EVALUATION OF MAIZE (*Zea mays* L.) INBRED LINES AND HYBRIDS FOR HEAT TOLERANCE

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CERTIFICATE

This is to certify that the thesis entitled **“EVALUATION OF MAIZE (*Zea mays* L.) INBRED LINES AND HYBRIDS FOR HEAT TOLERANCE"** submitted by **Mr. SHRISHAIL ANGADI**, for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **GENETICS AND PLANT BREEDING,** to the University of Agricultural Sciences, Raichur is a record of research work done by him during the period of his study in this university under my guidance and the thesis has not previously formed the basis for the award of any degree, diploma, associate ship, fellowship or other similar titles.

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(AMAREGOUDA. A)

AFECTIONATELY DEDICATED

TO

MY BELOVED PARENTS,
SMT. SHARADA & SRI. PAKIRAPPA
BROTHERS AND SISTERS

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RAICHUR
DECEMBER, 2014 ***(SHRISHAIL ANGADI)***

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LIST OF ABBREVIATIONS

Anon	:	Anonymous
ANOVA	:	Analysis of Variance
ASI	:	Anthesi silking interval
bhm	:	Brown husk maturity
CD (P=0.01%)	:	Critical Difference at 1 per cent level
CD (P=0.05%)	:	Critical Difference at 5 per cent level
cm	:	Centimeter
DAS	:	Days after sowing
EDPSD	:	End of pollen shed duration.
et al.	:	And other people
Fig.	:	Figure
gm	:	Gram
ha	:	Hectare
i.e.	:	That is
kg ha^{-1}	:	Kilogram per hectare
mm	:	Mili meter
mha	:	Million hectare
mt	:	Million tone
No. /no.	:	Number
NDVI	:	Normalized difference vegetative index.
SD	:	Standard Deviation
viz.,	:	Namely
%	:	Per cent
/	:	per

Introduction

I. INTRODUCTION

Maize (*Zea mays* L.) is one of the important food crops and ranks third next to wheat and paddy in production in the world. It is grown in diverse conditions ranging from 580^{O} N to 400^{O} S, from below sea level to altitudes higher than 3000 meters and in areas with 250 mm to more than 5000 mm rainfall per year. Most of the crop is grown in the warmer parts of temperate regions and in humid subtropical climate. The greatest production is in area having the warmest month isotherms from 21 to 27 ^{o}C and a frost free season of 120 to 180 days duration.

India ranks 4th in maize production in the world with 21.57 million tones and grown on an area of 8.71 million hectares with a productivity of 2507 kg ha^{-1} Karnataka is one of the important maize producing states in the country with a total area of 1.34 million hectares with a production of 4.0 million tonnes with a productivity of 3188 kg ha^{-1} (Anon., 2012).

Maize is now considered as an industrial crop because of its multiple uses. The kernel contains about 77% starch, 2% sugar, 9% protein, 2% ash on a water free basis, and 5% oil. Maize oil contains the highest poly unsaturated fatty acid (PUFA), linoleic acid (61.9%) and hence the oil is helpful in combating heart diseases. Maize oil is also low in linolenic acid (0.7%) and contains a high level of natural flavor. Maize is used primarily as a food for humans in most areas of the world, in contrast to the United States, where about 85% of the crop is used as cattle feed. Where as in India, major portion of the maize production is utilized for human consumption (35%), cattle feed (25%), poultry feed (25%) and industrial uses (15%).

Maize is highly productive under optimal environmental and crop management conditions. But it is very susceptible to drought and heat. Each year, an average of 15 to 20 per cent of the potential world maize production is lost due to these stresses (FAO STAT 2006-2008). The total yield loss depends on when the stress occurs (plant growth stage), as well as the duration and the severity of the stress.

Global climate changes have led to increased temperatures and increased frequency of droughts in some parts of the globe and floods in some other parts of the globe. High temperature stress at critical developmental stages of maize plants causes significant yield loss. Plants become susceptible to high temperature after reaching eight-leaf stage (Chen *et al.*, 2010)**.** It has been estimated that 2^{o}C increase in temperature above 30^{o}C reduces the maize yields by 13 per cent as compared to 20 per cent intra seasonal variation in the rainfall, which reduces the maize yields by 4.5 per cent (Lobell *et al.*, 2011).

