
gca effects	−0.726*	−0.193	0.787**	−1.180**	2.194**	1.057**	−0.812**	−1.096**	0.828**	−0.859**
Parental Means	16.417	16.933	20.000	15.233	22.823	18.507	16.287	13.793	19.037	14.753

* *Significant at P* = *0.05*

** *Significant at P* = *0.01*

Table 28b: Estimates of gca and sca effects for ear length (cm) (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-0.023	-0.305	0.812	-0.100	2.392**	-1.186	0.432	1.699*	3.020**
H77/29-2			-0.666	0.367	1.471*	1.097	1.085	1.090	1.641*	-0.541
G73-107				1.588*	0.159	1.212	0.590	1.735*	0.182	0.110
77/245					0.032	-0.475	0.299	-1.002	3.255**	1.129
CVJ-2-5-3-1-3						-0.210	-1.583*	1.702*	0.567	-0.213
1305							0.504	-0.938	1.829*	2.850**
77/371× BSECT CP-1								2.603**	0.951	1.448*
96AC-93									-1.051	1.653*
Togo-II										-1.506*
99HS-18										
gca effects	-0.711**	-0.266	0.562*	-1.077**	3.185**	1.092**	-1.329**	-1.581**	1.445**	-1.319**
Parental Means	16.667	18.167	20.283	16.303	26.917	19.513	16.447	15.187	20.567	14.847

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 28c: Estimates of gca and sca effects for ear length (cm) (environment–III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		0.140	−0.878	0.111	1.914*	2.187*	0.023	−0.041	0.222*	2.393**
H77/29-2			−1.233	0.562	1.532	2.032*	0.658	0.934	1.083	−0.889
G73-107				2.028*	−0.132	1.485	0.683	1.393	1.875*	0.693
77/245					1.087	−1.003	0.062	0.938	2.504**	1.082
CVJ-2-5-3-1-3						3.000**	−2.454**	0.908	1.114	−1.985*
1305							−0.041	−1.932*	0.361	2.778**
77/371× BSECT CP-1								2.000*	1.250	1.771*
96AC-93									1.602	1.843*
Togo-II										2.319*
99HS-18										
gca effects	−1.264**	−0.549*	0.358	−1.020**	3.676**	0.983**	−1.849**	−1.592**	2.092**	−0.835**
Parental Means	17.443	19.500	20.767	17.280	27.867	20.540	17.333	16.000	21.027	16.333

* *Significant at P* = *0.05*

** *Significant at P* = *0.01*



Fig. 24a: Estimates of gca effects for ear length (cm) in environment-I



Fig. 24b: Estimates of gca effects for ear length (cm) in environment-II

List of parents	
Sr. no.	Genotypes
1.	H77/833-2
2.	H77/29-2
3.	G73-107
4.	77/245
5.	CVJ-2-5-3-1-3
6.	1305
7.	77/371× BSECT CP-1
8.	96AC-93
9.	Togo-II
10.	99HS-18

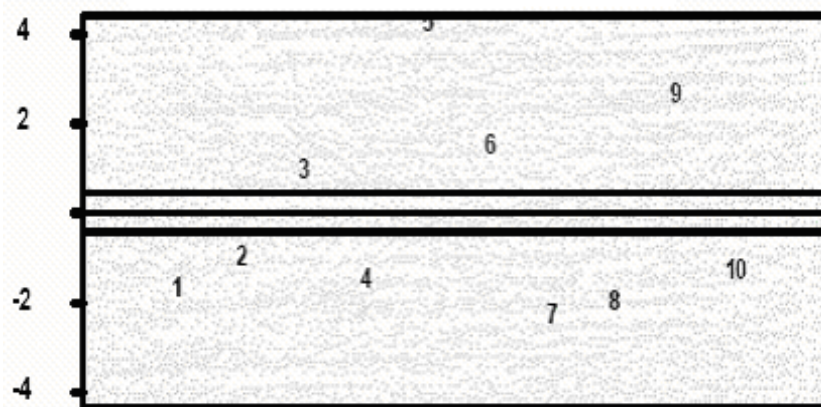


Fig. 24c: Estimates of gca effects for ear length (cm) in environment-III

Table 29a: Estimates of gca and sca effects for ear weight (g)/plant (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		1.615	11.080**	2.718	-1.982	13.535**	5.452*	5.652*	-0.693	5.459*
H77/29-2			-0.073	-8.675**	-0.545	22.355**	6.435**	11.245**	8.564*	5.273*
G73-107				-11.647**	8.197**	14.373**	6.396*	0.300	12.338**	-3.713
77/245					30.178**	11.938**	-3.225	16.982**	-10.380**	3.146
CVJ-2-5-3-1-3						-7.225**	12.288**	4.388	-4.417	-6.394*
1305							-4.879*	1.142	16.217**	5.295*
77/371× BSECT CP-1								-2.362	7.653**	-3.635
96AC-93									13.717**	-5.621*
Togo-II										10.917**
99HS-18										
gca effects	-1.583*	-3.204**	0.899	-3.073**	0.867	8.507**	-7.560**	1.880*	4.502**	-1.234
Parental Means	15.040	10.120	22.797	17.960	24.113	20.263	12.443	20.663	21.670	31.793

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 29b: Estimates of gca and sca effects for ear weight (g)/plant (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		−5.189**	−0.348	4.157*	14.343**	12.760**	5.190**	2.927	12.587**	5.956**
H77/29-2			−6.715**	0.526	5.258**	19.746**	7.702**	7.643**	4.656*	13.575**
G73-107				5.761**	6.900**	11.091**	0.924	16.668**	4.868**	5.667**
77/245					22.245**	4.635*	−14.222**	8.879**	7.489**	−5.372**
CVJ-2-5-3-1-3						−0.222	12.138**	−0.302	−10.948**	−12.826**
1305							3.248	−6.325**	21.162**	1.908
77/371× BSECT CP-1								6.048**	20.882**	−4.352
96AC-93									−2.677	−8.752**
Togo-II										8.502**
99HS-18										
gca effects	−0.773	−4.519**	0.417	0.355	1.749**	5.202**	−2.764**	0.118	5.235**	−5.021**
Parental Means	13.493	8.593	19.657	24.893	26.437	17.633	16.923	29.413	18.440	29.037

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 29c: Estimates of gca and sca effects for ear head weight (g)/plant (environment–III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		4.739*	–1.368	0.911	4.028	21.051**	8.322**	1.825	11.096**	2.295
H77/29-2			–9.815**	12.670**	–0.660	22.320**	8.460**	2.290	2.812	9.567**
G73-107				8.810**	2.156	9.783**	11.324**	9.990**	11.508**	17.457**
77/245					21.855**	2.229	–15.295**	8.159**	5.610*	–3.711
CVJ-2-5-3-1-3						8.065**	9.229**	8.082**	–5.613*	4.102
1305							4.122	–4.795*	10.320**	–1.561
77/371× BSECT CP-1								1.819	20.327**	–6.567**
96AC-93									15.560**	–2.681
Togo-II										2.017
99HS-18										
gca effects	–3.324**	–6.006**	2.341**	–0.361	3.135**	3.245**	–4.325**	1.318	6.017**	–2.039**
Parental Means	15.263	10.157	23.120	27.020	29.010	19.083	18.840	30.873	23.577	33.823

* *Significant at P* = 0.05

** *Significant at P* = 0.01

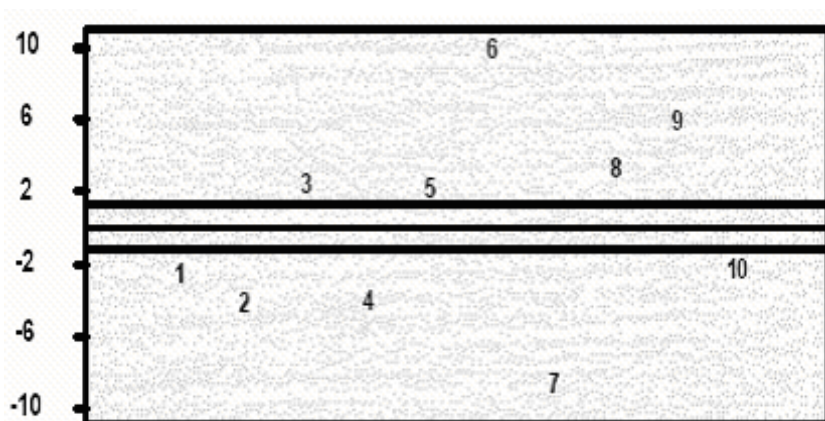
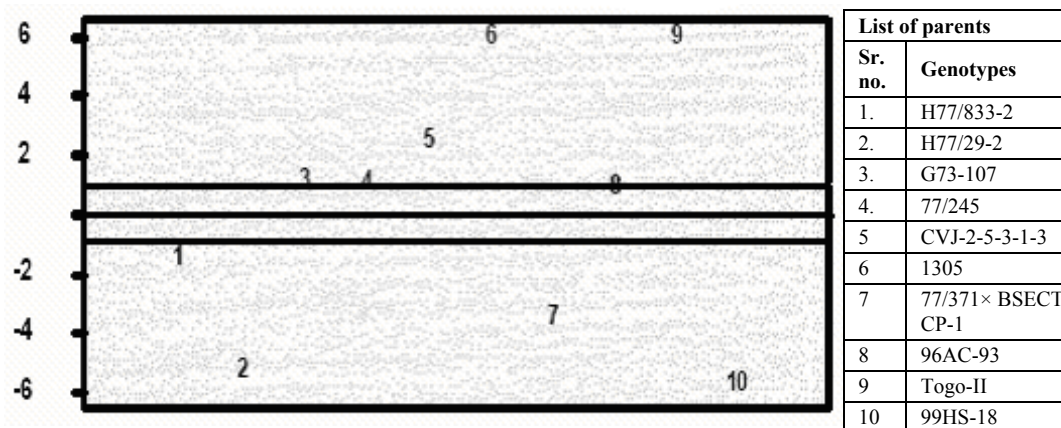


Fig. 25a: Estimates of gca effects for ear weight (g)/plant in environment-I



List of parents	
Sr. no.	Genotypes
1.	H77/833-2
2.	H77/29-2
3.	G73-107
4.	77/245
5	CVJ-2-5-3-1-3
6	1305
7	77/371× BSECT CP-1
8	96AC-93
9	Togo-II
10	99HS-18

Fig. 25b: Estimates of gca effects for ear weight (g)/plant in environment-II



Fig. 25c: Estimates of gca effects for ear weight (g)/plant in environment-III

xiii) Ear weight (g)/plant

Positive and significant gca effects were recorded for the parents 1305 and Togo-II for ear weight (g)/plant in all the three environments. The parent CVJ-2-5-3-1-3 exhibited significant positive gca effects in environment-II and III, also, the parents 96AC-93 in environment-I and G73-107 in environment-III were associated with significant and positive gca effects (figure 25a-c).

On the contrary, H77/29-2 and (77/371 $\times$ BSECT CP-1) in all the three environments, H77/833-2 in environment-I and III, and 99HS-18 in environment-II and III had significant but negative effects, indicating that these were poor combiners for Ear weight (g)/plant.

The sca effects of crosses for Ear weight/plant are presented in table 29a-c. The twelve cross combinations, namely, H77/833-2 $\times$ 1305, H77/833-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/29-2 $\times$ 1305, H77/29-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/29-2 $\times$ 99HS-18, G73-107 $\times$ 1305, G73-107 $\times$ Togo-II, 77/245 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ 96AC-93, CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1), 1305 $\times$ Togo-II and (77/371 $\times$ BSECT CP-1) $\times$ Togo-II showed significant and positive sca effects consistently over all the three environments. The six crosses, viz., H77/833-2 $\times$ 99HS-18, H77/29-2 $\times$ 96AC-93, H77/29-2 $\times$ Togo-II, G73-107 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ 1305 and Togo-II $\times$ 99HS-18 in environment-I and II, two crosses, i.e., G73-107 $\times$ (77/371 $\times$ BSECT CP-1) and 96AC-93 $\times$ Togo-II in environment-I and III, while, the five cross combinations, namely,

H77/833-2 Togo-II, G73-107 $\times$ 77/245, G73-107 $\times$ 96AC-93, G73-107 $\times$ 99HS-18 and 77/245 $\times$ Togo-II in environment-II and III showed the consistency over the two environments for the positive significant sca effects for Ear weight (g)/plant.

In addition, three crosses, i.e., H77/833-2 $\times$ G73-107, H77/833-2 $\times$ 96AC-93 and 1305 $\times$ 99HS-18 in environment-I, four cross combinations, viz., H77/833-2 $\times$ 77/245, H77/833-2 $\times$ CVJ-2-5-3-1-3, H77/29-2 $\times$ CVJ-2-5-3-1-3 and (77/371 $\times$ BSECT CP-1) $\times$ 96AC-93 in environment-II and four crosses, namely, H77/833-2 $\times$ H77/29-2, H77/29-2 $\times$ 77/245, 77/245 $\times$ CVJ-2-5-3-1-3 and CVJ-2-5-3-1-3 $\times$ 1305 in environment-III also showed the positive and significant sca effects for Ear weight (g)/plant.

xiv) Dry fodder yield (g) / plant

The parents CVJ-2-5-3-1-3, 1305 and Togo-II appeared to be good general combiners as indicated by significant positive gca effects in all the environments (E_1 , E_2 and E_3). While, the parent G73-107 also showed significant and positive gca effects in environment-II and III (table 30a-c).

The parents H77/833-2, H77/29-2, (77/371 $\times$ BSECT CP-1), 96AC-93 and 99HS-18 were found to be consistently poor cross combiners in all the environments for dry fodder yield (g)/plant (figure 26a-c).

Table 30a: Estimates of gca and sca effects for dry fodder yield (g)/plant (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		3.067	−8.536*	0.107	17.913**	51.725**	4.874	−4.682	24.295**	14.170**
H77/29-2			−8.606*	−4.373	7.503*	38.291**	17.647**	9.148*	−7.792*	12.593**
G73-107				21.967**	−11.458**	16.191**	24.557**	11.285**	14.031**	37.496**
77/245					46.199**	8.811*	−21.863**	28.265**	11.072**	−10.427**
CVJ-2-5-3-1-3						18.220**	13.029**	16.551**	7.631*	3.256
1305							10.811**	−5.558	2.399	9.991**
77/371× BSECT CP-1								2.755	37.578**	−9.083*
96AC-93									51.926**	−22.909**
Togo-II										5.441
99HS-18										
gca effects	−7.841**	−13.454**	0.216	−0.434	11.507**	13.515**	−2.788*	−3.289**	11.758**	−9.190**
Parental Means	27.830	34.330	46.947	54.230	58.570	46.567	49.250	45.010	45.203	56.333

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 30b: Estimates of gca and sca effects for dry fodder yield (g)/plant (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		0.702	-3.896	8.984**	16.157**	55.150**	-3.557	-10.450**	14.826**	15.470**
H77/29-2			-12.585**	4.362	14.005**	34.705**	6.431*	3.732	-9.489**	19.268**
G73-107				22.466**	-0.207	6.179*	22.359**	20.147**	12.672**	23.673**
77/245					26.463**	12.269**	-26.431**	5.183*	16.826**	-3.954
CVJ-2-5-3-1-3						10.325**	11.832**	11.216**	3.235	15.629**
1305							12.268**	-11.594**	8.932**	-6.165*
77/371× BSECT CP-1								6.226*	37.688**	-16.845**
96AC-93									50.926**	-14.254**
Togo-II										5.819*
99HS-18										
gca effects	-5.064**	-11.109*	2.383**	0.363	10.907**	12.150**	-7.026**	-4.677**	12.154**	-10.080**
Parental Means	24.050	28.087	40.233	48.513	48.357	44.137	41.833	40.950	34.460	41.390

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 30c: Estimates of gca and sca effects for dry fodder yield (g)/plant (environment–III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		5.976*	−12.968**	6.810*	11.003**	47.878**	3.353	−1.469	17.359**	10.367**
H77/29-2			−16.374**	15.737**	1.074	46.476**	10.517**	7.732*	−16.474**	16.594**
G73-107				14.537**	9.303**	16.495**	19.983**	15.115**	24.989**	33.734**
77/245					44.124**	8.913**	−32.029**	13.443**	21.320**	−12.015**
CVJ-2-5-3-1-3						11.956**	11.987**	14.759**	−0.247	14.761**
1305							8.959**	−19.172**	12.451**	−0.164
77/371× BSECT CP-1								6.179*	44.656**	−19.542**
96AC-93									47.585**	−12.260**
Togo-II										0.743
99HS-18										
gca effects	−8.067**	−12.544**	4.036**	−0.615	11.486**	12.450**	−7.621**	−4.193**	14.303**	−9.235**
Parental Means	26.340	25.910	42.293	44.980	50.240	44.633	44.353	42.287	39.043	52.050

* Significant at $P = 0.05$

** Significant at $P = 0.01$

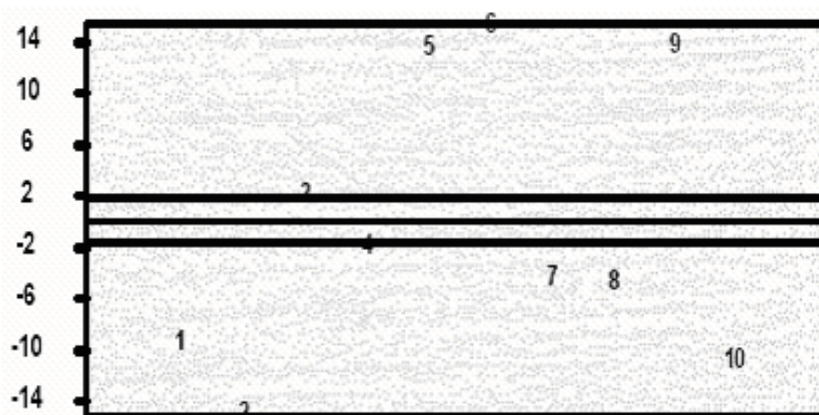
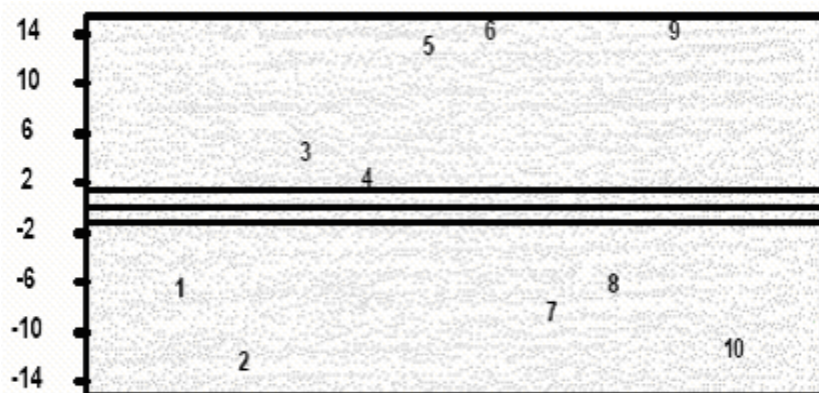


Fig. 26a: Estimates of gca effects for dry fodder yield/plant in environment-I



List of parents	
Sr. no.	Genotypes
1.	H77/833-2
2.	H77/29-2
3.	G73-107
4.	77/245
5	CVJ-2-5-3-1-3
6	1305
7	77/371× BSECT CP-1
8	96AC-93
9	Togo-II
10	99HS-18

Fig. 26b: Estimates of gca effects for dry fodder yield/plant in environment-II



Fig. 26c: Estimates of gca effects for dry fodder yield/plant in environment-III

Table 31a: Estimates of gca and sca effects for grain yield (g)/plant (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-1.332	7.931**	1.784	-0.996	7.703**	5.675**	-0.514	-2.038	7.404**
H77/29-2			4.381**	-7.806**	0.891	11.097**	0.399	12.603**	9.183**	1.165
G73-107				-9.840**	7.067**	9.753**	0.278	0.036	11.102**	-4.543**
77/245					19.380**	13.416**	0.318	11.938**	-10.285**	8.023**
CVJ-2-5-3-1-3						-6.964**	8.228**	4.532**	-0.765	-5.910**
1305							-4.756**	1.228	9.921**	6.396**
77/371× BSECT CP-1								-0.763	1.603	-1.415
96AC-93									7.967**	-0.528
Togo-II										10.515**
99HS-18										
gca effects	-1.966**	-1.660**	0.398	-2.075**	-0.155	6.742**	-7.030**	1.496**	3.240**	1.008*
Parental Means	8.357	6.487	12.810	7.483	12.057	14.683	6.253	9.840	12.977	16.560

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 31b: Estimates of gca and sca effects for grain yield (g)/plant (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		−7.836**	−1.776	5.141**	15.986**	7.149**	5.746**	−2.035	10.007**	7.000**
H77/29-2			−5.191**	−2.697*	6.451**	13.811**	4.061**	10.474**	3.219*	11.165**
G73-107				2.930*	7.272**	8.284**	−3.086*	16.994**	3.886**	2.702*
77/245					17.352**	4.862**	−11.148**	7.271**	6.723**	−0.335
CVJ-2-5-3-1-3						−2.763*	9.417**	0.236	−8.582**	−10.783**
1305							3.879**	−7.138**	22.391**	2.207
77/371× BSECT CP-1								8.742**	14.577**	−2.320*
96AC-93									−7.336**	−3.480**
Togo-II										8.191**
99HS-18										
gca effects	−0.998*	−3.223**	−0.716	0.277	0.752	5.279**	−1.645**	−0.814*	4.391**	−3.302**
Parental Means	7.453	5.967	11.700	14.643	13.350	13.357	10.917	15.647	11.383	15.363

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 31c: Estimates of gca and sca effects for grain yield (g)/plant (environment–III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		2.202	–5.625**	1.956	5.949**	18.677**	1.980	1.199	8.887**	4.032**
H77/29-2			–8.019**	8.265**	–0.238	21.480**	4.897**	3.222*	–5.026	9.155**
G73-107				6.062**	3.642**	7.956**	8.103**	8.088**	11.303**	16.608**
77/245					19.483**	2.104	–11.833**	6.903**	7.175**	–5.160**
CVJ-2-5-3-1-3						4.734**	5.961**	6.646**	–2.669*	6.920**
1305							4.545**	–7.686**	7.549**	1.384
77/371× BSECT CP-1								2.750*	18.422**	–7.036**
96AC-93									17.131**	–6.404**
Togo-II										–0.525
99HS-18										
gca effects	–3.210**	–5.326**	1.781**	–0.110	3.886**	5.315**	–3.201**	–1.213**	5.505**	–3.427**
Parental Means	9.083	6.510	14.633	17.433	17.690	15.390	14.833	16.780	15.017	18.790

* *Significant at P* = 0.05

** *Significant at P* = 0.01

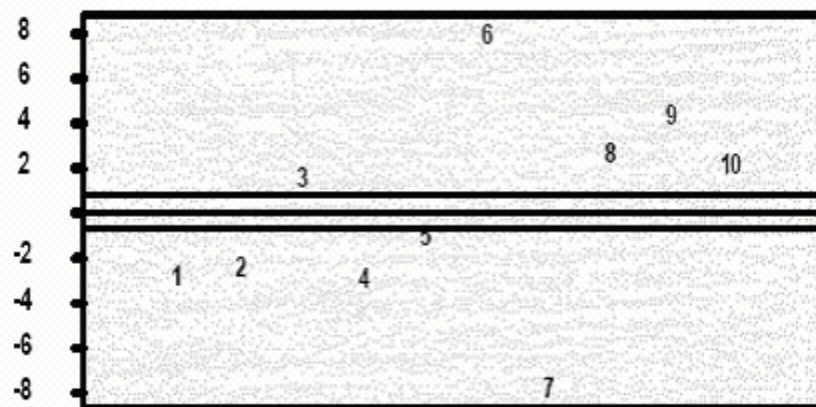
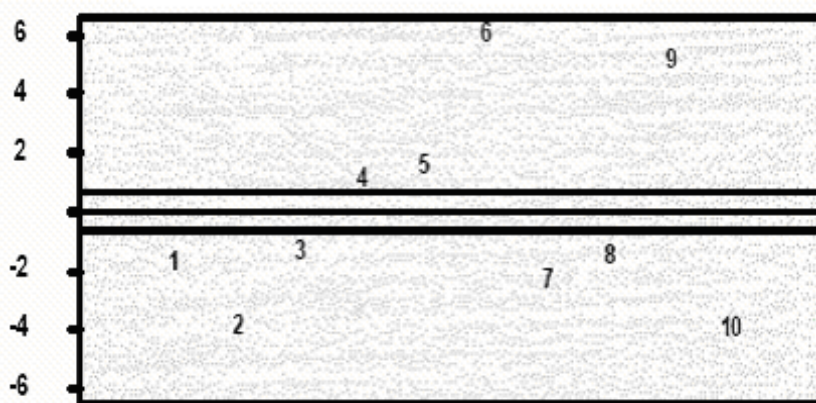


Fig. 27a: Estimates of gca effects for grain yield/plant in environment-I



List of parents	
Sr. no.	Genotypes
1.	H77/833-2
2.	H77/29-2
3.	G73-107
4.	77/245
5.	CVJ-2-5-3-1-3
6.	1305
7.	77/371× BSECT CP-1
8.	96AC-93
9.	Togo-II
10.	99HS-18

Fig. 27b: Estimates of gca effects for grain yield/plant in environment-II



Fig. 27c: Estimates of gca effects for grain yield/plant in environment-III

A consideration of sca effects revealed that out of 45 cross combinations, 23 crosses exhibited significant positive sca effects in all the three environments.

The cross $H77/29-2 \times CVJ-2-5-3-1-3$ in environment-I and II, the cross $H77/29-2 \times 96AC-93$ in environment-I and III showed significant positive sca effects. Other than those mentioned above, two crosses, $CVJ-2-5-3-1-3 \times Togo-II$ and $1305 \times 99HS-18$ in environment-II and three crosses, namely, $H77/833-2 \times H77/29-2$, $H77/29-2 \times 77/245$ and $G73-107 \times CVJ-2-5-3-1-3$ also showed significant and positive sca effects for dry fodder yield (g)/plant.

Similarly, five cross combinations, viz., $H77/29-2 \times G73-107$, $H77/29-2 \times Togo-II$, $77/245 \times (77/371 \times BSECT\ CP-1)$, $(77/371 \times BSECT\ CP-1) \times 99HS-18$ and $96AC-93 \times 99HS-18$ showed consistency for the significant but negative sca effects in all the three environments for dry fodder yield (g)/plant.

xv) Grain yield (g)/plant

The estimate of general combining ability (gca) effects in respect of grain yield/plant (table 31a-c) indicated that parents 1305 and Togo-II exhibited high positive gca effects in all the three environments. While, the parents, 96AC-93 and 99HS-18 in environment-I and the parents $G73-107$ and $CVJ-2-5-3-1-3$ in environment-III also significant positive gca effects.

On the contrary, the parents, $H77/833-2$, $H77/29-2$ and $(77/371 \times BSECT\ CP-1)$ were found to be consistently poor combiners

in all the three environments (E_1 , E_2 and E_3) while, the parents 96AC-93 and 99HS-18 in environment–II and III showed significant but negative gca effects in two environments for grain yield (g)/plant (figure 27a-c).

Significant positive sca effects in all the three environments for this trait were exhibited by eleven cross combinations, namely, H77/833-2 $\times$ 1305, H77/833-2 $\times$ 99HS-18, H77/29-2 $\times$ 1305, H77/29-2 $\times$ 96AC-93, G73-107 $\times$ CVJ-2-5-3-1-3, G73-107 $\times$ 1305, G73-107 $\times$ Togo-II, 77/245 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ 96AC-93, CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1) and 1305 $\times$ Togo-II. However, four crosses, namely, H77/833-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/29-2 $\times$ Togo-II, 77/245 $\times$ 1305 and Togo-II $\times$ 99HS-18 in environment–I and II (stress environments), two cross combinations viz., CVJ-2-5-3-1-3 $\times$ 96AC-93 and 96AC-93 $\times$ Togo-II in environment–I and III and eleven crosses, namely, H77/833-2 $\times$ CVJ-2-5-3-1-3, H77/833-2 $\times$ Togo-II, H77/29-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/29-2 $\times$ 99HS-18, G73-107 $\times$ 77/245, G73-107 $\times$ 96AC-93, G73-107 $\times$ 99HS-18, 77/245 $\times$ Togo-II, 1305 $\times$ (77/371 $\times$ BSECT CP-1), (77/371 $\times$ BSECT CP-1) $\times$ 96AC-93 and (77/371 $\times$ BSECT CP-1) $\times$ Togo-II in environment–II and III showed consistency for positive significant sca effects in two environments. However, four crosses, viz., H77/833-2 $\times$ G73-107, H77/29-2 $\times$ G73-107, 77/245 $\times$ 99HS-18 and 1305 $\times$ 99HS-18 in environment–I, two cross combinations, viz., H77/833-2 $\times$ 77/245 and H77/29-2 $\times$ CVJ-2-5-3-1-3 in environment–II and four crosses, namely, H77/29-2 $\times$ 77/245, G73-107 $\times$ (77/371 $\times$ BSECT CP-1),

CVJ-2-5-3-1-3 $\times$ 1305 and CVJ-2-5-3-1-3 $\times$ 99HS-18 in environment–III exhibited significant and positive sca effects for grain yield (g)/plant.

On the other hand, three cross combinations, namely, H77/29-2 $\times$ 77/245, CVJ-2-5-3-1-3 $\times$ 1305 and CVJ-2-5-3-1-3 $\times$ 99HS-18 in environment–I and II and five crosses, viz., H77/29-2 $\times$ G73-107, 77/245 $\times$ (77/371 $\times$ BSECT CP-1), CVJ-2-5-3-1-3 $\times$ Togo-II, 1305 $\times$ 96AC-93, (77/371 $\times$ BSECT CP-1) $\times$ 99HS-18 and 96AC-93 $\times$ 99HS-18 in environment–II and III showed significant negative sca effects in two environments for grain yield (g)/plant.

xvi) Total biological yield (g)/plant

The data for gca effects for each of the parents (table 32a-c) showed that the parents CVJ-2-5-3-1-3 , 1305 and Togo-II were the most desirable parents in respect of the total biological yield/plant (excluding roots) since they possessed consistently high positive gca effects under all the environments. The parent G73-107 showed significant positive gca effects in environment–II and III. Whereas, the parents, H77/833-2, H77/29-2, (77/371 $\times$ BSECT CP-1) and 99HS-18 were poor general combiners in all the three environments for total biological yield/plant (excluding roots). While, the parent 96AC-93 in environment–II and III showed significant negative gca effects (figure 28a-c).

The magnitude of sca effects for total biological yield (g)/plant revealed that 23 cross combinations exhibited significant positive sca

Table 32a: Estimates of gca and sca effects for total biological yield (g)/plant (environment-I)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		4.683	2.543	2.826	15.934**	65.264**	10.321*	0.966	23.601**	19.629**
H77/29-2			-8.679*	-13.046**	6.958	60.638**	24.082**	20.397**	0.772	17.867**
G73-107				10.317*	-3.265	30.561**	30.962**	11.584**	26.369**	33.780**
77/245					76.377**	20.751**	-25.089**	45.247**	0.692	-7.281
CVJ-2-5-3-1-3						11.002*	25.319**	20.941**	3.212	-3.140
1305							5.932	-4.416	18.612**	15.287**
77/371× BSECT CP-1								0.395	45.230**	-12.716**
96AC-93									65.645**	-28.531**
Togo-II										16.361**
99HS-18										
gca effects	-9.425**	-16.659**	1.115	-3.508*	12.374**	22.021**	-10.346**	-1.408	16.260**	-10.424**
Parental Means	42.870	44.450	69.747	72.190	82.683	66.830	61.693	65.673	66.877	88.127

* *Significant at P* = 0.05

** *Significant at P* = 0.01

Table 32b: Estimates of gca and sca effects for total biological yield (g)/plant (environment-II)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		-4.490	-4.240	13.140**	30.500**	67.910**	1.633	-7.520*	27.415**	21.424**
H77/29-2			-19.300**	4.891	19.264**	54.451**	14.130**	11.374**	-4.831	32.844**
G73-107				28.227**	6.690*	17.271**	23.280**	36.814**	17.535**	29.341**
77/245					48.707**	16.904**	-40.653**	14.057**	24.319**	-9.326**
CVJ-2-5-3-1-3						10.110**	23.970**	10.914**	-7.715**	2.801
1305							15.520**	-17.916**	30.089**	-4.259
77/371× BSECT CP-1								12.274**	58.572**	-21.199**
96AC-93									48.249**	-23.006**
Togo-II										14.322**
99HS-18										
gca effects	-5.837**	-15.628**	2.799*	0.719	12.656**	17.352**	-9.791**	-4.558**	17.388**	-15.101**
Parental Means	37.540	36.680	59.890	73.407	74.793	61.767	58.757	70.367	52.900	70.427

* *Significant at P = 0.05*

** *Significant at P = 0.01*

Table 32c: Estimates of gca and sca effects for total biological yield (g)/plant (environment–III)

Parents	H77/833-2	H77/29-2	G73-107	77/245	CVJ-2-5-3-1-3	1305	77/371× BSECT CP-1	96AC-93	Togo-II	99HS-18
H77/833-2		10.716*	−14.335**	7.718	15.028**	68.927**	11.678**	0.353	28.462**	12.659**
H77/29-2			−26.189**	28.408**	0.410	68.796**	18.978**	10.026*	−13.662**	26.159**
G73-107				23.350**	11.459**	26.282**	31.310**	25.098**	36.493**	51.194**
77/245					65.979**	11.142*	−47.323**	21.601**	26.927**	−15.729**
CVJ-2-5-3-1-3						20.021**	21.213**	22.844**	−5.864	18.867**
1305							13.078**	−23.970**	22.772**	−1.721
77/371× BSECT CP-1								8.005*	64.980**	−26.106**
96AC-93									63.148**	−14.941**
Togo-II										2.761
99HS-18										
gca effects	−11.391**	−18.551**	6.377**	−0.976	14.621**	15.695**	−11.946**	−2.874*	20.320**	−11.274**
Parental Means	41.603	36.067	65.413	72.000	79.253	63.717	63.190	73.160	62.620	85.870

* *Significant at P* = 0.05

** *Significant at P* = 0.01

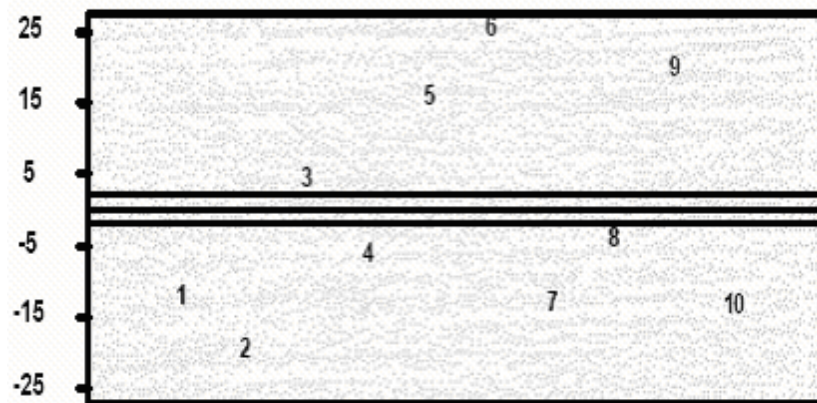


Fig. 28a: Estimates of gca effects for total biological yield/plant in environment-I

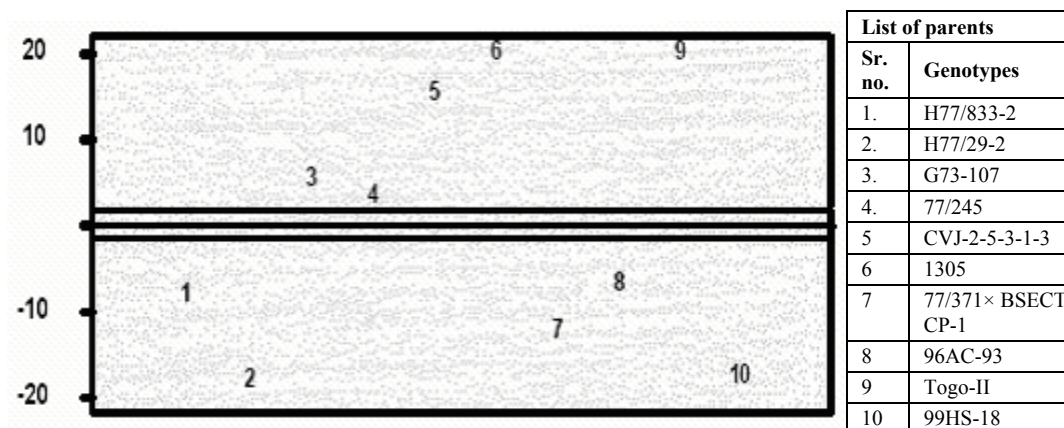


Fig. 28b: Estimates of gca effects for total biological yield/plant in environment-II

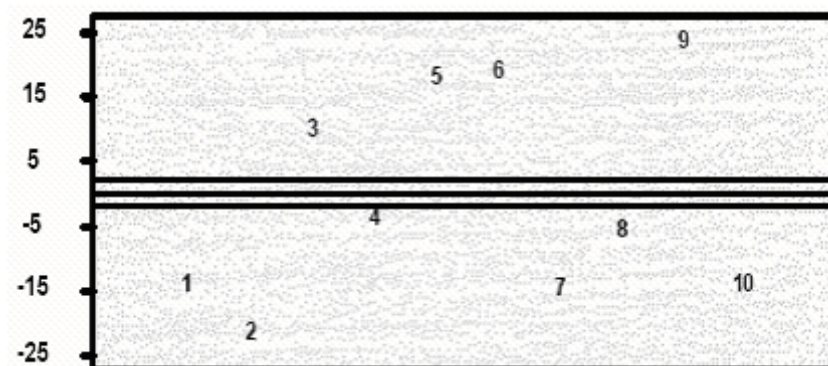


Fig. 28c: Estimates of gca effects for total biological yield/plant in environment-III

effects in all the three environments. The cross combination Togo-II $\times$ 99HS-18 was also of equally good value for its specific performance in stress environments. One cross H77/833-2 $\times$ (77/371 $\times$ BSECT CP-1) environment-I and III and four crosses, namely, G73-107 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ Togo-II, 1305 $\times$ (77/371 $\times$ BSECT CP-1) and (77/371 $\times$ BSECT CP-1) $\times$ 96AC-93 in environment-II and III showed positive significant sca effects in two environments. Also, the cross 1305 $\times$ Togo-II in environment-I, two crosses, H77/833-2 $\times$ 77/245 and H77/29-2 $\times$ CVJ-2-5-3-1-3 in environment-II and three cross combinations, namely, H77/833-2 $\times$ H77/29-2, H77/29-2 $\times$ 77/245 and CVJ-2-5-3-1-3 $\times$ 99HS-18 in environment-III were good specific cross combinations for total biological yield/plant.

However, four cross combinations, namely, H77/29-2 $\times$ G73-107, 77/245 $\times$ (77/371 $\times$ BSECT CP-1), (77/371 $\times$ BSECT CP-1) $\times$ 99HS-18 and 96AC-93 $\times$ 99HS-18 were identified as the poor specific cross combinations in all the three environments and two crosses i.e., 77/245 $\times$ 99HS-18 and 1305 $\times$ 96AC-93 in environment-II and III also showed significant but negative sca effects for total biological yield/plant.

4.2.4.3.2 Analysis of genetic components

The nature of genetic variance could be revealed by studying the $\sigma^2_{gca}/\sigma^2_{sca}$ ratio (table 33). This ratio was low for all the characters i.e. seedling thermo-tolerance index (STI), seed to seedling thermo-tolerance index (SSTI), germination (%), emergence rate (ER),

number of leaves/seedling, seedling height, seedling fresh weight (g), seedling dry weight (g), panicle emergence, number of effective tillers/plant, plant height, ear length, ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant in all the three environments, indicating that non-additive genetic variance (dominance variance) was mainly responsible in the inheritance of these characters. The additive and dominance components were calculated and used for the estimation of heritability in broad sense as well as narrow sense.

The magnitude of dominance component of variance was higher than additive variance for STI and SSTI. This would confirm most characters were predominantly under the control of non-additive variance and hybrids could be expected by proper use of dominance variance. However, the reverse was true for panicle emergence (environment-I) and ear length (environment-II and III) where there was a preponderance of additive genetic advance. Here the pedigree breeding for these two characters would expect to be more successful. The additive and dominance components were equally important for ear length in environment-I. The magnitude of dominance variance (σ^2_D) was higher than that of the additive variance (σ^2_A) for germination (%), emergence rate (ER), number of leaves/seedling, seedling height, seedling fresh weight (g), seedling dry weight (g), panicle emergence (environment-II and III), number of effective tillers/plant, plant height, ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant,

Table 33: Genetic component (fixed effect model) for different characters in two environments

Genetic Components	STI (%)				SSTI (%)		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
$\sigma^2 g$ (gca var)	22.42082	19.53103	—		13.05396	8.88597	—
$\sigma^2 s$ (sca var)	64.94767	90.44021	—		48.69676	52.42861	—
$\sigma^2 e$ (Environmental Var)	3.91228	3.49835	—		2.24779	2.11857	—
$\sigma^2 A$ (Additive var)	44.84164	39.06207	—		26.10791	17.77194	—
$\sigma^2 D$ (Dominance var)	64.94767	90.44021	—		48.69676	52.42861	—
$\sigma^2 p$ (Phenotypic var)	113.70158	133.00063	—		77.05246	72.31912	—
h^2_{ns} (Narrow Sense)	0.39438	0.29370	—		0.33883	0.24574	—
h^2_{bs} (Broad Sense)	0.96559	0.97370	—		0.97083	0.97071	—
gca / sca ratio	0.34521	0.21596	—		0.26807	0.16949	—

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Contd...

Contd... table 33

Genetic Components	Germination (%)				Emergence rate		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
$\sigma^2 g$ (gca var)	7.71184	5.02875	6.76721		2.85697	0.62704	1.64616
$\sigma^2 s$ (sca var)	24.24787	26.58174	31.08947		20.44057	5.40766	11.07630
$\sigma^2 e$ (Environmental Var)	0.93728	1.11587	2.60969		4.52277	3.65680	3.61815
$\sigma^2 A$ (Additive var)	15.42368	10.05750	13.53442		5.71393	1.25407	3.29232
$\sigma^2 D$ (Dominance var)	24.24787	26.58174	31.08947		20.44057	5.40766	11.07630
$\sigma^2 p$ (Phenotypic var)	40.60883	37.75510	47.23358		30.67727	10.31854	17.98677
h^2_{ns} (Narrow Sense)	0.37981	0.26639	0.28654		0.18626	0.12154	0.18304
h^2_{bs} (Broad Sense)	0.97692	0.97044	0.94475		0.85257	0.64561	0.79884
gca / sca ratio	0.31804	0.18918	0.21767		0.13977	0.11595	0.14862

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Contd...

Contd... table 33

Genetic Components	No. of leaves/ seedling				Seedling height (cm)		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
$\sigma^2 g$ (gca var)	0.31556	0.21556	0.66156		0.40477	0.32644	0.53036
$\sigma^2 s$ (sca var)	3.48507	1.87323	9.09747		6.22798	5.63056	21.35111
$\sigma^2 e$ (Environmental Var)	0.13368	0.22547	0.46590		1.02154	0.53525	0.97108
$\sigma^2 A$ (Additive var)	0.63112	0.43112	1.32313		0.80953	0.65288	1.06071
$\sigma^2 D$ (Dominance var)	3.48507	1.87323	9.09747		6.22798	5.63056	21.35111
$\sigma^2 p$ (Phenotypic var)	4.24987	2.52982	10.88650		8.05905	6.81870	23.38290
h^2_{ns} (Narrow Sense)	0.14850	0.17042	0.12154		0.10045	0.09575	0.04536
h^2_{bs} (Broad Sense)	0.96854	0.91088	0.95720		0.87324	0.92150	0.95847
gca / sca ratio	0.09055	0.11507	0.07272		0.06499	0.05798	0.02484

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Contd...

Contd... table 33

Genetic Components	Fresh weight (g) /seedling				Dry weight (g) /seedling		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
σ^2 g (gca var)	6.97765	49.66017	83.43813		0.06219	0.39144	0.90478
σ^2 s (sca var)	51.45761	908.81542	1336.00961		1.10767	7.74581	11.51282
σ^2 e (Environmental Var)	0.62196	2.31538	10.06390		0.01845	0.02069	0.08001
σ^2 A (Additive var)	13.95530	99.32034	166.87626		0.12438	0.78287	1.80956
σ^2 D (Dominance var)	51.45761	908.81542	1336.00961		1.10767	7.74581	11.51282
σ^2 p (Phenotypic var)	66.03488	1010.45114	1512.94977		1.25050	8.54936	13.40239
h^2_{ns} (Narrow Sense)	0.21133	0.09829	0.11030		0.09947	0.09157	0.13502
h^2_{bs} (Broad Sense)	0.99058	0.99771	0.99335		0.98525	0.99758	0.99403
gca / sca ratio	0.13560	0.05464	0.06245		0.05615	0.05054	0.07859

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Contd...

Contd... table 33

Genetic Components	Panicle emergence (days)				Effective tillers/plant		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
$\sigma^2 g$ (gca var)	3.76745	1.49947	2.49017		0.03193	0.03148	0.03498
$\sigma^2 s$ (sca var)	5.69495	6.36936	23.41766		0.24638	0.18043	0.26257
$\sigma^2 e$ (Environmental Var)	1.56053	1.69199	2.32327		0.01636	0.01943	0.02628
$\sigma^2 A$ (Additive var)	7.53490	2.99894	4.98035		0.06385	0.06295	0.06995
$\sigma^2 D$ (Dominance var)	5.69495	6.36936	23.41766		0.24638	0.18043	0.26257
$\sigma^2 p$ (Phenotypic var)	14.79039	11.06029	30.72127		0.32659	0.26281	0.35880
h^2_{ns} (Narrow Sense)	0.50945	0.27114	0.16211		0.19551	0.23953	0.19496
h^2_{bs} (Broad Sense)	0.89449	0.84702	0.92438		0.94992	0.92606	0.92677
gca / sca ratio	0.66154	0.23542	0.10634		0.12958	0.17445	0.13320

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Contd...

Contd... table 33

Genetic Components	Plant height (cm)				Ear length (cm)		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
$\sigma^2 g$ (gca var)	65.36373	56.24022	43.00617		1.24811	2.34545	3.11203
$\sigma^2 s$ (sca var)	1135.18302	920.08188	644.15161		2.51638	3.52083	4.73360
$\sigma^2 e$ (Environmental Var)	12.30700	17.44707	18.59502		0.74870	0.49802	0.76203
$\sigma^2 A$ (Additive var)	130.72745	112.48044	86.01233		2.49623	4.69091	6.22406
$\sigma^2 D$ (Dominance var)	1135.18302	920.08188	644.15161		2.51638	3.52083	4.73360
$\sigma^2 p$ (Phenotypic var)	1278.21747	1050.00939	748.75896		5.76130	8.70976	11.71968
h^2_{ns} (Narrow Sense)	0.10227	0.10712	0.11487		0.43327	0.53858	0.53108
h^2_{bs} (Broad Sense)	0.99037	0.98338	0.97517		0.87005	0.94282	0.93498
gca / sca ratio	0.05758	0.06113	0.06676		0.49600	0.66616	0.65743

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Contd...

Contd... table 33

Genetic Components	Ear weight (g)/plant				Dry fodder yield (g)/plant		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
$\sigma^2 g$ (gca var)	19.37054	12.14603	14.46386		87.81626	81.85089	98.34763
$\sigma^2 s$ (sca var)	193.74660	209.40014	247.51952		991.70128	784.02772	949.48088
$\sigma^2 e$ (Environmental Var)	5.70477	3.18378	4.97005		11.66042	7.14137	8.58074
$\sigma^2 A$ (Additive var)	38.74109	24.29205	28.92773		175.63252	163.70178	196.69526
$\sigma^2 D$ (Dominance var)	193.74660	209.40014	247.51952		991.70128	784.02772	949.48088
$\sigma^2 p$ (Phenotypic var)	238.19245	236.87597	281.41729		1178.99423	954.87088	1154.75688
h^2_{ns} (Narrow Sense)	0.16265	0.10255	0.10279		0.14897	0.17144	0.17033
h^2_{bs} (Broad Sense)	0.97605	0.98656	0.98234		0.99011	0.99252	0.99257
gca / sca ratio	0.09998	0.05800	0.05844		0.08855	0.10440	0.10358

* Significant at $P = 0.05$

** Significant at $P = 0.01$

Contd...

Contd... table 33

Genetic Components	Grain yield (g)/plant				Total biological yield(g)/plant		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
$\sigma^2 g$ (gca var)	13.11423	8.08803	15.31695		165.25901	154.08431	183.73874
$\sigma^2 s$ (sca var)	102.93658	146.41978	181.68620		1885.54762	1671.03606	2145.20817
$\sigma^2 e$ (Environmental Var)	2.27450	1.54104	1.49863		16.91756	10.91296	17.29235
$\sigma^2 A$ (Additive var)	26.22845	16.17605	30.63390		330.51803	308.16863	367.47749
$\sigma^2 D$ (Dominance var)	102.93658	146.41978	181.68620		1885.54762	1671.03606	2145.20817
$\sigma^2 p$ (Phenotypic var)	131.43953	164.13687	213.81873		2232.98321	1990.11764	2529.97801
h^2_{ns} (Narrow Sense)	0.19955	0.09855	0.14327		0.14802	0.15485	0.14525
h^2_{bs} (Broad Sense)	0.98270	0.99061	0.99299		0.99242	0.99452	0.99317
gca / sca ratio	0.12740	0.05524	0.08430		0.08765	0.09221	0.08565

* Significant at $P = 0.05$

** Significant at $P = 0.01$

indicating that these characters were mainly under the control of dominance component of variance.

The estimates of heritability in broad-sense (h^2_{bs}) were quite high for all the characters studied. Whereas, the estimates of heritability in narrow-sense (h^2_{ns}) were high for panicle emergence (environment–I) and ear length (environment–II and III) and moderate for seedling thermo-tolerance index (STI), seed to seedling thermo-tolerance index (SSTI), germination (%), panicle emergence (environment–II) and ear length (environment–I). The remaining characters emergence rate (ER), number of leaves/seedling, seedling height, seedling fresh weight (g), seedling dry weight (g), panicle emergence (environment–III), number of effective tillers/plant, plant height, ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant in all the three environments manifested low estimates of narrow-sense heritability.

4.2.4.4 Hayman's model of diallel analysis

The analysis of diallel model was also carried according to two approaches applied by Hayman's (1954).

4.2.4.4.1 Graphical analysis (Hayman, 1954)

The graphical approach of analysis is mainly based on the information drawn for the $V_r - W_r$ graphs, which shows a regression between variance of progenies in a parental array and covariance between parents and offspring in that array (table 34) . The graphs would show

Table 34: Estimates of Y-intercept (a), slope (b) and test of additivity for presence of epistasis.

Parameters	Envi- ronments	Characters							
		STI (%)	SSTI (%)	Germination (%)	Rate of emergence	No. of leaves/seedling	Seedling height (cm)	Fresh weight (g)/seedling	Dry weight (g)/seedling
	E ₁	19.143	-18.387	0.318	-8.139	-0.001	-2.589	1.627	0.065
a (Y-intercept)	E ₂	35.774	2.584	4.629	-5.007	-0.275	-0.845	-57.254	-0.204
	E ₃	—	—	7.498	-4.193	-1.659	5.748	-415.419	-3.340
	E ₁	0.386	0.646	0.262	0.845	0.244	0.582	0.058	0.004
b (slope)	E ₂	0.111	0.222	0.089	0.589	0.408	0.409	0.078	0.035
	E ₃	—	—	-0.030	0.844	0.329	-0.347	0.453	0.462
	E ₁	0.430	0.393	15.251**	0.408	21.801**	0.693	21.982*	42.437*
T ²	E ₂	0.794	7.570**	14.022**	28.346**	3.852*	3.271	127.232**	111.262**
	E ₃	—	—	6.410*	0.946	22.913**	4.183*	7.527**	3.590
	E ₁	1.520	3.191*	2.440	6.747*	2.614	2.882*	0.589	0.059
H : b = 0	E ₂	0.431	1.554	0.759	10.011*	2.545	2.434	1.797	0.762
	E ₃	—	—	0.192	8.138	3.786*	2.128	3.690*	2.956
	E ₁	2.413*	1.746	6.870**	1.236	8.108*	2.074	9.606*	13.557*
H : b = 1	E ₂	3.456*	5.438*	7.739**	6.999*	3.699*	3.522*	21.250*	20.733*
	E ₃	—	—	6.525**	1.505	7.727*	8.261*	4.452*	3.448*

* Significant at P = 0.05

Contd...

** Significant at P = 0.01

Contd... Table:

Parameters	Envi- ronments	Characters							
		Panicle emergence (days)	Effective tillers/plant	Plant height (cm)	Ear length (cm)	Ear weight (g)/plant	Dry fodder yield (g)/plant	Grain yield (g)/plant	Total biological yield(g)/plant
a (Y-intercept)	E ₁	-0.175	-0.005	-189.659	0.307	-16.054	-112.560	-3.728	-213.492
	E ₂	0.511	-0.013	-376.404	2.234	-37.038	-60.613	-7.127	-196.041
	E ₃	-4.091	-0.053	-258.579	-0.229	-20.632	-18.586	-21.138	-55.432
b (slope)	E ₁	0.709	-0.004	0.343	0.689	0.156	0.186	0.153	0.185
	E ₂	0.175	0.140	0.679	0.575	0.204	0.135	0.071	0.172
	E ₃	0.344	0.142	0.652	0.856	0.166	0.064	0.190	0.073
T²	E ₁	5.849*	27.947**	9.481*	0.747	18.988*	9.900**	24.905*	8.997*
	E ₂	2.253	13.765**	3.828*	0.621	1.380	9.398**	6.141*	4.614*
	E ₃	0.259	0.008	4.226*	0.005	4.444*	4.264*	1.064	3.290
H : b = 0	E ₁	7.907	0.044	2.782	4.047*	1.521	1.414	1.673	1.360
	E ₂	0.840	1.197	6.068*	2.777	0.891	0.991	0.447	1.004
	E ₃	1.256	0.418	5.705*	4.465*	0.958	0.355	0.786	0.378
H : b = 1	E ₁	3.250*	11.326*	5.319*	1.830	8.249*	6.193*	9.293*	5.981*
	E ₂	3.971*	7.329*	2.863*	2.052	3.473*	6.361*	5.818*	4.835*
	E ₃	2.390*	2.532*	3.042*	0.750	4.806*	5.230*	3.357*	4.817*

* Significant at $P = 0.05$

** Significant at $P = 0.01$

the degree of dominance, parental order of dominance, genetic diversity of parents, genetic variance and the test of adequacy of assumption on epistasis. The graphs of variance of all the progenies in each parental array (V_r) and covariance between parents and their offspring in each array (W_r) graphs are presented in figure 29 to 44. In all these figures, array points for parents H77/833-2, H77/29-2, G73-107, 77/245, CVJ-2-5-3-1-3, 1305, (77/371 $\times$ BSECT CP-1), 96AC-93, Togo-II and 99HS-18 have been designated as 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10, respectively. The results pertaining to the individual character are described as under:

i) Seedling thermo-tolerance index (STI)

The diallel analysis for STI was conducted on two environments (E_1 and E_2). Coefficient of regression was significantly different from zero and non-significant from unity in both the environments (environment-I and II), indicating absence of epistasis. The V_r , W_r graphs (figure 29a-b) showed partial dominance in both the stress environments.

The parents 3, 5 (G73-107 and CVJ-2-5-3-1-3) in both the environments (E_1 and E_2) appeared to have an excess of dominant genes, while, the parents 1, 6 (H77/833-2 and 1305) had maximum of recessive genes. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them. The array points were found scattered along the regression line, indicating wide genetic diversity for seedling thermo-tolerance index (STI).

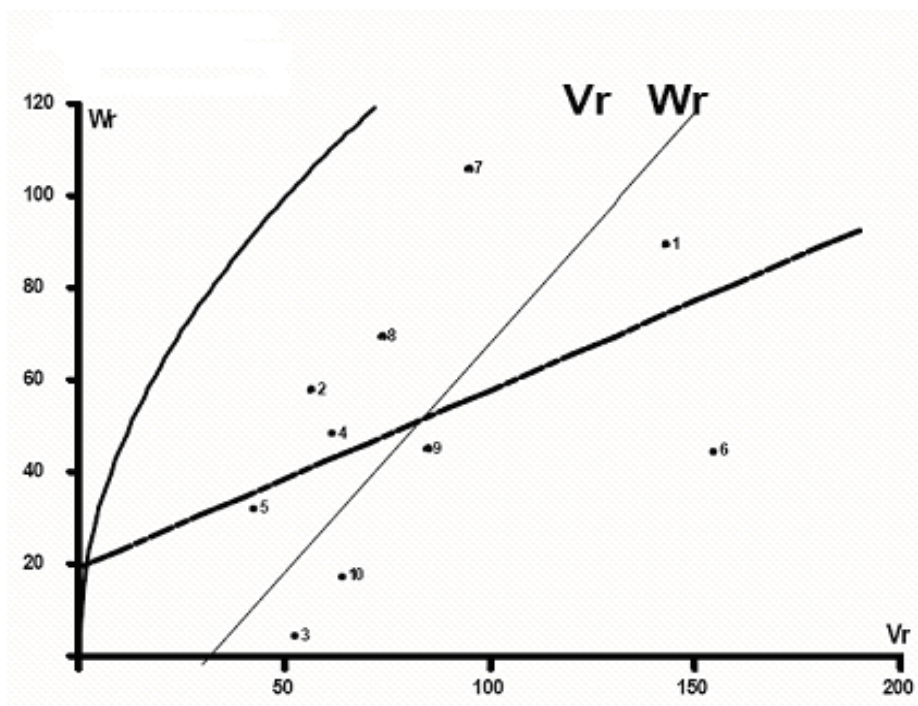


Fig. 29a: $V_r - W_r$ graph for STI in environment - I

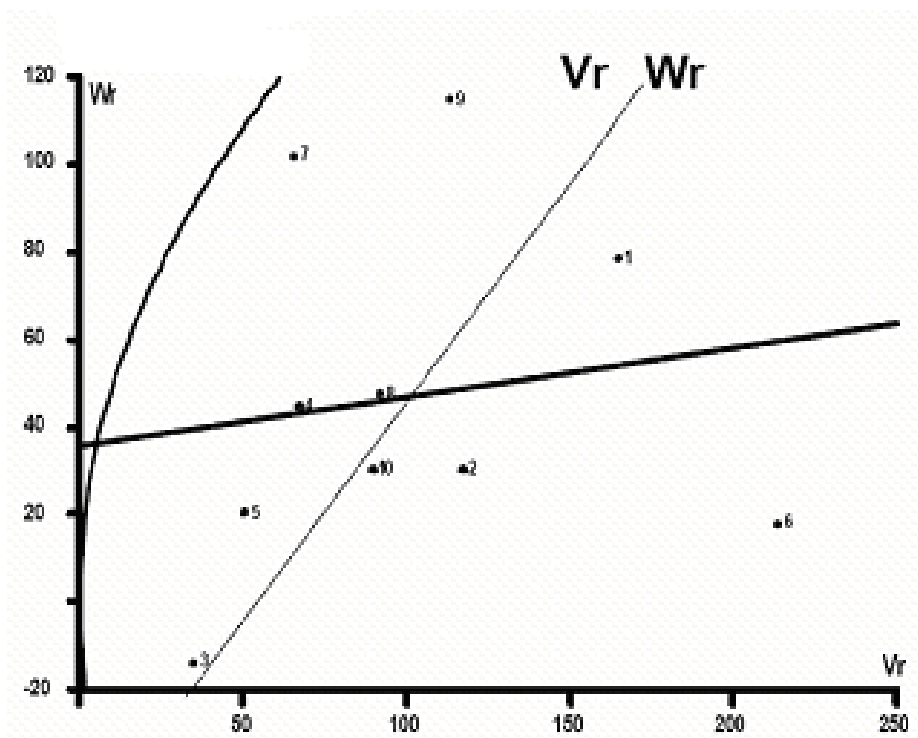


Fig. 29b: $V_r - W_r$ graph for STI in environment - II

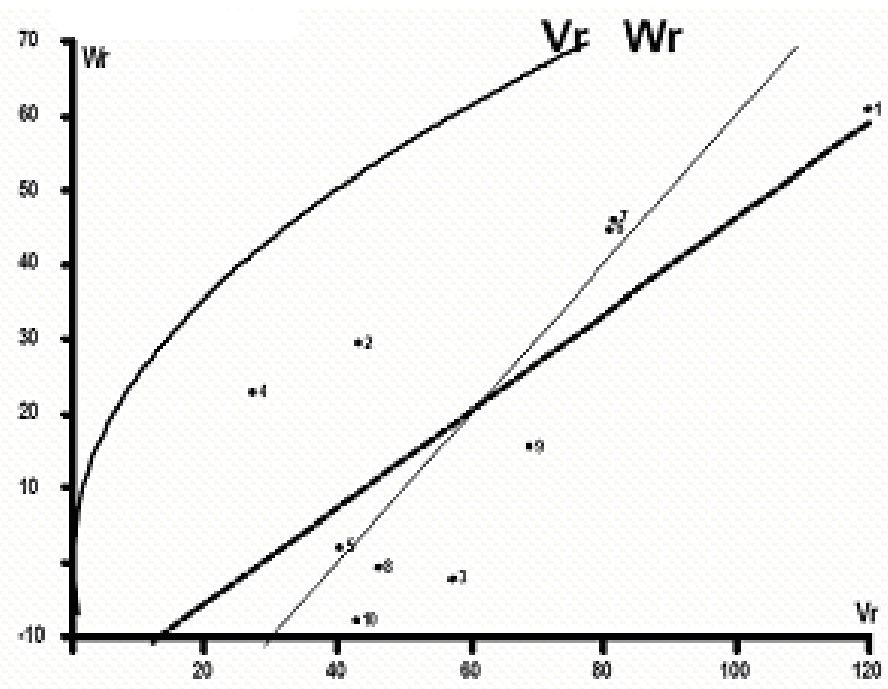


Fig. 30a: $V_r - W_r$ graph for SSTI in environment - I

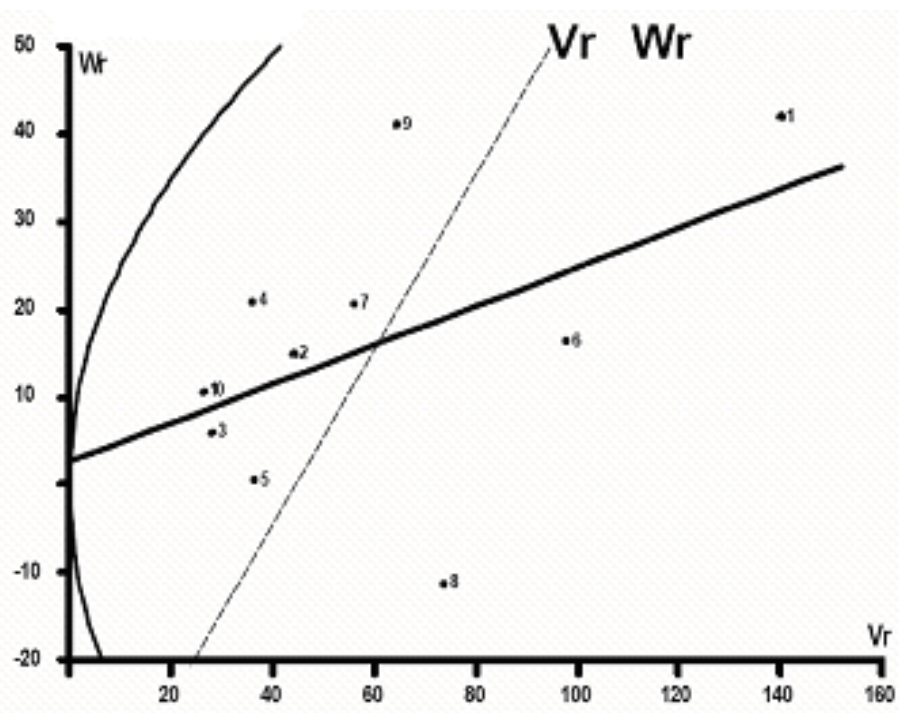


Fig. 30b: $V_r - W_r$ graph for SSTI in environment - II

ii) Seed to seedling thermo-tolerance index (SSTI)

In environment–I the coefficient of regression was not significantly different from zero as well as unity, indicating the possible absence of epistasis, whereas, in environment–II the epistasis was present. The V_r , W_r graphs (figure 30a-b) exhibited over dominance in environment–I and partial dominance in environment–II.

The array points 10, 5 (99HS-18 and CVJ-2-5-3-1-3) in environment–I and the array points 10, 5, 3 (99HS-18, CVJ-2-5-3-1-3 and G73-107) in environment–II appeared to possess maximum number of dominant genes. The parents 1, 6, 7 (H77/833-2, 1305 and 77/371 $\times$ BSECT CP-1) in environment–I and the array points 1, 6 (H77/833-2 and 1305) in environment–II possessed relatively more number of recessive genes. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them. The well scattered array points along the regression line indicated genetic diversity among the parents.

iii) Germination (%)

The V_r , W_r graphs for germination showed that the coefficient of regression was not significantly different from zero but it differed significantly from unity in all the three environments, suggesting the failure of some of the assumptions as presence of epistasis (table 34) in all the three environments. The estimates of genetic components may be derived even after a partial failure of the assumptions

(Hayman, 1957) but the information would be less reliable than when all the assumptions were satisfied.

The V_r , W_r graphs (figure 31a-c) for this character showed that the regression line intercepted the W_r -axis near the origin in environment-I showing almost complete dominance (table 34). In environment-II and III the regression line intercepted the W_r -axis above the origin indicating partial dominance in both the environments and the overall expression of germination was partial dominance. The array points were found scattered along the regression line, indicating wide genetic diversity for this character among the parents.

Array 1 (H77/833-2) was farthest away from origin in environment-I and II (stress environments) and array 6 (1305) was farthest away from origin in environment-III (normal environment) showing more of recessive genes for germination. While, the array 8, 3 (96AC-93 and G73-107) in environment-I, the array points 8, 10 (96AC-93 and 99HS-18) in environment-II and the array 8, 4, 3 (96AC-93, 77/245 and G73-107) in environment-III fell nearest to the origin, showing more of dominant genes for germination. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them. The array points changed their positions from one environment to another, probably because of the presence of environment interactions.

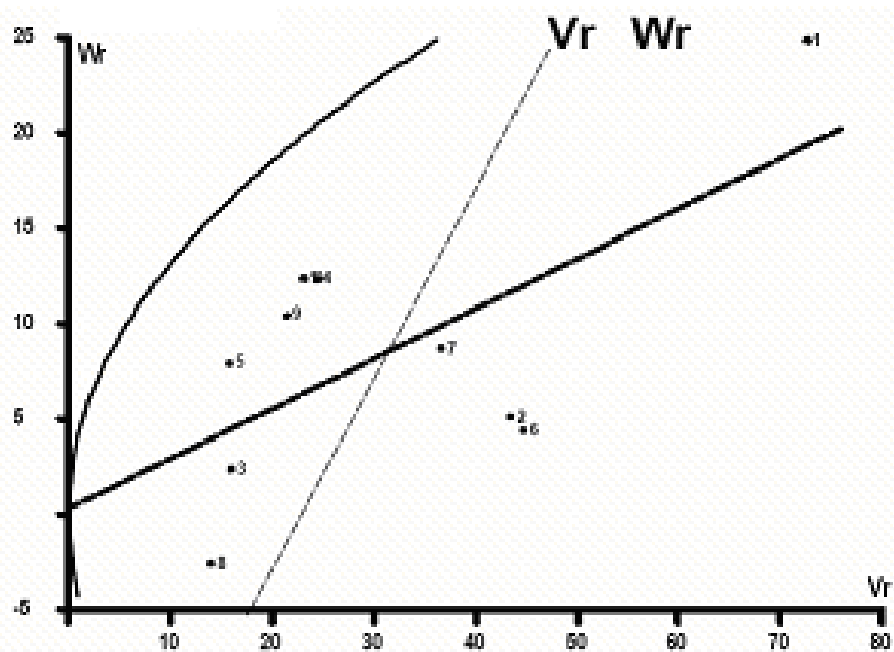


Fig. 31a: $V_r - W_r$ graph for germination in environment - I

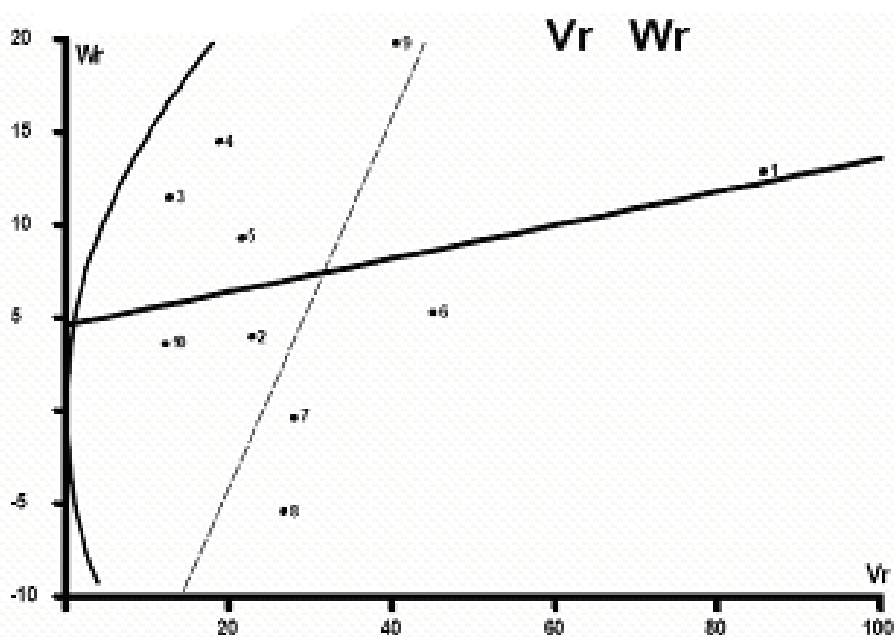
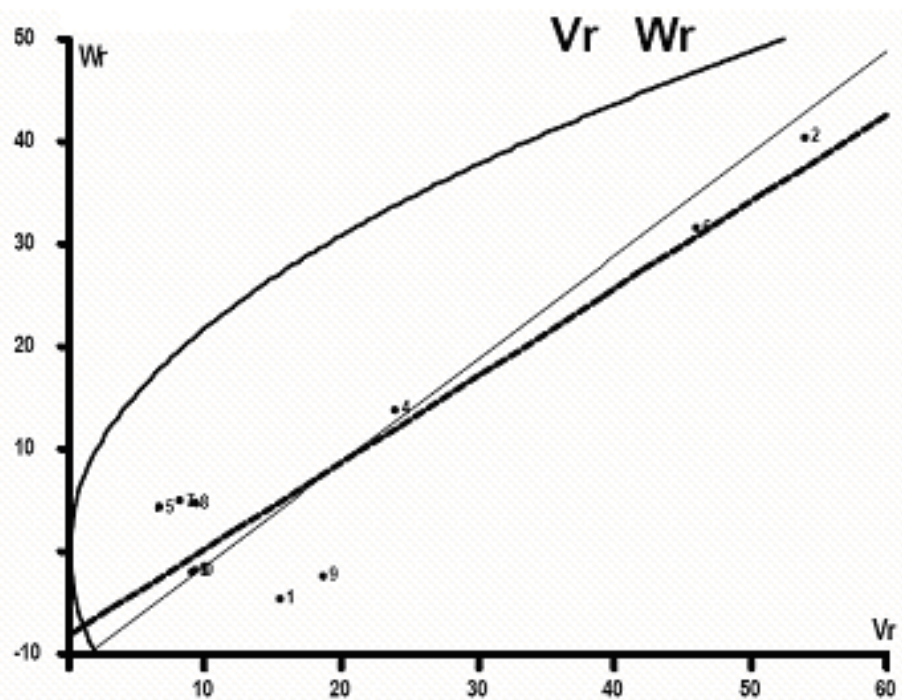
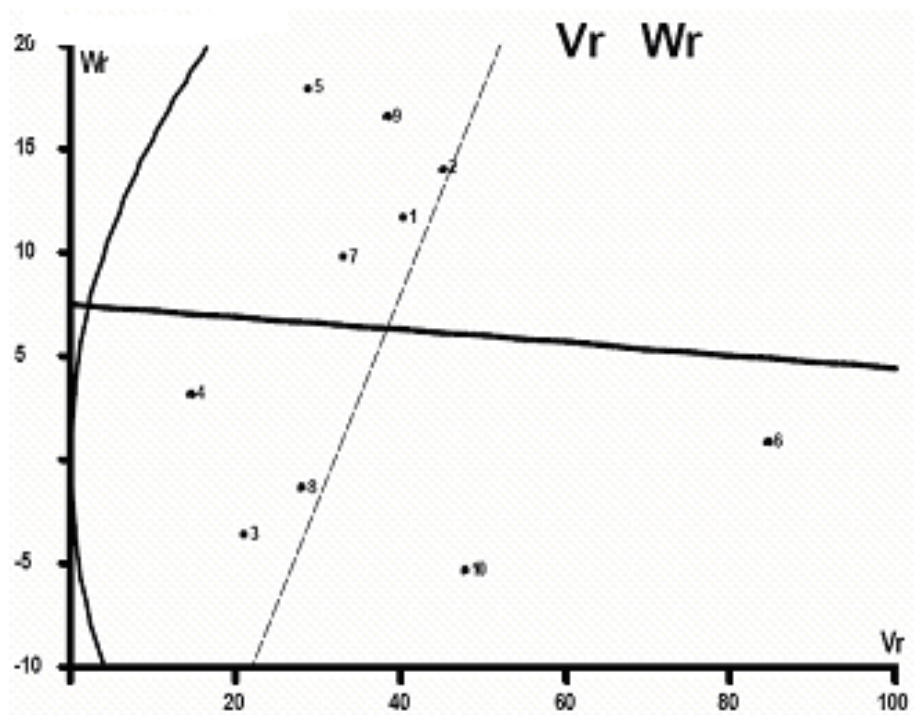


Fig. 31b: $V_r - W_r$ graph for germination in environment - II



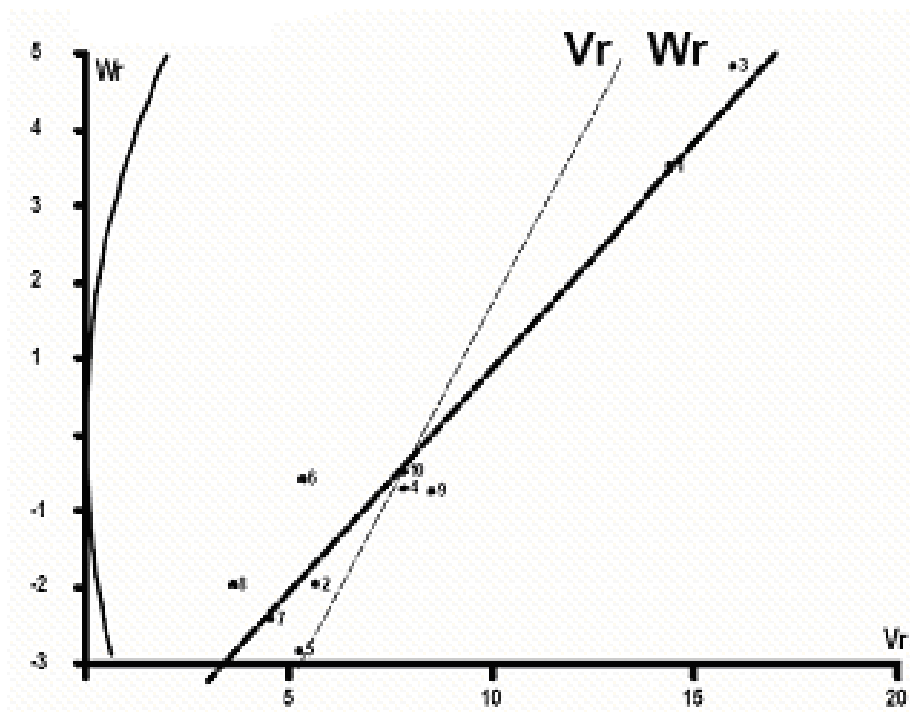


Fig. 32b: $V_r - W_r$ graph for rate of emergence in environment – II

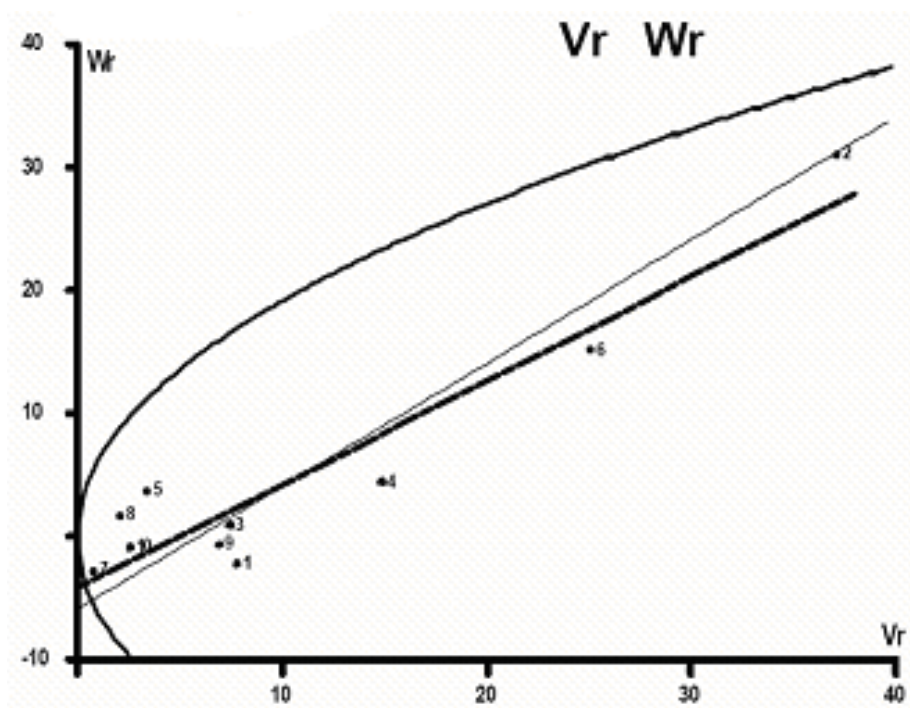


Fig. 32c: $V_r - W_r$ graph for rate of emergence in environment – III

iv) Emergence rate (ER)

The coefficient of regression was significantly away from zero and did not differ significantly from unity in environment-I and III, indicating the absence of epistasis but in environment-II the epistasis is present.

The Vr, Wr graphs (figure 32a-c) for this character showed that the regression line intercepted the Wr-axis below the origin, indicating over dominance in all the three environments

The parents exhibited wide genetic diversity among them as the array points were found scattered along the regression line. The array points 8, 5, 7, 10 (96AC-93, CVJ-2-5-3-1-3, 77/371 $\times$ BSECT CP-1 and 99HS-18 in environment-I, array points 8, 5, 7, 2, 6 (96AC-93, CVJ-2-5-3-1-3, (77/371 $\times$ BSECT CP-1), H77/29-2 and 1305) in environment-II and the array points 7, 10, 8, 5 (77/371 $\times$ BSECT CP-1, 99HS-18, 96AC-93 and CVJ-2-5-3-1-3) in environment-III were found nearest to the origin having excess of dominant genes while, the array points 2, 6 (H77/29-2 and 1305) in environment-I and environment-III were found farthest away from the origin, in Vr, Wr graph appeared to have excess of recessive genes. While, the array points 3, 1 (G73-107 and H77/833-2) in environment-II were identified as the parents with more of recessive genes. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them. The change in the position of some arrays in different environments reflects the presence of genotype-environment interactions.

v) Number of leaves/seedling

The V_r , W_r graphs for this character (figure 33a-c) showed that the slope of regression line in all the three environments was not significantly different from zero indicating the presence of inter-allelic interactions i.e. epistasis was present.

The regression line intercepted the W_r -axis near the origin indicating complete dominance in environment-I for this character, while, in environment-II and III the regression line intercepted the W_r -axis below the origin showing over dominance. The parents exhibited wide genetic diversity among them as the array points were found scattered along the regression line.