The degree of damage to the crop depends upon the intensity and duration of the heat spell. High temperature and heat waves especially coupled with low relative humidity can cause more damage to growing corn plant, pollination, seed set and yield. The situation may further be aggravated under drought condition. Warmer temperatures (especially at night) during grain filling results in less photosynthate conversion to plant carbohydrates (dry matter). During warm nights, the plant burns up excessive amounts of photosynthate through dark/light respiration and evolves carbon dioxide back to the atmosphere. This loss of potential plant carbohydrate leads to its lesser availablity to fill the ear.

Extremely high temperature causes permanent tissue injury to developing leaves and the injured tissues dry out quickly, a phenomenon called leaf firing. It can also cause desiccation of tassel tissues, a phenomenon called tassel blasting. Plants with severe leaf firing and tassel blasting lose considerable photosynthetic leaf area, produce small ears, and show reduced kernel set and kernel weight. Moderate heat stress occurring at early reproductive stages reduces pollen production, pollination rate, kernel set, and kernel weight, resulting in significant yield loss (Shaw 1983).

In north-eastern Karnataka, Upper Krishna Project (UKP) and Tungabhadra Project (TBP) are major command areas with 6.5 and 3.62 lakh hectares of irrigated area, respectively. Rice-Rice, Cotton-fallow, Red gram-fallow and Chilli-fallow are important cropping systems in these command areas. Rice-Rice is unsustainable and there is uncertainty of water for the second rice crop in these command areas. Similar situation exists in coastal Andhra Pradesh, where rice-maize is picking up and lot of maize is coming under zero till practices. However, when the sowings are delayed due to non-vacation of the *kharif* rice crop, the maize yields are drastically reduced because of unfavourable high temperature during March-April.

In order to promote Maize after rice in TBP and UKP Commands, there is a need to develop or identify hybrids that tolerate to high temperature during flowering and post flowering periods.

Therefore, an attempt was made in the present study to evaluate commercial hybrids and newly developed inbred lines for heat tolerance with the following objectives.

1. Screening of inbred lines and hybrids for heat stress tolerance and
2. To study the association of grain yield with morpho-physiological traits under heat stress condition.

Review of Literature

II. REVIEW OF LITERATURE

Global climate changes have led to increased temperatures and increased frequency of droughts in some parts of the globe and floods in some other parts of the globe. It has been estimated that 2 ^{o}C increases in temperature above 30 ^{o}C reduces the maize yields by 13% as compared to 20% intra seasonal variation in the rainfall, which reduces the maize yields by 4.5%. Further, every degree increase in day temperature above 30 ^{o}C would decrease yield by 1% in optimum conditions and 1.7% in drought conditions (Lobell *et al.*, 2011).

The relevant available information is presented in the following specific sections as indicated below.

2.1 Effect of climate change on maize

2.2 Effect of heat stress on morphological traits of maize

2.3 Effect of heat stress on physiological traits of maize

2.4 Screening of inbred lines and hybrids for heat stress tolerance

2.5 Association of grain yield with morpho-physiological traits under heat stress

2.6 Genetics of heat tolerance in maize

2.1 Effect of climate change on maize

Liverman and Brien (1991) predicted that if there was increase of 3.0 to 4.5°C in mean temperature it could lead to changes in rainfall of –10 to 30% and it could reduce the crop yield by 10 to 30% in Latin America.

Jones *et al*. (1999) reported that global mean temperature would rise 0.3 °C per decade reaching to approximately 1 and 3 °C above the present value by years 2025 and 2100, respectively and leading to global warming altering geographical distribution and growing season of agricultural crops.

Jane *et al.* (2000) reported that the individual crop growth processes were affected differently by climate change and also seasonal rise in temperature would increase the developmental rate of the crop, resulting in an earlier harvest with negative effects on crop production.

Lobell and Burke (2010) suggested that an increase in mean temperature of 2 °C would result in a greater reduction in maize yields within sub Saharan Africa than a decrease in precipitation by 20%.

Lobell *et al.* (2011) with the analysis of more than 20,000 historical maize trial yields in Africa over eight year period combined with weather data showed that every degree day above 30 °C, grain yield was reduced by 1 per cent and 1.7 per cent under optimal rainfed and drought conditions, respectively.

Meng *et al*. (2011) reported that average maize yield in the west and central regions of China is projected to decrease 15 per cent or more by 2050 as predicted by 90 per cent of 120 projected scenarios, due to climate change.