The array 3, 10, 5, 7 (G73-107, 99HS-18, CVJ-2-5-3-1-3 and 77/371 $\times$ BSECT CP-1) in environment-I and II (stress environments) and the array 3, 5, 8, 10 (G73-107, CVJ-2-5-3-1-3, 96AC-93 and 99HS-18) in environment-III (normal environment) fell near the origin, showing more dominant genes for number of leaves/seedling. While, the array 6, 2, 4 (1305, H77/29-2 and 77/245) in environment-I and II and the array points 6, 2 (1305 and H77/29-2) in environment-III were far away from origin indicating more number of recessive genes in the parents. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them.

vi) Seedling height (cm)

In environment-I and II (stress environments) the assumptions of the diallel analysis were fulfilled as the regression coefficient were

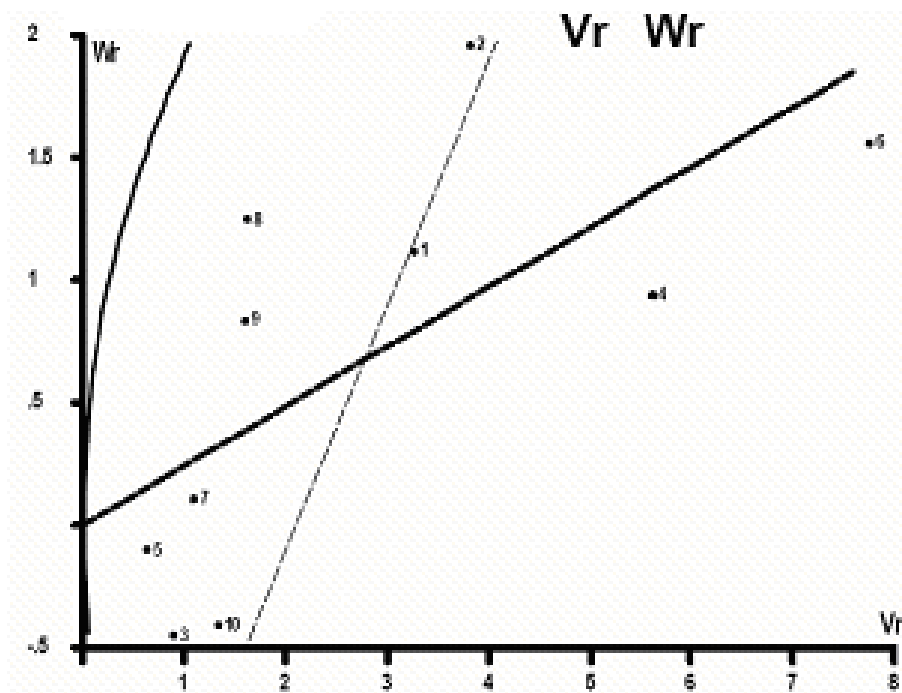


Fig. 33a: $V_r - W_r$ graph for number of leaves/seedling in environment-I

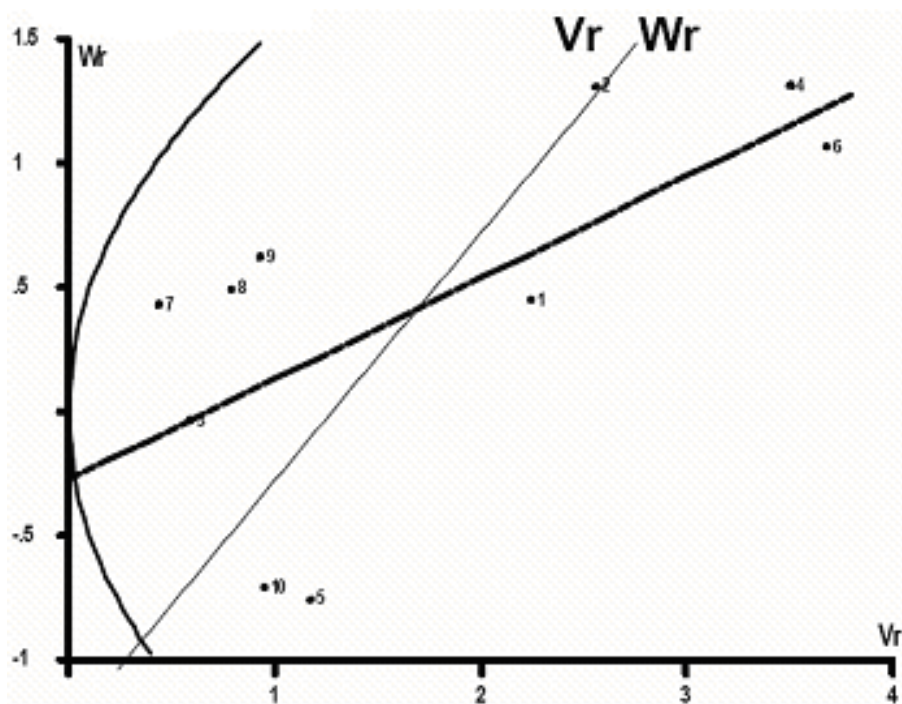


Fig. 33b: $V_r - W_r$ graph for number of leaves/seedling in environment-II

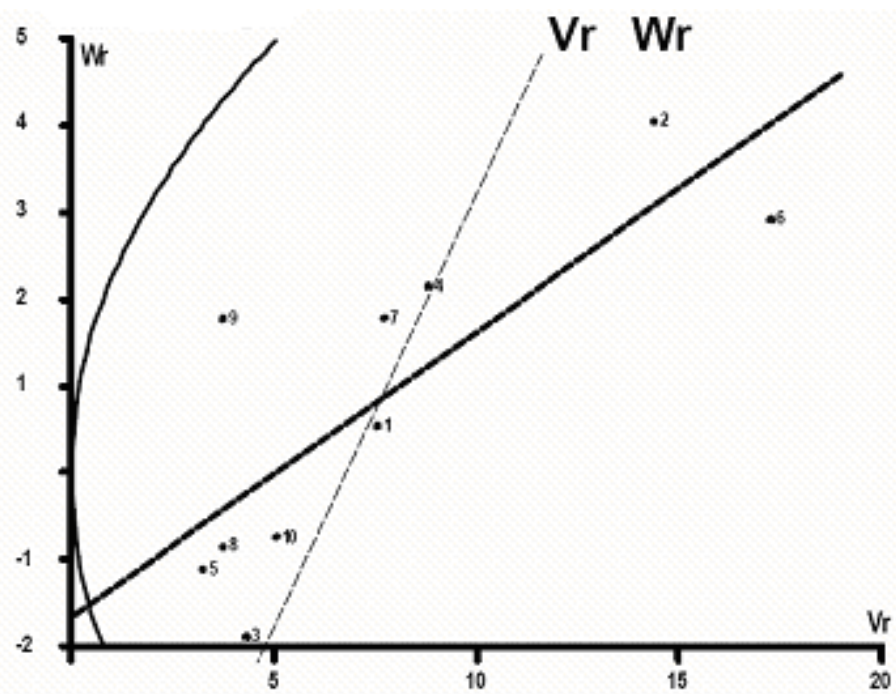


Fig. 33c: $V_r - W_r$ graph for number of leaves/seedling in environment - III

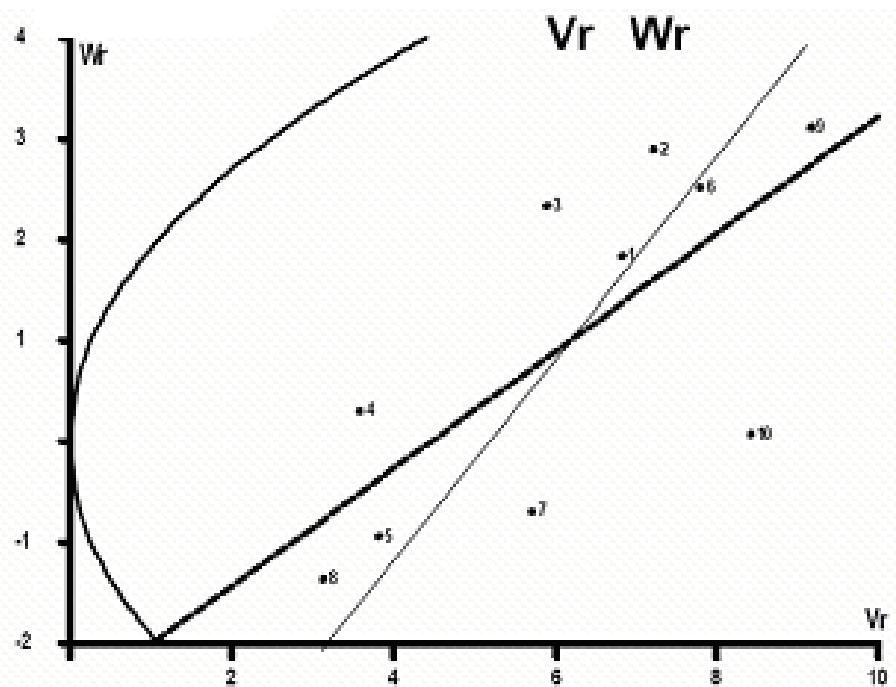


Fig. 34a: $V_r - W_r$ graph for seedling height in environment - I

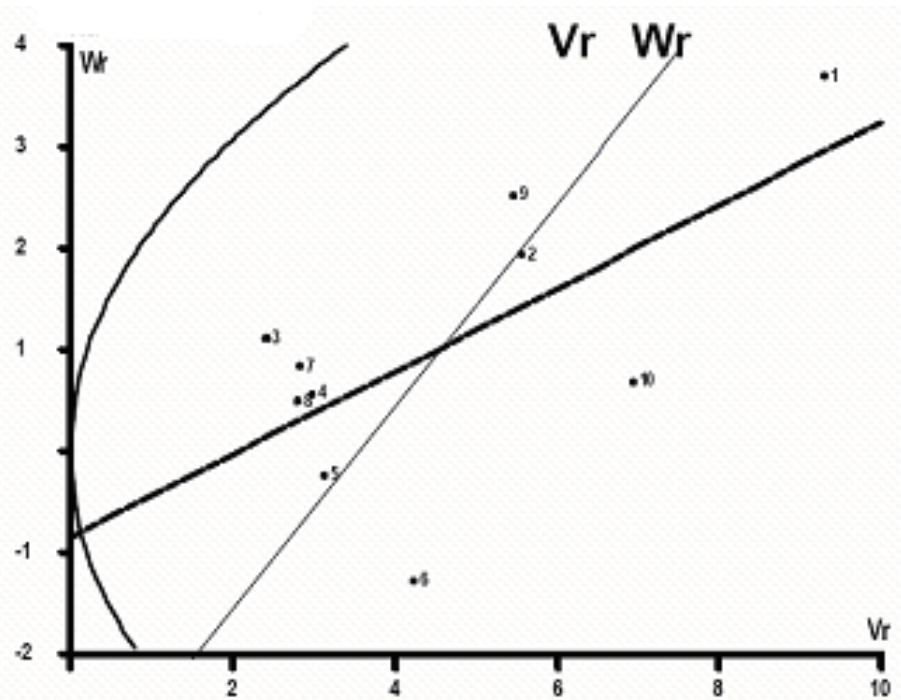


Fig. 34b: $V_r - W_r$ graph for seedling height in environment - II

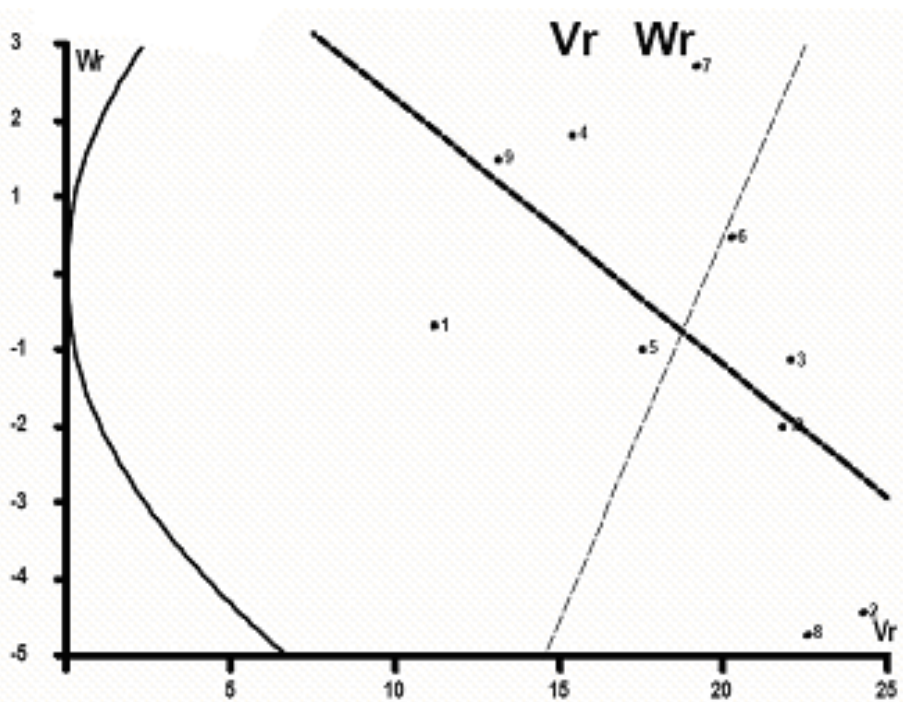


Fig. 34c: $V_r - W_r$ graph for seedling height in environment - III

significantly differ from zero and non-significant from unity, indicating the absence of epistasis. But in environment–III (normal environment) the assumptions of diallel analysis were not fulfilled as the regression coefficient was non-significant from zero and significantly different from unity, indicating presence of epistasis.

The V_r , W_r graphs (figure 34a-c) showed that the regression line intercepted the W_r -axis below the origin in environment–I and II (stress environments) indicating over dominance in both the environments. While, in environment–III (normal environment) the regression line intercepts the W_r -axis above the origin indicating the partial dominance.

The array 8, 5, 4 (96AC-93, CVJ-2-5-3-1-3 and 77/245) in environment–I, the array 8, 5, 4, 7, 3 (96AC-93, CVJ-2-5-3-1-3, 77/245, 77/371 $\times$ BSECT CP-1 and G73-107) in environment–II and array 1 (H77/833-2) in environment–III have an excess of dominant genes, while, the array 6, 9, 2 (1305, Togo-II and H77/29-2) in environment–I, array point 1 (H77/833-2) in environment–II and array 6, 3 (1305 and G73-107) in environment–III had maximum number of recessive genes. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them. The change in the position of some arrays in different environments reflects the presence of genotype-environment interactions. The parents exhibited wide genetic diversity among them as the array points were found scattered along the regression line.

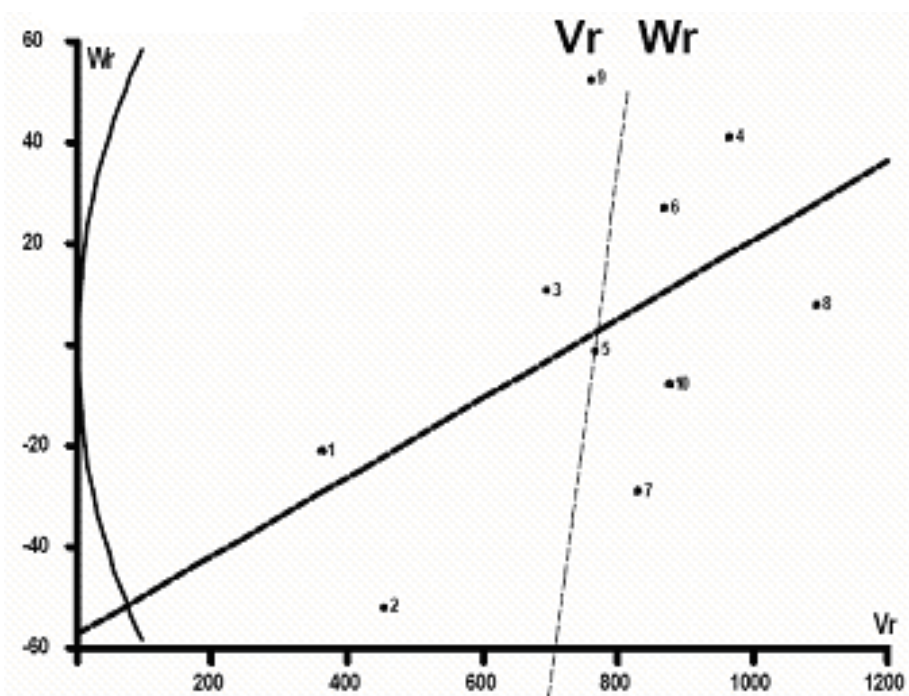
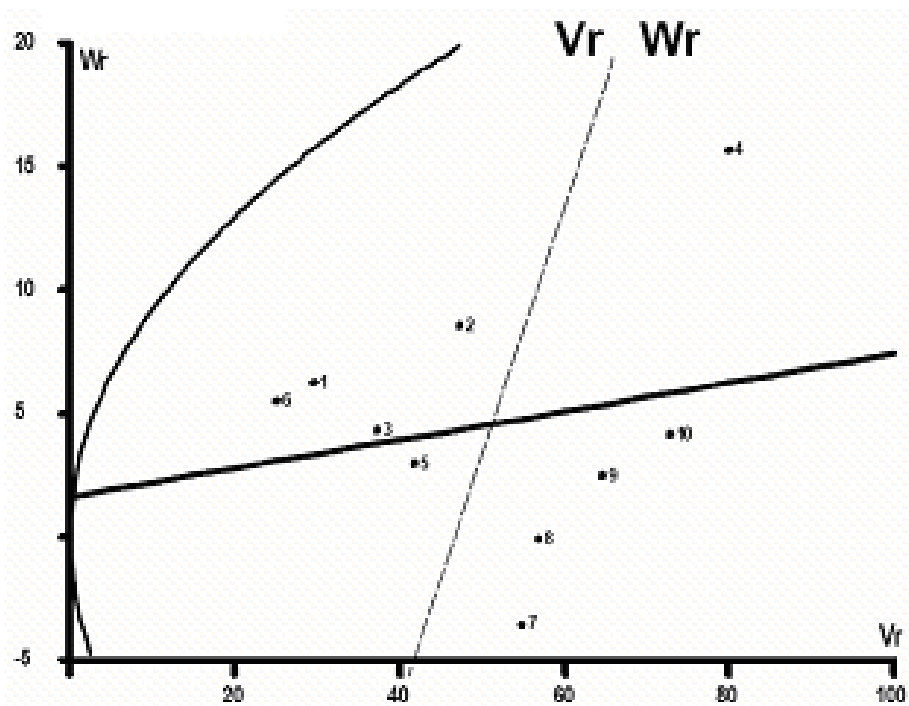
vii) Fresh weight (g)/seedling

In both of the stress environments, the coefficient of regression did not differ significantly from zero and it differed significantly from unity but in environment–III significant from zero as well as unity, suggested the failure of some of the assumptions. The estimates of genetic components may be derived even after a partial failure of the assumptions (Hayman, 1957) but the information would be less reliable than when all the assumptions were satisfied. Nevertheless, the V_r , W_r graphs (figure 35a-c) exhibited partial dominance in environment–I and over dominance in environment–II and III.

The array points 6, 1 (1305 and H77/833-2) in environment–I, array points 1, 2 (H77/833-2 and H77/29-2) in environment–II and the array points 6, 9, 8 (1305, Togo-II and 96AC-93) in environment–III appeared to possess maximum number of dominant genes. While, the parent 4 (77/245) in environment–I, array 4, 8 (1305 and 96AC-93) in environment–II and the array points 1, 2, 4 (H77/833-2, H77/29-2 and 77/245) in environment–III showed maximum number of recessive genes. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them. The parents exhibited wide genetic diversity among the parents as the array points were found scattered along the regression line.

viii) Dry weight (g)/seedling

The slope of regression line did not differ significantly from zero and differ significantly from unity in all the three environments suggesting failure of some of the assumptions as epistasis was present.



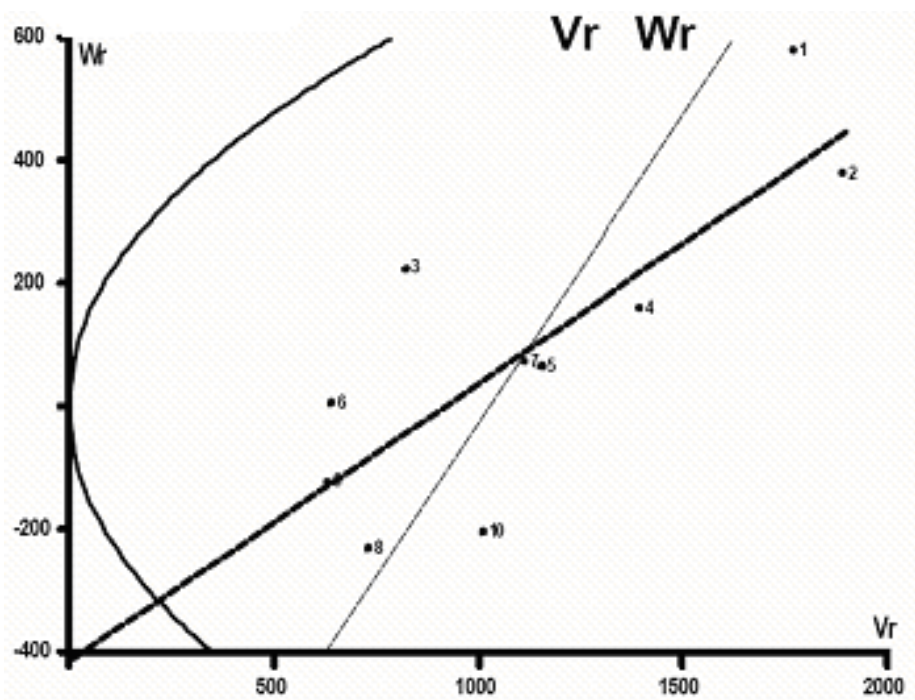


Fig. 35c: $V_r - W_r$ graph for fresh weight/seedling in environment - III

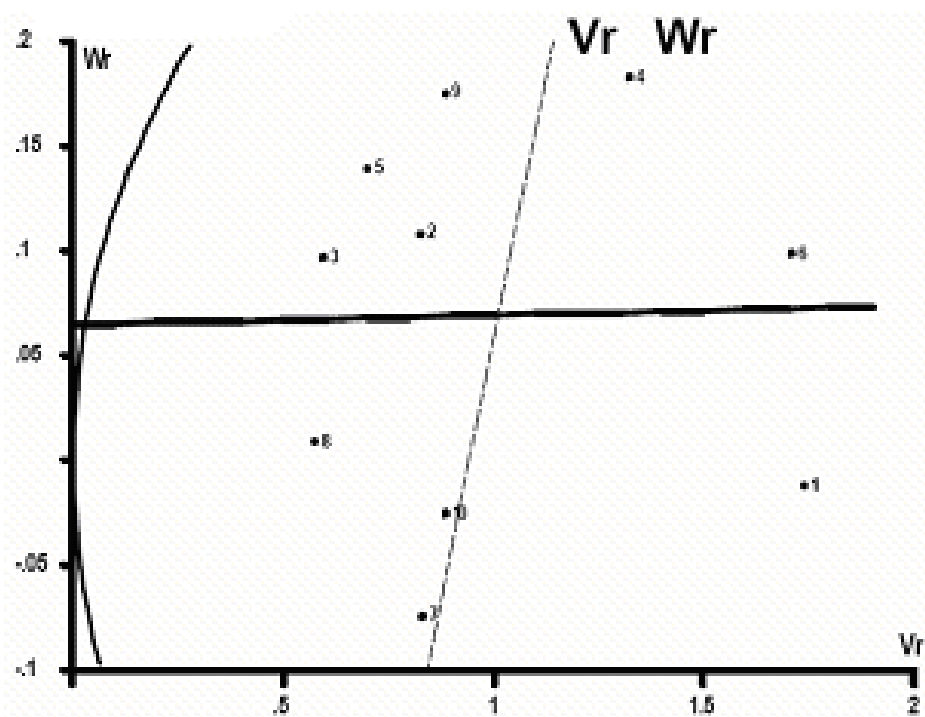
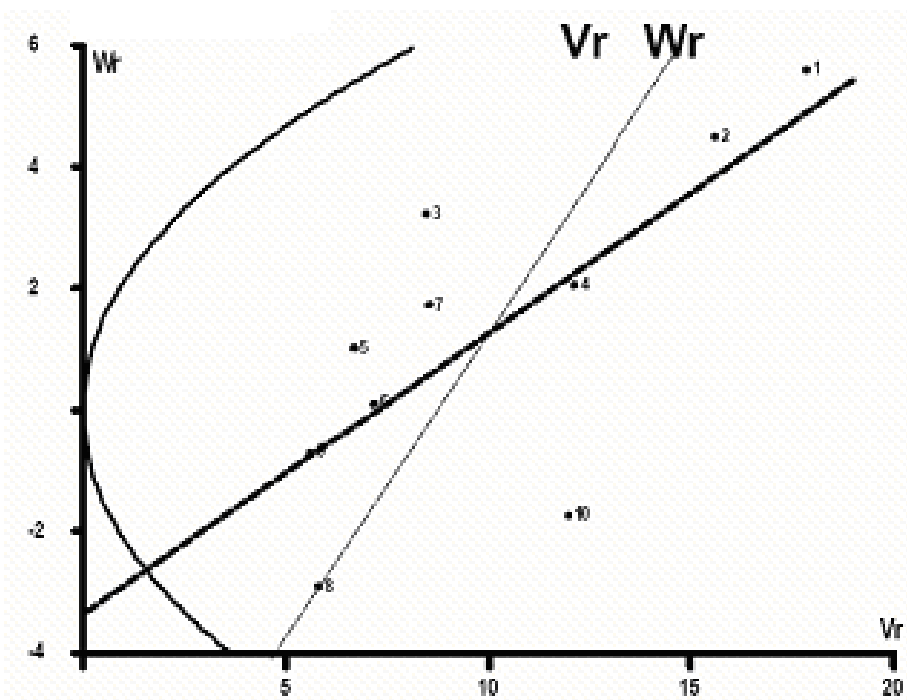
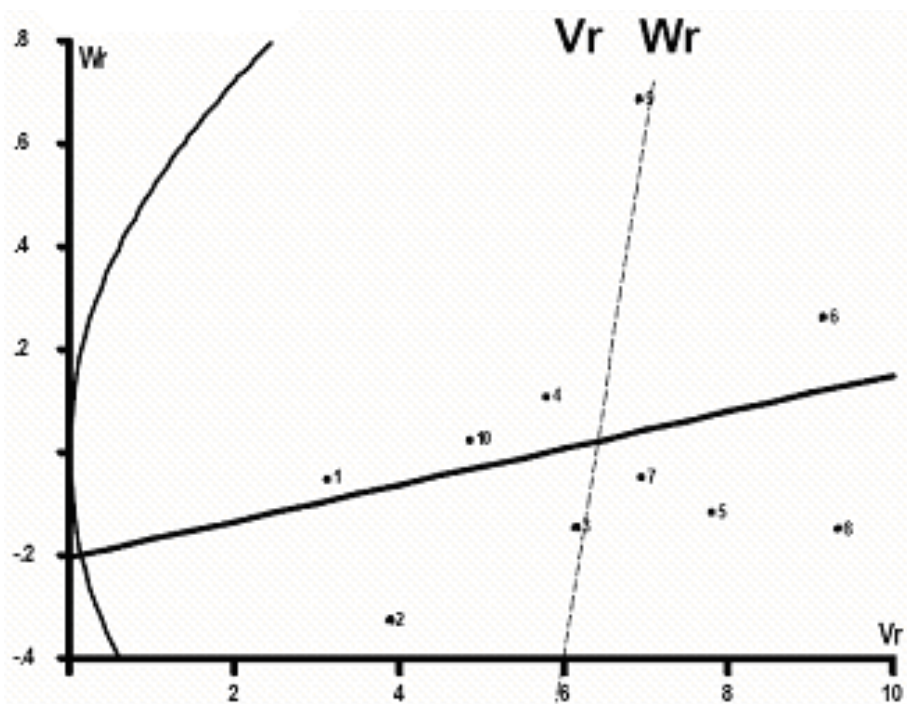


Fig. 36a: $V_r - W_r$ graph for dry weight/seedling in environment - I



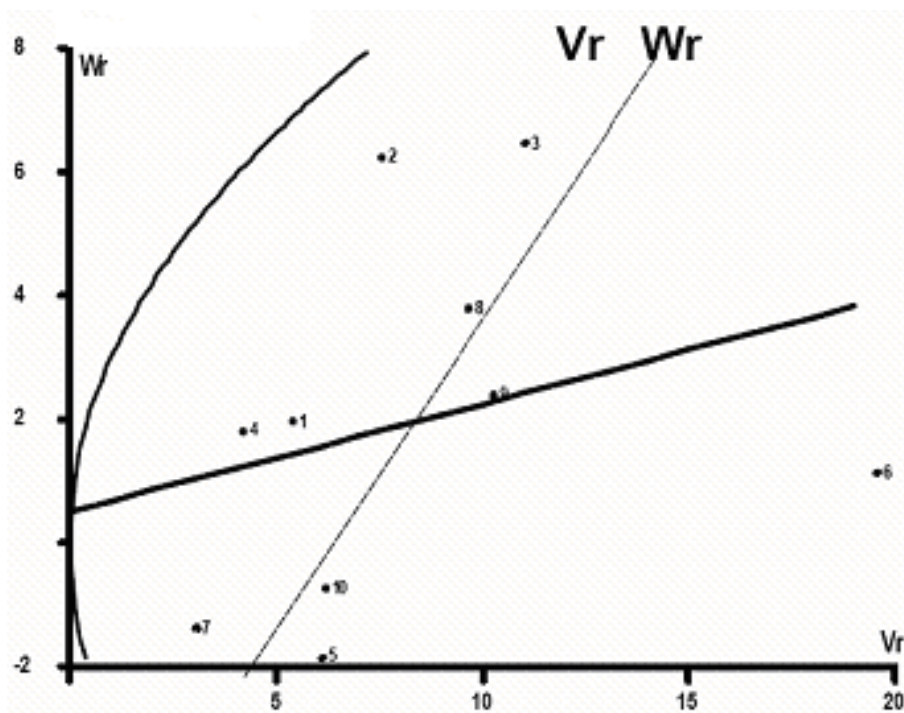
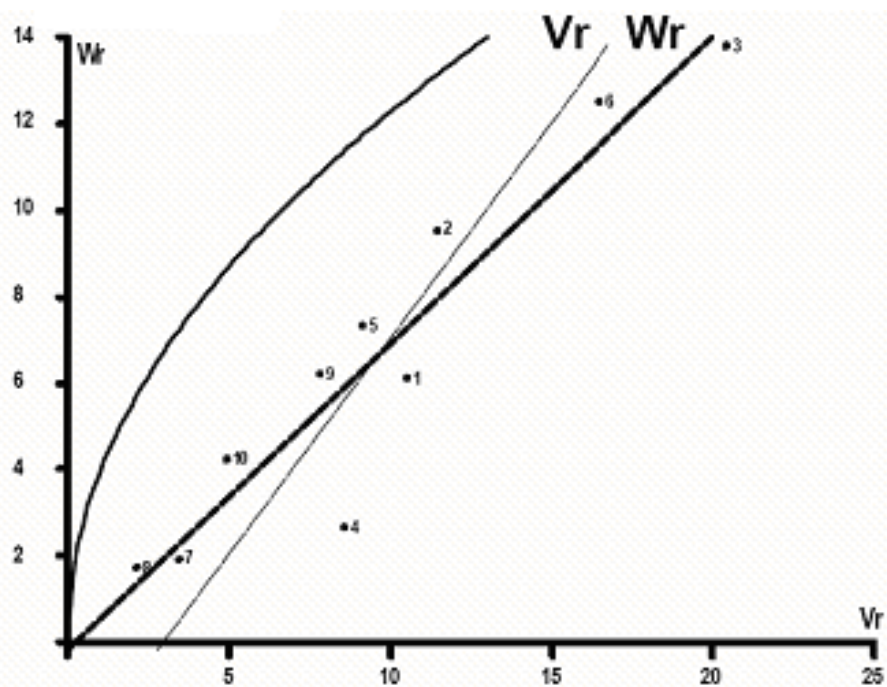
The V_r , W_r graphs (figure 36a-c) showed that the regression line intercepted W_r -axis above the origin in environment-I suggesting partial dominance, while, regression line intercepted W_r -axis below the origin and suggested over dominance in environment-II and III. The well scattered array points along the regression line indicated genetic diversity among the parents.

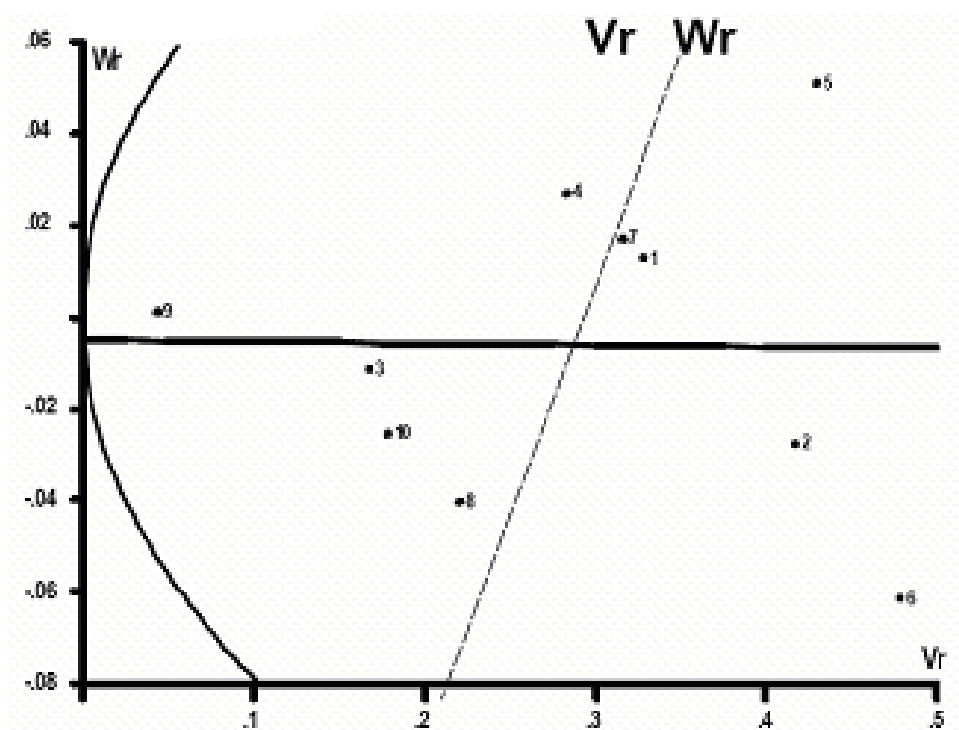
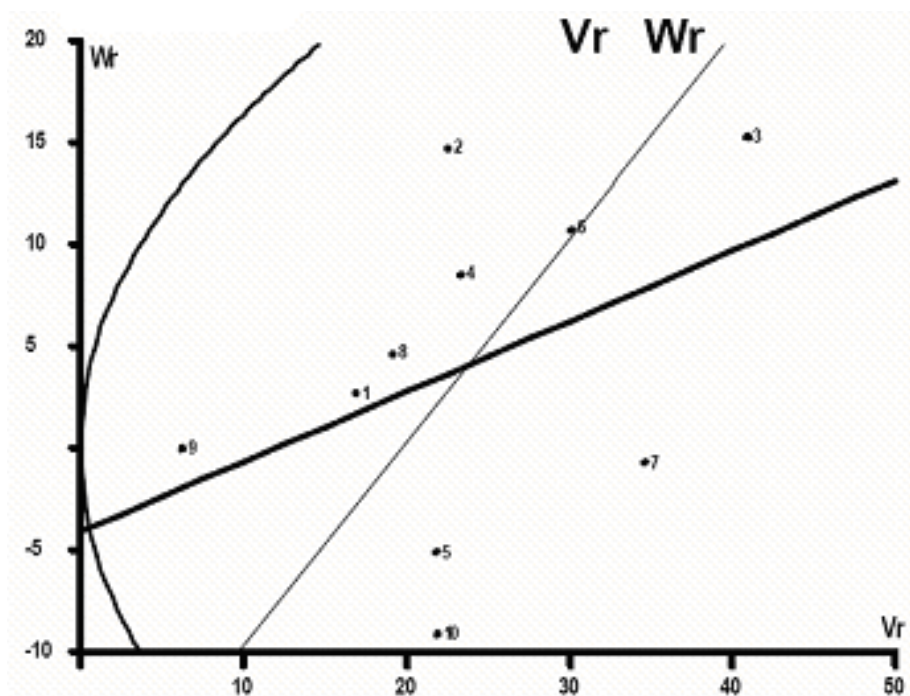
The array 8, 3, 7 (96AC-93, G73-107 and 77/371×BSECT CP-1) in environment-I, array 1, 2 (H77/833-2 and H77/29-2) in environment-II and the array 8, 9, 5, 6 (96AC-93, Togo-II, CVJ-2-5-3-1-3 and 1305) in environment-III had excess of dominant genes. While, the array 6, 1, 4 (1305, H77/833-2 and 77/245) in environment-I, array 6, 8, 9 (1305, 96AC-93 and Togo-II) environment-II and the array 1, 2 (H77/833-2 and H77/29-2) environment-III had maximum number of recessive genes for dry weight/seedling. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them.

ix) Panicle emergence (days)

The V_r , W_r graphs for panicle emergence (figure 37a-c) showed that the coefficient of regression was not significantly different from zero but it differed significantly from unity in all the three environments suggesting failure some of the assumptions as presence of epistasis.

The regression line in environment-I intercepted the W_r -axis near origin towards below suggesting almost complete dominance towards over dominance direction. In environment-II partial dominance and in environment-III over dominance was suggested.





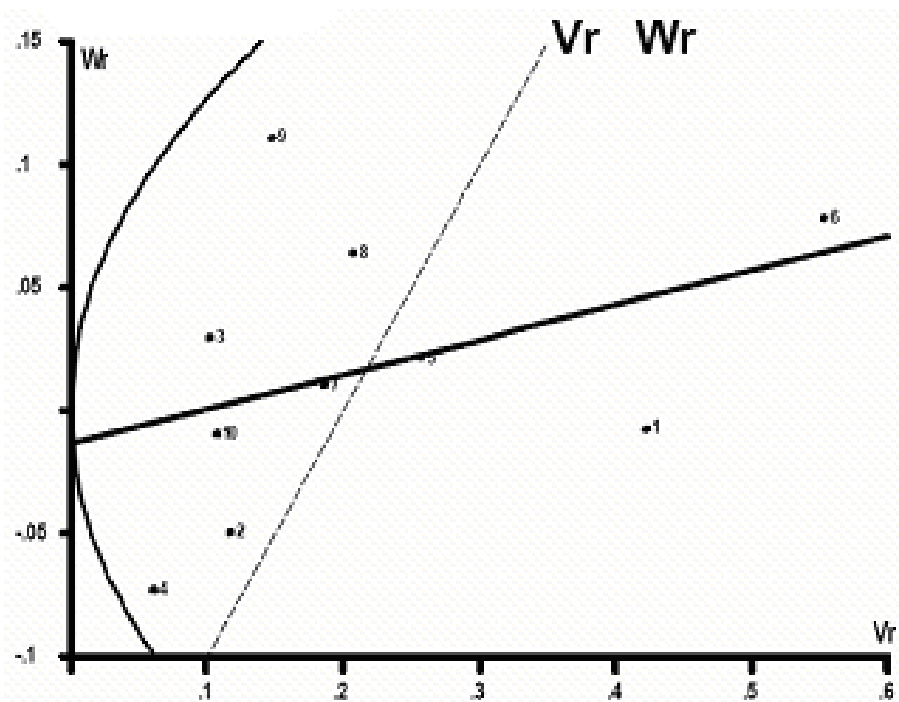


Fig. 38b: $V_r - W_r$ graph for effective tillers/plant in environment - II

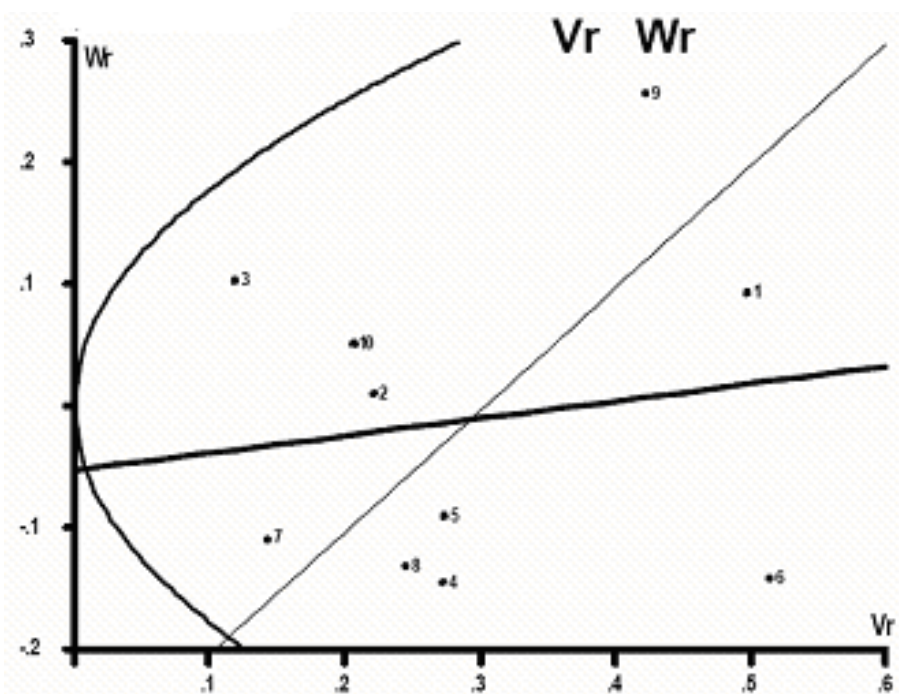


Fig. 38c: $V_r - W_r$ graph for effective tillers/plant in environment - III

The array points scattered all along the regression line suggested wide genetic variability for panicle emergence.

The array points 8, 7 (96AC-93 and 77/371 $\times$ BSECT CP-1) in environment-I, array points 7, 5, 10, 4, 1 (77/371 $\times$ BSECT CP-1, CVJ-2-5-3-1-3, 99HS-18, 77/245 and H77/833-2) in environment-II and array 9 (Togo-II) in environment-III appeared to possess more of dominant genes, while, the array points 3, 6 (G73-107 and 1305) in environment-I and II (stress environments) and array 3 (G73-107) in environment-III were showing more number of recessive genes. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them.

x) Number of effective tillers/plant

The coefficient of regression was not significantly different from zero and significant from unity in all the three environments, suggesting the failure of some of the assumptions. The V_r , W_r graphs (figure 38a-c) showed over dominance as the regression line intercepts the W_r -axis below the origin in all the three environments. The well scattered array points along the regression line indicated genetic diversity among the parents.

The array points 9, 3 (Togo-II and G73-107) in environment-I, array points 4, 2, 10, 3 (77/245, H77/29-2, 99HS-18 and G73-107) in environment-II and the array 7, 3 (77/371 $\times$ BSECT CP-1 and G73-107) in environment-III showed the more number of dominant genes while, the array points 6, 5, 2 (1305, CVJ-2-5-3-1-3 and H77/29-2) in environment-I, array 6 (1305) in environment-II and the array points

9, 1, 6 (Togo-II, H77/833-2 and 1305) in environment-III showed more number of recessive genes for effective tillers/plant. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them.

xi) Plant height (cm)

The slope of regression line did not differ significantly from zero and differed significantly from unity in environment-I, indicating presence of epistasis while, in environment-II and III the regression coefficient differ significantly from zero and non-significant from unity indicating the absence of epistasis and fulfilled the assumptions of diallel analysis in both the environments.

The V_r , W_r graphs (figure 39a-c) showed that the regression line intercepted W_r -axis well below the origin in all the three environments showing that the plant height was controlled by over dominance. The well scattered array points along the regression line indicated genetic diversity among the parents.

The parent 5 (CVJ-2-5-3-1-3) in environment-I, the array points 6, 1, 2 (1305, H77/833-2 and H77/29-2) in environment-II and the array points 1, 5 (H77/833-2 and CVJ-2-5-3-1-3) in environment-III appeared to have most of the dominant genes. Whereas, the parents corresponding to the array points 10, 9 (99HS-18 and Togo-II) in environment-I and II and the array point 9 (Togo-II) in environment-III appeared to have most of the recessive genes for plant height. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them.

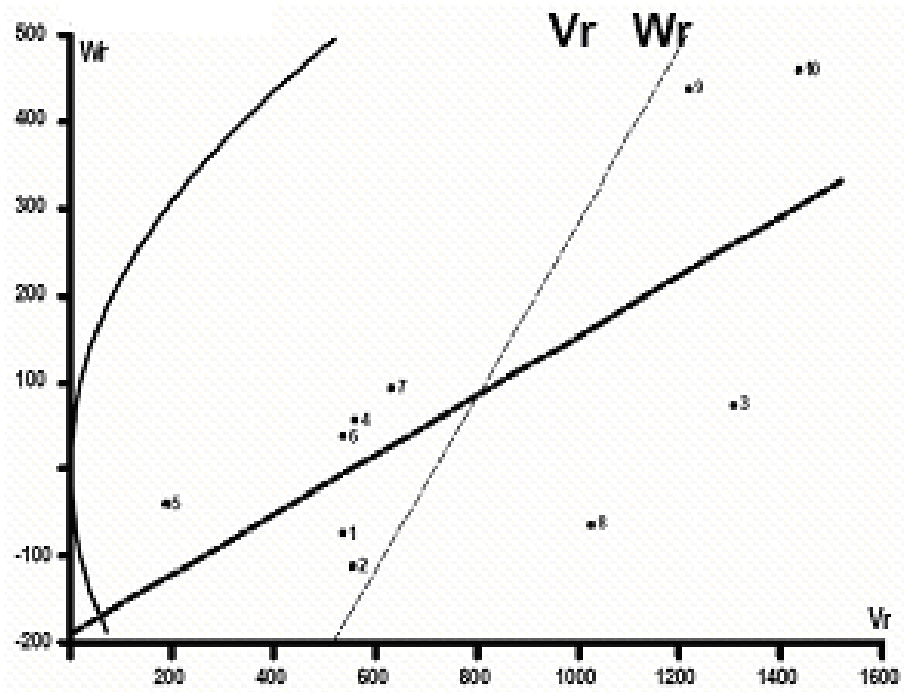


Fig. 39a: $V_r - W_r$ graph for plant height in environment - I

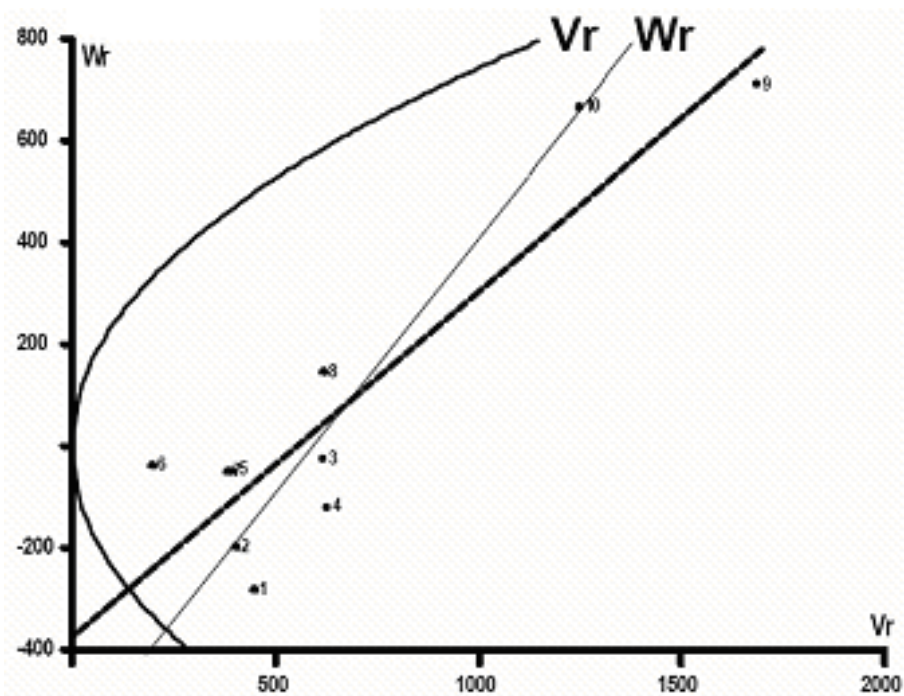


Fig. 39b: $V_r - W_r$ graph for plant height in environment - II

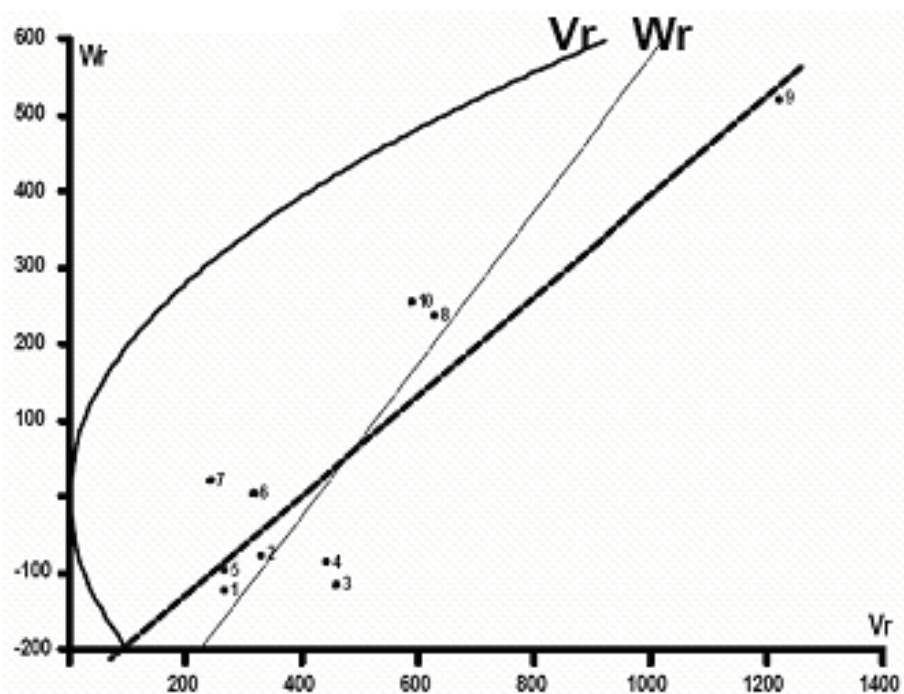


Fig. 39c: $V_r - W_r$ graph for plant height in environment - III

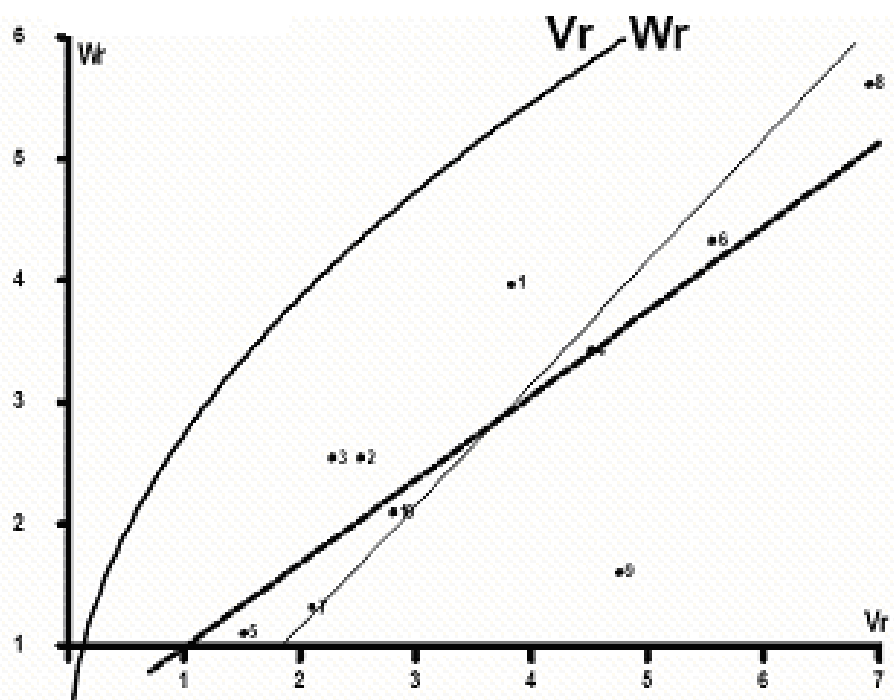
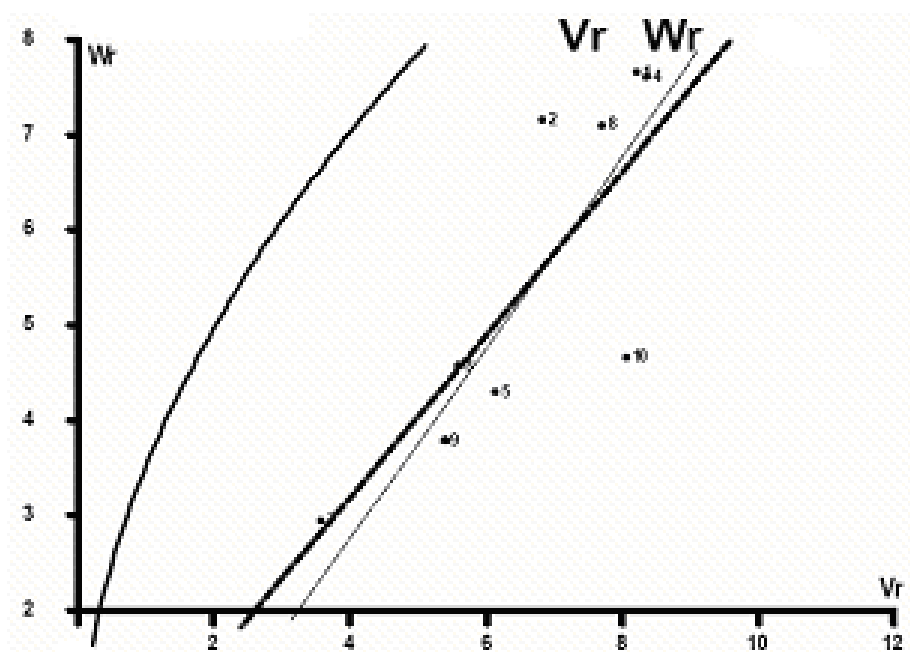
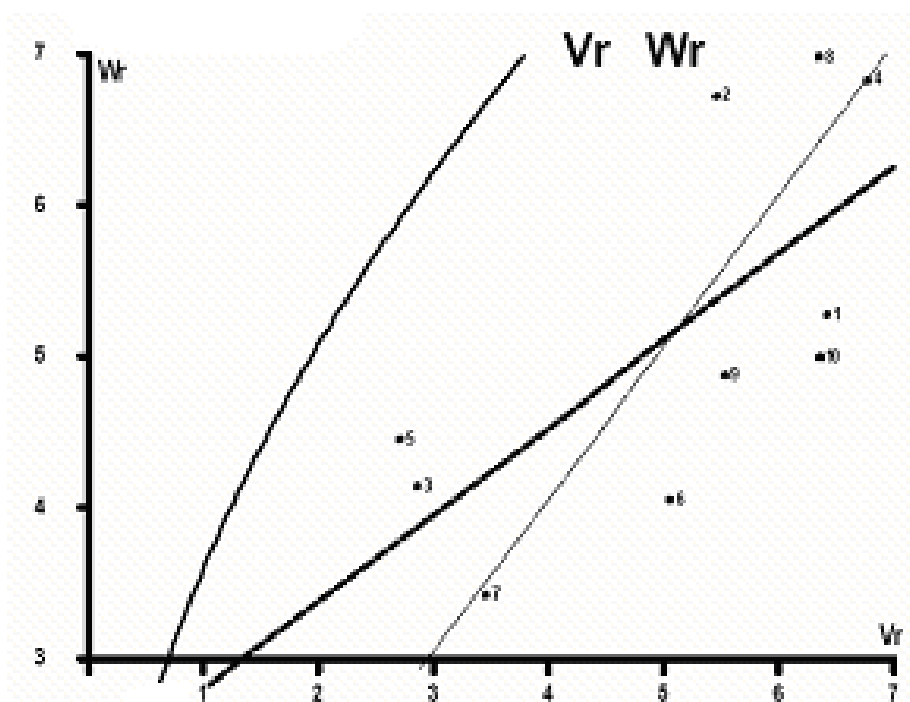


Fig. 40a: $V_r - W_r$ graph for ear length in environment - I



xii) Ear length (cm)

The coefficient of regression was significantly away from zero and did not differ significantly from unity in all the three environments (two stress and one normal) indicating absence of epistasis and fulfilment of all the assumptions of diallel analysis.

The V_r , W_r graphs (figure 40a-c) for ear length showed that the regression line intercepted the W_r -axis well above the origin in environment-I indicating somewhat partial dominance nearly complete dominance. But in environment-II the regression line intercepts above the origin indicating partial dominance. Whereas, in environment-III over dominance was detected as the regression line intercepts below the origin. Wide genetic diversity was exhibited by the parents as the array points were scattered along the regression line.

The array points 5, 7 (CVJ-2-5-3-1-3 and 77/371 $\times$ BSECT CP-1) in environment-I, the array points 7, 3, 5 (77/371 $\times$ BSECT CP-1, G73-107 and CVJ-2-5-3-1-3) in environment-II whereas, in environment-III the array points 7, 9 (77/371 $\times$ BSECT CP-1 and Togo-II) were found nearest to the origin having most of the dominant genes while, the array 8 (Togo-II) in environment-I, the array points 4, 8, 2 (77/245, Togo-II and H77/29-2) and the array points 6, 4, 1, 8 (1305, 77/245, H77/833-2 and 96AC-93) in environment-III were found farthest away from the origin, in V_r , W_r graphs appeared to have most of the recessive genes. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them.

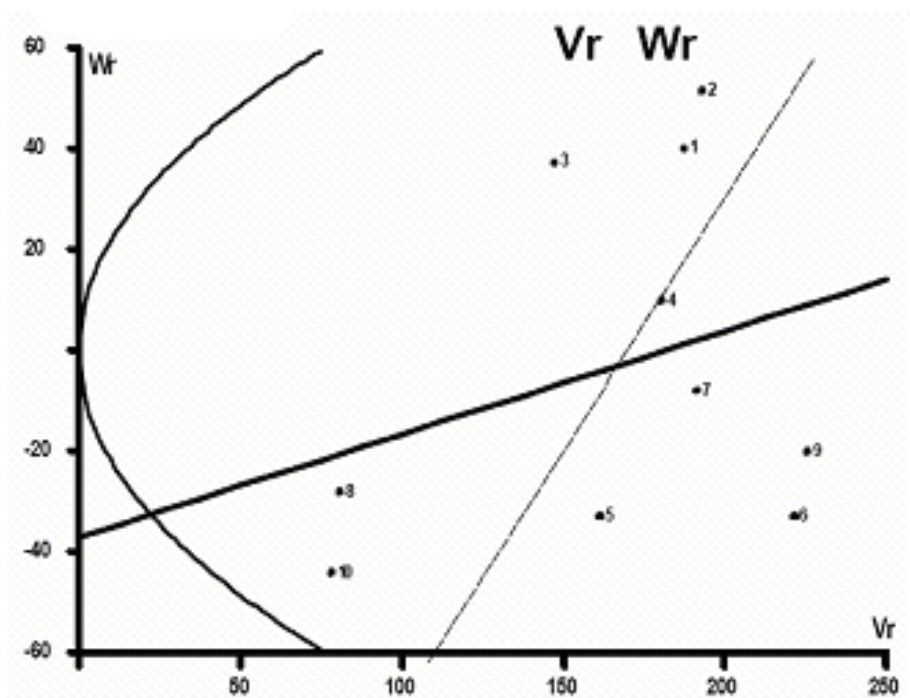
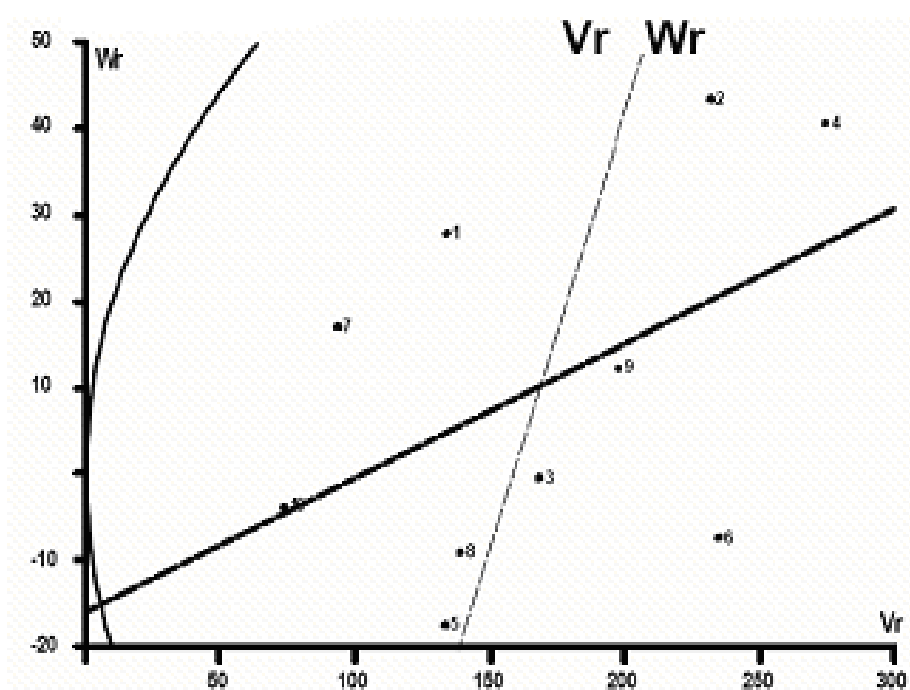
xiii) Ear weight (g)/plant

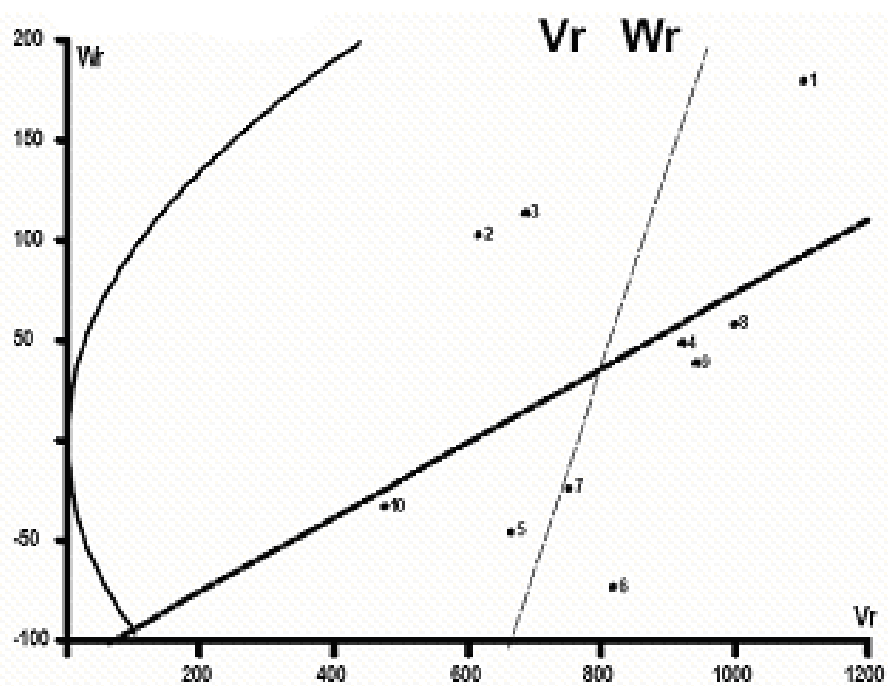
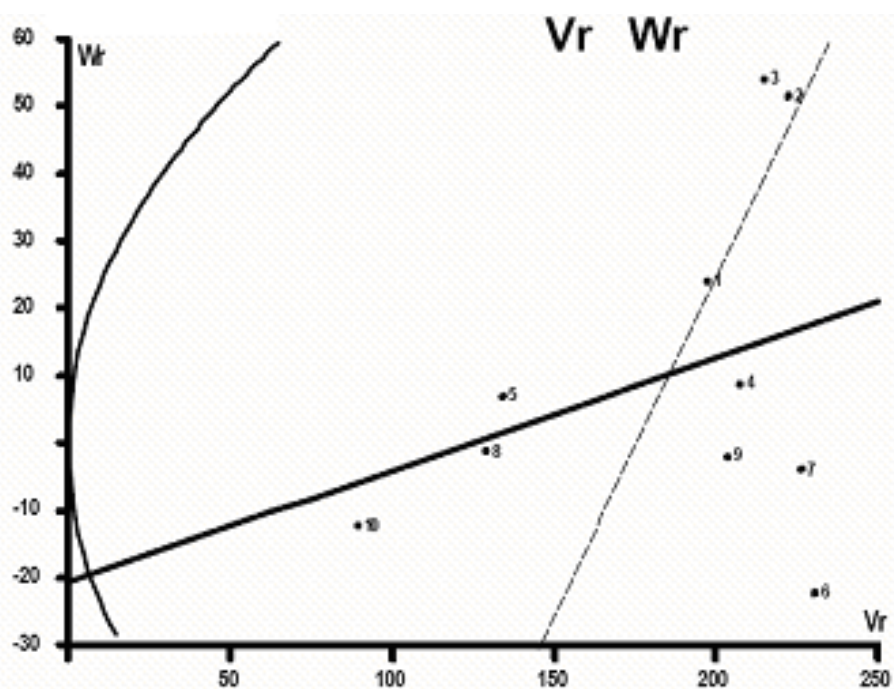
The slope of regression line did not differ significantly from zero and differed significantly from unity in all the three environments indicating the presence of epistasis suggesting failure of the assumptions of diallel analysis.

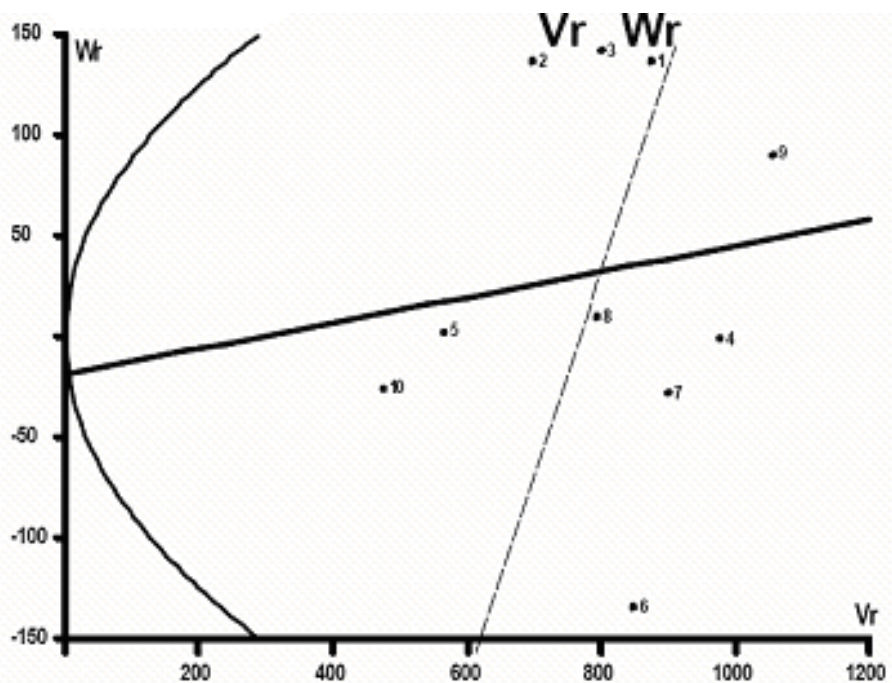
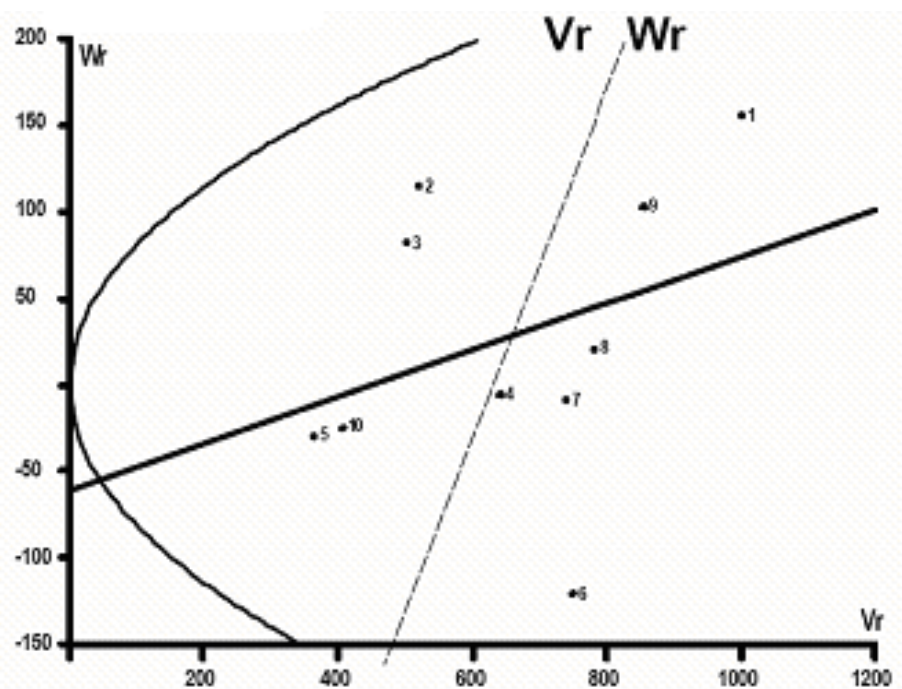
The regression line intercepted the W_r -axis well below the origin in all the three environments suggesting clear cut over dominance. The array 10 (99HS-18) in environment-I and III and the array points 10, 8 (99HS-18 and 96AC-93) in environment-II were found nearest to the origin having most of the dominant genes while, the array 4, 2 (77/245 and H77/29-2) in environment-I, the array 2, 1 (H77/29-2 and H77/833-2) in environment-II and the array points 2, 3 (H77/29-2 and G73-107) in environment-III were found farthest away from the origin in the V_r , W_r graphs (figure 41a-c) appeared to have most of the recessive genes in them. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them. The parents exhibited wide genetic diversity for ear weight/plant among them as the array points were found scattered along the regression line.

xiv) Dry fodder yield/plant

In all the three environments, the coefficient of regression did not differ significantly from zero and differed significantly from unity suggesting, failure of some of the assumptions of diallel analysis as the epistasis was present. The V_r , W_r graphs (figure 42a-c) exhibited







over dominance in all the three environments as the regression line intercepted W_r -axis well below the origin.

The array 10 (99HS-18) in environment-I, and the array points 10, 5 (99HS-18 and CVJ-2-5-3-1-3) in environment-II and III were found nearest to the origin indicating more number of dominant genes while, the array 1 (H77/833-2) in environment-I and the array points 1, 9 (H77/833-2 and Togo-II) in environment-II and III fell far away from the origin indicating more number of recessive genes. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them for dry fodder yield/plant.

The parents exhibited wide genetic diversity among them as the array points were found scattered along the regression line.

xv) Grain yield (g)/plant

The coefficient of regression was not significantly different from zero and significant from unity in all the three environments, suggesting the failure of some of the assumptions for diallel analysis.

The V_r , W_r graphs (figure 43a-c) showed over dominance as the regression line intercepted the W_r -axis below the origin in all the three environments. The well scattered array points along the regression line indicated genetic diversity among the parents. The array 7, 5 (77/371 $\times$ BSECT CP-1 and CVJ-2-5-3-1-3) in environment-I, the array points 10, 8 (99HS-18 and 96AC-93) in environment-II and in environment-III, the array points 10, 5 (99HS-18 and CVJ-2-5-3-1-3) showed more number of dominant genes while, the array points 4, 2 (77/245 and H77/29-2) in environment-I,

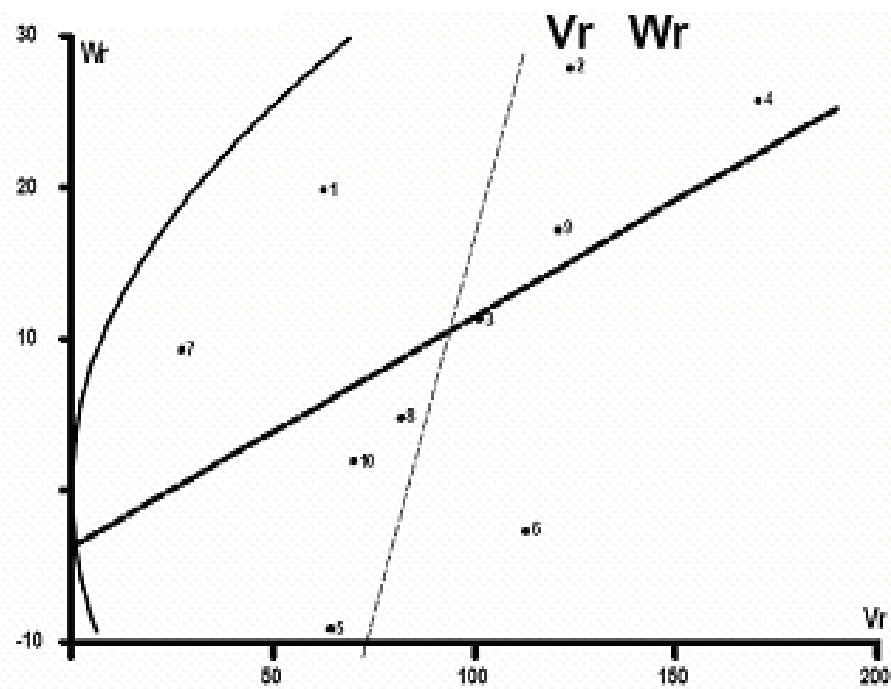


Fig. 43a: $V_r - W_r$ graph for grain yield/plant in environment - I

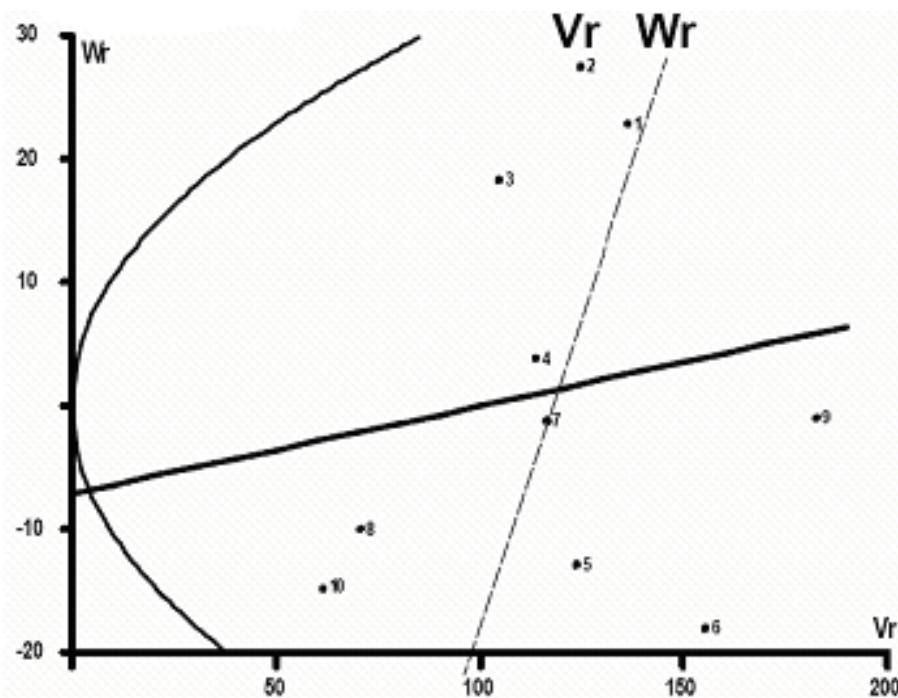


Fig. 43b: $V_r - W_r$ graph for grain yield/plant in environment - II

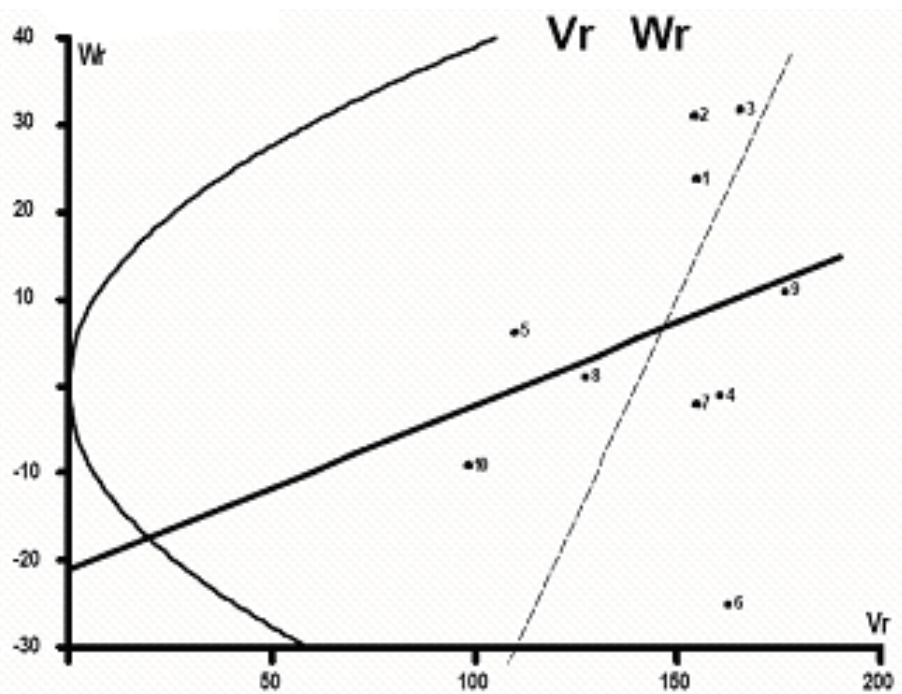


Fig. 43c: $V_r - W_r$ graph for grain yield/plant in environment - III

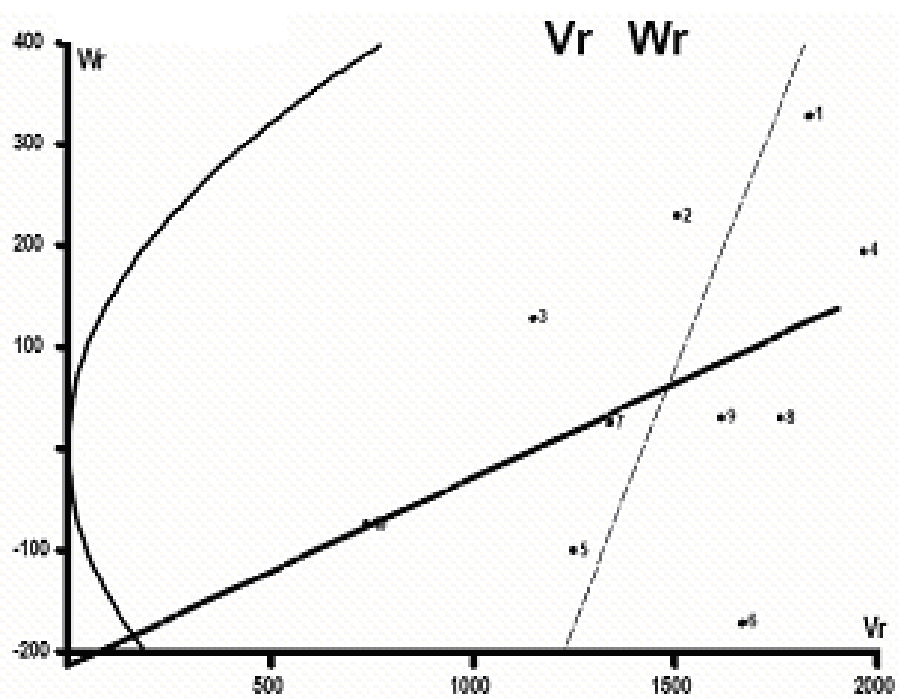


Fig. 44a: $V_r - W_r$ graph for total biological yield/plant in environment - I

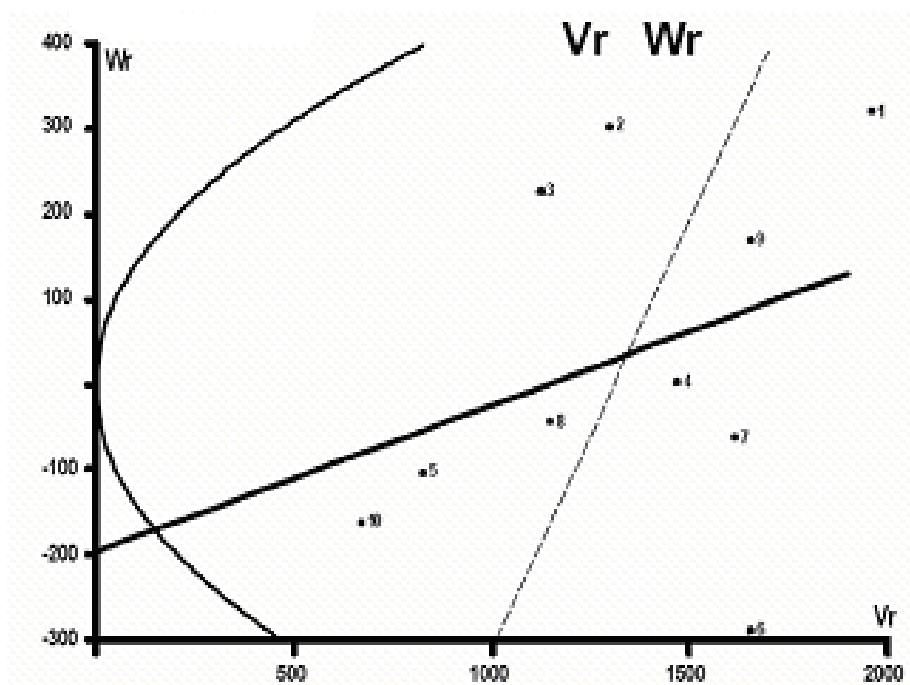


Fig. 44b: $V_r - W_r$ graph for total biological yield/plant in environment – II

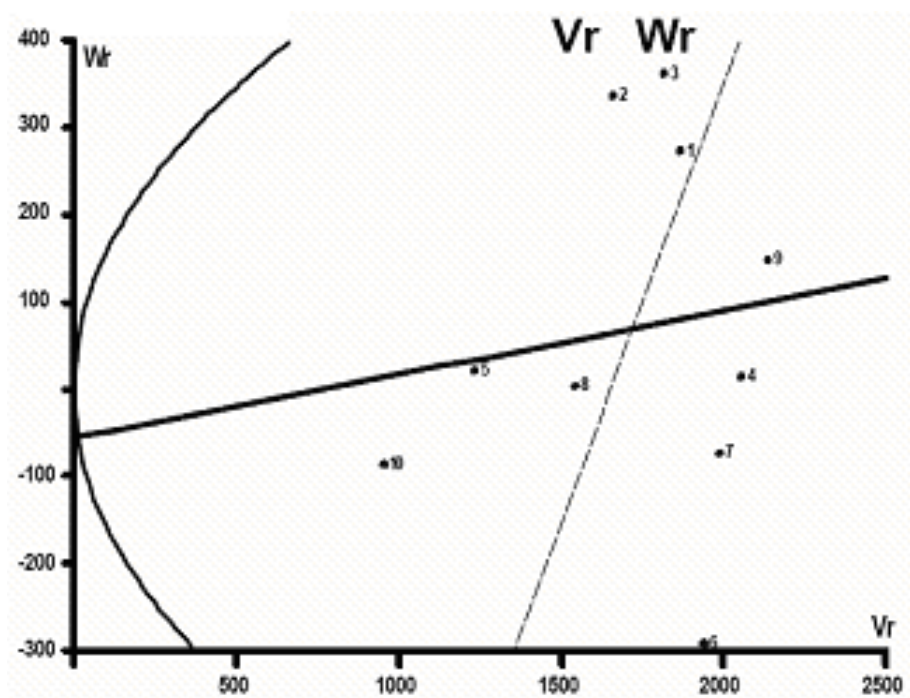


Fig. 44c: $V_r - W_r$ graph for total biological yield/plant in environment – III

the array points 9, 1, 2 (Togo-II, H77/833-2 and H77/29-2) in environment-II and in environment-III the array 3, 9, 2, 1 (G73-107, Togo-II, H77/29-2 and H77/833-2) showed more number of recessive genes for grain yield/plant in them. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them.

xvi) Total biological yield (g)/plant

The slope of regression line did not differ significantly from zero and differ significantly from unity in all the three environments suggesting failure of some of the assumptions as the epistasis was present.

The regression line intercepted the W_r -axis well below the origin in V_r , W_r graphs (figure 44a-c) suggesting over dominance in all the three environments. The well scattered array points along the regression line indicated genetic diversity among the parents.

The array 10 (99HS-18) in environment-I and the array points 10, 5 (99HS-18 and CVJ-2-5-3-1-3) in environment-II and III showed more number of dominant genes while, the array 4, 1 (77/245 and H77/833-2) in environment-I, array points 1, 9 (H77/833-2 and Togo-II) in environment-II and the array points 3, 1, 9 in environment-III showed more number of recessive genes for total biological yield/plant (except roots) in the parents. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them.

4.2.4.4.2 Numerical approach

Genetic component of variance were estimated. The additive variance (D), dominance variance (H_1), mean covariance of D and H_1 (F), proportion of positive and negative genes (H_2), overall dominance effect (h^2) and environmental component (E) together with the allied genetic parameters such as mean degree of dominance $(H_1/D)^{0.5}$, proportion of dominant genes with positive and negative effects in parents ($H_2/4H_1$), proportion of dominant and recessive genes in parents $[(4DH_1)^{0.5} + F / (4DH_1)^{0.5} - F]$, number of dominant gene groups (h^2/H_2) and heritability in narrow sense (h^2_{ns}) are estimated through this approach of Hayman. Since the diallel progenies consisted of hybrids only. The genetic interpretation to F_1 diallel had been applied for estimation of the parameters. The estimates of different parameters are given in table 35.

The additive component of variance (D) had a significant presence for STI and SSTI in both the stress environments. At the same time the dominance component of variance (H_1) for these characters was not only significant but also in higher magnitude. This effect of over dominance was also reflected by higher degree of overall dominance effect (h^2) for both these characters. The covariance between D and H_1 showed a symmetrical distribution of dominant and recessive alleles for SSTI which was however shown to be asymmetrical for STI due to its significant mean squares. The proportion of dominant genes was also higher over the recessive genes in parents for both STI and SSTI. It was also seen that proportion of

Table 35: Genetic parameters for different characters

Genetic variance components	STI (%)				SSTI (%)		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
D (Additive effect)	193.161*	229.356*	—		60.602*	57.859*	—
H ₁ (Dominance effect)	313.485*	440.438*	—		216.063*	232.345*	—
F (Mean cov. of D & H ₁)	182.869*	272.067*	—		38.245	52.322	—
H ₂	242.416*	331.183*	—		181.913*	201.346*	—
h ² (Overall dominance effect)	3.744	0.198	—		50.591*	16.747	—
E (Environmental component)	3.889	3.532	—		2.332	2.092	—
Allied Genetic Parameters							
Mean degree of dominance	1.274	1.386	—		1.888	2.004	—
:: of Genes with +/- effects in parents	0.193	0.188	—		0.210	0.217	—
:: of Dom & rec genes in parents	2.183	2.497	—		1.401	1.583	—
Va (Additive gene effects)	40.680	33.272	—		28.254	18.268	—
Vd (Dominance deviations)	60.604	82.796	—		45.478	50.336	—
h ² / H ₂ (No. of dominant gene blocks)	0.015	0.001	—		0.278	0.083	—
h ² (Heritability in narrow sense)	0.387	0.278	—		0.371	0.258	—

* Significant at $P = 0.05$

Contd...

** Significant at $P = 0.01$

Contd... table 35

Genetic variance components	Germination (%)				Emergence rate (ER)		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
D (Additive effect)	16.101	20.562	21.169		43.156*	8.581*	32.744*
H ₁ (Dominance effect)	105.727*	115.161*	144.523*		80.098*	34.787*	49.381*
F (Mean cov. of D & H ₁)	-1.581	11.763	18.052		52.719*	20.061*	47.114*
H ₂	86.246*	101.515*	113.949*		61.786*	18.925*	30.007*
h ² (Overall dominance effect)	57.329*	21.008	45.839*		214.367*	32.271*	133.257*
E (Environmental component)	0.960	1.131	2.617		4.477*	3.815*	3.844*
Allied Genetic Parameters							
Mean degree of dominance	2.563	2.367	2.613		1.362	2.013	1.228
:: of Genes with +/- effects in parents	0.204	0.220	0.197		0.193	0.136	0.152
:: of Dom & rec genes in parents	0.962	1.275	1.390		2.625	3.768	3.829
V _a (Additive gene effects)	18.581	11.222	16.845		4.375	2.191	2.502
V _d (Dominance deviations)	21.561	25.379	28.487		15.447	4.731	7.502
h ² / H ₂ (No. of dominant gene blocks)	0.665	0.207	0.402		3.469	1.705	4.441
h ² _{ns} (Heritability in narrow sense)	0.452	0.297	0.351		0.180	0.204	0.181

* Significant at $P = 0.05$

Contd...

** Significant at $P = 0.01$

Contd... table 35

Genetic variance components	No. of leaves/ seedling				Seedling height (cm)		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
D (Additive effect)	3.482*	2.128*	4.435		2.603*	4.142*	2.750
H ₁ (Dominance effect)	11.656*	6.835*	30.712*		21.442*	17.358*	79.162*
F (Mean cov. of D & H ₁)	4.308	2.687	5.661		1.621	4.402	8.940
H ₂	9.660*	5.397*	26.418*		20.752*	16.080*	69.181*
h ² (Overall dominance effect)	38.066*	19.838*	92.499*		56.026*	68.155*	144.259*
E (Environmental component)	0.132	0.223	0.461		1.023*	0.553	0.959
Allied Genetic Parameters							
Mean degree of dominance	1.830	1.792	2.631		2.870	2.047	5.365
:: of Genes with +/- effects in parents	0.207	0.197	0.215		0.242	0.232	0.218
:: of Dom & rec genes in parents	2.022	2.088	1.640		1.243	1.701	1.869
V _a (Additive gene effects)	0.585	0.440	1.534		0.837	0.509	1.896
V _d (Dominance deviations)	2.415	1.349	6.605		5.188	4.020	17.295
h ² / H ₂ (No. of dominant gene blocks)	3.941	3.676	3.501		2.700	4.238	2.085
h ² (Heritability in narrow sense)	0.187	0.219	0.178		0.119	0.100	0.094

* Significant at $P = 0.05$

Contd...

** Significant at $P = 0.01$

Contd... table 35

Genetic variance components	Fresh weight (g) /seedling				Dry weight (g) /seedling		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
D (Additive effect)	7.744	33.047	443.496*		0.122	0.237	4.279*
H ₁ (Dominance effect)	193.052*	3092.264*	4532.592*		3.851*	25.727*	39.055*
F (Mean cov. of D & H ₁)	-2.609	56.392	525.394		-0.026	0.391	3.468
H ₂	167.039*	2785.773*	4058.554*		3.696*	23.341*	35.830*
h ² (Overall dominance effect)	308.850*	7437.132*	11330.007*		7.078*	68.129*	91.883*
E (Environmental component)	0.613	2.328	10.109		0.018	0.021	0.080
Allied Genetic Parameters							
Mean degree of dominance	4.993	9.673	3.197		5.612	10.411	3.021
:: of Genes with +/- effects in parents	0.216	0.225	0.224		0.240	0.227	0.229
:: of Dom & rec genes in parents	0.935	1.193	1.455		0.964	1.172	1.310
V _a (Additive gene effects)	18.182	141.573	196.070		0.151	1.116	2.018
V _d (Dominance deviations)	41.760	696.443	1014.639		0.924	5.835	8.958
h ² / H ₂ (No. of dominant gene blocks)	1.849	2.670	2.792		1.915	2.919	2.564
h ² (Heritability in narrow sense)	0.300	0.168	0.161		0.138	0.160	0.182

* Significant at $P = 0.05$

Contd...

** Significant at $P = 0.01$

Contd... table 35

Genetic variance components	Panicle emergence (days)				Effective tillers/plant		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
D (Additive effect)	13.313*	7.066*	24.420*		0.021	0.141	0.287*
H ₁ (Dominance effect)	22.019*	29.515*	99.166*		1.119	0.906	1.452*
F (Mean cov. of D & H ₁)	0.989	6.940	33.279*		0.081	0.221	0.630*
H ₂	18.105*	22.457*	79.667*		0.872*	0.660*	0.904*
h ² (Overall dominance effect)	55.829*	34.830*	114.240*		0.016*	0.133*	0.061
E (Environmental component)	1.725*	1.701	2.283		0.041	0.019	0.027
Allied Genetic Parameters							
Mean degree of dominance	1.286	2.044	2.015		7.387	2.534	2.250
:: of Genes with +/- effects in parents	0.206	0.190	0.201		0.195	0.182	0.156
:: of Dom & rec genes in parents	1.060	1.633	2.022		1.735	1.894	2.904
Va (Additive gene effects)	8.119	3.592	5.320		0.093	0.083	0.103
Vd (Dominance deviations)	4.526	5.614	19.917		0.218	0.165	0.226
h ² / H ₂ (No. of dominant gene blocks)	3.084	1.551	1.434		0.019	0.201	0.067
h ² (Heritability in narrow sense)	0.565	0.329	0.193		0.264	0.311	0.288

* Significant at $P = 0.05$

Contd...