Jerry *et al.* (2012) assessed the impacts of climate change on the yield of eight major crops in Africa and South Asia using a systematic review and meta-analysis of data in 52 original publications from an initial screen of 1144 studies. They showed that projected mean change in yield of all crops was 8% by the 2050 in both regions. Across Africa, mean yield changes would be 17% (wheat), 5% (maize), 15% (sorghum) and 10% (millet) while across South Asia 16% and 11% for maize and sorghum respectively.

2.2 Effect of heat stress on morphological traits of maize

Walker (1969) noted that maize seedling growth was accelerated at a high soil temperature of 26°C and above this temperature, root and shoot mass both decreased by 10 per cent per degree Celsius, until at 35°C at which growth was severely retarded.

Cross and Zuber (1972) revealed the actual number of calendar days required to reach particular phonological stage in the corn life cycle can vary widely from season to season and the rate of corn crop development is highly dependent on temperature. Corn growth proceeds at a slow rate beginning at approximately 10°C and increases at a near-linear rate until temperatures approach 30°C.

Tollenaar and Daynard (1978) observed the pattern of leaf senescence among ten adapted dent corn hybrids and attributed a faster rate of leaf senescence to a warmer, drier weather pattern during the grain fill period that accelerated the rate of grain filling.

In corn, pollen viability is reduced accordingly with progressive rise in environmental temperature Herrero and Johonson (1980). Calorimetric properties of dehydrating pollen were described by Buitink *et al.*, 1996. They analyzed the desiccation tolerant and intolerant species of corn using differential scanning calorimetry technique. It was concluded that although no major differences in the physical behaviour of water could be distinguished between desiccation tolerant and intolerant pollen, the physiological response to the loss of water differed between the two pollen types.

Badu-Aprak-u *et al.* (1983) reported that high temperature reduced whole plant dry matter accumulation during grain filling. The reduction in dry matter accumulation was primarily related to a reduction in the period of time from 18 days after silking until 100 per cent leaf senescence and to a limited extent to a lower rate of whole plant dry matter production. Grain yield per plant was also lower under higher temperature.

The heat stress results in detrimental effects on plant growth and events involved in the growth and development of reproductive organs, such as tassel initiation, time of flowering, pollination, fertilization, and pollen sterility in maize Warrington and Kanemasu (1983).

Kiniry and Ritchie (1985) reported that high temperature can also cause kernel abortion, especially 10 days after pollination, as abortion commences early in kernel development before 12 days after pollination, at about the same period normal kernels undergo endosperm cell division and kernel enlargement begins.

Thompson (1986) reported the average temperature during the grain-filling period of maize in the U.S. Corn Belt is above optimum (22.5°C) for maximum dry matter accumulation in kernels, resulting in early senescence of active leaves and reduction in grain yield.

Dupuis and Dumas (1990) found that maize fertilization rate was highly reduced when pollinated spikelets are exposed to temperatures above 36°C.

Muchow *et al.* (1990) studied the effects of variation in solar radiation and temperature on grain yield. Temperature primarily affected the growth duration with lower temperature increasing the length of time that the crop could intercept radiation. The solar radiation response was related to the amount of incident radiation and to the fraction of radiation intercepted by the crop. In the tropics high temperature decreased the duration of growth and grain yield.

Selection of mature pollen grains by Lyakh and Soroka (1993) for heat resistance led to a marked increase in the drought resistance of the developing sporophyte. Selection for low temperature resistance of the micro gametophyte at the stage of pollen germination and pollen tube growth led to an appreciable increase in the cold resistance of the segregating populations obtained.

Morrison and Doug (1993) showed that high temperature resulted in lower fertility in maize due to reduced pollen viability and female fertility and poor pollination and fertilization. Heat stress may damage the ovary and reduce the number of fertilized ovules.

Bonhomme *et al*. (1994) reported that the time of silking for a particular hybrid depends heavily on in-season temperature. Time to silking can vary as much as 20 days for the same hybrid when average temperatures increases from 20°C to 32°C during the growing season.

Filippov *et al.* (1994) observed the effect of high temperature on growth processes and physiological or biochemical features of the metabolism in different maize genotypes. There was a reduction in weight of the above-ground organs, stem weight or root weight ratio, photosynthetic rate, enzyme activity and total metabolic rate.

Leipner *et al*. (1999) reported that high growth temperature reduced the total leaf area in maize. However, part-exotic cultivars were much more affected by high growth temperature. They concluded that photosynthesis-related traits are more chilling stable in Mexican highland material but reduction in fitness at high temperature is a major obstacle for fast integration in European breeding material.