** Significant at $P = 0.01$

Contd... table 35

Genetic variance components	Plant height (cm)				Ear length (cm)		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
D (Additive effect)	456.261*	530.989*	367.961*		6.722*	12.367*	11.584*
H ₁ (Dominance effect)	3298.191*	2851.594*	2033.408*		8.746*	11.137*	15.167*
F (Mean cov. of D & H ₁)	574.310	769.235*	530.747*		2.346	4.274*	0.397
H ₂	2887.823*	2367.494*	1675.760*		8.300*	10.240*	13.322*
h ² (Overall dominance effect)	15198.321*	11614.782*	8045.172*		28.661*	42.517*	62.390*
E (Environmental component)	13.097	20.862	18.830		0.745*	0.539*	0.757*
Allied Genetic Parameters							
Mean degree of dominance	2.689	2.317	2.351		1.141	0.949	1.144
:: of Genes with +/- effects in parents	0.219	0.208	0.206		0.237	0.230	0.220
:: of Dom & rec genes in parents	1.611	1.909	1.885		1.361	1.445	1.030
V _a (Additive gene effects)	146.159	122.927	97.431		2.411	4.495	6.516
V _d (Dominance deviations)	721.956	591.873	418.940		2.075	2.560	3.331
h ² / H ₂ (No. of dominant gene blocks)	5.263	4.906	4.801		3.453	4.152	4.683
h ² (Heritability in narrow sense)	0.166	0.167	0.182		0.461	0.592	0.615

* Significant at $P = 0.05$

Contd...

** Significant at $P = 0.01$

Contd... table 35

Genetic variance components	Ear weight (g)/plant				Dry fodder yield (g)/plant		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
D (Additive effect)	33.180	43.913	49.411		78.015	57.997	68.746
H ₁ (Dominance effect)	656.101*	717.622*	742.711*		3110.412*	2564.172*	3125.955*
F (Mean cov. of D & H ₁)	27.935	100.882	59.820		16.449	6.508	11.581
H ₂	557.859*	589.321*	657.962*		2695.446*	2167.276*	2643.239*
h ² (Overall dominance effect)	1922.075*	2088.571*	3092.474*		11404.485*	8401.513*	9979.659*
E (Environmental component)	5.666	3.162	4.939		12.032	7.149	8.708
Allied Genetic Parameters							
Mean degree of dominance	4.447	4.043	3.877		6.314	6.649	6.743
:: of Genes with +/- effects in parents	0.213	0.205	0.221		0.217	0.211	0.211
:: of Dom & rec genes in parents	1.209	1.794	1.370		1.034	1.017	1.025
V _a (Additive gene effects)	51.744	35.666	37.170		238.266	224.192	269.941
V _d (Dominance deviations)	139.465	147.330	164.490		673.861	541.819	660.810
h ² / H ₂ (No. of dominant gene blocks)	3.445	3.544	4.700		4.231	3.877	3.776
h ² (Heritability in narrow sense)	0.263	0.192	0.180		0.258	0.290	0.287

* Significant at $P = 0.05$

Contd...

** Significant at $P = 0.01$

Contd... table 35

Genetic variance components	Grain yield (g)/plant				Total biological yield(g)/plant		
	Envt-I	Envt-II	Envt-III		Envt-I	Envt-II	Envt-III
D (Additive effect)	10.605	8.913	13.652		187.096	179.963	221.103
H ₁ (Dominance effect)	339.360*	477.422*	570.427*		5842.912*	5395.716*	6798.573*
F (Mean cov. of D & H ₁)	-20.217	12.960	1.298		136.059	223.613	170.077
H ₂	302.985*	427.867*	500.072*		4994.586*	4497.222*	5851.731*
h ² (Overall dominance effect)	995.314*	1424.975*	2036.408*		22697.064*	18871.279*	24186.592*
E (Environmental component)	2.257	1.529	1.528		17.310	10.806	17.181
Allied Genetic Parameters							
Mean degree of dominance	5.657	7.319	6.464		5.588	5.476	5.545
:: of Genes with +/- effects in parents	0.223	0.224	0.219		0.214	0.208	0.215
:: of Dom & rec genes in parents	0.712	1.221	1.015		1.139	1.256	1.149
Va (Additive gene effects)	33.599	22.754	41.354		449.681	427.422	498.934
Vd (Dominance deviations)	75.746	106.967	125.018		1248.647	1124.305	1462.933
h ² / H ₂ (No. of dominant gene blocks)	3.285	3.330	4.072		4.544	4.196	4.133
h ² (Heritability in narrow sense)	0.301	0.173	0.246		0.262	0.274	0.252

* Significant at $P = 0.05$

** Significant at $P = 0.01$

dominant genes with positive effect was higher than those with negative effects in control of STI and SSTI. Only one dominant gene appears to be responsible for expression of STI and SSTI. Narrow sense heritability (h^2_{ns}) for STI was estimated as 39 % and 28% for environment I and II and 37% and 26% respectively for SSTI.

The estimates of D (additive genetic variance) were significant for emergence rate, panicle emergence, plant height and ear length in all the three environments. The characters, number of leaves/seedling, seedling height were significant in two environments (stress environments), while, the characters fresh weight/seedling, dry weight/seedling and effective tillers/plant showed significant D value (additive genetic variance) only in environment-III (normal environment). For the remaining characters i.e. germination, ear weight/plant, dry fodder yield/plant, grain yield/plant and total biological yield/plant D value was non-significant. The two dominance components, H_1 and H_2 are interlinked. H_1 is dominance variance due to dominance effect of genes, while, H_2 is dominance component indicating asymmetry of positive and negative effects of genes. These two parameters together reflect the contribution of genes with positive effects and those with negative effects.

Both these H_1 and H_2 components were significant for all the traits in all the three environments except for number of effective tillers/plant where, environment-I and II (stress environments) were non-significant. The magnitude of H_1 was higher than that of D for all the characters in all the environments (except the ear length in

environment-II) indicating a preponderance of non-additive gene effects in the inheritance of these characters.

The h^2 component, which reflects net dominance of genes (as the algebraic sum over all the loci in the heterozygous phase in all the crosses), was significant for germination (environment-I and II), emergence rate, number of leaves/seedling, seedling height (cm), fresh weight (g)/seedling, dry weight (g)/seedling, panicle emergence (days), number of effective tillers/plant (environment-I and II), plant height (cm), ear length (cm), ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant in all the three environments, while, for the remaining characters and environments it was non-significant.

The sign of the parameter 'F' which is the mean covariance of additive and non-additive effects in the arrays is used to determine the relative frequency of dominant to recessive alleles in the parental population. The value of parameter F was significant and positive for emergence rate, panicle emergence (environment-III), plant height (environment-II and III) and ear length (environment-II), indicating the excess of dominant genes among the parents for these characters. None of the character the value of F was significant and negative. For the remaining characters, the value of F was non-significant and thus, indicating equal proportion of dominant and recessive genes.

The significant values of the environmental component of variance (E) were recorded for panicle emergence (environment-I) and ear length (cm) in all the three environments.

4.2.4.4.3 Allied genetic parameters

The inter relationship of the H_1 and H_2 parameters is reflected in the allied genetic parameter $H_2/4H_1$ index that estimates the proportion of genes with positive/negative effects, showing dominance in the parents. The value of this index was less than the expected values of 0.25 for all the characters in all the three environments indicating the asymmetrical distribution of dominant genes having positive and negative effects in parents. However, this ratio $H_2/4H_1$ showed a slight deviation from symmetrical distribution of dominant genes with positive and negative effects for the characters, germination in environment-II (0.220), seedling height in environment-I and II (0.242 and 0.232), fresh weight (g)/seedling in environment-II and III (0.225 and 0.224), dry weight (g)/seedling (0.240, 0.227 and 0.229) in environment-I, II and III, ear length (0.237, 0.230 and 0.220), ear weight (g)/plant in environment-III (0.221) and grain yield (g)/plant (0.223 and 0.224) in environment-I and II.

The mean degree of dominance $(H_1/D)^{0.5}$ indicated over dominance for germination (%), emergence rate (ER), number of leaves/seedling, seedling height (cm), fresh weight (g)/seedling, dry weight (g)/seedling, panicle emergence (days), effective tillers/plant, plant height (cm), ear length (environment-I and III), ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant, while, partial dominance was observed for ear length (environment-II). None of the character showed complete dominance in any environment.

Regarding proportion of dominant and recessive genes in parents positive F value caused the ratio $(4DH_1)^{0.5}+F/(4DH_1)^{0.5}-F$ to be greater than unity for germination (environment-II and III), emergence rate, number of leaves/seedling, seedling height (cm), fresh weight (g)/seedling (environment-II and III), dry weight (g)/seedling (environment-II and III), panicle emergence (days), effective tillers/plant, plant height (cm), ear length (cm), ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant (environment-II and III) and total biological yield (g)/plant in all the three environments, indicating that these characters were controlled by more of dominant genes in the parents. The negative sign of F causing the ratio to be less than unity indicating that germination (environment-I), fresh weight (g)/seedling (environment-I), dry weight (g)/seedling (environment-I), grain yield (g)/plant (environment-I) were controlled by an excess of recessive genes.

The ratio h^2/H_2 denotes the number of gene groups exhibiting dominance. The value of this ratio indicated one group of genes for germination (%), and number of effective tillers/plant in all the three environments. The characters i.e. emergence rate (environment-I), fresh weight (g)/seedling (environment-I), dry weight (g)/seedling (environment-I) and panicle emergence (environment-II and III) indicated two gene groups exhibiting dominance. Three gene groups were shown by the characters i.e. seedling height (environment-I and III), fresh weight (g)/seedling (environment-II and III) and dry weight (g)/seedling (environment-II and III). The characters, emergence rate

(environment-I), number of leaves/seedling, panicle emergence (environment-I), ear length (environment-I), ear weight (g)/plant (stress environments), dry fodder yield (g)/plant (environment-II and III) and grain yield (g)/plant (stress environments) exhibited four gene groups.

Five gene groups were exhibited by the characters, namely, emergence rate (environment-III), seedling height (environment-II), plant height (environment-II and III), ear length (environment-II and III), ear weight (g)/plant (environment-III), dry fodder yield (g)/plant (environment-I), grain yield (g)/plant (environment-III) and total biological yield (g)/plant in all the three environments and the only character, plant height exhibited six gene groups in environment-I.

The estimate of narrow-sense heritability (h^2_{NS}) were high for panicle emergence (environment-I) and ear length (environment-II and III). Contrarily, the heritability estimates were low for rest of the characters.

4.2.5 Stability analysis

Stability analysis was carried out based on Freeman and Perkins (1971) model for 14 characters. The stability analysis could not be conducted for seedling thermo-tolerance index (STI) and seed to seedling thermo-tolerance index (SSTI) for the precise reason that variation in values of these indices were available only in two environments making the data inadequate for analysis based on above model. As a matter of fact the seedling mortality during third

environment i.e. the monsoon period was practically nil (zero) and it had to be excluded. The investigation was carried out on the basis of:

- i) Regression analysis
- ii) Estimation of adaptation parameters of the individual genotypes.

4.2.5.1 Regression analysis

The analysis of variance indicated significant differences among the genotypes and the environments for all the characters (table 36). The environmental effects were portioned into combined regression and the environmental residual. The combined regression S.S. was again significant for all the characters except three i.e. emergence rate (ER), number of effective tillers/plant and total biological yield (g)/plant. It would mean the combined regression gave the true measure of environment except for these three characters. The environmental residual component indicated significant differences for six characters, namely, germination (%), emergence rate (ER), seedling height, fresh weight (g)/seedling, number of effective tillers/plant and total biological yield (g)/plant indicating thereby that the environmental index for these characters was adequately the index of additive environmental effect. The interaction between genotype $\times$ environment sum of squares (non-linear interaction) was also significant for all the characters except ear length. The results of the analysis showed that both the linear and non-linear effects of environments were important for different characters. The

Table 36: Analysis of variance for stability (Freeman and Perkins) for different characters in three environments

Source of Variations	D.F	Mean Sum of Squares						
		Germination (%)	Rate of emergence	No. of leaves/ seedling	Seedling height (cm)	Fresh weight (g) /seedling	Dry weight (g) /seedling	Panicle emergence (days)
Genotypes (G)	54	167.69660**	70.63286**	26.88289**	44.81673**	2437.31132**	23.59961**	72.82357**
Environments (E)	2	9154.06525**	186.57745**	595.35686**	3217.38112**	185981.39783**	1052.40026**	9292.33030**
Combined Regression	1	18263.78615*	172.96284	1190.07123*	6426.47583*	371903.41514**	2104.53900**	18581.89834**
Residual (1)	1	44.34436**	200.19207**	0.64249	8.28642*	59.38051**	0.26151	2.76227
Interaction (G×E)	108	28.98332**	17.79143**	3.62682**	12.86898**	985.58497**	8.05048**	16.82104**
Heterogeneity of Reg.	54	41.71580**	22.31156*	6.03638**	22.28129**	1165.92229	10.39908*	22.29366**
Residual (2)	54	16.25083**	13.27131	1.21727**	3.45668**	805.24766**	5.70189**	11.34843**
Error between Rep.	165	5.27695	11.04573	0.60923	2.04760	8.34948	0.07246	5.26061

* Significant at $P = 0.05$

Contd...

** Significant at $P = 0.01$

Contd... table 36

Source of Variation	D.F	Mean Sum of Squares						
		Effective tillers/plant	Plant height (cm)	Ear length (cm)	Ear weight (g)/plant	Dry fodder yield (g)/plant	Grain yield (g)/plant	Total biological yield(g)/plant
Genotypes (G)	54	1.12821**	4834.68170**	45.04829**	1109.53498**	5574.66174**	698.32608**	11172.66508**
Environments (E)	2	5.51043**	65006.50547**	263.74177**	2560.08331**	5137.35033**	2994.75407**	5713.71047**
Combined Regression	1	9.69938	129952.99724*	527.42039**	5117.47042*	10264.57557*	5987.05138*	11151.57635
Residual (1)	1	1.32147**	60.01370	0.06316	2.69620	10.12509	2.45677	275.84460*
Interaction (G×E)	108	0.29990**	207.82874**	2.57045	81.33772**	77.51664**	85.67626**	188.41293**
Heterogeneity of Reg.	54	0.32509	270.89791*	3.68049**	83.53068	93.66263	109.28721*	179.18030
Residual (2)	54	0.27470**	144.75957**	1.46041	79.14476**	61.37065**	62.06532**	197.64556**
Error between Rep	165	0.10449	47.25350	2.71412	14.69108	27.43295	4.89902	43.87503

* Significant at $P = 0.05$

** Significant at $P = 0.01$

significance of residual (2) sum of squares for most of the characters gave credence to the adequacy of non-linear interaction component. The magnitude of linear effects was however always higher for the former.

4.2.5.2 Estimation of stability parameters of the individual genotypes

The estimates of these stability parameters or adaptability parameters viz. mean (X_i), regression coefficient (b_i) and deviation from regression (S^2_{di}) for parents and one set of 10×10 diallel cross F_1 's in respect of the characters studied are presented in table 37. The results for each character are described as follows:

i) Germination (%)

A consideration of the two parameters b_i and S^2_{di} of the individual genotypes revealed that neither the regression mean square nor the deviation from regression mean square was significant for all the ten parents and 38 F_1 hybrids. This indicated the absence of $G \times E$ interaction for these genotypes. Only seven hybrids were such as had non significant regression values and the significant deviation from regression mean square which indicated the only non-linear portion of $G \times E$ interaction was active in this case. It would make their performance unpredictable under the environmental changes.

The conclusion from the individual analysis thus confirmed the information obtained from analysis of variance table for stability parameters (table 37) where a major portion of the $G \times E$ interaction

Table 37 : Parameter estimation for stability of the parents and the crosses for different characters

Sr. no.	Genotypes	Germination (%)			Emergence rate (ER)		
		Mean	bi	S ² di	Mean	bi	S ² di
1.	H77/833-2	46.140	1.381	8.320	41.420	-1.304	-7.895
2.	H77/29-2	54.430	0.626	2.765	36.840	25.143	11.354
3.	G73-107	52.600	0.720	-5.278	43.820	-5.941	-4.260
4.	77/245	49.780	0.668	-4.954	40.920	11.907	1.784
5	CVJ-2-5-3-1-3	55.180	1.162	4.438	49.700	-0.568	-3.858
6	1305	45.400	0.943	-4.629	40.020	25.065	-1.797
7	77/371 × BSECT CP-1	51.900	1.152	-2.145	50.250	4.384	-4.211
8	96AC-93	47.300	0.986	9.093	46.600	5.643	-1.191
9	Togo-II	46.090	0.626	1.666	45.930	0.750	13.973
10	99HS-18	48.820	1.310	-3.619	45.740	4.616	31.674
1.	H77/833-2 × H77/29-2	59.380	0.774	-5.010	49.890	0.261	-10.981
2.	H77/833-2 × G73-107	54.310	1.033	11.931	53.700	0.483	-10.827
3.	H77/833-2 × 77/245	44.290	0.916	-4.089	53.000	1.931	-7.558
4.	H77/833-2 × CVJ-2-5-3-1-3	50.000	0.864	-5.133	49.110	-0.669	-10.630
5	H77/833-2 × 1305	35.330	0.980	-5.253	50.740	-3.247	-10.956
6	H77/833-2 × (77/371 × BSECT CP-1)	58.110	0.366	-5.125	49.080	5.658	18.872
7	H77/833-2 × 96AC-93	58.570	0.386	-5.174	50.210	2.075	-2.793
8	H77/833-2 × Togo-II	46.750	1.156	34.333**	49.250	3.462	-5.287
9	H77/833-2 × 99HS-18	48.130	0.595	-4.015	50.400	-2.422	-5.577
10	H77/29-2 × G73-107	56.170	0.778	-2.474	52.410	5.475	-2.501
11	H77/29-2 × 77/245	56.390	0.661	-5.218	49.350	1.678	-7.339
12	H77/29-2 × CVJ-2-5-3-1-3	57.180	0.682	-5.194	50.260	0.852	-5.079
13	H77/29-2 × 1305	43.800	1.006	9.468	42.360	10.150	46.129*
14	H77/29-2 × (77/371 × BSECT CP-1)	62.090	1.466	26.180*	51.480	4.325	-9.262
15	H77/29-2 × 96AC-93	55.580	1.002	-5.199	49.710	3.992	3.850
16	H77/29-2 × Togo-II	60.240	0.475	-5.121	52.070	0.156	-6.584
17	H77/29-2 × 99HS-18	60.990	1.747	-1.061	49.640	1.877	-7.750
18	G73-107 × 77/245	52.880	0.951	-5.274	52.230	1.926	-7.370

Contd...

Sr. no.	Genotypes	Germination (%)			Emergence rate (ER)		
		Mean	bi	S ² di	Mean	bi	S ² di
19	G73-107 × CVJ-2-5-3-1-3	54.850	0.874	-4.743	51.330	3.019	-2.525
20	G73-107 × 1305	56.800	1.692	6.575	47.610	-0.637	-10.669
21	G73-107 × (77/371 × BSECT CP-1)	58.120	0.427	-4.995	51.360	1.331	-9.387
22	G73-107 × 96AC-93	55.550	0.924	38.836**	51.020	1.737	-8.223
23	G73-107 × Togo-II	49.530	0.918	-0.286	48.290	7.533	41.969
24	G73-107 × 99HS-18	54.010	0.958	25.021*	50.370	-3.094	-10.591
25	77/245 × CVJ-2-5-3-1-3	51.170	0.805	-1.335	49.960	-1.588	-8.694
26	77/245 × 1305	48.950	1.164	-2.277	52.100	0.157	-11.021
27	77/245 × (77/371 × BSECT CP-1)	53.220	0.643	0.266	52.850	1.787	-8.081
28	77/245 × 96AC-93	54.660	0.708	0.081	51.130	-1.391	-9.243
29	77/245 × Togo-II	52.110	0.708	3.159	50.410	-2.317	-6.038
30	77/245 × 99HS-18	55.700	1.460	49.095**	51.350	0.293	-10.964
31	CVJ-2-5-3-1-3 × 1305	46.690	0.990	-5.238	47.140	1.637	2.741
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	49.760	1.758	-1.582	51.010	-2.613	-4.947
33	CVJ-2-5-3-1-3 × 96AC-93	49.340	0.799	-3.184	49.740	0.674	-10.619
34	CVJ-2-5-3-1-3 × Togo-II	50.820	1.077	-0.087	46.140	2.495	-5.227
35	CVJ-2-5-3-1-3 × 99HS-18	59.490	1.184	-4.638	51.410	-2.132	-10.029
36	1305 × (77/371 × BSECT CP-1)	49.560	0.800	-0.294	50.070	1.019	-10.073
37	1305 × 96AC-93	58.270	0.942	-4.258	49.740	-2.156	-6.712
38	1305 × Togo-II	43.040	1.006	-1.119	44.380	1.460	-9.050
39	1305 × 99HS-18	56.290	1.429	-4.916	49.890	-3.546	0.684
40	(77/371 × BSECT CP-1) × 96AC-93	58.280	1.563	4.684	50.970	0.753	-10.504
41	(77/371 × BSECT CP-1) × Togo-II	53.620	0.772	-1.156	51.440	-2.113	-6.883
42	(77/371 × BSECT CP-1) × 99HS-18	53.960	1.083	36.538**	48.830	1.518	-0.933
43	96AC-93 × Togo-II	51.600	1.408	3.916	51.500	3.586	0.976
44	96AC-93 × 99HS-18	57.770	1.030	0.347	52.090	1.823	-7.937
45	Togo-II × 99HS-18	54.870	1.819	18.075*	46.110	-1.714	-11.045

* Significant at P = 0.05

** Significant at P = 0.01

Contd...

Contd... table 37

Sr. no.	Genotypes	No. of leaves/seedling			Seedling height (cm)		
		Mean	bi	S ² di	Mean	bi	S ² di
1.	H77/833-2	6.540	0.552	-0.609	13.130	1.397	5.174
2.	H77/29-2	3.610	0.126	0.184	13.630	0.805	-1.969
3.	G73-107	8.410	0.342	0.696	15.360	0.644	4.461
4.	77/245	3.690	0.189	-0.609	16.320	0.720	-0.746
5	CVJ-2-5-3-1-3	7.680	0.599	0.380	14.860	0.487	-1.596
6	1305	3.490	0.076	-0.609	12.440	0.713	3.191
7	77/371 × BSECT CP-1	6.210	0.403	-0.581	15.850	0.470	-2.015
8	96AC-93	7.300	0.643	-0.581	14.710	0.669	-1.009
9	Togo-II	7.210	0.514	-0.496	15.160	1.254	-1.986
10	99HS-18	7.380	0.852	-0.459	13.870	0.603	0.637
1.	H77/833-2 × H77/29-2	6.920	0.460	-0.608	17.210	0.927	-0.463
2.	H77/833-2 × G73-107	10.490	1.133	0.062	18.380	0.667	-1.343
3.	H77/833-2 × 77/245	7.440	0.751	-0.609	17.870	0.830	4.412
4.	H77/833-2 × CVJ-2-5-3-1-3	10.470	0.873	-0.557	19.040	0.546	-0.354
5	H77/833-2 × 1305	12.420	1.545	-0.590	21.280	1.346	-2.048
6	H77/833-2 × (77/371 × BSECT CP-1)	10.500	1.737	4.081**	20.290	1.771	2.380
7	H77/833-2 × 96AC-93	10.580	0.639	0.129	20.150	0.700	1.188
8	H77/833-2 × Togo-II	9.190	0.961	0.256	18.760	0.984	-1.645
9	H77/833-2 × 99HS-18	9.490	0.793	-0.013	18.140	0.343	-0.151
10	H77/29-2 × G73-107	10.280	1.541	-0.600	17.130	0.370	-2.047
11	H77/29-2 × 77/245	7.990	0.681	0.332	19.020	1.052	0.382
12	H77/29-2 × CVJ-2-5-3-1-3	11.210	1.346	0.904	22.570	1.047	-1.319
13	H77/29-2 × 1305	10.490	1.599	-0.178	20.340	1.822	-0.778
14	H77/29-2 × (77/371 × BSECT CP-1)	10.090	1.504	-0.558	23.170	1.250	1.606
15	H77/29-2 × 96AC-93	9.740	1.351	0.215	20.020	1.290	-1.628
16	H77/29-2 × Togo-II	8.770	0.621	-0.495	18.050	0.595	0.779
17	H77/29-2 × 99HS-18	11.140	1.647	0.266	22.920	1.496	1.649
18	G73-107 × 77/245	10.340	0.914	-0.390	19.600	0.319	-1.880

Contd...

Sr. no.	Genotypes	No. of leaves/seedling			Seedling height (cm)		
		Mean	bi	S ² di	Mean	bi	S ² di
19	G73-107 × CVJ-2-5-3-1-3	10.520	0.864	-0.500	18.970	0.903	-1.105
20	G73-107 × 1305	12.260	1.869	0.055	18.520	1.806	-0.880
21	G73-107 × (77/371 × BSECT CP-1)	10.250	1.486	-0.256	21.770	0.927	-1.804
22	G73-107 × 96AC-93	10.670	0.733	-0.107	21.400	1.203	-2.039
23	G73-107 × Togo-II	9.920	0.513	0.574	21.920	1.620	-2.007
24	G73-107 × 99HS-18	11.910	2.065	-0.607	21.480	2.094	-1.457
25	77/245 × CVJ-2-5-3-1-3	10.330	0.354	0.059	18.100	0.557	-1.939
26	77/245 × 1305	12.170	1.543	-0.340	16.980	0.729	-1.946
27	77/245 × (77/371 × BSECT CP-1)	7.870	0.694	0.142	20.160	1.360	-1.654
28	77/245 × 96AC-93	8.380	0.755	-0.591	18.560	0.439	-0.891
29	77/245 × Togo-II	9.900	1.234	-0.031	22.010	1.578	-0.859
30	77/245 × 99HS-18	10.310	0.532	-0.405	22.800	0.825	3.856
31	CVJ-2-5-3-1-3 × 1305	10.630	1.226	3.857**	16.530	0.770	-0.608
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	8.410	0.517	-0.570	18.260	1.020	-0.239
33	CVJ-2-5-3-1-3 × 96AC-93	10.500	1.471	0.258	21.640	1.999	-1.957
34	CVJ-2-5-3-1-3 × Togo-II	9.990	0.786	-0.549	18.890	1.208	-1.947
35	CVJ-2-5-3-1-3 × 99HS-18	10.470	0.906	-0.504	19.120	1.185	-1.762
36	1305 × (77/371 × BSECT CP-1)	8.020	0.782	0.324	17.740	0.657	0.475
37	1305 × 96AC-93	10.150	1.904	2.112*	20.140	1.055	2.167
38	1305 × Togo-II	6.660	0.385	-0.586	17.020	0.784	2.647
39	1305 × 99HS-18	11.140	1.308	-0.600	21.020	1.179	-1.283
40	(77/371 × BSECT CP-1) × 96AC-93	10.570	1.696	-0.206	22.380	1.504	3.019
41	(77/371 × BSECT CP-1) × Togo-II	8.480	0.367	-0.353	22.080	0.775	-0.270
42	(77/371 × BSECT CP-1) × 99HS-18	8.830	0.947	-0.164	19.640	1.200	-0.934
43	96AC-93 × Togo-II	9.670	0.969	-0.552	18.340	0.591	-1.291
44	96AC-93 × 99HS-18	10.000	1.575	0.117	19.660	1.462	-2.047
45	Togo-II × 99HS-18	10.180	1.792	0.139	16.590	1.502	-1.276
*	Significant	at P	=	0.05	Contd...		
**	Significant	at P	=	0.01			

Contd... table 37

Sr. no.	Genotypes	Fresh weight (g)/seedling			Dry weight (g)/seedling		
		Mean	bi	S ² di	Mean	bi	S ² di
1.	H77/833-2	14.400	0.135	-7.902	1.520	0.005	-0.043
2.	H77/29-2	18.430	0.322	31.216*	1.790	0.289	-0.016
3.	G73-107	25.440	0.496	85.825**	2.130	0.391	0.700**
4.	77/245	28.090	0.682	149.922**	2.690	0.695	0.774**
5	CVJ-2-5-3-1-3	23.130	0.368	92.138**	2.400	0.402	1.415**
6	1305	21.230	0.522	200.645**	2.100	0.487	1.811**
7	77/371 × BSECT CP-1	23.060	0.319	10.509	2.360	0.277	0.079
8	96AC-93	28.250	0.581	254.501**	3.060	0.659	2.702**
9	Togo-II	38.340	0.996	885.162**	3.860	1.256	7.795**
10	99HS-18	37.150	0.726	153.461**	3.560	0.669	2.305**
1.	H77/833-2 × H77/29-2	47.090	0.870	0.001	4.800	1.029	0.418**
2.	H77/833-2 × G73-107	34.120	0.567	6.297	3.310	0.693	-0.058
3.	H77/833-2 × 77/245	55.700	0.936	221.713**	5.300	0.858	0.154
4.	H77/833-2 × CVJ-2-5-3-1-3	51.090	0.385	1455.443**	5.370	0.129	10.733**
5	H77/833-2 × 1305	55.960	0.974	30.106*	6.540	0.484	0.517**
6	H77/833-2 × (77/371 × BSECT CP-1)	52.910	1.227	85.196**	4.920	1.141	0.505**
7	H77/833-2 × 96AC-93	84.290	1.686	624.319**	8.240	1.902*	3.205**
8	H77/833-2 × Togo-II	61.050	1.175	224.124**	5.790	1.109	0.631**
9	H77/833-2 × 99HS-18	67.990	1.589	675.240**	7.650	2.347*	4.279**
10	H77/29-2 × G73-107	48.770	0.951	-3.714	4.220	0.778	0.006
11	H77/29-2 × 77/245	44.450	0.479	209.675**	4.840	0.233	0.744**
12	H77/29-2 × CVJ-2-5-3-1-3	81.990	1.671	1.703	6.380	1.359	-0.061
13	H77/29-2 × 1305	76.820	1.484	31.408*	7.280	1.499	0.389*
14	H77/29-2 × (77/371 × BSECT CP-1)	67.340	1.592	542.542**	6.720	1.774*	3.245**
15	H77/29-2 × 96AC-93	61.560	1.115	555.838**	6.890	1.514*	4.128**
16	H77/29-2 × Togo-II	94.890	1.691	-6.888	9.500	1.910*	0.135
17	H77/29-2 × 99HS-18	63.700	1.246	33.674*	6.170	1.143	-0.038
18	G73-107 × 77/245	62.710	0.686	784.870**	5.280	0.459	2.209**

Contd...

Sr. no.	Genotypes	Fresh weight (g)/seedling			Dry weight (g)/seedling		
		Mean	bi	S ² di	Mean	bi	S ² di
19	G73-107 × CVJ-2-5-3-1-3	61.400	0.963	266.883**	6.770	1.112	6.264**
20	G73-107 × 1305	60.380	1.115	88.888**	6.910	1.451	0.446**
21	G73-107 × (77/371 × BSECT CP-1)	52.330	0.989	453.884**	4.230	0.803	2.277**
22	G73-107 × 96AC-93	84.490	1.591	79.320**	8.070	1.530*	0.616**
23	G73-107 × Togo-II	50.360	0.989	8.838	5.480	1.306	0.108
24	G73-107 × 99HS-18	77.810	1.172	32.423*	6.780	1.059	-0.053
25	77/245 × CVJ-2-5-3-1-3	61.510	1.170	406.322**	6.230	1.395	4.612**
26	77/245 × 1305	78.140	1.333	926.957**	6.760	1.341	10.528**
27	77/245 × (77/371 × BSECT CP-1)	81.200	1.105	24.310*	8.120	1.029	0.290*
28	77/245 × 96AC-93	65.110	1.157	5.692	6.080	0.918	-0.071
29	77/245 × Togo-II	84.810	1.723*	20.319	8.160	1.991*	0.033
30	77/245 × 99HS-18	65.910	0.085	6457.576**	5.490	-0.223	26.763**
31	CVJ-2-5-3-1-3 × 1305	47.500	1.141	608.200**	4.110	1.107	2.490**
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	63.180	1.406	158.658**	5.830	1.300	1.058**
33	CVJ-2-5-3-1-3 × 96AC-93	79.010	1.228	638.293**	7.790	1.338	7.365**
34	CVJ-2-5-3-1-3 × Togo-II	54.120	1.271	354.344**	5.100	1.130	2.146**
35	CVJ-2-5-3-1-3 × 99HS-18	44.610	0.496	247.058**	4.690	0.389	3.923**
36	1305 × (77/371 × BSECT CP-1)	48.220	0.719	-5.365	5.020	0.597	0.386*
37	1305 × 96AC-93	78.380	1.339	701.411**	9.110	1.638*	11.286**
38	1305 × Togo-II	49.890	1.032	4.549	4.970	0.895	-0.038
39	1305 × 99HS-18	57.970	1.027	228.415**	5.800	1.139	1.750**
40	(77/371 × BSECT CP-1) × 96AC-93	95.010	1.551	1463.862**	8.330	1.508	15.255**
41	(77/371 × BSECT CP-1) × Togo-II	57.470	0.863	-7.532	6.500	1.064	0.000
42	(77/371 × BSECT CP-1) × 99HS-18	69.980	1.194	-3.352	6.950	1.220	0.147
43	96AC-93 × Togo-II	80.330	1.295	723.598**	7.740	1.195	3.636**
44	96AC-93 × 99HS-18	75.690	1.080	38.977*	7.060	1.020	0.200
45	Togo-II × 99HS-18	73.740	1.027	62.612 **	8.170	1.197	0.017

* Significant at P = 0.05

** Significant at P = 0.01

Contd...

Contd... table 37

Sr. no.	Genotypes	Panicke emergence (days)			Effective tillers/plant		
		Mean	bi	S ² di	Mean	bi	S ² di
1.	H77/833-2	49.670	1.459	-4.969	2.290	0.541	-0.099
2.	H77/29-2	57.110	1.050	4.510	2.100	0.478	-0.051
3.	G73-107	58.110	0.979	-4.223	2.250	0.784	-0.104
4.	77/245	53.330	0.731	22.605*	2.350	0.136	-0.083
5	CVJ-2-5-3-1-3	52.780	1.085	-5.170	2.450	0.079	-0.030
6	1305	54.560	0.994	-1.970	2.380	0.015	0.032
7	77/371 × BSECT CP-1	49.890	0.830	12.074	2.520	0.824	0.209
8	96AC-93	47.220	0.939	28.179*	2.930	0.677	-0.073
9	Togo-II	51.000	1.017	3.781	1.530	-0.864	-0.098
10	99HS-18	50.890	0.973	-4.537	2.470	1.220	1.107**
1.	H77/833-2 × H77/29-2	46.670	1.248	-4.928	2.820	-0.959	-0.093
2.	H77/833-2 × G73-107	48.110	1.121	1.109	2.650	-0.627	-0.007
3.	H77/833-2 × 77/245	48.330	0.387	-3.228	2.460	-0.621	0.053
4.	H77/833-2 × CVJ-2-5-3-1-3	45.110	1.084	-2.118	2.820	2.716	0.304*
5	H77/833-2 × 1305	44.670	1.550	-1.044	4.060	1.607	-0.053
6	H77/833-2 × (77/371 × BSECT CP-1)	42.220	1.121	1.109	2.510	0.789	0.108
7	H77/833-2 × 96AC-93	44.670	1.070	-5.016	2.460	-0.041	-0.074
8	H77/833-2 × Togo-II	48.670	0.752	-2.509	2.130	0.208	0.384*
9	H77/833-2 × 99HS-18	48.780	1.197	-3.150	2.470	-0.445	-0.020
10	H77/29-2 × G73-107	53.440	0.661	4.799	2.710	-0.711	-0.102
11	H77/29-2 × 77/245	50.220	0.784	-2.101	2.210	2.455	-0.104
12	H77/29-2 × CVJ-2-5-3-1-3	50.560	1.417	-5.088	1.990	0.798	-0.104
13	H77/29-2 × 1305	48.670	1.609	8.320	3.070	0.890	0.175
14	H77/29-2 × (77/371 × BSECT CP-1)	47.330	1.190	-4.147	2.040	1.068	-0.082
15	H77/29-2 × 96AC-93	47.890	0.882	-4.822	2.320	0.696	0.089
16	H77/29-2 × Togo-II	50.220	1.197	-3.150	2.460	-0.070	-0.067
17	H77/29-2 × 99HS-18	49.670	1.216	-4.777	1.940	0.063	-0.080
18	G73-107 × 77/245	48.440	0.753	-5.226	2.540	1.170	-0.099

Contd...

Sr. no.	Genotypes	Panicle emergence (days)			Effective tillers/plant		
		Mean	bi	S ² di	Mean	bi	S ² di
19	G73-107 × CVJ-2-5-3-1-3	45.330	1.427	-4.826	2.720	1.074	-0.093
20	G73-107 × 1305	53.220	1.564	-5.215	2.690	0.317	0.361*
21	G73-107 × (77/371 × BSECT CP-1)	44.670	1.226	-2.129	2.380	0.130	0.217
22	G73-107 × 96AC-93	50.890	0.563	6.778	2.710	0.175	-0.050
23	G73-107 × Togo-II	50.000	1.076	-3.370	2.170	0.335	-0.088
24	G73-107 × 99HS-18	45.890	1.243	0.724	2.290	1.501	0.036
25	77/245 × CVJ-2-5-3-1-3	48.440	1.203	5.776	3.000	1.053	0.738**
26	77/245 × 1305	46.890	1.415	14.083	2.440	1.787	-0.086
27	77/245 × (77/371 × BSECT CP-1)	45.330	0.852	-4.399	2.210	0.787	-0.078
28	77/245 × 96AC-93	44.780	0.962	-2.387	1.840	-0.050	-0.094
29	77/245 × Togo-II	49.110	1.118	-5.084	2.390	1.413	-0.104
30	77/245 × 99HS-18	46.780	1.129	-0.740	1.950	0.461	-0.038
31	CVJ-2-5-3-1-3 × 1305	46.220	1.639	-0.874	2.780	0.273	1.090**
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	45.560	1.252	7.132	2.980	-1.336	-0.043
33	CVJ-2-5-3-1-3 × 96AC-93	48.440	0.810	-5.260	2.300	1.952	0.017
34	CVJ-2-5-3-1-3 × Togo-II	52.220	1.067	0.738	2.520	1.755	0.124
35	CVJ-2-5-3-1-3 × 99HS-18	46.560	1.104	-1.848	1.830	1.181	-0.093
36	1305 × (77/371 × BSECT CP-1)	45.780	1.167	-5.242	2.730	0.087	-0.024
37	1305 × 96AC-93	43.560	1.247	-4.459	2.360	0.722	0.179
38	1305 × Togo-II	56.000	1.081	3.983	2.590	0.978	-0.095
39	1305 × 99HS-18	47.220	1.243	0.724	1.500	1.138	-0.103
40	(77/371 × BSECT CP-1) × 96AC-93	44.440	1.153	0.523	1.850	1.387	-0.076
41	(77/371 × BSECT CP-1) × Togo-II	48.220	0.943	0.700	2.470	1.081	-0.099
42	(77/371 × BSECT CP-1) × 99HS-18	50.110	0.384	13.832	1.730	-0.337	-0.077
43	96AC-93 × Togo-II	47.890	1.175	-5.193	2.740	1.786	-0.070
44	96AC-93 × 99HS-18	50.110	0.674	-4.545	1.770	1.077	-0.055
45	Togo-II × 99HS-18	51.560	1.049	4.720	2.010	0.554	-0.102

* Significant at P = 0.05

** Significant at P = 0.01

Contd...

Contd... table 37

Sr. no.	Genotypes	Plant height (cm)			Ear length (cm)		
		Mean	bi	S ² di	Mean	bi	S ² di
1.	H77/833-2	147.900	0.406	-47.023	16.840	0.643	-2.507
2.	H77/29-2	176.010	0.731	7.920	18.200	0.824	-2.712
3.	G73-107	144.920	0.212	-39.669	20.350	0.081	-2.293
4.	77/245	131.930	0.518	-47.238	16.270	0.710	-2.647
5	CVJ-2-5-3-1-3	173.910	0.868	-46.744	25.870	1.712*	-1.846
6	1305	144.020	0.753	60.837	19.520	0.840	-2.625
7	77/371 × BSECT CP-1	142.790	0.442	-42.414	16.690	0.195	-1.377
8	96AC-93	132.030	1.063	-46.898	14.990	0.776	-2.674
9	Togo-II	122.280	0.891	37.614	20.210	0.350	-2.672
10	99HS-18	110.520	0.494	58.145	15.310	0.438	-2.006
1.	H77/833-2 × H77/29-2	183.090	1.162	28.170	20.630	0.452	-2.502
2.	H77/833-2 × G73-107	191.700	1.121	-23.852	20.960	0.532	-2.593
3.	H77/833-2 × 77/245	184.870	1.235	4.942	19.650	1.006	-2.625
4.	H77/833-2 × CVJ-2-5-3-1-3	196.700	1.014	-37.224	24.410	1.630*	-2.218
5	H77/833-2 × 1305	184.320	0.923	50.004	23.740	0.611	-2.659
6	H77/833-2 × (77/371 × BSECT CP-1)	187.620	0.890	-46.645	18.680	0.547	-1.359
7	H77/833-2 × 96AC-93	194.820	1.355	-36.456	19.030	0.975	-2.103
8	H77/833-2 × Togo-II	224.240	1.062	40.767	22.410	1.074	0.747
9	H77/833-2 × 99HS-18	208.270	1.187	-44.405	21.720	1.110	-1.947
10	H77/29-2 × G73-107	208.840	1.427	-41.242	20.790	0.675	-1.118
11	H77/29-2 × 77/245	183.190	1.275	161.965*	20.320	1.116	-2.498
12	H77/29-2 × CVJ-2-5-3-1-3	225.560	1.246	-31.101	25.230	1.859*	-2.614
13	H77/29-2 × 1305	194.860	0.827	-14.713	23.520	0.969	-2.714
14	H77/29-2 × (77/371 × BSECT CP-1)	209.550	0.824	122.994	20.490	0.556	-2.400
15	H77/29-2 × 96AC-93	202.660	1.075	97.927	20.870	0.202	-2.350
16	H77/29-2 × Togo-II	236.780	1.037	-31.726	23.770	1.631*	-1.963
17	H77/29-2 × 99HS-18	214.440	1.418	73.919	19.690	0.556	-2.705
18	G73-107 × 77/245	184.360	0.809	-15.358	21.770	1.679*	-1.654

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Sr. no.	Genotypes	Plant height (cm)			Ear length (cm)		
		Mean	bi	S ² di	Mean	bi	S ² di
19	G73-107 × CVJ-2-5-3-1-3	216.890	1.057	-45.768	25.170	0.733	-2.621
20	G73-107 × 1305	192.610	0.992	-39.435	24.150	1.135	-2.567
21	G73-107 × (77/371 × BSECT CP-1)	205.020	1.299	68.892	20.970	0.665	-2.667
22	G73-107 × 96AC-93	222.910	2.324	620.941**	22.170	0.614	-2.675
23	G73-107 × Togo-II	236.990	0.665	28.185	24.450	1.149	-2.481
24	G73-107 × 99HS-18	210.330	1.415	69.056	21.430	1.063	-2.537
25	77/245 × CVJ-2-5-3-1-3	198.260	0.834	-44.323	23.810	1.750*	-2.701
26	77/245 × 1305	176.990	0.989	-43.834	20.720	0.730	-2.704
27	77/245 × (77/371 × BSECT CP-1)	192.020	0.954	-45.580	19.360	0.396	-1.874
28	77/245 × 96AC-93	192.750	1.268	-24.141	18.810	1.252	-0.927
29	77/245 × Togo-II	218.180	0.486	375.193**	24.890	1.154	-2.714
30	77/245 × 99HS-18	201.630	1.116	19.125	20.750	0.314	-0.771
31	CVJ-2-5-3-1-3 × 1305	196.890	1.098	15.024	26.750	2.077*	-2.182
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	195.720	0.974	3.372	21.840	0.389	-2.054
33	CVJ-2-5-3-1-3 × 96AC-93	221.900	0.994	11.559	24.760	0.522	-2.702
34	CVJ-2-5-3-1-3 × Togo-II	222.430	0.856	-44.201	25.830	2.903*	-1.178
35	CVJ-2-5-3-1-3 × 99HS-18	198.840	1.177	-45.196	22.420	0.862	-0.630
36	1305 × (77/371 × BSECT CP-1)	192.410	1.304	58.304	21.290	0.642	-1.287
37	1305 × 96AC-93	197.970	1.643	-11.778	19.570	0.587	-2.304
38	1305 × Togo-II	204.440	0.504	-20.736	25.910	0.482	-2.117
39	1305 × 99HS-18	197.120	1.218	10.491	23.570	1.491*	-1.780
40	(77/371 × BSECT CP-1) × 96AC-93	207.470	1.153	-19.675	21.090	-0.039	-2.451
41	(77/371 × BSECT CP-1) × Togo-II	208.080	1.208	139.839*	21.900	1.571*	-2.026
42	(77/371 × BSECT CP-1) × 99HS-18	193.250	1.152	-20.255	20.770	0.425	-0.861
43	96AC-93 × Togo-II	205.600	1.322	-11.424	21.640	1.224	-0.132
44	96AC-93 × 99HS-18	211.010	1.261	212.022*	20.720	0.896	-2.198
45	Togo-II × 99HS-18	158.530	0.752	-28.581	21.990	1.951*	1.962
*	Significant	at P	=	0.05	Contd...		
**	Significant	at P	=	0.01			

Contd... table 37

Sr. no.	Genotypes	Ear weight (g)/plant			Dry fodder yield (g)/plant		
		Mean	bi	S ² di	Mean	bi	S ² di
1.	H77/833-2	14.60	0.099	-9.071	26.070	0.422	-23.155
2.	H77/29-2	9.62	0.285	-14.677	29.440	0.638	-27.365
3.	G73-107	21.86	0.284	-14.245	43.160	0.299	-27.353
4.	77/245	23.29	0.611	16.808	49.240	0.454	25.475
5	CVJ-2-5-3-1-3	26.52	0.516	-14.674	52.390	0.643	-25.167
6	1305	18.99	0.217	-14.330	45.110	0.161	-16.338
7	77/371 × BSECT CP-1	16.07	0.693	-0.019	45.150	0.524	-27.107
8	96AC-93	26.98	0.741	17.101	42.750	0.420	-26.434
9	Togo-II	21.23	0.219	-8.462	39.570	0.753	-26.311
10	99HS-18	31.55	0.492	-4.662	49.920	0.593	-14.605
1.	H77/833-2 × H77/29-2	36.99	1.260	44.927*	71.380	0.768	-20.147
2.	H77/833-2 × G73-107	45.52	0.072	0.726	74.250	0.438	33.260
3.	H77/833-2 × 77/245	42.75	0.194	4.320	85.570	-0.059	-22.451
4.	H77/833-2 × CVJ-2-5-3-1-3	48.56	1.286	140.631**	106.830	0.682	8.170
5	H77/833-2 × 1305	62.61	1.247	-12.968	144.790	0.876	88.684*
6	H77/833-2 × (77/371 × BSECT CP-1)	42.62	1.437	6.664	76.250	1.724	12.321
7	H77/833-2 × 96AC-93	45.75	0.307	-14.648	70.920	1.266	-27.306
8	H77/833-2 × Togo-II	54.09	1.772	67.213*	112.070	0.976	-22.751
9	H77/833-2 × 99HS-18	42.98	0.640	-12.319	84.330	0.657	22.563
10	H77/29-2 × G73-107	34.18	0.301	23.332	64.810	0.585	-27.127
11	H77/29-2 × 77/245	38.98	3.476*	13.661	80.140	-0.037	107.813*
12	H77/29-2 × CVJ-2-5-3-1-3	41.76	0.496	-9.562	93.950	0.388	97.618*
13	H77/29-2 × 1305	65.62	0.562	-7.892	127.650	0.787	44.715
14	H77/29-2 × (77/371 × BSECT CP-1)	41.15	1.117	-8.230	80.840	2.002	-25.380
15	H77/29-2 × 96AC-93	46.66	-0.578	-3.156	77.940	1.095	0.591
16	H77/29-2 × Togo-II	49.09	0.150	1.979	76.610	0.874	-21.035
17	H77/29-2 × 99HS-18	45.20	1.277	0.211	81.770	0.394	-27.413
18	G73-107 × 77/245	44.24	3.422	122.542**	109.130	0.743	12.426

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Sr. no.	Genotypes	Ear weight (g)/plant			Dry fodder yield (g)/plant		
		Mean	bi	S ² di	Mean	bi	S ² di
19	G73-107 × CVJ-2-5-3-1-3	51.96	1.201	-14.686	100.220	-0.357	205.972**
20	G73-107 × 1305	61.69	0.127	35.971	115.360	1.677	10.065
21	G73-107 × (77/371 × BSECT CP-1)	45.62	2.762	-13.870	106.190	1.187	-24.234
22	G73-107 × 96AC-93	54.38	1.511	69.795*	101.170	0.472	-15.551
23	G73-107 × Togo-II	59.11	1.684	9.192	119.670	0.696	119.473*
24	G73-107 × 99HS-18	48.00	3.933*	-14.476	111.840	1.910	2.997
25	77/245 × CVJ-2-5-3-1-3	68.72	0.937	22.167	137.490	2.078	86.856*
26	77/245 × 1305	53.97	-0.143	-13.236	109.960	0.542	-3.280
27	77/245 × (77/371 × BSECT CP-1)	26.25	0.838	-11.848	54.680	1.562	16.376
28	77/245 × 96AC-93	54.49	0.629	7.237	98.840	2.616	-11.201
29	77/245 × Togo-II	48.20	2.643	218.372**	116.410	0.419	-3.914
30	77/245 × 99HS-18	37.30	1.003	20.986	68.960	0.449	-23.456
31	CVJ-2-5-3-1-3 × 1305	50.85	2.628	6.616	125.000	1.731	-24.959
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	51.32	1.239	-1.811	105.260	1.703	-17.151
33	CVJ-2-5-3-1-3 × 96AC-93	50.15	1.965	38.934	108.910	1.764	-26.359
34	CVJ-2-5-3-1-3 × Togo-II	43.25	2.048	8.387	115.070	0.866	-27.433
35	CVJ-2-5-3-1-3 × 99HS-18	37.19	3.107	37.699	100.510	0.427	-5.645
36	1305 × (77/371 × BSECT CP-1)	44.67	1.736	16.059	105.070	1.327	-23.631
37	1305 × 96AC-93	46.50	0.196	4.850	84.040	1.198	-11.591
38	1305 × Togo-II	69.87	-0.461	5.795	120.860	0.339	-17.968
39	1305 × 99HS-18	47.84	-0.175	20.449	91.920	2.145	-27.449
40	(77/371 × BSECT CP-1) × 96AC-93	41.13	1.132	50.635*	82.680	0.712	-25.945
41	(77/371 × BSECT CP-1) × Togo-II	59.73	2.793	195.485**	134.390	0.869	39.425
42	(77/371 × BSECT CP-1) × 99HS-18	30.57	0.993	-14.487	57.020	2.073	-8.559
43	96AC-93 × Togo-II	58.30	2.296	282.661**	146.320	0.684	-26.718
44	96AC-93 × 99HS-18	35.73	2.269	59.461*	57.460	0.422	-26.335
45	Togo-II × 99HS-18	52.70	0.166	-7.288	94.730	0.761	-22.715

* Significant at P = 0.05

** Significant at P = 0.01

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Contd... table 37

Sr. no.	Genotypes	Grain yield (g)/plant			Total biological yield (g)/plant		
		Mean	bi	S ² di	Mean	bi	S ² di
1.	H77/833-2	8.300	0.066	-2.321	40.670	0.684	-43.192
2.	H77/29-2	6.320	0.158	-4.865	39.060	0.558	-38.816
3.	G73-107	13.050	0.307	-4.522	65.020	0.370	-43.872
4.	77/245	13.190	0.920	7.837	72.530	-0.383	-31.009
5	CVJ-2-5-3-1-3	14.370	0.569	-2.857	78.910	0.558	-39.714
6	1305	14.480	0.300	-4.340	64.100	0.391	-35.135
7	77/371 × BSECT CP-1	10.670	0.987	-2.529	61.210	0.240	-37.294
8	96AC-93	14.090	0.631	2.486	69.730	0.022	-25.093
9	Togo-II	13.130	0.151	-2.154	60.800	0.835	-21.556
10	99HS-18	16.900	0.287	0.004	81.470	1.036	-41.595
1.	H77/833-2 × H77/29-2	22.010	0.967	40.826**	108.370	1.668	-35.338
2.	H77/833-2 × G73-107	28.400	-0.281	-2.162	119.770	0.336	52.408
3.	H77/833-2 × 77/245	30.060	0.789	26.968*	128.320	-0.517	-43.166
4.	H77/833-2 × CVJ-2-5-3-1-3	36.210	2.060	121.163**	155.380	-0.625	-39.557
5	H77/833-2 × 1305	44.690	1.972	3.667	207.400	0.512	9.140
6	H77/833-2 × (77/371 × BSECT CP-1)	28.240	0.651	43.831**	118.860	0.952	-12.001
7	H77/833-2 × 96AC-93	27.100	0.803	-4.777	116.670	1.074	-9.781
8	H77/833-2 × Togo-II	37.730	2.400	31.260**	166.160	0.411	38.364
9	H77/833-2 × 99HS-18	31.970	0.171	-0.929	127.320	0.163	-12.495
10	H77/29-2 × G73-107	23.930	-0.284	33.503**	98.990	1.058	-28.705
11	H77/29-2 × 77/245	25.000	2.663	-4.362	119.110	0.642	966.366**
12	H77/29-2 × CVJ-2-5-3-1-3	30.250	0.724	4.212	135.710	-0.355	22.198
13	H77/29-2 × 1305	47.630	1.827	-3.254	193.270	1.407	-17.956
14	H77/29-2 × (77/371 × BSECT CP-1)	25.550	1.703	4.549	121.990	1.706	-33.531
15	H77/29-2 × 96AC-93	34.980	-0.569	-4.899	124.600	1.391	-4.517
16	H77/29-2 × Togo-II	33.220	-0.650	-3.155	125.700	0.992	12.717
17	H77/29-2 × 99HS-18	31.640	1.062	13.609	126.980	0.187	-6.299
18	G73-107 × 77/245	29.360	3.045*	12.438	153.370	-0.178	143.014*

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Sr. no.	Genotypes	Grain yield (g)/plant			Total biological yield (g)/plant		
		Mean	bi	S ² di	Mean	bi	S ² di
19	G73-107 × CVJ-2-5-3-1-3	37.760	1.538	-3.473	152.170	0.667	436.270**
20	G73-107 × 1305	44.720	0.727	15.414*	177.060	2.364	-8.788
21	G73-107 × (77/371 × BSECT CP-1)	28.080	2.748	8.393	151.820	1.613	64.772
22	G73-107 × 96AC-93	38.470	1.742	57.485**	155.550	-0.002	90.461
23	G73-107 × Togo-II	43.420	1.591	39.704**	178.780	1.896	167.791*
24	G73-107 × 99HS-18	33.290	3.174*	25.114*	159.830	2.472	230.802*
25	77/245 × CVJ-2-5-3-1-3	49.390	1.734	10.556	206.210	2.968	-43.461
26	77/245 × 1305	41.730	0.071	-4.181	163.930	0.292	27.926
27	77/245 × (77/371 × BSECT CP-1)	17.640	0.651	-1.600	80.930	1.263	61.585
28	77/245 × 96AC-93	37.680	0.404	-0.329	153.330	2.508	222.237*
29	77/245 × Togo-II	34.740	3.200*	92.164**	164.610	-0.333	415.310**
30	77/245 × 99HS-18	28.090	-0.443	6.432	106.260	0.968	-43.840
31	CVJ-2-5-3-1-3 × 1305	35.400	2.743	-4.594	175.850	1.387	-16.567
32	CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1)	35.190	1.648	8.225	156.590	1.149	-24.726
33	CVJ-2-5-3-1-3 × 96AC-93	34.910	1.399	50.145**	159.070	2.394	-40.573
34	CVJ-2-5-3-1-3 × Togo-II	31.660	1.866	49.006**	158.320	1.479	-14.344
35	CVJ-2-5-3-1-3 × 99HS-18	26.120	2.591	100.457**	137.690	1.737	261.285**
36	1305 × (77/371 × BSECT CP-1)	32.830	2.346	21.914*	149.740	0.803	-38.416
37	1305 × 96AC-93	30.860	0.155	12.292	130.540	1.228	65.428
38	1305 × Togo-II	53.230	0.681	127.163**	190.740	-0.037	-43.291
39	1305 × 99HS-18	36.990	-0.047	13.076	139.760	2.292	188.919*
40	(77/371 × BSECT CP-1) × 96AC-93	29.230	1.534	63.041**	123.810	0.002	-29.863
41	(77/371 × BSECT CP-1) × Togo-II	41.740	3.621*	76.086**	194.120	0.305	451.294**
42	(77/371 × BSECT CP-1) × 99HS-18	20.330	0.499	-1.995	87.600	1.641	52.561
43	96AC-93 × Togo-II	39.910	2.173	344.587**	204.620	2.517	-17.294
44	96AC-93 × 99HS-18	24.230	-0.617	8.096	93.190	1.537	40.174
45	Togo-II × 99HS-18	38.320	-0.248	-4.859	147.430	1.015	-38.012

* Significant at P = 0.05

** Significant at P = 0.01

appeared to be a linear function of the environmental value. The non-linear portion was significant was also, however important.

The parent CVJ-2-5-3-1-3 showed the highest mean performance as well as response to environmental changes and high stability, while, the parent H77/29-2 had high average performance and stability and was adaptive in poor environment. Rest of the parents had below average mean performance and high stability. The parents H77/833-2, (77/371× BSECT CP-1) and 99HS-18 showed above average response. The parents 96AC-93 and 1305 had average response while, the parents G73-107, 77/245 and Togo-II showed below average response or adaptive in poor environments.

The behaviour of arrays involving parent G73-107 was interesting. Their hybrids had in general high mean performance and average responsiveness to environments. The array involving parent CVJ-2-5-3-1-3 had below average mean performance and high stability (very low S^2_{di} value). Therefore it appeared possible to make prediction for $G \times E$ interaction for most of its F_1 crosses.

For the array involving parent 1305 had low S^2_{di} value and average response. The array H77/29-2 had above average mean performance for germination (%) and low S^2_{di} value except one hybrid.

An examination of the adaptation of the individual F_1 crosses showed that hybrids 17, 20 and 39 were the high responsive ($b_i > 1$) and high mean performance and also had low S^2_{di} values thus, showed a tendency to be particularly suited to favourable environments.

Whereas, the hybrids 14, 30 and 45 were the high responsive ($b_i > 1$) and also high mean performance but had high and significant S^2_{di} values which make their performance unpredictable. The crosses 7, 9, 11, 12 and 16 showed high mean performance and below average response ($b_i < 1$) might, therefore, be specially suited to poor environments for germination.

A comparison of the stability parameters (b_i and S^2_{di}) of the parents and the F_1 crosses showed that F_1 crosses had a higher range for both of these parameters ($b_i = 0.475$ to 1.819 and $S^2_{di} = -5.274$ to 49.095) when compared with parents ($b_i = 0.626$ to 1.381 and $S^2_{di} = -5.278$ to 9.093). The greater range in F_1 hybrids as compared to parents could result from interaction of genes governing this trait.

ii) Emergence rate

an examination of adaptation parameters of the individual genotypes showed that neither the regression mean square nor the deviation from regression mean square was significant for all the 10 parents and 44 hybrids thus indicating the absence of $G \times E$ interaction and only one hybrid had the significant deviation from regression mean square indicating the non-linear portion of the $G \times E$ interaction.

The parent (77/371 $\times$ BSECT CP-1) had the highest mean value for emergence rate (ER) and appeared to be highly responsive ($b_i > 1$) to changes in environments and also the stable genotype showing a tendency to prefer favourable environments. While, the parents 77/245, 1305 and 96AC-93 showed above average response ($b_i > 1$)

but below average performance as well as stability. On the other hand, the parents H77/833-2, G73-107 and CVJ-2-5-3-1-3 had below average response as well as average mean performance and high stability. The parents H77/29-2, Togo-II and 99HS-18 had high S^2_{di} value indicating that the performance under different environments was unpredictable.

The hybrids (array) having parent H77/833-2 as one of the parents showed in general average performance and high stability, while, the array involving parent H77/29-2 as one of the parents showed above average response as well as high stability except one hybrid only. The array involving parent 77/245 as one of the parents had high mean performance and stability but adapted to poor environments only. On the other hand, the array involving parent G73-107 as one of the parents showed average mean performance with high stability except one hybrid and found adapted in the favourable environments. Likewise, the array involving parent 96AC-93 as one of the parents with high mean performance and high stability found to be adapted in favourable environments.

Judging from the mean and linear regression estimate of the F_1 's, hybrids 3, 10, 14, 18, 19, 21, 22, 27, 43 and 44 had high mean performance and above average responsiveness to environmental change and were thus, better suited to more favourable environments. While, the hybrids 31, 34, 38 and 42 had above average response but low mean performance and above average response, but also high S^2_{di} value which make their performance unpredictable to changes in

environmental conditions. The hybrids 2, 5, 9, 16, 26, 28, 30, 32, 35 and 41 were better suited to poor environmental conditions with high mean performance as reflected by their low b_i estimates.

iii) Number of leaves/seedling

A consideration of the adaptation parameters of the individual genotypes showed that $G \times E$ interaction was absent in all the ten parents and 42 of the hybrids as neither the regression mean square, nor the deviation from regression mean square were significant. Further, three hybrids showed the presence of only non-linear portion of $G \times E$ interaction.

All the ten parents had the low mean performance for number of leaves/seedling and also appeared to be adapted in poor environmental conditions as the $b_i < 1$ and also the S^2_{di} was low.

The array having the parent H77/29-2 as one of the parents, showed in general above average responsiveness and high stability with high mean performance. While, the array involving parent H77/833-2 as one of the parents had high mean performance, low b_i and low S^2_{di} values (except one hybrid with significant S^2_{di} value). Whereas, the arrays with parents G73-107, 77/245 and 96AC-93 as one of the parents, had high mean performance and high stability. In each case, the general behaviour of the array was in contrast to that of the parent. However, this might be possible under a system of genetic interaction leading to over-dominance. The hybrids 6, 31 and 37

showed high and significant S^2_{di} estimates. This also appears to be a case of over-dominance.

Judging from the means, linear regression estimates and S^2_{di} estimates of the hybrids 2, 5, 6, 10, 12, 13, 14, 17, 20, 21, 24, 26, 31, 33, 37, 39, 44 and 45 had high average stability, high means and response and were thus, better suited to more favourable environments. The hybrids 6, 31 and 37 showed high mean performance, above average responsiveness but also significant S^2_{di} values which make their performance unpredictable to changing environmental conditions. Whereas, the hybrids 25 and 30 had high mean performance and below average responsiveness thus, best suited to poor environmental conditions.

The F_1 's had a higher range of b_i and S^2_{di} estimates ($b_i = 0.354$ to 2.065 and $S^2_{di} = -0.608$ to 4.081) as compared to parents ($b_i = 0.076$ to 0.853 and $S^2_{di} = -0.609$ to 0.696). As mentioned earlier, the genetic interactions for these attributes appear to be responsible in giving rise to a wider range in F_1 hybrids.

iv) Seedling height (cm)

The data given in table 37 indicated that among the genotypes tested, none showed any $G \times E$ interaction. They showed a response similar to the mean of all the genotypes. These genotypes can be said to possess high ecovalence, i.e., a wide ecological range.

The parents H77/833-2 and Togo-II had above average responsiveness but low mean performance. Rest of the other parents showed below average response as well as low mean performance.

The arrays involving the parents H77/833-2 and H77/29-2 as one of the parents had average performance and responsiveness with high stability. Whereas, the arrays having the parents G73-107 and (77/371 $\times$ BSECT CP-1) showed high mean performance and stability with average responsiveness.

A detailed examination of three parameters (mean, b_i and S^2_{di}) in respect of the hybrids revealed some interesting results. The hybrids 4, 7 and 41 combined high performance with below average responsiveness and high stability which make them desirable under low valued environments. While, the hybrids 5, 6, 13, 14, 15, 17, 22, 23, 24, 27, 29, 33 and 40 combined high responsiveness with high mean performance and high stability which make them specially desirable under high valued environments. It could thus be seen that, high average performance and high stability (low S^2_{di} value) could be combined with variable degrees of responsiveness.

The hybrids showed a higher range both for b_i and S^2_{di} estimates as against the parents. Various genetic interactions which have been shown above may have caused the wider variation of F_1 hybrids in respect of these attributes. Also, this indicated that hybrids suited to extreme environmental conditions would be available.

v) Fresh weight (g)/seedling

A consideration of the parameters (b_i and S^2_{di}) of the individual genotypes revealed that neither the regression mean square, nor the deviation from regression mean square was significant for two parents and 11 hybrids thus, indicating the absence of $G \times E$ interaction. Another one hybrid had only regression mean square as significant while, their deviation from regression mean square was non-significant. This showed that linear regression alone accounted for almost all of the $G \times E$ interaction. The presence of non-linear portion of $G \times E$ interaction was indicated by the remaining genotypes, i.e., eight parents and 33 hybrids as they had significant S^2_{di} value, while, the regression mean square was non-significant, it would make their performance under environmental changes unpredictable.

A simultaneous consideration of the three adaptation parameters for the individual parents indicated that parents H77/833-2 and (77/371 $\times$ BSECT CP-1) had low mean performance, below average response and low S^2_{di} value. While, the remaining parents H77/29-2, G73-107, 77/245, CVJ-2-5-3-1-3, 1305, 96AC-93, Togo-II and 99HS-18 had low mean performance, low b_i and significant high S^2_{di} estimates which make their performance unpredictable to changing environmental condition.

The examination of the adaptation parameters of the individual hybrids showed that hybrids 12, 16, 28, 29 and 42 exhibited high mean performance, high responsiveness to environmental changes ($b_i > 1$) and stability thus, showed a tendency to be particularly suited to

favourable environmental condition. These hybrids perform less in the poor environments, but as the environment improved, their performance increased at a rate well above the average for overall population and under the most favourable conditions, they were at par with the best performer. On the other hand, hybrids 7, 8, 9, 13, 14, 17, 20, 22, 24, 25, 26, 27, 32, 33, 37, 40 and 43 had high mean performance and above average responsiveness but significant high S^2_{di} to changing environmental condition.

A comparison of the stability parameters (b_i and S^2_{di}) of the parents and F_1 showed that F_1 had higher range for both of these parameters when compared with parents. The greater range in F_1 hybrids could result from interaction of genes governing these traits.

vi) Dry weight (g) / seedling

The test for the significance of two measures of $G \times E$ interaction, namely, b_i and S^2_{di} values of the individual genotype showed absence of $G \times E$ interaction for three parents and 13 hybrids. The presence of only linear portion was indicated by two hybrids as only b_i was found significant.

Further, six hybrids not only had regression mean square which were significant, but also had significant deviation from regression mean square showing there by that linear regression did not account for all the $G \times E$ interaction. The presence of only non-linear portion of the $G \times E$ interaction was indicated by the remaining genotypes i.e. seven parents and 24 hybrids. As they had significant S^2_{di} values,

while, the regression mean square was non-significant. It would make their performance under environmental change unpredictable.

All the parents gave below average performance and below average response except the parent Togo-II. The performances of the parents G73-107, 77/245, CVJ-2-5-3-1-3, 1305, 96AC-93 and 99HS-18 was unpredictable to environmental change as they had significant high S^2_{di} values. The remaining parents namely, H77/833-2, H77/29-2 and (77/371× BSECT CP-1) had below average performance and response and were relatively insensitive to environmental changes (b_i and low S^2_{di} values).

The array having the parent 77/245, (77/371× BSECT CP-1) and 96AC-93 as one of the parents had high mean performance but sensitive to environmental changes. The array involving the parent CVJ-2-5-3-1-3 had average performance but above average response and significantly high S^2_{di} value.

Considering the adaptation parameters of the individual F_1 hybrids 12, 16, 17, 23, 24, 29, 41, 42, 44 and 45 were found to possess high average performance coupled with responsiveness to environmental changes and low S^2_{di} values, thus, suited to favourable environmental condition. Among the other F_1 's, hybrid 10 had high mean performance with low responsiveness and S^2_{di} values. The hybrids 7, 9, 13, 14, 15, 19, 20, 22, 25, 26, 27, 33, 37, 39, 40 and 43 had high mean with high responsiveness but significant high S^2_{di} value which make their performance unpredictable. Whereas, the

hybrids 1, 6, 11, 18, 21 and 35 had low mean performance as well as below average responsiveness with unpredictable performance.

The b_i values for the hybrids ranged from -0.223 to 2.347 as against 0.005 to 1.256 for the parents. The range for the S^2_{di} estimates was also higher for the hybrids (-0.071 to 26.763) as compared to a range of hybrids may have resulted from interaction of genes governing these attributes.

vii) Panicle emergence (days)

For panicle emergence absence of $G \times E$ interaction was indicated for eight parents and all the 45 hybrids as revealed by their respective b_i and S^2_{di} values. The presence of only non-linear portion of the $G \times E$ interaction was recorded for two parents (table 37).

The parents H77/833-2, H77/29-2, G73-107, CVJ-2-5-3-1-3, 1305, (77/371 $\times$ BSECT CP-1), Togo-II and 99HS-18 had the above mean performance (late flowering) and average responsiveness with high stability. While, the parents 77/245 and 96AC-93 showed unpredictable performance to environmental change (S^2_{di} significantly high). It might be noted that the array involving parents H77/833-2, 77/245, CVJ-2-5-3-1-3 and 1305 gave rise to hybrids with below average performance (early flowering) high responsiveness ($b_i > 1$) and low deviation from linearity. Whereas, the array involving parent H77/29-2 gave rise to late flowering hybrids with high responsiveness and stability. While the array with parent G73-107 showed average performance and above average response.

Among the hybrids, 1, 4, 5, 6, 7, 14, 19, 21, 24, 26, 30, 31, 32, 35, 36, 37, 39 and 40 showed the early panicle emergence, high responsiveness and high stability. On the other hand, the hybrids 12, 16, 17, 20, 29, 34, 38 and 45 showed the late panicle emergence, high responsiveness and high stability. The hybrids 15, 27 and 28 showed early panicle emergence with below average responsiveness and high stability.

viii) Effective tillers / plant

The data in the table 37 indicated high variation due to both linear as well as non-linear components of $G \times E$ interaction. The absence of $G \times E$ interaction was indicated for the nine parents and 40 hybrids. However, one parent and five F_1 crosses indicated the presence of only non-linear portion of $G \times E$ interaction. The parent (77/371 $\times$ BSECT CP-1) and 96AC-93 had higher number of tillers per plant and good stability but below average response. These parents, therefore, appeared to be suited to poor environmental conditions. The parent 99HS-18 showed average performance and above average response but high significant S^2_{di} value make its performance unpredictable. The remaining parents H77/833-2, H77/29-2, G73-107, 77/245, CVJ-2-5-3-1-3, and 1305 had average to below average performance and high stability and suited to poor environmental conditions.

Most of the F_1 crosses having parent H77/833-2 as a parent showed high tillering and low estimates of linear regression as well as

low S^2_{di} values except two hybrids. The array involving parent H77/29-2 had below average responsiveness and low mean performance with high stability. It therefore, appeared that both the linear and non-linear portion were independent of each other. Again, genetic interactions leading to dominance or over-dominance appeared to be involved.

A perusal of adaptability parameters of the individual hybrids showed that the hybrids 5, 18, 26, 34 and 43 had the high number of tillers per plant, high responsiveness to environments and had good measure of stability. These hybrids thus were well suited to most favourable environments. The hybrid 4 had high mean performance, high responsiveness but significant high S^2_{di} values. While, the hybrids 8, 20, and 31 had low mean performance, low b_i value with unpredictable performance.

Whereas, the hybrids 1, 2, 3, 6, 7, 10, 13, 16, 22, 32, 36 and 38 showed above average performance, high stability and best stability to environmental conditions. The hybrids had a higher range of b_i and S^2_{di} estimates as compared to parents. As mentioned earlier, the genetic interactions for these attributes appear to be responsible in giving rise to a wide range in the hybrids.

ix) Plant height (cm)

The absence of $G \times E$ interaction was observed for all the ten parents and 40 hybrids. Linear portion of $G \times E$ interaction was conspicuously absent for the above indicated hybrids. The $G \times E$ interaction was

observed only for five hybrids and that too in non-linear form of interaction.

The parent 96AC-93 had below average performance for plant height whereas the response was average with high stability. The parents H77/833-2, H77/29-2, G73-107, 77/245, CVJ-2-5-3-1-3 and (77/371× BSECT CP-1) had low plant height, high stability. They were suited to poor environmental conditions. The remaining parents 1305, Togo-II and 99HS-18 also had low plant height and weak response to environmental conditions but high S^2_{di} values which make their performance unpredictable.

In general, the hybrids of the array involving parent H77/833-2 as one of the parents were highly responsive to environmental changes and stable. Whereas, the array with parent H77/29-2 had above average plant height and high response to environmental changes. The array involving parent CVJ-2-5-3-1-3 had above average plant height with average responsiveness. Whereas, the array involving parent (77/371× BSECT CP-1) and 96AC-93 had above average plant height and above average performance.

A perusal of adaptability parameters of the individual hybrids showed that the hybrids 9, 10, 12, 17, 21, 24, 30, 35, 37, 39, 40 and 43 had the above average plant height, above average responsiveness to environmental changes with non-significant deviation value. These tall hybrids are well suited to the favourable environments. The hybrids 11, 22, 29, 41 and 44 showed unpredictable performance to the environmental change. Whereas, the hybrids 1, 3, 6, 13, 14, 18,

23, 25, 34, 38 and 45 were found suitable for poor environmental conditions as their ($b_i < 1$).

In general, the hybrids exhibited higher range for all the three adaptability parameters than the parental material. The former had a range of $X_i = 158.530$ to 236.990 , $b_i = 0.486$ to 2.324 and $S^2_{di} = -46.645$ to 620.000 as against the later with a range of $X_i = 110.520$ to 176.010 , $b_i = 0.212$ to 1.063 and $S^2_{di} = -47.023$ to 60.837 .

x) Ear length (cm)

The test for the significance of two measures of $G \times E$ interaction, namely, b_i and S^2_{di} values of the individual genotype showed absence of $G \times E$ interaction for nine parents and 35 hybrids. The presence of only linear portion was indicated by one parent and 10 hybrids. The deviation around regression slopes was non-significant for all the parents and hybrids. It was case of where only the linear interaction counted for entire amount of $G \times E$ interaction.

The parent CVJ-2-5-3-1-3 showed the highest average performance as well as response to environmental changes and also had high stability ($X_i = 25.870$, $b_i = 1.712$ and $S^2_{di} = -1.846$). Rest of the other parents H77/833-2, H77/29-2, G73-107, 77/245, 1305, 77/371 $\times$ BSECT CP-1, 96AC-93, Togo-II and 99HS-18 showed short ear length, high stability and suited to poor environmental conditions ($b_i < 1$).

It was interesting to note that the array with parent G73-107 and CVJ-2-5-3-1-3 had in general, longer ear length and high stability index. While, the array involving parent 1305 had longer ear heads and non-significant deviation and low response to environmental changes.

The hybrids 4, 8, 12, 16, 18, 20, 23, 25, 29, 31, 34, 39, 41, 43 and 45 showed longer ear heads, high stability and were indicated to be well suited to favourable conditions. While, the hybrids having the long ear head, high stability and suitability to poor environmental conditions were 5, 19, 22, 32, 33, 35 and 38. The hybrids showed a higher range both for b_i and S^2_{di} estimates as against the parents.

xi) Ear weight (g) / plant

The data in the table 37 indicated high variation due to both linear as well as non-linear components of $G \times E$ interaction. Absence of $G \times E$ interaction was indicated for all the ten parents and 33 hybrids. Two other hybrids showed the presence of only linear portion, whereas, another ten hybrids indicated only the non-linear portion of $G \times E$ interaction.

A simultaneous consideration of the three adaptation parameters for the individual parents indicated that parents all the parents had low mean performance, below average response and low S^2_{di} value. The behaviour of array involving parents G73-107 and CVJ-2-5-3-1-3 had in general, high mean performance, above average responsiveness, low order deviation from regression except two

hybrids only. While, the array with parents 77/245 and 1305 showed high mean performance, below average response and high stability except one hybrid only.

The examination of the adaptation parameters of the individual hybrids showed that hybrids 5, 17, 19, 21, 23, 24, 31, 32 and 33 exhibited high mean performance, high responsiveness to environmental changes ($b_i > 1$) and stability thus, showed a tendency to be particularly suited to favourable environmental condition. These hybrids perform less in the poor environments, but as the environment improves, they perform well. On the other hand, the hybrids 1, 4, 8, 18, 22, 29, 40, 41, 43 and 44 had high responsiveness ($b_i > 1$) and also high and significant S^2_{di} value which make their performance unpredictable under environmental changes.

The hybrids highly stable and suited to poor environmental conditions were 2, 7, 13, 15, 16, 20, 26, 28, 37, 38, 39 and 45. A comparison of the stability parameters (b_i and S^2_{di}) of the parents and F_1 showed that F_1 had higher range for both of these parameters when compared with parents. The greater range in F_1 hybrids could result from interaction of genes governing these traits.

xii) Dry fodder yield (g) / plant

The test for the significance of two parameters of $G \times E$ interaction, namely, b_i and S^2_{di} values of the individual genotype showed absence of $G \times E$ interaction for all the parents and 39

hybrids. Remaining six hybrids showed only the presence of non-linear environmental interactions.

All the parents gave below average performance and response with high stability. The array having the parents H77/833-2 and H77/29-2 had in general low mean and below average responsiveness. The hybrids in the array with parent G73-107, 77/245 and CVJ-2-5-3-1-3 had above average mean performance and stability.

Considering the adaptation parameters of the individual F_1 's, hybrids, 20, 21, 24, 28, 31, 32, 33, 36 and 39 were found to possess high mean performance coupled with high responsiveness to environmental changes and low S^2_{di} values, thus, suited to favourable environmental condition. Among the other remaining hybrids 4, 8, 13, 18, 22, 26, 29, 34, 35, 38, 41, 43 and 45 had high mean values with low responsiveness and low S^2_{di} values. Whereas, the hybrids 5, 11, 12, 19, 23 and 25 had significantly high S^2_{di} values which make their performance unpredictable.

In general, the hybrids exhibited higher range for all the three adaptability parameters than the parental material. The former had a range of $X_i = 54.680$ to 146.320 , $b_i = -0.357$ to 2.616 and $S^2_{di} = -27.449$ to 205.972 as against the later with a range of $X_i = 26.070$ to 52.390 , $b_i = 0.161$ to 0.753 and $S^2_{di} = -27.353$ to 25.475 .

xiii) Grain yield (g) / plant

The $G \times E$ interaction was noticed in any of the parents and also 25 hybrids. Out of remaining 17 hybrids one had linear portion and 16 showed non-linear portion of $G \times E$ interaction. Whereas, three hybrids showed the importance of both the linear and non-linear $G \times E$ interaction.

All the ten parents had the low mean performance for grain yield per plant and also adapted in poor environmental conditions as the $b_i < 1$ and also the non-significant S^2_{di} values. The array having the parent G73-107 and CVJ-2-5-3-1-3 showed in general, high mean performance and above average response. While, the array with parent 77/245 showed high mean and below average performance.

Judging from the mean, linear regression and S^2_{di} estimates, the hybrids 5, 13, 17, 19, 25, 31 and 32 had high mean performance and above average responsiveness with significant stability values and were thus, better suited to more favourable environments. While, the hybrids 15, 16, 26, 28, 39 and 45 showed high mean performance, below average responsiveness thus, suited to average environmental conditions.

The hybrids 1, 3, 4, 6, 8, 10, 20, 22, 23, 24, 29, 33, 34, 35, 36, 38, 40, 41 and 43 had significant high S^2_{di} values which make their performance unpredictable to changing environmental conditions.

The F_1 's had a higher range of b_i and S^2_{di} estimates ($b_i = -0.650$ to 3.621 and $S^2_{di} = -4.899$ to 344.587) as compared to parents ($b_i = 0.066$ to 0.987 and $S^2_{di} = -4.865$ to 7.837). As mentioned earlier,

the genetic interactions for these attributes appear to be responsible in giving rise to a wider range in F_1 hybrids.

xiv) Total biological yield (g) / plant

The data in the table 37 indicated the importance of only non-linear portion of $G \times E$ interaction and that too limited only to ten hybrids. The parents and the remaining ten hybrids had no effect of environmental interactions. The parent 99HS-18 had low mean performance for total biological yield / plant, average response and high stability. While, the other remaining parents had low performance, high stability and below average responsiveness to environments.

Most of the F_1 crosses having parent G73-107, 77/245 and 1305 as a parent showed high mean performance and average responsiveness while, the array with parent CVJ-2-5-3-1-3 had high mean as well as above average responsiveness.

Adaptability parameters of the individual hybrids showed that the hybrids 13, 14, 20, 21, 25, 31, 32, 33, 34 and 43 had the higher total biological yield / plant, high responsiveness to environments and non-significant deviation. These hybrids could suit well to most favourable environments. The hybrid 11, 18, 19, 23, 24, 28, 29, 35, 39 and 41 had significant high S^2_{di} values which make their performance unpredictable.

Whereas, the hybrids 4, 5, 8, 22, 26, 36 and 38 showed above average performance, high stability and best suited to poor

environmental conditions. The hybrids had a higher range of b_i and S^2_{di} estimates as compared to parents. As mentioned earlier, the genetic interactions for these attributes appear to be responsible in giving rise to a wide range in the hybrids.

CHAPTER-V

DISCUSSION

The objective of this present investigation was to obtain an understanding of phenotypic and genotypic response of cultivars of pearl millet to high temperature stress. The literature available so far on the subject does not provide a standardized methodology. There have been reports that give encouragement as well as disappointment in this area. Arnon (1980) commented to the extent of calling the adaptational breeding (particularly drought resistance) as the greatest source of wasted efforts in the whole field of plant breeding. Our problem however, is centred on the theme of thermo-tolerance, provides for an effort in broadening the scope of adaptational breeding. The general frame work of the breeding programme consisted of the following points:

- i) Presence of useful genetic variation for adaptation to stress.
- ii) Systematic screening for genetic differences.
- iii) Development of a breeding methodology or selection tool for improved adaptation.

5.1 Screening for thermo-tolerance

In the frame work of present case, some good systematic work has been done in developing screening methods and identification of genetic variability in pearl millet. All this holds a good justification and promise to initiate a breeding programme for adaptation to temperature stress. High soil surface temperatures are known to inhibit the emergence and establishment of seedling in the field. The soil temperature as high as 60 °C and above have been observed (Soman *et al.*, 1981; Peacock *et al.*, 1993 and Singh, 1993a). In our experiment too, the air temperature shot up to 49 °C and soil surface temperature to 63 °C. The summer of 2004 and 2005 (the time of screening and main experiment, respectively) were one of the hottest seasons of the recent years at Hisar location. It provided us the best opportunity to evaluate our material under real supra-optimal temperature regime.

Field screening technique and laboratory screening technique were simultaneously used. The heat tolerance was measured as seedling thermo-tolerance index (STI) through the field screening technique of Peacock *et al.* (1993). Whereas, membrane thermo-stability (MTS) was taken as index for heat tolerance in the laboratory technique. Another index known as seed to seedling thermo-tolerance index (SSTI) was also calculated as an improvement and extension of seedling thermo-tolerance index (STI) (figure 45).

The parent material for developing the crosses were chosen after appropriate screening in the previous years. A set of 46

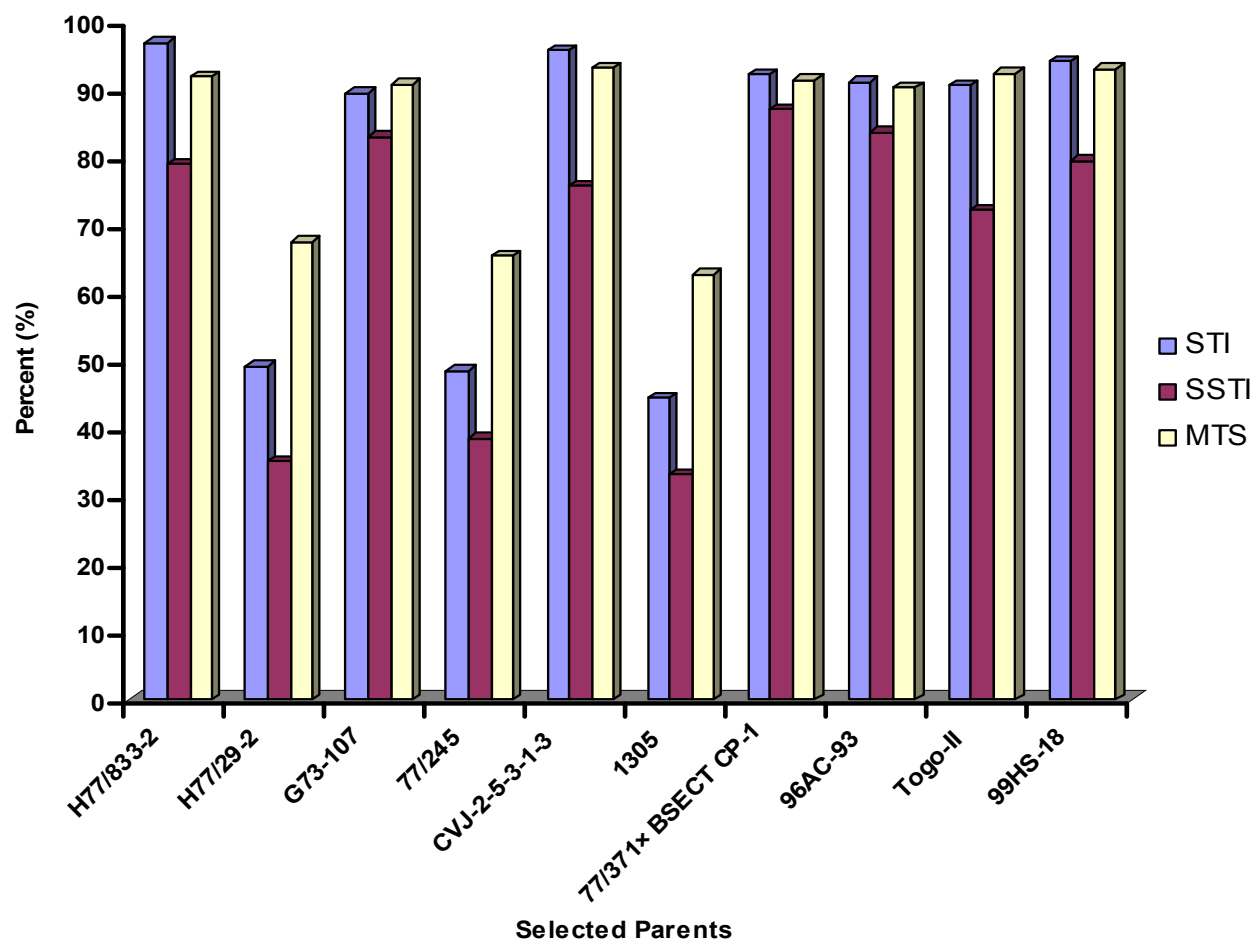


Figure 45: Values for STI, SSTI and Membrane thermo-stability during screening experiment

genotypes were put through a screening technique in the field during high temperature environment of May 2004 in order to obtain the thermo-tolerance index values at seedling growth stage. It was further attempted to establish correlation of the thermo-tolerance to other seedling characters. Ten inbred lines were selected and crossed in diallel manner. Among the ten parents selected, seven parents belonged to tolerant group and three parents belonged to the susceptible group. It was ensured that drought did not become a limiting factor for germination and growth of seedlings. The experiment was terminated before the soil moisture depleted to drought level. Two of the environments of May and June 2005 represented high temperature regime. The third environment was rainy season environment in which the temperature was optimum for growth and development of pearl millet. The main experiment was a 10×10 diallel with three replications in three environments. The data related to one set of F_1 s and parents were analysed according to Hayman (1954) and Griffings (1956b) approach to draw information about the nature of genetic variance and inheritance of thermo-tolerance of other characters. The data was also analysed to study the genotype $\times$ environment interaction and responsiveness of genotypes. A brief discussion also presented for the utilization of these results for any possible genetic improvement of pearl millet. The intensive screening and selection of the inbreds with high general combining ability and desirable genotype $\times$ environment interaction for heat

tolerance and grain yield / components should be the genotypes of prior importance in our breeding approach.