Wilhelm *et al.* (1999) conducted the experiment in green house with seven inbred maize lines and observed that kernel dry weights reduced by an average of 7 per cent under 33.5/25°C (day/night) compared to the control temperature at 25/20°C (day/night).

Engelen-Eigles *et al.* (2000) reported that high temperature affects the maize endosperm cell cycle, the magnitude of endoreduplication and leads to reduced nucleic number and mature kernel mass. Because the maize endosperm makes up 70 to 90 per cent of kernel mass. High temperature suppresses the endosperm cell division and also greatly reduces the dry mass of kernels.

Bechoux *et al*. (2000) examined the effect of various environmental conditions on the initiation of tassel branches (NTB) and spikelet's pairs (NSP) in stress sensitive corn inbred F53. Chilling at the end of vegetative stage and at the start of reproductive stage resulted in decrease in both NTB and NSP. Oxidative stress produced by chilling aborted the tassel. High NTB and NSP values were reported at high temperature.

Karim *et al*. (2000) studied the effects of high temperature on seedling growth and photosynthesis of tropical corn genotypes. In six corn genotypes, high temperature caused a marked decrease in growth parameters. They concluded that leaf areas, daytime leaf expansion rate etc. were the good indicators of the thermo-tolerance of tropical corn genotypes at the seedling stage.

Carcova and Otegui (2001) found that an increase in ear temperature by 4-5°C during the kernel development leads to 73 per cent decrease in kernel number per ear.

Commuri and Jones (2001) showed that treating maize plants with a brief high temperature for five days after pollination reduced kernel dry weights from 40 per cent to 60 per cent *in vitro* and 79 per cent to 90 per cent under the field conditions.

Morrison and Stewart (2002) grouped the effects of heat stress on reproduction of maize crop into three areas as reduced flower number prior to anthesis, reduced flower fertility because of pollen sterility or ovary damage and a reduced capacity of the plant to support development of seed after fertilization.

Kakani *et al*. (2002) reported that a modified bilinear model which accurately described the response of per cent pollen germination and pollen tube length to temperature and identified maximum percentage pollen germination and pollen tube length of the genotypes under high temperature.

Carolino *et al.* (2003) concluded that the effect of seed-vigour on emergence depends on the type of environmental stress to which the seeds are exposed. The stress to which the grains were exposed demonstrated highest sensitivity varied with species and also high temperature stress was the one that most impaired the emergence of maize.

Reduction in grain yield per plant was noticed by Badu-Apraku *et al.* (2003) under higher temperature condition. The decreases in grain yield were almost entirely determined by shorter duration of grain filling. Under the highest temperature regime, assimilates remobilized from other plant parts was an indication that higher night temperature resulted an increased proportion of grain weight.

Ashraf and Hafeez (2004) revealed the thermo tolerance of maize at germination and vegetative stage. Final percentage of germinated seeds and rate of germination decreased due to high temperature (45°C). In the vegetative stage, high temperature (38/27°C) caused a significant reduction in shoot dry mass of maize. Overall, maize showed lower tolerance to high temperature.

Bannayan *et al.* (2004) reported that in maize cultivars increasing T-max up to 35°C at any given T-min enhanced biomass production for all cultivars, a further increase of T-max above 35°C had a negative impact on biomass. Increasing temperature also accelerated developmental rates for both anthesis and maturity.

The early maturing varieties exhibited higher chlorophyll content and grain yield compared to late mature varieties. Further, early maturing varieties showed lower values with regard to relative injury (RI), Leaf temperature (LT) and days to flowering than late maturing varieties. Correlation analysis revealed significant relations among the characteristics measured. It was concluded that early maturing varieties have lower LT and RI levels compared to late mature varieties could be recommended as second crop for the region with extremely high temperatures during the second crop season (Yalcaum *et al.,* 2011**).**

2.3 Effect of heat stress on physiological traits of maize

Daubenmire (1974) reported at many metabolic activities, *viz.,* respiration, photosynthesis, transpiration, activation of enzymes, formation of sexual organs were affected in maize by extreme high temperature. Exposure to temperature above optimal temperature during growth stage caused adverse effect on final yield, because plant could not maintain appropriate metabolism to keep normal development like photosynthesis, nutrient uptake, photorespiration, cell development, and so on.

Christiansen (1978) revealed that high temperature disrupts the movement of water, ion and organic solute across plant membranes, which interferes with photosynthesis and respiration.

Berry and Bjorkman (1980) reported that high temperatures were responsible for changes in physiochemical properties and its functional organization of the thylakoid membrane. Reduction of leaf photosynthetic capacity was considered to be the result of shortage of available for photosynthetic components, such as CO_2 due to stomata closure, H_2O vapour, and carboxylase enzymes activity and photosystem II (PS II) is the most heat-susceptible component of photosynthetic function in plant cells under heat stress.

Burker (1990) reported that chloroplast function was disrupted almost entirely by deactivation of PS II. Damage to PS II by the high temperatures was generally considered to be irreversible, although partial or full recovery of activity may occur with time. Thus, high temperatures can limit both the current and future photosynthetic capacity of a crop plant.

Howard and Watschke (1991) observed that high temperature affects the amount of total non structural carbohydrate but variable high temperature tolerance among cultivars is probably not related to differences in total or the levels of the non structural carbohydrates and sucrose is the principal form of translocated sugar in most plant species. Its synthesis is catalyzed by sucrose-phosphate synthase (SPS), and its degradation is catalyzed by sucrose synthase (SS) or invertase.

Soroka (1991) reported that generative and vegetative cell nuclei at high temperatures in lines showing contrasting response to heat stress, with the resistant lines showing no change or an increase in values for the traits studied relative to the control. While susceptible ones showed a marked decrease in values. Comparatively, the vegetative cell nucleus was more temperature sensitive than the generative cell nucleus.

Eleven enzymes were assayed for starch synthesis extracted from kernels exposed to a short-term (3 h) high temperature stress *in vitro*. The activity of soluble starch synthase (SSS) was reduced most by high temperature and reached a maximal rate at 25°C. Other enzymes (with the exception of branching enzyme) showed increased activity up to a temperature of 45°C. Reductions in the rate of SSS were similar to losses in the rate of starch synthesis caused by heat stress (Keeling *et al*., 1994).

When plants are exposed to high temperatures above the optimum, they will change cell membrane thermal stability that is positively associated with yield performance under heat stressed conditions (Reynolds *et al.*, 1994).

Singletary *et al.* (1994) studied 13 enzymes of sugar and starch metabolism in maize kernels grown *in vitro* and exposed to a range of chronic heat stresses to determine the mechanisms limiting starch synthesis in chronically heat-stressed maize kernels. The activities of ADP glucose pyrophosphorylase (AUPase) and SSS were reduced the most, and their activities were prematurely terminated compared with other enzymes.

Cheikh and Jones (1995) concluded from their study that the increase in ABA concentration later in the kernel development, in response to heat stress was very likely associated with accelerated kernel maturity and embryo dormancy of heat-stressed kernels and the decline in kernel ABA levels early in development of non stressed kernels.

Cheikh and Jones (1995a) found that stem infusion of cytokinins could greatly reduce kernel dry weight compared with control. Also the role of cytokinins in the acquisition of increased thermo tolerance was documented in a few plant systems.

Roy *et al*. (1995) conducted an experiment to determine the effect of pollination control on seed yield and of temperature on pollen viability of corn. Pollen viability decreased significantly with an increase in temperature but the duration of specific temperature did not show any significant effect.

Shmat-Ko and Zhuk (1998) reported that changes in the water and temperature regimes of maize reduced cell growth in the intercalary meristems of leaves with marked inhibition of cell proliferation, while high temperature disturbed the mitosis and post-mitotic processes. Increasing water deficit reduced the number of mitosis in the meristem cells.

According to Heckathorn *et al*. (1999) small heat shock proteins (HSPs) protect electron transport in chloroplasts and mitochondria during high temperature stress mostly *in vitro* condition. Thus, HSPs are involved in stress tolerance in this way. In some other cases small HSPs were found to be an important determinant of whole plant thermo-tolerance.

Commuri and Jones (2001) reported structural changes in maize endosperm resulting from exposure to high temperature during, cell division. Four days of high temperature treatment reduced kernel mass by 40 per cent and increased kernel absorption three-fold. The six days high temperature treatment resulted in 75 per cent reduction in kernel mass and 12 fold increase in kernel absorption.

Stone (2001) reported the acute high temperatures can cause an array of morphological, anatomical, physiological and biochemical changes within maize and the most significant factors associated with maize yield reduction include shortened life cycle, reduced light interception and increased sterility.

Todd *et al.* (2001) investigated the HSP101expression profile in developing maize. The HSP101 protein was most abundant in the developing tassel, ear, silks, endosperm, and embryo under heat stress condition.