Peacock *et al.* (1993) in his experiments of 1989 and 1990 had evaluated the materials on the basis of survival of young seedlings only. But thermo-sensitivity is also an established fact for germination (Garcia-Huidbro *et al.*, 1985; Howarth, 1989a; Khalifa and Ong, 1990). It is imperative, therefore, to study the germination along seedling response to understand the effect of temperature on stand of pearl millet. The loss of germination due to heat can be measured only after a standard germination test. The difference, however, are bound to occur in germination of seed under laboratory and field conditions (Singh, 1993a). For present investigation the germination obtained in rainy season (environment – III) with surface temperature remaining below 35°C, was considered as standard germination under field condition. This was true for all the genotypes. The seeds of all the genotypes were produced in uniform environmental condition during 2004. The seeds of all the genotypes were, therefore, expected to express to their full genotypic potential, because of little differences in background environment (Singh, 1993a). The effect of high soil surface temperature on germination was measured as deviation from the standard germination test. The mean germination was lowest (44.82) in environment – II. The genotypic variation for germination was also observed among the crosses.

The effect of high soil and air temperature on the seedling was studied with two methods. (1) Survival of seedling against

temperature stress termed as Seedling Thermo-tolerance Index (STI). (2) Ability of seeds to germinate combined with ability of seedling to survive. It was termed as Seed to Seedling Thermo-tolerance Index (SSTI). The STI is same as the Thermo-tolerance Index (TI) of Peacock *et al.* (1993). However, a considerable variation was observed for STI and SSTI in the stress environments. The crosses showing high order indices were from combination of different parents without a set pattern.

The necessity of SSTI arises in case of genotypes which show low germination under heat stress. The germinating seeds may be killed before their emergence. This type of mortality or restriction escapes the notice in calculating STI. In general the STI count is invariably high whereas the SSTI has lower values. The reduction in values, however, is not proportionate. The reduction is dependent on thermo-sensitivity of germination. The selection under SSTI would, therefore, be more rigorous. We also come across such genotypes and also crosses which showed poor germination and high STI. A caution is needed for evaluating such genotypes under STI. Referring to figure 46 and table 7, the genotypes (G73-107×BSECT CP-1), 36B, HHB-117, HHB-181 and 96AC-82 had STI values 56.64, 59.89, 64.39, 63.90, 50.59, respectively and SSTI values 44.13, 35.43, 46.43, 46.82, 36.79, respectively, during 2004. This changed the whole status of the genotypes in respect to thermo-tolerance. Similarly, the crosses such as H77/29-2 × 1305, Togo-II × 99HS-18, CVJ-2-5-3-1-3 × (77/371× BSECT CP-1) and G73-107 × 1305 during 2005 had STI

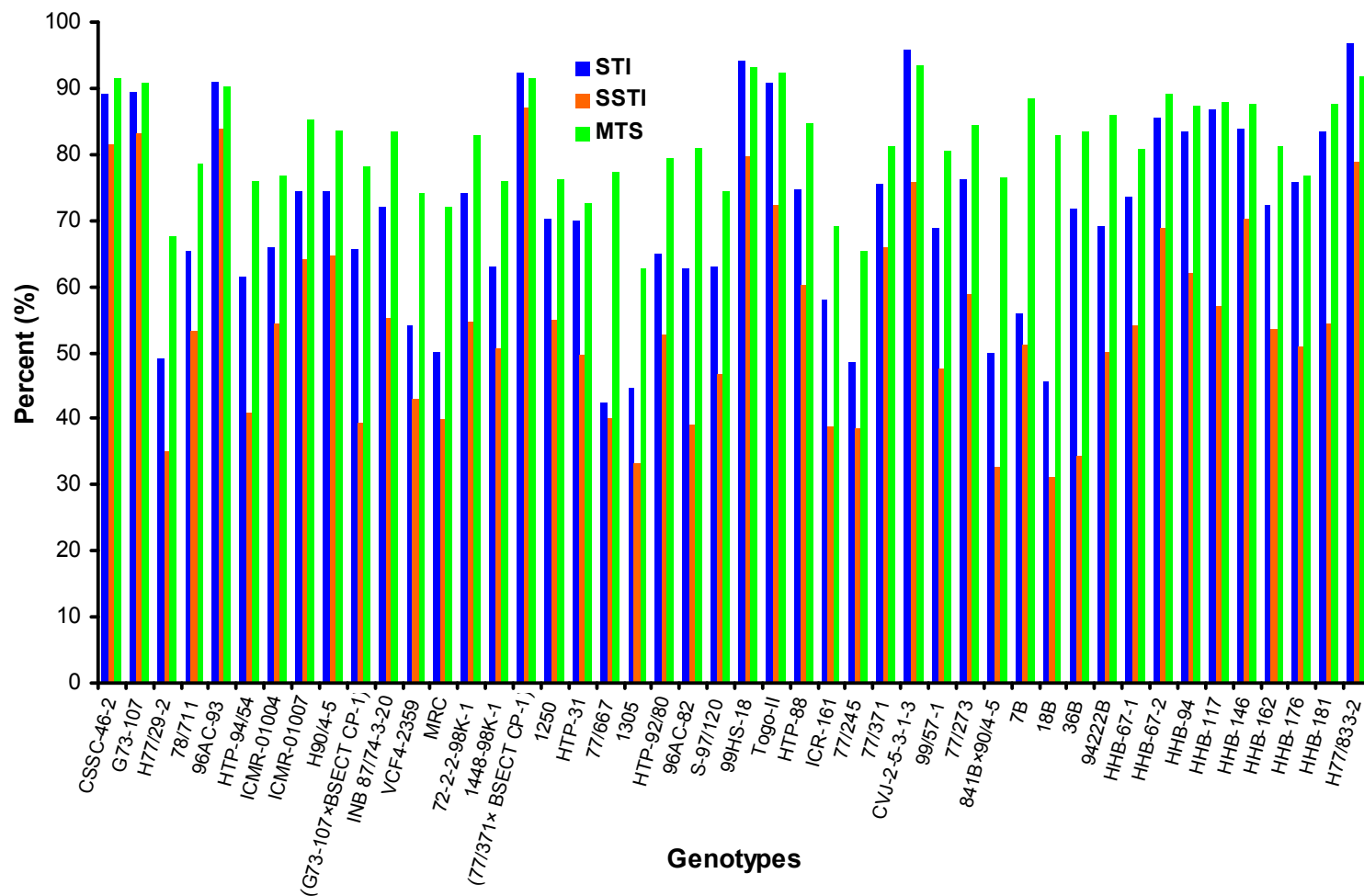


Fig. 46- Values of STI, SSTI and Membrane thermo-stability during screening experiment

Table 38: Top hybrids for heat tolerance (Mean basis)

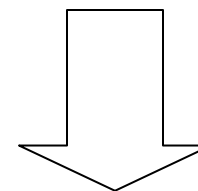
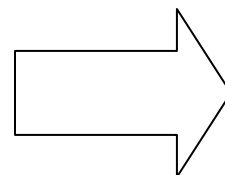
Sr. No	STI
1	H77/29-2 × CVJ-2-5-3-1-3
2	H77/833-2 × 96AC-93
3	(77/371 × BSECT CP-1) × Togo-II
4	(77/371 × BSECT CP-1) × 99HS-18
5	1305 × 99HS-18
6	CVJ-2-5-3-1-3 × 96AC-93
7	G73-107 × (77/371 × BSECT CP-1)
8	1305 × 96AC-93
9	H77/833-2 × G73-107
10	CVJ-2-5-3-1-3 × 99HS-18

Sr. No	SSTI
1	H77/833-2 × 96AC-93
2	G73-107 × (77/371 × BSECT CP-1)
3	H77/833-2 × (77/371 × BSECT CP-1)
4	H77/29-2 × CVJ-2-5-3-1-3
5	(77/371 × BSECT CP-1) × Togo-II
6	H77/833-2 × H77/29-2
7	(77/371 × BSECT CP-1) × 99HS-18
8	1305 × 96AC-93
9	CVJ-2-5-3-1-3 × 96AC-93
10	H77/833-2 × G73-107

Sr. No	MTS
1	(77/371 × BSECT CP-1) × Togo-II
2	H77/29-2 × CVJ-2-5-3-1-3
3	CVJ-2-5-3-1-3 × 96AC-93
4	1305 × 99HS-18
5	H77/833-2 × 96AC-93
6	1305 × 96AC-93
7	(77/371 × BSECT CP-1) × 96AC-93
8	(77/371 × BSECT CP-1) × 99HS-18
9	CVJ-2-5-3-1-3 × 99HS-18
10	H77/833-2 × G73-107



Sr. No	Common for STI and SSTI
1	H77/833-2 × G73-107
2	H77/833-2 × 96AC-93
3	H77/29-2 × CVJ-2-5-3-1-3
4	G73-107 × (77/371 × BSECT CP-1)
5	CVJ-2-5-3-1-3 × 96AC-93
6	1305 × 96AC-93
7	(77/371 × BSECT CP-1) × Togo-II
8	(77/371 × BSECT CP-1) × 99HS-18



Sr. No	Common (STI, SSTI and MTS)
1	(77/371 × BSECT CP-1) × Togo-II
2	H77/29-2 × CVJ-2-5-3-1-3
3	CVJ-2-5-3-1-3 × 96AC-93
4	H77/833-2 × 96AC-93
5	1305 × 96AC-93
6	(77/371 × BSECT CP-1) × 99HS-18
7	H77/833-2 × G73-107

values 74.79, 67.06, 71.39, 73.61 respectively and SSTI values 59.16, 55.48, 55.56, 58.90, respectively. The SSTI gave a highly reduced value putting these crosses in the susceptible list. While looking for the desirable of such an index it was also necessary to see that its vigours did not act very severely in the resultant variability.

In our experiment a considerable genotypic variability was witnessed in stress environments for SSTI. That ranged from 46.05 in cross H77/833-2 $\times$ 1305 to 72.87 for the cross combination H77/833-2 $\times$ 96AC-93. It may be concluded therefore, that SSTI is more dependable and desirable tool for screening and evaluating the genotypes for heat tolerance.

The range of index values is required to be classified in to the designate groups to attach values to the genotypes falling with in the group interval. Since the lower values of STI or SSTI are coming around 50, it would be safe to conclude that genotypes with index values up to 50 can be considered as susceptible to heat tolerance. In such situation only a quartile classification would be workable. However, some more data and some more experiments would be required to produce an index classification based on group intervals.

An important fact of commonality has emerged from the examination of mean values of STI, SSTI and MTS for top ten hybrids, respectively. Between STI and SSTI eight hybrids out of top ten were common (table 38). While including MTS, the number of common hybrids was seven. The same trend was witnessed during the screening of parents. Also in the analysis these three indices were

highly correlated among themselves. The question would then arise as to why not to go in for laboratory tests like MTS which may screen a large number of genotypes and with all time ease. The question has to be answered in affirmative. Nonetheless the SSTI as a direct evidence of heat tolerance of seeds and seedlings would precede the MTS as an indirect test. Moreover, the MTS generally records higher values (figure 8). Here also there is no consideration of pre-emergence heat effect. Looking to the advantages, disadvantages and effect of laboratory technologies (here MTS) and field technologies (here SSTI). We may suggest that i) Membrane thermo-stability test (MTS) may be used when there are large number of genotypes such as germplasm and accessions. ii) The STI or SSTI may be used and must be used for evaluation of hybrids and varieties before they are released.

The impact of high air temperature was clearly discernible on the development of seedlings as seen through the height of seedling and number of leaves of two week old seedlings. Average height of seedling was higher in normal environment and low in stress environments (E_1 and E_2). The impact of environment was same in case of germination (%), number of leaves/seedling, fresh weight and dry weight/seedling also.

5.2 Correlation among various characters

The correlations among the characters were calculated around heat tolerance indices STI and SSTI at two levels. One set of correlation

was studied at the time of screening of the parents. These were limited to seedling characters only. The other set of correlation coefficients was calculated while evaluating the diallel progenies which also included the seedling characteristics and other morphological and agronomic characters. It was observed that STI, SSTI and MTS recorded highest significant correlation among themselves (table 8). Here again the competence of all the three tests was established. The field based indices STI and SSTI also showed significant correlation with other growth traits of seedling e.g. emergence rate, height of seedling, number of leaves/seedling, fresh weight and dry weight/seedling. These growth characters of seedling can also give some credible indications for heat tolerance in genotypes. The faster germination and early vigours in seedling could act as physical indicators for heat tolerance which could be attributed to their efficiency to escape the lethal effect of heat.

While evaluating the diallel progenies it was seen that the heat tolerance indices STI and SSTI were not showing any perceptible correlation with either the developmental traits or the maturity characters. Since experiment proceeded without any stress after the establishment of seedling, the pearl millet plants show great resilience and recovery. Hence the early heat effects could have no impact on its later growth and development. The association of grain yield/plant and total biological was almost parallel with all the other traits (table 14). The most important character was dry fodder yield in both the cases. The other important characters were ear weight, ear length and

plant height. The character of early vigour of seedling also contributed for good grain yield.

5.3 Nature of genetic variation and inheritance

Fisher (1918) was the first to recognise the importance of components of genotypic variance. He divided the total genetic variance into three components, viz., additive portion resulting from the average effect of genes, the dominance portion resulting from intra-allelic interaction and the epistatic part associated with non-allelic interactions. Much of the subsequent work in this field has been directed to the further development of these concepts. Gardner (1963) has listed the various kinds of genetic parameters of interest to the plant breeders.

Several statistical techniques have now become available, which are used to estimate these components. In general, these techniques are based on the analysis of variance and covariance and on the regression applied to the data collected over a number of related generations grown in appropriate designs. Many such designs are theoretically possible but not all are amenable to analysis by standard, statistical procedure or of being genetically interpreted.

The method of diallel cross analysis is one design which has proved to be a powerful technique in the study of genetic basis of quantitative variation. It involves all possible crossing among 'p' lines to yield 'p²' progenies and consists of analysing the variance and covariance among the group of families. This analysis provides information about additive and dominance

components of variance and helps to detect the presence of epistatic variance.

There are three aspects differentiating these approaches. The first one concerns the sampling of material under investigations. Hayman (1954, 1957) considers the parents included in the crossing plan as the reference as well as the inference population (fixed effects). Kempthorne (1956) conceives his inference population as some random mating population in equilibrium of which the reference population is a random sample (random effects). Under these circumstances, the inference drawn from this sample (reference population) is applicable to the original population in equilibrium (inference population). Griffing (1956 a, b) developed the diallel analysis to cover either kinds of population sampled, using different models namely, the fixed effect model (Model 1), the random effect model (Model 2) and the Mixed Model A and the Mixed Model B.

Hayman (1954) proposed that five components of variance along with the regression slope W_r , V_r (covariance and variance of the parents, respectively) would approximately represent the genetic situation in a given set of parents. Griffing (1956 a, b) on the other hand, laid stress on the statistical concepts of general and specific combining ability.

Closely allied to the second, the third difference pertains to the estimation procedure. Griffing (1956b) and Kempthorne (1956) used the analysis of variance approach to obtain the estimates of general and specific combining ability variances which in turn can be equated in

terms of the nature of gene action involved. Hayman (1956, 1957) on the other hand, attempted to obtain estimates of genetic components from the statistics involving parents and off-springs.

For the material at hand in the present investigation the analytical approaches of Hayman (1954) and Griffing (1956b) were considered appropriate and were thus utilized for the present study.

The results obtained from Griffing's analysis revealed that both additive (gca) and non-additive (sca) genetic variances played an important role in this material for most of the characters studied. The relative magnitudes of the respective variances, however, showed that the later was more important, particularly in case of characters such as seedling thermo-tolerance index (STI), seed to seedling thermo-tolerance index (SSTI), germination (%), emergence rate (ER), number of leaves/seedling, seedling height, seedling fresh weight (g), seedling dry weight (g), number of effective tillers/plant, plant height, ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant indicating that non-additive genetic variance (dominance variance) was mainly responsible in the inheritance of these characters. It may be mentioned that the analysis of Hayman also showed the preponderance of over dominance for most of the characters which confirms that non-additive component of variance was more important. The preponderance of non-additive interaction as seen for many characters in this analysis is also some times caused due to presence of epistasis and / or a correlated gene distribution (Jinks, 1955). The over dominance might also arise from

the repulsion phase of linkage (Comstock and Robinson, 1952). A further bias may also be caused as according to Matzinger *et al.*, (1962) due to interaction of non-additive variance with the environment. However, the reverse was true for panicle emergence and ear length where there was a preponderance of additive genetic advance. Here the pedigree breeding for these characters would be expected to be more successful.

The results of the previous investigations available in the literature and summarized in table 39 with regard to gene action controlling heat tolerance and yield along with certain other characters in pearl millet may also be examined with reference to the present study. It may be observed that nature of gene action would vary with the material and also with the analytical procedure employed. It is, therefore, difficult to generalize the type of gene action that governs different characters in this crop plant (Kapoor, 1972). More consistent data are available in respect of ear length showing predominantly an additive kind of gene action governing these traits. With regard to the complex characters such as grain yield, ear weight, plant height and number of tillers per plant, it may be expected that substantial magnitude of either or both additive and non-additive genetic variance would be found. Thus it would be important for a breeder to continuously assess his breeding material.

Realising that individual components of genetic variance also interact with environment and can thus be biased, it becomes important to evaluate these interactions also (Gardner, 1963). Previous

Table 39: Magnitude of gene effects reported by earlier workers for different traits in pearl millet

Characters	Additive >Dominance	Additive < Dominance
Seedling Thermo-tolerance Index (STI)		Baljeet Singh (1993)
Seed to Seedling Thermo-tolerance Index (SSTI)		Baljeet Singh (1993)
Grain yield (g)/plant	Kapoor <i>et al.</i> (1979) Vaidya <i>et al.</i> (1983) Singh <i>et al.</i> (1984) Vyas and Pokhriyal (1985) Shinde and Desale (1985) Navale <i>et al.</i> (1991) Yadav <i>et al.</i> (2000)	Chinna (1981) Mukherji <i>et al.</i> (1981) Sachdeva (1981) Sachdeva <i>et al.</i> (1982) Yadav <i>et al.</i> (1981) Tyagi <i>et al.</i> (1982) Kunjir and Patil (1986) Singh (1986) Kataria (1991) Chavan and Nerker (1994) Sahane <i>et al.</i> (1996) Saraswathi <i>et al.</i> (1996) Sagar and Singh (1996) Karale <i>et al.</i> (1998) Mohan <i>et al.</i> (1999) Nijhawan <i>et al.</i> (1999) Sheoran <i>et al.</i> (2000 a) Rasal and Patil (2003) Sharma (2005) Kumar (2006)
Panicle emergence (days)	Sahane <i>et al.</i> (1996) Karale <i>et al.</i> (1998) Rasal and Patil (2003)	Naik <i>et al.</i> (1996) Saraswathi <i>et al.</i> (1996) Nijhawan <i>et al.</i> (1999) Singh <i>et al.</i> (2000) Sheoran <i>et al.</i> (2000 a,b) Sharma (2005)

Contd....

Contd....Table: 39

Characters	Additive >Dominance	Additive < Dominance
Plant height (cm)	Sachdeva (1981) Singh <i>et al.</i> (1984) Dass <i>et al.</i> (1985) Kunjeer and Patil (1986) Khairwal <i>et al.</i> (1987) Mangat <i>et al.</i> (1994) Karale <i>et al.</i> (1998) Singh <i>et al.</i> (2000) Yadav <i>et al.</i> (2002) Rasal and Patil (2003) Sharma (2005)	Basavaraju <i>et al.</i> (1980) Chinna (1981) Dass (1981) Singh (1986) Kataria (1991) Mangat <i>et al.</i> (1994) Sagar and Singh (1996) Naik <i>et al.</i> (1996) Sahane <i>et al.</i> (1996) Saraswathi <i>et al.</i> (1996) Nijhawan <i>et al.</i> (1999) Sheoran <i>et al.</i> (2000 a,b)
Effective tillers/plant	Kapoor <i>et al.</i> (1979) Singh <i>et al.</i> (1984) Dass <i>et al.</i> (1985) Kunjir and Patil (1986) Kataria (1991) Sheoran <i>et al.</i> (2000a)	Chinna (1981) Sachdeva (1981) Yadav <i>et al.</i> (1981) Dass (1981) Singh (1986) Sagar and Singh (1996) Singh <i>et al.</i> (2000) Sheoran <i>et al.</i> (2000 b) Kumar (2006)
Ear length (cm)	Kataria (1991) Mangat <i>et al.</i> (1994) Karale <i>et al.</i> (1998) Mohan <i>et al.</i> (1999) Singh <i>et al.</i> (2000) Rasal and Patil (2003)	Mukherji <i>et al.</i> (1981) Sachdeva (1981) Dass (1981) Singh (1986) Sagar and Singh (1996) Naik <i>et al.</i> (1996) Sahane <i>et al.</i> (1996) Nijhawan <i>et al.</i> (1999) Sheoran <i>et al.</i> (2000 b) Sharma (2005)

Contd....

Contd...Table: 39

Characters	Additive >Dominance	Additive < Dominance
Ear weight (g)/plant	Vyas and Pokhriyal (1985)	Kapoor <i>et al.</i> (1979) Singh (1986) Sagar and Singh (1996) Singh <i>et al.</i> (2000) Sheoran <i>et al.</i> (2000 b) Sharma (2005)
Dry fodder yield (g)/plant	Kapoor (1972) Badwal <i>et al.</i> (1973) Singh (1986) Yadav <i>et al.</i> (2002)	Kapoor <i>et al.</i> (1982) Sagar and Singh (1996) Naik <i>et al.</i> (1996) Nijhawan <i>et al.</i> (1999) Sharma (2005)
Total biological yield (g)/plant	Badwal <i>et al.</i> (1973)	Kapoor <i>et al.</i> (1982) Kumar (1983) Sagar (1983) Kataria (1991) Sharma (2005)

interactions have shown that both the additive and dominance components can interact with changes in the environment (Rojas and Sprague, 1952; Matzinger *et al.*, 1959; Liang, 1967; Paroda and Joshi, 1970 and Kapoor, 1972).

A consideration of the gca and sca effects might be of help in isolating suitable genotypes for more conventional breeding work. The parent CVJ-2-5-3-1-3 was identified as the best general combiner for STI followed by four other parents H77/833-2, (77/371× BSECT CP-1), 96AC-93 and 99HS-18 which exhibited high gca effect. The parents (77/371× BSECT CP-1) and G73-107 exhibited highest gca effect for SSTI. On the other hand 1305 and Togo-II were good general combiners for grain yield, dry fodder yield (g)/plant, ear length (cm) in all these environments. The parent CVJ-2-5-3-1-3 was the good general combiner for seedling thermo-tolerance index (STI), number of leaves/seedling, plant height (cm), ear length (cm), dry fodder yield (g)/plant and total biological yield (g)/plant. While, the parent H77/833-2, good general combiner for STI was also desirable for early panicle emergence in all the environments and high tillering during stress environments.

The parent (77/371× BSECT CP-1) had high gca effect for STI and SSTI as well as for germination, emergence rate (ER), seedling height (cm) and panicle emergence in all the environments. The parent 96AC-93 showed good general combining ability for STI, SSTI, seedling fresh weight (g), seedling dry weight (g) and panicle

emergence. The parents which showed the good gca for both STI and SSTI were (77/371 × BSECT CP-1) and 96AC-93.

The parent G73-107 also showed the good gca for SSTI, number of leaves/seedling, plant height (cm) in all environments and germination and ear length (cm) in stress environments only. The overall result, however, maintained the trend that good per se performer were also the good combiner for this trait and reverse was also true. The magnitude of sca effects, of course differed for specific crosses in different environment but the direction (+ve or -ve) generally remained the same. Ten cross combinations, namely, H77/833-2 × H77/29-2, H77/833-2 × 77/245, H77/833-2 × 96AC-93, H77/29-2 × CVJ-2-5-3-1-3, H77/29-2 × 1305, G73-107 × 77/245, G73-107 × 1305, 1305 × 96AC-93, 1305 × 99HS-18 and (77/371 × BSECT CP-1) × Togo-II showed consistency for positive significant values for STI in both the stress environments (E_1 and E_2).

The cross H77/29-2 × 1305 was the best specific combination (19.245) for STI in environment-I but in environment-II the cross (77/371 × BSECT CP-1) × Togo-II showed the highest sca value (13.925) while the cross combination H77/833-2 × 1305 was identified as the poorest specific cross combination for STI in both the stress environments (E_1 and E_2). It was a matter of enormous importance that the best specific cross had resulted from the two susceptible parents. That would mean the genes for heat tolerance are distributed across the parents. In such a situation the estimation of gca and sca assume added significance.

As regards the sca effects for SSTI the results were almost similar to STI. In both the environments (E_1 and E_2) ten cross combinations i.e. H77/833-2 $\times$ H77/29-2, H77/833-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/833-2 $\times$ 96AC-93, H77/29-2 $\times$ CVJ-2-5-3-1-3, H77/29-2 $\times$ Togo-II, G73-107 $\times$ 77/245, G73-107 $\times$ (77/371 $\times$ BSECT CP-1), 1305 $\times$ 96AC-93, 1305 $\times$ 99HS-18 and (77/371 $\times$ BSECT CP-1) $\times$ Togo-II were identified as the crosses having the positive significant sca values for SSTI.

The cross 1305 $\times$ 99HS-18 was the best specific combination (11.204) followed by the cross H77/833-2 $\times$ 96AC-93 as close runner up with a value (11.088) in environment-I but in environment-II the cross H77/833-2 $\times$ 96AC-93 showed the highest sca value (18.303) followed by the cross 1305 $\times$ 96AC-93 as close runner up with a value (15.162). While the cross H77/833-2 $\times$ 1305 was identified as the poorest specific cross combination for SSTI in both the environments (E_1 and E_2). The best specific cross 1305 $\times$ 99HS-18 involves the one susceptible parent (1305). This parent also gave best specific cross for STI. It is a re-assertion of the fact the heat tolerant genes are also contributed by parents with poor performance per se. This indicates a complex nature of gene distribution and the control system for the trait. The contribution of positive genes by the poor performer has a special significance in plant breeding. We can expect the genes being disbursed in large germplasm and coming from any parent. This would also suggest that in absence of particular sources, the trait could be tested in hybrids as a qualifying standard.

Among the top hybrids selected on the basis of high sca for STI and SSTI seven cross combinations, namely, H77/833-2 $\times$ 96AC-93, 1305 $\times$ 96AC-93, (77/371 $\times$ BSECT CP-1) $\times$ Togo-II, H77/29-2 $\times$ CVJ-2-5-3-1-3, 1305 $\times$ 99HS-18, G73-107 $\times$ 77/245 and H77/833-2 $\times$ H77/29-2 were common (table 40). The ten hybrids were also selected for the grain yield / plant on the basis of high sca. The hybrid (77/371 $\times$ BSECT CP-1) $\times$ Togo-II was common among the top hybrids for STI and SSTI as well as showed high sca for grain yield. This hybrid was a tolerant $\times$ tolerant type. The cross had high sca for ear weight (g)/plant, germination (%), seedling height and seedling dry weight (g) in stress environments.

The estimate of general combining ability (gca) effects in respect of germination (%) indicated that parents H77/29-2 and (77/371 $\times$ BSECT CP-1) exhibited significant positive gca effects in all the three environments. The parent G73-107 showed positive gca effect in both the stress environments (environment-I and environment-II). A consideration of specific combining ability (sca) effects reveals that out of 45 cross combinations only five crosses, namely, H77/833-2 $\times$ H77/29-2, H77/29-2 $\times$ Togo-II, CVJ-2-5-3-1-3 $\times$ 99HS-18, 1305 $\times$ 96AC-93 and 1305 $\times$ 99HS-18 exhibited significant positive sca effects in all the three environments. The crosses H77/833-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/833-2 $\times$ 96AC-93, H77/29-2 $\times$ CVJ-2-5-3-1-3, G73-107 $\times$ (77/371 $\times$ BSECT CP-1) and (77/371 $\times$ BSECT CP-1) $\times$ Togo-II showed significant and

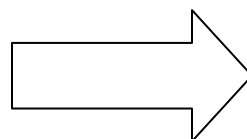
Table 40: Top hybrids for heat tolerance (sca basis)

Sr. No	STI
1	H77/29-2 × 1305
2	H77/29-2 × CVJ-2-5-3-1-3
3	1305 × 96AC-93
4	1305 × 99HS-18
5	H77/833-2 × 96AC-93
6	(77/371 × BSECT CP-1) × Togo-II
7	G73-107 × 1305
8	G73-107 × 77/245
9	H77/833-2 × 77/245
10	H77/833-2 × H77/29-2

Sr. No	SSTI
1	H77/833-2 × 96AC-93
2	1305 × 96AC-93
3	(77/371 × BSECT CP-1) × Togo-II
4	H77/29-2 × CVJ-2-5-3-1-3
5	1305 × 99HS-18
6	H77/833-2 × (77/371 × BSECT CP-1)
7	G73-107 × (77/371 × BSECT CP-1)
8	G73-107 × 77/245
9	H77/833-2 × H77/29-2
10	H77/29-2 × Togo-II

Sr. No	Grain Yield
1	1305 × Togo-II
2	77/245 × CVJ-2-5-3-1-3
3	H77/29-2 × 1305
4	G73-107 × 1305
5	H77/833-2 × 1305
6	G73-107 × Togo-II
7	(77/371 × BSECT CP-1) × Togo-II
8	77/245 × 1305
9	96AC-93 × Togo-II
10	G73-107 × 96AC-93

Sr. No	Tolerant hybrids with high sca
1	H77/833-2 × 96AC-93
2	1305 × 96AC-93
3	(77/371 × BSECT CP-1) × Togo-II
4	H77/29-2 × CVJ-2-5-3-1-3
5	1305 × 99HS-18
6	G73-107 × 77/245
7	H77/833-2 × H77/29-2



Sr. No	Tolerant hybrids with high yield	
	(77/371 × BSECT CP-1) × Togo-II	T×T

positive sca effects in stress environments (environment–I and environment–II).

The parent (77/371 × BSECT CP-1) was found to be the best general combiner for emergence rate (ER). Significant positive sca effects in all the three environments for this trait were exhibited by only one cross combination, namely, H77/29-2 × G73-107. However, the cross H77/833-2 × G73-107 in environment–I and II showed consistency for positive significant values in two environments.

For number of leaves/seedling positive and significant gca effects were recorded for the parents G73-107 and CVJ-2-5-3-1-3 in all the three environments (E_1 , E_2 and E_3). These parents could, therefore be termed as overall best combiners for number of leaves/seedling. Six cross combinations, namely, H77/833-2 × 1305, H77/29-2 × CVJ-2-5-3-1-3, H77/29-2 × 1305, G73-107 × 1305, 77/245 × 1305 and 77/245 × Togo-II showed consistency for positive significant sca values in all the three environments (E_1 , E_2 and E_3). Three crosses, namely, H77/833-2 × 96AC-93, 77/245 × CVJ-2-5-3-1-3 and 1305 × 99HS-18 exhibited significant and positive sca effects in stress environments–I and II.

Only one parent i.e. (77/371 × BSECT CP-1) showed the consistency for significant positive gca effects for seedling height and hence was the best general combiner for this trait. The seven cross combinations, namely, H77/833-2 × 1305, H77/29-2 × CVJ-2-5-3-1-3, H77/29-2 × (77/371 × BSECT CP-1), H77/29-2 × 99HS-18, G73-107 × Togo-II, 77/245 × 99HS-18 and 1305 × 99HS-18 showed

significant positive sca effects consistently over all the three environments. The four crosses, namely, H77/833-2 $\times$ CVJ-2-5-3-1-3, H77/833-2 $\times$ 96AC-93, G73-107 $\times$ (77/371 $\times$ BSECT CP-1) and (77/371 $\times$ BSECT CP-1) $\times$ Togo-II in environment-I and II showed the consistency over the two environments for the positive significant sca values.

The parent 96AC-93 appeared to be good general combiner for seedling fresh weight (g) as indicated by significant positive gca effect in all the environments (E_1 , E_2 and E_3), while, the parents 77/245 and 99HS-18 showed the positive significant gca values in stress environments-I and II. A consideration of sca effect reveals that out of 45 cross combinations ten crosses, namely, H77/833-2 $\times$ 1305, H77/833-2 $\times$ 96AC-93, H77/29-2 $\times$ CVJ-2-5-3-1-3, H77/29-2 $\times$ 1305, H77/29-2 $\times$ Togo-II, G73-107 $\times$ 99HS-18, 77/245 $\times$ (77/371 $\times$ BSECT CP-1) and Togo-II $\times$ 99HS-18 exhibited significant positive sca effects in all the three environments. The crosses i.e., H77/833-2 $\times$ CVJ-2-5-3-1-3, G73-107 $\times$ 77/245 and 77/245 $\times$ 99HS-18 showed significant and positive sca effects in stress environments (E_1 and E_2).

For dry weight (g)/seedling the parent 96AC-93 was identified as the best general combiner over all the three environments and 99HS-18 in stress environments-I and II having highest positive gca effect. Significant positive sca effects in all the three environments for dry weight (g)/seedling were exhibited by eight cross combinations, namely, H77/833-2 $\times$ 96AC-93, H77/29-2 $\times$ 1305, H77/29-2 $\times$ Togo-II, G73-107 $\times$ 1305, G73-107 $\times$ 96AC-93, G73-107 $\times$ 99HS-18,

77/245 $\times$ (77/371 $\times$ BSECT CP-1) and Togo-II $\times$ 99HS-18. However, six crosses, namely, H77/833-2 $\times$ CVJ-2-5-3-1-3, H77/833-2 $\times$ 1305, G73-107 $\times$ 77/245, 77/245 $\times$ 99HS-18, (77/371 $\times$ BSECT CP-1) $\times$ Togo-II and 96AC-93 $\times$ Togo-II in environment-I and II (stress environments), showed consistency for positive significant sca effects in two environments.

For panicle emergence the negative values of gca are considered favourable as an indication of earliness. The parents H77/833-2, (77/371 $\times$ BSECT CP-1) and 96AC-93 in all the three environments had significant and negative gca effects and were, therefore, considered as good general combiners for earliness. Only one cross i.e. G73-107 $\times$ 99HS-18 showed significant negative sca effects in all the three environments and thus, was good cross combination for early flowering.

Positive and significant gca effects for number of effective tillers/plant were recorded for the parent 1305 in all the three environments. The parent H77/833-2 in environment-I and II (stress environments) exhibited significant positive gca effects. Only one cross combination i.e. H77/833-2 $\times$ 1305 exhibited significant and positive sca effects in all the three environments. However, three cross combinations H77/29-2 $\times$ G73-107, H77/29-2 $\times$ Togo-II and CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1) environment-I and II exhibited significant positive sca effects for number of effective tillers/plant.

The parents H77/29-2, G73-107 and CVJ-2-5-3-1-3 had significant and positive gca effects indicating good general combining

abilities for tallness in pearl millet. The sca effects revealed that 16 cross combinations showed significant and positive sca effects in all the three environments. In stress environments (E_1 and E_2) five crosses, namely, H77/833-2 $\times$ 96AC-93, H77/29-2 $\times$ G73-107, G73-107 $\times$ 96AC-93, 1305 $\times$ (77/371 $\times$ BSECT CP-1) and (77/371 $\times$ BSECT CP-1) $\times$ 99HS-18 exhibited significant and positive sca effects for tallness.

The parents CVJ-2-5-3-1-3, 1305 and Togo-II were found to be the most desirable parents in respect of the ear length since they possessed consistently high positive gca effects under all the environments. The parent G73-107 showed high and significant gca effect in environment-I and II. The magnitude of sca effects for ear length (cm) revealed that only five crosses viz. H77/833-2 $\times$ 1305, 77/245 $\times$ Togo-II, (77/371 $\times$ BSECT CP-1) $\times$ 96AC-93, (77/371 $\times$ BSECT CP-1) $\times$ 99HS-18 and 96AC-93 $\times$ 99HS-18 exhibited significant positive sca effects in all the three environments. The crosses G73-107 $\times$ 96AC-93, CVJ-2-5-3-1-3 $\times$ 96AC-93 and 1305 $\times$ Togo-II in environment-I and II tend to show high significant sca effects in two environments only.

Positive and significant gca effects were recorded for the parents 1305 and Togo-II for ear weight (g)/plant in all the three environments. The twelve cross combinations, namely, H77/833-2 $\times$ 1305, H77/833-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/29-2 $\times$ 1305, H77/29-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/29-2 $\times$ 99HS-18, G73-107 $\times$ 1305, G73-107 $\times$ Togo-II, 77/245 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$

96AC-93, CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1), 1305 $\times$ Togo-II and (77/371 $\times$ BSECT CP-1) $\times$ Togo-II showed significant and positive sca effects consistently over all the three environments. The six crosses, viz., H77/833-2 $\times$ 99HS-18, H77/29-2 $\times$ 96AC-93, H77/29-2 $\times$ Togo-II, G73-107 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ 1305 and Togo-II $\times$ 99HS-18 in environment-I and II showed the consistency over the two environments for the positive significant sca effects for Ear weight (g)/plant.

For dry fodder yield (g) / plant the parents CVJ-2-5-3-1-3, 1305 and Togo-II appeared to be good general combiners as indicated by significant positive gca effects in all the environments (E_1 , E_2 and E_3). A consideration of sca effects revealed that out of 45 cross combinations, 23 crosses exhibited significant positive sca effects in all the three environments. The cross H77/29-2 $\times$ CVJ-2-5-3-1-3 in environment-I and II, showed significant positive sca effects for dry fodder yield (g)/plant.

The estimate of general combining ability (gca) effects in respect of grain yield/plant indicated that parents 1305 and Togo-II exhibited high positive gca effects in all the three environments. Significant positive sca effects in all the three environments for this trait were exhibited by eleven cross combinations, namely, H77/833-2 $\times$ 1305, H77/833-2 $\times$ 99HS-18, H77/29-2 $\times$ 1305, H77/29-2 $\times$ 96AC-93, G73-107 $\times$ CVJ-2-5-3-1-3, G73-107 $\times$ 1305, G73-107 $\times$ Togo-II, 77/245 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ 96AC-93, CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1) and 1305 $\times$ Togo-II. However, four crosses,

namely, H77/833-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/29-2 $\times$ Togo-II, 77/245 $\times$ 1305 and Togo-II $\times$ 99HS-18 in environment-I and II (stress environments), showed consistency for positive significant sca effects in two environments for grain yield (g)/plant.

The parents CVJ-2-5-3-1-3 , 1305 and Togo-II were the most desirable parents in respect of the total biological yield/plant (excluding roots) since they possessed consistently high positive gca effects under all the environments. The magnitude of sca effects for total biological yield (g)/plant revealed that 23 cross combinations exhibited significant positive sca effects in all the three environments. The cross combination Togo-II $\times$ 99HS-18 was also of equally good value for its specific performance in stress environments.

5.3.1 Analysis of genetic components of variance (Griffings Analysis)

The $\sigma^2_{gca} / \sigma^2_{sca}$ ratio was low for all the characters i.e. seedling thermo-tolerance index (STI), seed to seedling thermo-tolerance index (SSTI), germination (%), emergence rate (ER), number of leaves/seedling, seedling height, seedling fresh weight (g), seedling dry weight (g), panicle emergence, number of effective tillers/plant, plant height (cm), ear length (cm), ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant in all the three environments, the low ratio as well as the higher magnitude of dominance component of variance than additive variance would confirm that most characters were predominantly

under the control of non-additive variance. This should facilitate the success of hybrid breeding by making use of the expected heterosis. The heterosis breeding has been the hallmark of genetic improvement of pearl millet for grain productivity and other traits. The results in this investigation suggest that hybrid breeding could probably hold true for thermo-tolerance too. However, the reverse was true for panicle emergence and ear length where there was a preponderance of additive genetic variance. Here the pedigree breeding for these two characters would expect to be more successful. Expected in the estimates narrow sense heritability were also very high for these characters. The selection in the segregating population is expected to be really effective. These estimates for STI and SSTI germination (%) and panicle emergence were of moderate magnitude which also indicated good chances of effective selection. The values of broad sense heritability for most other characters were quite high. This would be of little significance or for the fixation of genes is concerned, but would certainly suggest the adoption of heterotic breeding as a method. The analysis of genetic components overwhelmingly supported the method of hybrid breeding as the principal approach for genetic improvement in pearl millet.

5.3.2 Hayman's graphical approach

The $V_r - W_r$ graph provide information on: (i) the test of the adequacy of the model, in the absence of non-allelic interaction and with independent distribution of genes among the parents, W_r is

related to V_r by a straight regression line of unit slope, (ii) given that the model is adequate, a measure of the average level of dominance is provided by the departure from the origin of point where the regression line cuts the W_r axis, and (iii) the relative order of the points along the regression line indicates the distribution of dominant and recessive genes among the parents; the array points near the origin correspond to the parents with the most dominant genes and the array points farthest from the origin correspond to the parents with most recessive genes. In the present study $V_r - W_r$ graph indicated over dominance for emergence rate, number of leaves/seedling, seedling height (cm), fresh weight (g)/seedling, dry weight (g)/seedling, panicle emergence (days), number of effective tillers/plant, plant height (cm), ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant. Partial dominance was observed for seedling thermo-tolerance index and ear length (cm). The epistasis was found to be absent for emergence rate, seedling thermo-tolerance index, seed to seedling thermo-tolerance index, ear length (cm), seedling height (cm) and plant height (cm).

The parents 3, 5 (G73-107 and CVJ-2-5-3-1-3) in both the environments (E_1 and E_2) appeared to have an excess of dominant genes for seedling thermo-tolerance index (STI) while, the parents 1, 6 (H77/833-2 and 1305) had maximum of recessive genes. The array points 10, 5 (99HS-18 and CVJ-2-5-3-1-3) appeared to possess maximum number of dominant genes for seed to seedling thermo-

Table 41: Degree of dominance for different characters in three environments

Characters	Degree of Dominance			
	E ₁	E ₂	E ₃	Overall Expression
STI	Partial	Partial	—	Partial Dominance
SSTI	Over	Partial	—	No Conclusion
Germination (%)	Partial	Partial	Partial	Partial Dominance
Rate of emergence	Over	Over	Over	Over Dominance
No. of leaves/ seedling	Over	Over	Over	Over Dominance
Seedling height (cm)	Over	Over	Partial	Over Dominance
Fresh weight (g) /seedling	Partial	Over	Over	Over Dominance
Dry weight (g) /seedling	Partial	Over	Over	Over Dominance
Panicle emergence (days)	Over	Partial	Over	Over Dominance
Effective tillers/plant	Over	Over	Over	Over Dominance
Plant height (cm)	Over	Over	Over	Over Dominance
Ear length (cm)	Partial	Partial	Over	Partial Dominance
Ear weight (g)/plant	Over	Over	Over	Over Dominance
Dry fodder yield (g)/plant	Over	Over	Over	Over Dominance
Grain yield (g)/plant	Over	Over	Over	Over Dominance
Total biological yield (g)/plant	Over	Over	Over	Over Dominance

Table 42: Test of additivity for different characters in three environments

Characters	Epistasis			
	E ₁	E ₂	E ₃	Overall Expression
STI (%)	Absent	Absent	—	Absent
SSTI (%)	Absent	Present	—	No Conclusion
Germination (%)	Present	Present	Present	Present
Rate of emergence	Absent	Present	Absent	Absent
No. of leaves/ seedling	Present	Present	Present	Present
Seedling height (cm)	Absent	Absent	Present	Absent
Fresh weight (g) /seedling	Present	Present	Present	Present
Dry weight (g) /seedling	Present	Present	Present	Present
Panicle emergence (days)	Present	Present	Present	Present
Effective tillers/plant	Present	Present	Present	Present
Plant height (cm)	Present	Absent	Absent	Absent
Ear length (cm)	Absent	Absent	Absent	Absent
Ear weight (g)/plant	Present	Present	Present	Present
Dry fodder yield (g)/plant	Present	Present	Present	Present
Grain yield (g)/plant	Present	Present	Present	Present
Total biological yield (g)/plant	Present	Present	Present	Present

Table 43: Parental order of dominance for different characters in three environments

Characters	Parental Order of Dominance		
	Dominant	Recessive	Others
STI (%)	3, 5	1, 6	2, 4, 7, 8, 9, 10
SSTI (%)	10, 5	1, 6	2, 3, 4, 7, 8, 9
Germination (%)	8, 3	1	2, 4, 5, 6, 7, 9, 10
Rate of emergence	8, 5, 7, 10	2, 6	1, 3, 4, 9
No. of leaves/ seedling	3, 10, 5, 7	6, 2, 4	1, 8, 9
Seedling height (cm)	5, 8, 4	6	1, 2, 3, 4, 7, 8, 9, 10
Fresh weight (g) /seedling	6, 1	4	2, 3, 5, 7, 8, 9, 10
Dry weight (g) /seedling	8	6, 1, 9	2, 3, 4, 5, 7, 10
Panicle emergence (days)	7	3, 6	1, 2, 4, 5, 8, 9, 10
Effective tillers/plant	3	6	1, 2, 4, 5, 7, 8, 9, 10
Plant height (cm)	5, 1	9, 10	2, 3, 4, 6, 7, 8
Ear length (cm)	5, 7	8, 4	1, 2, 3, 6, 9, 10
Ear weight (g)/plant	10	2	1, 3, 4, 5, 6, 7, 8, 9
Dry fodder yield (g)/plant	10, 5	1, 9	2, 3, 4, 6, 7, 8
Grain yield (g)/plant	10, 5	2, 9, 1	3, 4, 6, 7, 8
Total biological yield (g)/plant	10, 5	1, 9	2, 3, 4, 6, 7, 8

tolerance index (SSTI). The parents 1, 6 (H77/833-2 and 1305) possessed relatively more number of recessive genes. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them. The well scattered array points along the regression line indicated genetic diversity among the parents. The information regarding degree of dominance, test of additivity and parental order of dominance for all the characters have been summarised in table 41 to 43.

5.3.3 Hayman's numerical approach

The additive component of variance (D) had a significant presence for STI and SSTI in both the stress environments. At the same time the dominance component of variance (H_1) for these characters was not only significant but also in higher magnitude. This effect of over dominance was also reflected by higher degree of overall dominance effect (h^2) for both these characters. The covariance between D and H_1 showed a symmetrical distribution of dominant and recessive alleles for SSTI which was however shown to be asymmetrical for STI due to its significant mean squares. The proportion of dominant genes was also higher over the recessive genes in parents for both STI and SSTI. It was also seen that proportion of dominant genes with positive effect was higher than those with negative effects in control of STI and SSTI. Only one dominant gene appears to be responsible for expression of STI and SSTI.

Both these H_1 and H_2 components were significant for all the traits in all the three environments except for number of effective tillers/plant. The magnitude of H_1 was higher than that of D for all the characters in all the environments indicating a preponderance of non-additive gene effects in the inheritance of these characters.

The h^2 component, which reflects net dominance of genes (as the algebraic sum over all the loci in the heterozygous phase in all the crosses), was significant for germination, emergence rate, number of leaves/seedling, seedling height (cm), fresh weight (g)/seedling, dry weight (g)/seedling, panicle emergence (days), number of effective tillers/plant, plant height (cm), ear length (cm), ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant in all the three environments, while, for the remaining characters and environments it was non-significant.

The inter relationship of the H_1 and H_2 parameters is reflected in the allied genetic parameter $H_2/4H_1$ index that estimates the proportion of genes with positive/negative effects, showing dominance in the parents. The value of this index was less than the expected values of 0.25 for all the characters in all the three environments indicating the asymmetrical distribution of dominant genes having positive and negative effects in parents.

The ratio h^2/H_2 denotes the number of gene groups exhibiting dominance. The value of this ratio indicated one group of genes for STI, SSTI, germination (%), and number of effective tillers/plant. The character panicle emergence indicated two gene groups exhibiting

dominance. Three gene groups were shown by the characters i.e. seedling height, fresh weight (g)/seedling and dry weight (g)/seedling. The characters, ear weight (g)/plant (stress environments), dry fodder yield (g)/plant and grain yield (g)/plant (stress environments) exhibited four gene groups. Five gene groups were exhibited by the characters, namely, plant height, ear length and total biological yield (g)/plant.

5.4 Stability analysis

Maximum level of production and stability of yield are the two desired features in a commercial variety. The nature and importance of genotype-environment interaction in this context has been discussed in detail by a good number of scientists (Comstock and Moll, 1963, Allard and Bradshaw, 1964). Frankel (1958) proposed two possible ways in which a plant breeder can develop varieties exhibiting a low genotype-environment interaction (i) the sub-division of a heterogeneous area for which the varieties are being bred into smaller regions, or in other words, stratification of environments, such that each of the strata is more homogeneous with its own characteristic varieties; (ii) the introduction of varieties which show a high degree of stability in performance over a wide range of environments i.e., varieties showing wide and general adaptability. The first strategy may not be very efficient, especially in the case of dry land field crops like pearl millet since, even in a uniform environment, performance levels could vary greatly because of

marked fluctuation of the climatic conditions from year to year. The second strategy thus, interests the breeder a great deal. Indeed, development of varieties showing wide adaptability has received increasing attention in recent years.

Techniques of regression analysis based on original work by Yates and Cockerham (1938) are now available which provide two simple measures of genotype-environment interaction in respect of individual genotypes when they are tested over a wide range of environments. However, two approaches have been used to describe the potential performance in a set of genotypes in terms of these measures. The first one is purely a statistical approach (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966 and Breese, 1969). The second one relates the components of regression analysis to a basic biometrical genetic model. It consists of fitting models, which specify the contribution of genetic, environmental and genotype – environment interaction to generation means and variances, which allows for estimates of the contribution of additive, dominance and epistatic gene action to the genetic and interaction components (Mather and Jones, 1958; Jinks and Stevens, 1959; Bucio Alanis, 1966; Bucio Alanis and Hill, 1966; Perkins and Jinks, 1968 a, b; Bucio Alanis *et al.*, 1969; Baker, 1969 and Samuel *et al.*, 1970).

The term b_i or the regression slope was originally used by Finlay and Wilkinson (1963) to refer to the stability of a genotype. Genotypes with the most gentle slope being preferred to as the most stable in contrast to the genotypes having the steepest slopes, which

were the least stable. Later, Eberhart and Russell (1966) defined both the linear and non-linear functions of genotype – environment interaction as ‘stability parameters’. It has come to be recognized, however, that since the linear response represents very definite and measurable responses of a genotype to changes in environment, it would be more appropriate to consider this component as a measure of ‘responsiveness’ of the genotype and the term ‘stability’ should be used (Breese, 1969) to refer to the absence of a low magnitude of unpredictable variation of a genotype in response to change in environments. This measure is provided by the deviation from regression (S^2_{di}). These two measures have also been referred to by Friff and Caton (1971) as ‘linear sensitivity’ and ‘non-linear sensitivity’, respectively. Such a concept of stability in response to changing environments would then be the same as second parameter of stability given by Eberhart and Russell (1966), also conforms very closely to the concept of developmental homeostasis of Lerner (1958) that complex stress gives rise to developmental responses which are coordinated to result adaptive phenotypes.

The results of several investigations reported so far show (Breese, 1969) that of the three parameters ($x_{i.}$, b_i , S^2_{di}), the estimates of regression coefficients are relatively unaffected for a given set of genotypes even if the sample of environments considered is biased, while the distribution of population means on the other hand, depends on specific nature of set of environment studied. To obtain reliable

estimates of S^2_{di} several environments of which this estimate is a function, are also required.

Freeman and Perkins (1971) however, criticized on statistical grounds the use of all test genotypes as an estimate of the environment and advocated the use of independent assessment of each environment by the use of controls. These might be standard varieties or extra replicate of the material under study.

With the availability of these simple and powerful techniques and measures of genotype-environment interaction, numerous workers have attempted to study the phenomenon of adaptability in a wide range of crop plants (Russell and Eberhart, 1968 in corn; Joppa *et al.*, 1971 in wheat; Perkins and Jinks, 1971 in *Nicotiana*; Paroda and Hayes, 1971 in barley etc.). Although a fairly extensive sample of environments is used for the present investigation, yet it needs not to visualize as an unbiased sample of the *bajra* growing environments in this country.

In the present study the results obtained from $g \times e$ interaction based on the approach suggested by Freeman and Perkins (1971) is being discussed hereafter. Analysis of variance for stability revealed the presence of genetic variability in the material for all the characters under study. Highly significant mean squares due to environment plus genotype $\times$ environment interaction indicated that genotypes interacted significantly with different environmental conditions. This showed the presence of genotype $\times$ environment interaction in the F_1 hybrids. The present findings of genotype $\times$ environment interaction is

in agreement with earlier workers viz., Maiti and Soto (1990), Chavan and Nerker (1992), Pethani (1993), Sagar and Singh (1995), Suryavanshi *et al.* (1995), Ramamoorthi *et al.* (1996) Karale *et al.* (1997), Yadav *et al.* (1999) Anarase *et al.* (2000), Anarase *et al.* (2002), Kumar and Sahib (2003), Sharma (2004) and Kumar (2006).

Stability analysis was carried out based on Freeman and Perkins (1971) model for 14 characters. The stability analysis could not be conducted for seedling thermo-tolerance index (STI) and seed to seedling thermo-tolerance index (SSTI) for the precise reason that variation in values of these indices were available only in two environments making the data inadequate for analysis based on above model. As a matter of fact the seedling mortality during third environment i.e. the monsoon period was practically nil (zero) and it had to be excluded.

It was revealed from the table 44 that the majority of genotypes were found predictable for germination (%), emergence rate (ER), number of leaves/seedling, seedling height, panicle emergence, number of effective tillers/plant, plant height, ear length, ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant over environments was possible only for these characters. While, for seedling fresh weight (g) and seedling dry weight (g) characters majority of genotypes were unpredictable. These findings are in agreement with earlier workers viz., Pethani and Kapoor (1986), Chavan and Nerker (1994), Yadav *et al.* (1997) and Yadav *et al.* (1999).

Table 44: Distribution of parents and hybrids on the basis of genotype-environment interaction components

Characters	Predictable				Unpredictable			
	G×E absent b_i & S^2_{di} non-significant		G×E (linear) present b_i significant S^2_{di} non-significant		G×E (non-linear) present b_i non-significant S^2_{di} significant		G×E present b_i & S^2_{di} significant	
	Parents	F ₁	Parents	F ₁	Parents	F ₁	Parents	F ₁
Germination (%)	10	38	0	0	0	7	0	0
Rate of emergence	10	44	0	0	0	1	0	0
No. of leaves/ seedling	10	42	0	0	0	3	0	0
Seedling height (cm)	10	45	0	0	0	0	0	0
Fresh weight (g) /seedling	2	11	0	1	8	33	0	0
Dry weight (g) /seedling	3	13	0	2	7	24	0	6
Panicle emergence (days)	8	45	0	0	2	0	0	0
Effective tillers/plant	9	40	0	0	1	5	0	0
Plant height (cm)	10	40	0	0	0	5	0	0
Ear length (cm)	9	35	1	10	0	0	0	0
Ear weight (g)/plant	10	33	0	2	0	10	0	0
Dry fodder yield (g)/plant	10	39	0	0	0	6	0	0
Grain yield (g)/plant	10	25	0	1	0	16	0	3
Total biological yield (g)/plant	10	35	0	0	0	10	0	0

The simultaneous examination of three stability parameters namely $\bar{x}$, b_i and S^2_{di} revealed that F_1 hybrid H77/833-2 $\times$ 1305 was found stable for most of the character viz., emergence rate (ER), number of leaves/seedling, seedling height, panicle emergence, number of effective tillers/plant, ear length, ear weight (g)/plant, grain yield (g)/plant and total biological yield (g)/plant. The cross combination H77/29-2 $\times$ 1305 was stable for number of leaves/seedling, seedling height, number of effective tillers/plant, plant height, ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant. The cross H77/29-2 $\times$ Togo-II exhibited stability for germination (%), emergence rate (ER), seedling fresh weight (g), seedling dry weight (g), number of effective tillers/plant, ear length, ear weight (g)/plant and grain yield (g)/plant.

The cross combination 77/245 $\times$ 1305 was stable for emergence rate (ER), number of leaves/seedling, panicle emergence, number of effective tillers/plant, ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant.

The cross combination CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1) was stable for emergence rate (ER), panicle emergence, number of effective tillers/plant, ear length, ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant.

The cross combination 1305 $\times$ 99HS-18 was stable for germination (%), number of leaves/seedling, panicle emergence, plant

height, ear length, ear weight (g)/plant, dry fodder yield (g)/plant and grain yield (g)/plant.

This indicated that the stability of various component traits might be responsible for observed stability of genotypes for grain yield (Grafius, 1956; Luthra *et al.* 1979, Sharma, 2005 and Kumar, 2006). The F_1 hybrids studied in the present investigation in general did not exhibit uniform pattern of environmental response (Linear). This attribute appears to be specific for individual genotypes.

The simultaneous assessment of three stability parameters viz., $\bar{x}$, b_i and S^2_{di} revealed that cross combinations H77/833-2 $\times$ 1305, H77/29-2 $\times$ 1305, H77/29-2 $\times$ 96AC-93, H77/29-2 $\times$ Togo-II, H77/29-2 $\times$ 99HS-18, G73-107 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ 1305, 77/245 $\times$ 96AC-93, CVJ-2-5-3-1-3 $\times$ 1305, CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1), 1305 $\times$ 99HS-18 and Togo-II $\times$ 99HS-18 for grain yield; H77/833-2 $\times$ CVJ-2-5-3-1-3, H77/833-2 $\times$ Togo-II, H77/29-2 $\times$ 1305, G73-107 $\times$ 77/245, G73-107 $\times$ 1305, G73-107 $\times$ (77/371 $\times$ BSECT CP-1), G73-107 $\times$ 96AC-93, G73-107 $\times$ 99HS-18, 77/245 $\times$ 1305, 77/245 $\times$ 96AC-93, 77/245 $\times$ Togo-II, CVJ-2-5-3-1-3 $\times$ 1305, CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1), CVJ-2-5-3-1-3 $\times$ 96AC-93, CVJ-2-5-3-1-3 $\times$ Togo-II, CVJ-2-5-3-1-3 $\times$ 99HS-18, 1305 $\times$ (77/371 $\times$ BSECT CP-1), 1305 $\times$ Togo-II, 1305 $\times$ 99HS-18, (77/371 $\times$ BSECT CP-1) $\times$ Togo-II, 96AC-93 $\times$ Togo-II and Togo-II $\times$ 99HS-18 for dry fodder yield; H77/833-2 $\times$ CVJ-2-5-3-1-3, H77/833-2 $\times$ 1305, H77/833-2 $\times$ Togo-II, H77/29-2 $\times$ CVJ-2-5-3-1-3, H77/29-2 $\times$ Togo-II, G73-107 $\times$ 77/245, G73-107 $\times$

CVJ-2-5-3-1-3, G73-107 $\times$ 1305, G73-107 $\times$ 96AC-93, G73-107 $\times$ Togo-II, 77/245 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ Togo-II, CVJ-2-5-3-1-3 $\times$ 1305, CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1), CVJ-2-5-3-1-3 $\times$ 96AC-93, CVJ-2-5-3-1-3 $\times$ Togo-II, CVJ-2-5-3-1-3 $\times$ 99HS-18, 1305 $\times$ Togo-II, 1305 $\times$ 99HS-18, (77/371 $\times$ BSECT CP-1) $\times$ Togo-II, 96AC-93 $\times$ Togo-II and Togo-II $\times$ 99HS-18 for ear length exhibited high mean performance and were stable also; H77/833-2 $\times$ H77/29-2, H77/833-2 $\times$ CVJ-2-5-3-1-3, H77/833-2 $\times$ 1305, H77/833-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/833-2 $\times$ 96AC-93, H77/29-2 $\times$ (77/371 $\times$ BSECT CP-1), H77/29-2 $\times$ 96AC-93, G73-107 $\times$ CVJ-2-5-3-1-3, G73-107 $\times$ (77/371 $\times$ BSECT CP-1), G73-107 $\times$ 99HS-18, 77/245 $\times$ 1305, 77/245 $\times$ (77/371 $\times$ BSECT CP-1), 77/245 $\times$ 96AC-93, 77/245 $\times$ 99HS-18, CVJ-2-5-3-1-3 $\times$ 1305, CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1), CVJ-2-5-3-1-3 $\times$ 99HS-18, 1305 $\times$ (77/371 $\times$ BSECT CP-1), 1305 $\times$ 96AC-93, 1305 $\times$ 99HS-18 and (77/371 $\times$ BSECT CP-1) $\times$ 96AC-93 for early panicle emergence and were stable also.

The results clearly indicated that hybrids showing high and stable grain yield also exhibited either high, above average or below average response for a number of yield contributing traits. It can therefore be suggested that while making selection, attention should be paid to the phenotypic stability of the characters associated with grain yield and genotypes having average response for different characters could be used in identifying stable hybrids. More or less similar findings have been reported by earlier workers (Suryanvanshi

et al. 1991; Yadav *et al.*, 1997; Anarase *et al.*, 2000; Ramamoorthi *et al.*, 1996; Anarase *et al.*, 2002; Sharma, 2005 and Kumar, 2006).

Judging from the mean, linear regression and S^2_{di} estimates for grain yield, the hybrids H77/833-2 $\times$ 1305, H77/29-2 $\times$ 1305, H77/29-2 $\times$ 99HS-18, G73-107 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ CVJ-2-5-3-1-3, CVJ-2-5-3-1-3 $\times$ 1305 and CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1) had high mean performance and above average responsiveness with significant stability values and were thus, better suited to more favourable environments (Table 45). While, the hybrids H77/29-2 $\times$ 96AC-93, H77/29-2 $\times$ Togo-II, 77/245 $\times$ 1305, 77/245 $\times$ 96AC-93, 1305 $\times$ 99HS-18 and Togo-II $\times$ 99HS-18 showed high mean performance, below average responsiveness thus, suited to average environmental conditions. Phenotypic stability of grain yield and one or more contributing traits and hence could be considered as promising combinations but after evaluating them over the locations & years.

In this respect, ear length, ear weight and plant height could be important to study for stability as they showed greater association with yield in this experiment. The parent CVJ-2-5-3-1-3 was of particular value for its involvement in 4 of the seven stable hybrids in fertile environment. This parent was also tolerant to heat stress and was the best general combiner also. Another parent which could become the basis of further breeding programme were 1305 and H77/833-2. The parent H77/833-2 is also a good combiner and performer for heat tolerance and is also one of the parent of world's

Table 45: The hybrids with high grain yield mean and stable performance

Sr. no.	Hybrids
	<i>Above average response</i>
1	H77/833-2 $\times$ (77/371 $\times$ BSECT CP-1)
2	H77/29-2 $\times$ 1305
3	H77/29-2 $\times$ 99HS-18
4	G73-107 $\times$ CVJ-2-5-3-1-3
5	77/245 $\times$ CVJ-2-5-3-1-3
6	CVJ-2-5-3-1-3 $\times$ 1305
7	CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1)
	<i>Below average response</i>
8	H77/29-2 $\times$ 96AC-93
9	H77/29-2 $\times$ Togo-II
10	77/245 $\times$ 1305
11	77/245 $\times$ 96AC-93
12	1305 $\times$ 99HS-18
13	Togo-II $\times$ 99HS-18

earliest maturing hybrid HHB-67. The status of H77/833-2 in heat tolerance breeding is again authenticated in the present investigation. Conclusively, the present investigation give some reflection and hints for adoption of appropriate breeding strategy and screening methods for heat tolerance. The preponderance of dominance component for heat tolerance and other characters including grain yield suggested that hybrid breeding was most likely to succeed. There were, off course, indications for alternative approach for pedigree breeding for panicle emergence and ear length.

Another important conclusion related to adoption of screening method. It was realised that in a situation of large number of genotypes we may adopt laboratory screening technique such as MTS as it facilitates to work at any time. Where as SSTI or STI may be adopted for evaluation and testing of hybrids and varieties over the locations. It was also seen that heat tolerant hybrid e.g. H77/29-2 $\times$ 1305 could be obtained from the involvement of both the susceptible parents. It suggested that genes for heat tolerance are widely distributed in complex combinations. It further suggested that we can resort to direct testing of hybrids and varieties before the final release. It may be further stressed that method of SSTI should be preferred over STI for testing of varieties at least at final stage as this method would take care of under soil mortality (USM) of germinating seeds.

CHAPTER-V

SUMMARY AND CONCLUSIONS

The establishment of plant population depends mainly on satisfactory germination and seedling establishment. It is here the climatic-physical factor play the major role. The temperature is one of the key climatic factors and has profound effect on the growth and development of the pearl millet plant. The supra-optimal temperatures are known to be the most important cause of poor crop stands in farmers' field. It is particularly so in dry and semi-arid zones where the soil surface temperature rises up to 60°C or more. Such high temperature not only effects the germination but also the survival and development of seedlings after germination. The importance of breeding for adaptation to temperature stress is thus well realizable.

In the present investigation a set of 46 genotypes were put through a screening technique in the field during high temperature environment of May, 2004 in order to examine the thermo-tolerance response at seedling growth stage. It was further attempted to establish correlation of the thermo-tolerance to other seedling characters. A no drought condition was ensured by constant measurement of soil moisture. Soil surface temperatures were recorded. The effect of supra-optimal temperature was witnessed for

most characters in the stress environments as a deviation from the mean of the normal temperature.

The screening of the material for heat tolerance was done during May, 2004. Three methods of screening were employed.

- i) Seedling Thermo-tolerance Index (STI) - same as the thermo-tolerance index (TI) of Peacock *et al.* (1993).
- ii) Seed to Seedling Thermo-tolerance Index (SSTI) - extension of seedling thermo-tolerance index (STI) based on the pre and post emergence heat effect.
- iii) Membrane Thermo-Stability (MTS) - a laboratory technique based on membrane thermo-stability.

Ten genotypes namely, H77/833-2, H77/29-2, G73-107, 77/245, CVJ-2-5-3-1-3, 1305, (77/371× BSECT CP-1), 96AC-93, Togo-II and 99HS-18 were selected. They were crossed in diallel manner in the same season and same field. Among these ten parents, seven belonged to tolerant group and three parents belonged to the susceptible group based on STI.

The main experiment was a 10×10 diallel with three replications in three environments. Two of the environments of May and June 2005 represented high temperature regime. The third environment was rainy season environment in which the temperature was optimum for growth and development of pearl millet. The data related to one set of F_1 s and parents were analysed according to Hayman (1954) and Griffings (1956b) approach to draw information about the nature of genetic variance and inheritance of thermo-

tolerance and some other characters. The data was also analysed to study the genotype $\times$ environment interaction and responsiveness of the genotypes according to Freeman and Perkins (1971) model.

The range of index values is required to be classified in to the designate groups to attach values to the genotypes falling with in the group interval. Since the lower values of STI or SSTI are coming around 50, it would be safe to conclude that genotypes with index values up to 50 can be considered as susceptible to heat tolerance. In such situation only a quartile classification would be workable. However, some more data and some more experiments would be required to produce an index classification based on group intervals.

An important fact of commonality has emerged from the examination of mean values of STI, SSTI and MTS for top ten hybrids, respectively. Between STI and SSTI eight hybrids out of top ten were common. While including MTS, the number of common hybrids was seven. The same trend was witnessed during the screening of parents. Also in the analysis these three indices were highly correlated among themselves. The question would then arise as to why not to go in for laboratory tests like MTS which may screen a large number of genotypes and with all time ease. The question has to be answered in affirmative. Nonetheless the SSTI as a direct evidence of heat tolerance or seeds and seedlings would precede the MTS is an indirect test. Moreover, the MTS generally records higher values. Here also there is no consideration of pre-emergence heat effect. Looking to the advantages, disadvantages and effect of laboratory

technologies (here MTS) and field technologies (here SSTI). We may suggest that

- i) Membrane thermo-stability test (MTS) may be used when there are large number of genotypes such as germplasm and accessions.
- ii) The STI or SSTI may be used and must be used for evaluation of hybrids and varieties before they are released.

It may be concluded therefore, that SSTI is more dependable and desirable tool for screening and evaluating the genotypes for heat tolerance.

The correlations among the characters were calculated around heat tolerance indices STI and SSTI at two levels. One set of correlation was studied at the time of screening of the parents. These were limited to seedling characters only. The other set of correlation coefficients was calculated while evaluating the diallel progenies which also included the seedling characteristics and other morphological and agronomic characters.

It was observed that STI, SSTI and MTS recorded highest significant correlation among themselves. Here again the competence of all the three tests was established. The field based indices STI and SSTI showed significant correlation with other seedling traits e.g. emergence rate, height of seedling, number of leaves/seedling, fresh weight and dry weight/seedling. While evaluating the diallel progenies it was seen that the heat tolerance indices STI and SSTI were not showing any perceptible correlation with either the

developmental traits or the maturity characters. Since experiment proceeded without any stress after the establishment of seedling, the pearl millet plants show great resilience and recovery. Hence the early heat effects could have no impact on its later growth and development. The association of grain yield/plant and total biological yield was almost parallel with all the other traits. The most important character was dry fodder yield in both the cases. The other important characters were ear weight, ear length and plant height. The character of early vigour of seedling also contributed for good grain yield.

The association of heat tolerance was particular witnessed with character related to seedling growth. These characters which could be said to be related to the early vigour of seedling including the speed of germination could therefore be taken as indirect indicators of associated heat tolerance. The early vigour seedlings perhaps help the plants to escape the lethal effect of heat.

For the material at hand the analytical approaches of Hayman (1954) and Griffing (1956a) were considered appropriate and were thus utilized for the present study. It was revealed through the combining ability analysis that both additive (gca) and non-additive (sca) genetic variances played an important role in this material for most of the characters studied. The relative magnitudes of the respective variances, however, showed that the later was more important, particularly in case of characters such as seedling thermo-tolerance index (STI), seed to seedling thermo-tolerance index (SSTI), germination (%), emergence rate (ER), number of leaves/seedling,

seedling height, seedling fresh weight (g), seedling dry weight (g), number of effective tillers/plant, plant height, ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant indicating that non-additive genetic variance (dominance variance) was mainly responsible in the inheritance of these characters. It may be mentioned that the regression analysis of Hayman also showed the preponderance of over dominance for most of the characters which confirms that non-additive component of variance was more important. However, the reverse was true for panicle emergence and ear length where there was a preponderance of additive genetic advance. Here the pedigree breeding for these characters would expected to be more successful.

A consideration of the gca and sca effects might be of help in isolating suitable genotypes for more conventional breeding work. The gca analysis threw up some valuable parents. The parents (77/371 × BSECT CP-1) and 96AC-93 were of particular importance for showing favourable response to heat tolerance in both the environments. The parent CVJ-2-5-3-1-3 and H77/833-2 were also good general combiners for heat tolerance as well as some other characters. Togo-II was the parent which combined well for grain yield and also the heat tolerance.

The magnitude of sca effects, of course differed for specific crosses in different environments but the direction (+ve or -ve) generally remained the same. Ten cross combinations, namely, H77/833-2 × H77/29-2, H77/833-2 × 77/245, H77/833-2 × 96AC-93,

H77/29-2 $\times$ CVJ-2-5-3-1-3, H77/29-2 $\times$ 1305, G73-107 $\times$ 77/245, G73-107 $\times$ 1305, 1305 $\times$ 96AC-93, 1305 $\times$ 99HS-18 and (77/371 $\times$ BSECT CP-1) $\times$ Togo-II showed consistency for positive significant values for STI. Eight of the hybrids were common for both these indices.

The cross 1305 $\times$ 99HS-18 was the best specific combination with the cross H77/833-2 $\times$ 96AC-93 as close runner up. The best specific cross 1305 $\times$ 99HS-18 involves the one susceptible parent (1305). This parent also gave best specific cross for STI. It is a re-assertion of the fact the heat tolerant genes are also contributed by parents with poor performance per se. This indicates a complex nature of gene distribution and the control system for the trait. The contribution of positive genes by the poor performer has a special significance in plant breeding. We can expect the genes being disbursed in large germplasm and coming from any parent. This would also suggest that in absence of particular sources, the trait could be tested in hybrids as a qualifying standard.

Among the top hybrids selected on the basis of high sca for STI and SSTI seven cross combinations, namely, H77/833-2 $\times$ 96AC-93, 1305 $\times$ 96AC-93, (77/371 $\times$ BSECT CP-1) $\times$ Togo-II, H77/29-2 $\times$ CVJ-2-5-3-1-3, 1305 $\times$ 99HS-18, G73-107 $\times$ 77/245 and H77/833-2 $\times$ H77/29-2 were common. The ten hybrids were also selected for the grain yield / plant on the basis of high sca. The hybrid (77/371 $\times$ BSECT CP-1) $\times$ Togo-II was common among the top hybrids for STI

and SSTI as well as for grain yield. This hybrid was a tolerant × tolerant type.

Significant positive sca effects in all the three environments were exhibited by eleven cross combinations, namely, H77/833-2 × 1305, H77/833-2 × 99HS-18, H77/29-2 × 1305, H77/29-2 × 96AC-93, G73-107 × CVJ-2-5-3-1-3, G73-107 × 1305, G73-107 × Togo-II, 77/245 × CVJ-2-5-3-1-3, 77/245 × 96AC-93, CVJ-2-5-3-1-3 × (77/371 × BSECT CP-1) and 1305 × Togo-II. However, four crosses, namely, H77/833-2 × (77/371 × BSECT CP-1), H77/29-2 × Togo-II, 77/245 × 1305 and Togo-II × 99HS-18 in environment-I and II (stress environments), showed consistency for positive significant sca effects for grain yield (g)/plant.

The $\sigma^2_{gca} / \sigma^2_{sca}$ ratio was low for all the characters studied. The low ratio as well as the higher magnitude of dominance component of variance than additive variance would confirm that most characters were predominantly under the control of non-additive variance. This should facilitate the success of hybrid breeding by making use of the expected heterosis. The heterosis breeding has been the hallmark of genetic improvement of pearl millet for grain productivity and other traits. This result in this investigation suggest that hybrid breeding could probably hold true for thermo-tolerance too. However, the reverse was true for panicle emergence and ear length where there was a preponderance of additive genetic variance. Here the pedigree breeding for these two characters would expect to be more successful.

The analysis of $V_r - W_r$ graph indicated over dominance for emergence rate, number of leaves/seedling, seedling height (cm), fresh weight (g)/seedling, dry weight (g)/seedling, panicle emergence (days), number of effective tillers/plant, plant height (cm), ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant. Partial dominance was observed for seedling thermo-tolerance index and ear length (cm). The epistasis was found to be absent for emergence rate, seedling thermo-tolerance index, seed to seedling thermo-tolerance index, ear length (cm), seedling height (cm) and plant height (cm).

The parents 3, 5 (G73-107 and CVJ-2-5-3-1-3) appeared to have an excess of dominant genes for seedling thermo-tolerance index (STI) while, the parents 1, 6 (H77/833-2 and 1305) had maximum of recessive genes. The array points 10, 5 (99HS-18 and CVJ-2-5-3-1-3) appeared to possess maximum number of dominant genes for seed to seedling thermo-tolerance index (SSTI). The parents 1, 6 (H77/833-2 and 1305) possessed relatively more number of recessive genes. The rest of the parents indicated to have almost equal proportion of dominant and recessive genes in them.

The additive effect (D) had a significant presence for STI and SSTI in both the stress environments. At the same time the dominance component of variance (H_1) for these characters was not only significant but also in higher magnitude. This effect of over dominance was also reflected by higher degree of overall dominance effect (h^2) for both these characters. The covariance between D and

H_1 showed a symmetrical distribution of dominant and recessive alleles for SSTI which was however shown to be asymmetrical for STI due to its significant mean squares. The proportion of dominant genes was also higher over the recessive genes in parents for both STI and SSTI. It was also seen that proportion of dominant genes with positive effect was higher than those with negative effects in control of STI and SSTI. Only one dominant gene appears to be responsible for expression of STI and SSTI. For other characters too the magnitude of H_1 was higher than that of D in all the environments. This indicated the preponderance of non-additive gene effects in the inheritance of these characters. Such a phenomenon was also found in combining ability analysis

The h^2 component, which reflects net dominance of genes (as the algebraic sum over all the loci in the heterozygous phase in all the crosses), was significant for germination, emergence rate, number of leaves/seedling, seedling height (cm), fresh weight (g)/seedling, dry weight (g)/seedling, panicle emergence (days), number of effective tillers/plant, plant height (cm), ear length (cm), ear weight (g)/plant, dry fodder yield (g)/plant, grain yield (g)/plant and total biological yield (g)/plant in all the three environments, while, for the remaining characters and environments it was non-significant.

The inter relationship of the H_1 and H_2 parameters is reflected in the allied genetic parameter $H_2/4H_1$ index that estimates the proportion of genes with positive/negative effects, showing dominance in the parents. The value of this index was less than the

expected values of 0.25 for all the characters in all the three environments. This indicated that distribution of dominant genes having positive and negative effects in parents was generally assymetrical.

The ratio h^2/H_2 denotes the number of gene groups exhibiting dominance. The number of gene groups in control of dominance expression ranged from 1 to 5 for different characters. The heat tolerance was seen to be in the simplest control of one gene group. This would further strengthen our view that hybrid breeding for heat tolerance could be feasible and possible. Few other characters such as grain yield, total biological yield, plant height and ear length showed a complex control of 4 or 5 gene groups.

Maximum level of production and stability of yield are the two desired features in a commercial variety. Indeed, development of varieties showing wide adaptability has received increasing attention in recent years. Stability analysis was carried out based on Freeman and Perkins (1971) model for 14 characters. The stability analysis could not be conducted for seedling thermo-tolerance index (STI) and seed to seedling thermo-tolerance index (SSTI) for the precise reason that variation in values of these indices were available only in two environments making the data inadequate for analysis based on above model. As a matter of fact the seedling mortality during third environment i.e. the monsoon period was practically nil (zero) and it had to be excluded.

Judging from the mean, linear regression and S^2_{di} estimates for grain yield, the hybrids H77/833-2 $\times$ 1305, H77/29-2 $\times$ 1305, H77/29-2 $\times$ 99HS-18, G73-107 $\times$ CVJ-2-5-3-1-3, 77/245 $\times$ CVJ-2-5-3-1-3, CVJ-2-5-3-1-3 $\times$ 1305 and CVJ-2-5-3-1-3 $\times$ (77/371 $\times$ BSECT CP-1) had high mean performance and above average responsiveness with stable performance and were thus, better suited to more favourable environments. While, the hybrids H77/29-2 $\times$ 96AC-93, H77/29-2 $\times$ Togo-II, 77/245 $\times$ 1305, 77/245 $\times$ 96AC-93, 1305 $\times$ 99HS-18 and Togo-II $\times$ 99HS-18 showed high mean performance, below average responsiveness thus, suited to low input environmental conditions. Phenotypic stability of grain yield and one or more contributing traits could be considered as promising combinations but after evaluating them over the locations and years.

In this respect, ear length, ear weight and plant height could be important to study for stability as they showed greater association with yield in this experiment. The parent CVJ-2-5-3-1-3 was of particular value for its involvement in 4 of the seven stable hybrids in fertile environment. This parent was also tolerant to heat stress and was the best general combiner also. Another parents which could become the basis of further breeding programme were 1305 and H77/833-2. The parent H77/833-2 is also a good combiner and performer for heat tolerance and is also one of the parents of world's earliest maturing hybrid HHB-67. The status of H77/833-2 in heat tolerance breeding is again authenticated in the present investigation.

Conclusively, the present investigation give some reflection and hints for adoption of appropriate breeding strategy and screening methods for heat tolerance. The preponderance of dominance component for heat tolerance and other characters including grain yield suggested that hybrid breeding was most likely to succeed. There were, off course, indications for alternative approach for pedigree breeding for panicle emergence and ear length. Another important conclusion related to adoption of screening method. It was realised that in a situation of large number of genotypes we may adopt laboratory screening technique such as MTS as it facilitates to work at any time. Where as SSTI or STI may be adopted for evaluation and testing of hybrids and varieties over the locations. It was also seen that heat tolerant hybrid e.g. H77/29-2 $\times$ 1305 could be obtained from the involvement of both the susceptible parents. It was suggested that genes for heat tolerance are widely distributed in complex combinations. It further suggested that we can resort to direct testing of hybrids and varieties before the final release. It may be further stressed that method of SSTI should be preferred over STI for testing of varieties at least at final stage as this method would take care of under soil mortality (USM) of germinating seeds.

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ABSTRACT

Title of thesis	: Screening and inheritance studies under supra-optimal temperature conditions at seedling stage in pearl millet (<i>Pennisetum glaucum</i> (L.) R. Br.)
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This investigation was carried out at Hisar during 2004 and 2005, in two sets of experiments. One set was related to screening of the genotypes for heat tolerance and the other was related to study the genetic aspects. A set of 46 genotypes were put through a screening technique in the field during high temperature environment of May, 2004 in order to examine the thermo-tolerance response at seedling growth stage. It was further attempted to establish correlation of the thermo-tolerance to other seedling characters.

Three methods of screening were employed i) Seedling Thermo-tolerance Index (STI)- same as the thermo-tolerance index (TI) of Peacock *et al.* (1993). ii) Seed to Seedling Thermo-tolerance Index (SSTI)- an extension of STI based on the pre and post emergence heat effect. iii) Membrane Thermo-Stability (MTS)- a laboratory technique. Ten genotypes namely, H77/833-2, H77/29-2, G73-107, 77/245, CVJ-2-5-3-1-3, 1305, (77/371× BSECT CP-1), 96AC-93, Togo-II and 99HS-18 were selected. Among these ten parents, seven belonged to tolerant group and three parents belonged to the susceptible group based on STI. They were then crossed in diallel manner in the same season and same field.

The main experiment was a 10×10 diallel with three replications in three environments. Two of the environments of May and June 2005 represented high temperature regime. The third environment was rainy season environment in which the temperature was optimum for growth and development of pearl millet. The data related to one set of F_1 s and parents were analysed according to Hayman (1954) and Griffings (1956a) approach to draw information about the nature of genetic variance and inheritance of thermo-tolerance and some other characters. The data was also analysed to study the genotype×environment interaction and responsiveness of the genotypes (Freeman and Perkins (1971 model).

An important fact of commonality emerged from the examination of mean values of STI, SSTI and MTS for top ten hybrids. Seven hybrids were common for each method. Such commonality was also witnessed among parents. The SSTI was particularly important in situation of low germination. It produced a more stringent and rigorous selection. It was an improved index over STI and was hence more dependable and desirable tool for screening in certain situations.

It was observed that STI, SSTI and MTS recorded highest significant correlation among themselves. The field based indices STI and SSTI showed significant correlation with other seedling traits also eg. emergence rate, seedling height, number of leaves/seedling, fresh weight and dry weight/seedling. Such an association was, however, not existing in case of maturity traits. It was perhaps due to extra-ordinary resilience in this crop plant. Two hybrids, namely, (77/371×BSECT CP-

1)×Togo-II and H77/29-2×1305 were of special importance as they were heat tolerant as well as high yielders.

In the stability analysis the hybrids, H77/833-2×1305, H77/29-2×1305, H77/29-2×99HS-18, G73-107×CVJ-2-5-3-1-3, 77/245×CVJ-2-5-3-1-3, CVJ-2-5-3-1-3×1305 and CVJ-2-5-3-1-3×(77/371×BSECT CP-1) were better suited to favourable environments while, the hybrids H77/29-2×96AC-93, H77/29-2×Togo-II, 77/245×1305, 77/245×96AC-93, 1305×99HS-18 and Togo-II×99HS-18 were suited to low input environments.

The parent CVJ-2-5-3-1-3 was of particular value for its involvement in 4 of the seven stable hybrids in fertile environment. This parent was also tolerant to heat stress and also the best general combiner. Another parents which could become the basis of further breeding programme were 1305 and H77/833-2. The parent H77/833-2 is also a good combiner and performer for heat tolerance and is also one of the parents of world's earliest maturing hybrid HHB-67. The status of H77/833-2 in heat tolerance breeding is again authenticated in the present investigation.

Conclusively, the present investigation gave some reflection and hints for adoption of appropriate breeding strategy and screening methods for heat tolerance. The preponderance of dominance component for heat tolerance and other characters including grain yield suggested that hybrid breeding was most likely to succeed. There were, ofcourse, indications for alternative approach of pedigree breeding for panicle emergence and ear length. Another important conclusion related to adoption of screening method. It was realized that in a situation of large number of genotypes we may adopt laboratory screening technique such as MTS whereas the SSTI or STI may be adopted for evaluation and testing of hybrids and varieties over the locations. It was also seen that heat tolerant hybrid e.g. H77/29-2 × 1305 could be obtained from the involvement of both the susceptible parents. It suggested that genes for heat tolerance are widely distributed in complex combinations. It further suggested that we can resort to direct testing of hybrids and varieties before the final release. It may be underlined that method of SSTI should be preferred over STI for testing of varieties at least at final stage as this method would take care of under soil mortality (USM) of germinating seeds.

Keywords: Heat tolerance, STI, SSTI, Membrane thermo stability, Combining ability, Stability, Pearl millet

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SIGNATURE OF STUDENT

HEAD OF THE DEPARTMENT