Moriarity *et al.* (2002) reported the synthesis of increased amounts of chloroplast protein synthesis elongation factor (EF-Tu) under heat stress conditions in a heat-tolerant maize line.

Fu and Huang (2003) reported that shoot growth rate declined during heat stress, regardless of nutrient treatments. The activities of superoxide dismutase (SOD), catalase (CAT) and hydrogen peroxidase (POD) were suppressed, but the content of a lipid peroxidation product, malondialdehyde (MDA) was increased with heat stress.

Monjardino *et al.* (2005) observed that high temperature affects the endosperm development in maize and final grain yield. These effects are due to dry matter accumulation, interruption of cell division, aberrant sugar metabolism and starch biosynthesis in endosperm of kernels.

2.4 Screening of inbred lines and hybrids for heat stress tolerance

Evaluation of seedlings of six maize inbred lines of different temperature adaptations and the F1 progeny of 15 crosses was carried out by Herczgh and Marton (1986) in a growth chamber at 14, 22, 30 and 38 °C. They concluded that early field growth may be predicted from seedling traits within a group of genotypes adapted to different climates.

Giauffret and Derieux (1991) observed the rates of radical elongation in 13 maize genotypes at 18 temperatures from 6 to 40°C. Genetic variation for seedling growth at a different temperature was found. The inbred W64A exhibited the greatest mean rate of elongation at 6 and 10°C.

Ristic *et al*. (2004) identified a maize mutant with decreased capacity to synthesize and accumulate EF-Tu under heat stress and tested the ability of that mutant to tolerate heat stress. Importantly, chloroplast stromal proteins from the EF-Tu-deficient mutant displayed greater aggregation during exposure to high temperature than chloroplast stromal proteins from the wild type. They concluded that maize EF-Tu plays a role in the development of heat tolerance by acting as a molecular chaperone and protecting chloroplast stromal proteins from thermal aggregation.

Chen *et al.* (2012) evaluated a selection of maize inbred lines for drought and heat stress tolerance under field conditions and identified several inbred lines that showed high tolerance to drought. Tolerant inbred lines (Tx205, C2A554-4, and B76) were able to maintain relatively high leaf relative water content when subjected to drought stress, while sensitive lines (B73 and C273A) showed a rapid reduction in leaf relative water content at very early stage of drought. The tolerant lines also showed significantly greater ability to maintain vegetative growth and alleviate damage to reproductive tissues under drought conditions compared to the sensitive lines. They also evaluated hybrids, made from selected heat-tolerant and sensitive inbred lines. Heat-induced leaf firing and tassel blast phenotypes were observed in hybrids.

Nava *et al.* (2012) evaluated 28 accessions for the changes in agronomic characteristics affected by high temperatures in all growing seasons. Results indicated that in late planting dates, air temperatures become excessively high during the flowering period and growing season; in these conditions a loss in grain yield could be sustained.

Saleem *et al*. (2013) evaluated the 25 maize hybrids for heat tolerance and observed the all maize hybrids were significantly affected by high temperature stress but hybrids like YH-1898, KJ. Surabhi, FH-793 ND-6339 and NK -64017 showed reasonable tolerance against high temperature with higher grain yield production per unit area as compared to other maize hybrids.

Cairns *et al*. (2013) evaluated 300 maize inbred lines test crossed to CML539. Experiments were conducted under optimal conditions, reproductive stage drought stress, and heat stress and combined drought and heat stress. Lines with high levels of tolerance to drought and combined drought and heat stress were identified. Significant genotype x trial interaction and very large plot residuals were observed.

2.5 Association of grain yield with morpho-physiological traits under heat stress

Jiangping (2008) concluded that under heat stress yield per plant was negatively correlated with per cent leaf firing and days to flowering and positively correlated with chlorophyll fluorescence and number of tassel branches. Percent leaf firing was negatively correlated with chlorophyll fluorescence. Number of tassel branches was positively correlated with plant height and ear height. Leaf firing and chlorophyll fluorescence did not show strong correlation with plant height, ear height, number of tassel branches and leaves above ear.

Jewel *et al*. (2011) studied field component traits and reported that the largest genotypic variation related to heat stress response were recorded for grain yield, number of ears per plant, cob length and No of kernels per cob.

Muhammad *et al.* (2011) observed the strong relationships between grain yield with temperature stress among the hybrids and identified the FH- 810 hybrid for heat tolerant among 28 entries with 9320 kg/ha grain yield under maximum temperature stress 47.8°C.

Zahra (2012) explored the genetic variability in maize hybrids under heat stress condition. Thirty morphological traits of twenty eight hybrids were analysed in a randomized complete block design with three replications in 2010 at two planting dates, 6th July (to coincide heat stress with the pollination and grain filling periods) and 27th July (normal) in Shoushtar City in the Southern part of Iran. The results showed that the traits *viz.,* grain filling period, plant growth period, rows per ear and grains per ear in the both conditions showed positive and significant correlation with grain yield. Under heat stress condition, the highest coefficient of phenotypic variation was obtained for grain yield, grains per ear and grains per row.

2.6 Genetics of heat tolerance in maize

Rupinder Kaur and Saxena (2011) carried out the genetic analysis of heat tolerance traits in maize involving two spring environments. Their study revealed that both additive and dominance variance were significant for most of the heat tolerance traits (*viz.*, plant height, ear height, days to 50% anthesis, days to 50% silking, leaf firing , tassel blast, chlorophyll a & b, total chlorophyll content and membrane thermostability). Over dominance was observed for all the traits except proline content. Epistatic interactions were involved in leaf firing, shelling per cent and membrane thermostability only. Non additive gene action was predominant in the inheritance of majority of the heat tolerance traits.

Rupinder Kaur *et al*. (2010) reported from the combining ability analysis that the both additive and non additive gene action were involved in the inheritance of all the heat tolerance and yield contributing characters in the two environments like February (E1) and March (E2).

Material and Methods

III. MATERIAL AND METHODS

The present investigation was carried out during early summer (January-2014) and late summer (March 2014) at Agriculture College Farm, Bheemarayanagudi situated at 16°44' N latitude and 76°47' E longitude with an altitude of 458 m above mean sea level. The average rainfall received during the period of crop growth was 144.5 mm. The data on climatic parameters such as rainfall and minimum and maximum temperature recorded at Agricultural Research Station, Bheemarayanagudi during crop growth period are furnished in Appendix I.

3.1 Experimental material

Thirty two promising inbred lines and 11 hybrids were evaluated during early summer (January-sowing) and late summer (Mid March sowing). The details of inbreds and hybrids are given in Table 1.

3. 2 Field plot technique used

The experiment consisting of 43 genotypes (32 inbreds and 11 hybrids) was laid out in Restricted Randomized Block Design (RBD) at Agriculture College Farm Bheemarayanagudi. The hybrids were randomized and sown with three replications, while inbreds were sown in the same block but randomized separately with two replications. Each entry was grown at a spacing of 60 cm x 20 cm, in a plot size of one row of 4 m length.

After thorough land preparation, sowing was done by hand dibbling of seeds with two seeds per hill and later thinned to retain one seedling per hill. Then the plot was irrigated. The recommended dose of fertilizers (150 N, 75 P_2O_5 and 37.5 K_2O kg ha^{-1}) was given to the crop. The entire dose of P_2O_5, K_2O and one third of nitrogen was applied as basal dose and remaining two third nitrogen was top dressed in two equal splits at fourth and seventh week after planting. Weeding, irrigation, pesticide and other recommended cultural practices were followed to raise a healthy crop.

3.3 Recording of observations

3.3.1 Morphological parameters

The following morphological characters were recorded during various stages of crop growth.

Table 1. List of inbred lines and hybrids

Sl. No.	Inbred lines	Sl. No.	Inbred lines
1	CI-4	23	R-92
2	CM-111	24	R-95
3	CML-446	25	R-96
4	HS-2	26	R-134
5	HS-4	27	R-111
6	HS-7	28	YP-52
7	HS-15	29	YP-58
8	HS-17	30	YP-67
9	KDMI-15	31	YP-70
10	NEI-9202B	32	YP-75
11	NEI-9208B	**Sl. No.**	**Hybrids**
12	P-2	36	Arjun
13	P-16	37	CP-818
14	P-21	38	DKC-9135
15	P-24	39	DMH-117
16	P-25	40	GH-0727
17	P-26	41	GK-3059
18	P-28	42	GK-3140
19	P-40	43	NK-6240
20	P-41	44	MRM-3845
21	P-51	45	P-3441
22	R-84	46	900-M-G

Inbred lines that prefixed with P, R and YP are isolated from Parbhat, Renuka and Yellow Pool populations, respectively at College of Agriculture, Bheemarayanagudi and other inbred lines are obtained from Maize Breeder, ARS, Arabhavi; HS= Hyd Sel;

3.3.1.1 Days to 50 per cent anthesis

The number of days taken from sowing to pollen shedding in 50 per cent of the population in a plot.

3.3.1.2 Days to 50 per cent silking

The number of days taken from sowing to silk emergence in 50 per cent of the population in a plot.

3.3.1.3 Anthesis-silking interval (ASI)

This is calculated by subtracting the number of days taken for pollen shedding from the number of days taken to silk emergence.

ASI = Days to 50% silking - Days to 50% anthesis.

3.3.1.4 Leaf firing percentage

Leaf firing was obtained by the counting the number of plants that showed leaf firing symptoms (younger leaves near tassel burnt or dried) in the total number of plants in a particular plot. Then the value was expressed in percentage. Leaf firing percentage was calculated by using following formula.

$$\text{Leaf firing (\%)} = \frac{\text{Number of plants with leaf firing symptom per plot}}{\text{Total number of plants per plot}} \text{ X } 100$$

3.3.1.5 Tassel blast percentage

Tassel blast was obtained by the counting the number of plants that showed tassel blast symptoms (tassel dried with partial or no pollen shedding) in the total number of plants in particular plot. Then the value was expressed in percentage. Tassel blast percentage was calculated by using fallowing formula.

$$\text{Tassel blast (\%)} = \frac{\text{Number of plants with tassel blast symptom per plot}}{\text{Total number of plants per plot}} \text{ X } 100$$

3.3.1.6 Days to 75 per cent brown husk maturity

It was recorded as number of days taken from planting to the day on which 75 per cent of plants showed drying and browning of first husk cover on the ear.

3.3.1.7 Plant height (cm)

The height of the plant was recorded at maturity from the base of plant to the tip of the tassel.

The Ear height was recorded at maturity from the base of the plant to the node bearing the uppermost cob.

3.4.1.9 Silk length

Silk length was measured from base to end of silk of the ear with help of a measuring scale after complete emergence of silk from ear.

3.4.1.10 Ear length (cm)

The ear length was measured from base to tip of the ear after harvesting the ear.

3.4.1.11 Ear girth (cm)

The ear girth was measured at maximum girth of the ear.

3.4.1.12 Number of kernels per cob

The number of kernels in an ear was counted.

3.4.1.13 Shelling percentage

The shelling percentage was computed as the ratio of kernel weight to weight of cob (grain weight + pith weight), then the value was expressed in percentage.

3.4.1.14 100 grain weight (g)

The weight of 100 randomly selected grains was recorded separately and expressed in grams.

3.4.1.15 Yield per plant (g)

The yield per plant (g) was calculated by dividing the grain yield per plot by total number of plants in the plot.

3.3.2 Physiological parameters

The following Physiological characters were recorded at 60 and 90 days after sowing (DAS).

3.3.2.1 Canopy temperature

The canopy temperature was recorded with the help of infrared thermometer at 60 and 90 DAS. The leaf temperature was recorded in degree Celsius (ºC). It was focused on the canopy targeted by holding gun pistol-grip at an angle of 45° and at a distance of 0.5 to 1 m from canopy for taking observation.

3.3.2.2 Normalized Difference Vegetation Index (NDVI)

The ‘Green Seeker’ hand held optical sensor unit (Trimble Navigation Limited, CA, and USA) is a tool used for taking the NDVI values. The NDVI values of each genotype were recorded at 60 and 90 DAS. It is the “sensor” value displayed on the optical sensor. This indicates photosyntheticaly active radiation absorbed by plant and also healthiness of plant.

3.3.2.3 Chlorophyll a and Chlorophyll b estimation.

Chlorophyll was estimated following the standard procedure (Hiscox and Israelstam, 1979). The third fresh leaves from top of the plants were collected. A known fresh weight of leaf sample were cut in to small pieces and immersed in solution of acetone and dimethyl sulphoxid (DMSO) in 1:1 proportion for 24 hours, the solution was filtered through Whatmann No. 1 filter paper using suction filter and the extract was made up to a known volume. The absorbance of the extract was read at 647 and 664 nm using DMSO as blank in Systronic spectrophotometer-169 and chlorophyll was expressed as mg/g of fresh weight.

$$\text{Chl. a (mg/g)} = [12.7(OD663)-2.69(OD645)] \times V/1000 \times W$$

$$\text{Chl. b (mg/g)} = [22.9(OD645) - 4.68(OD663)] \times V/1000 \times W$$

$$\text{Total Chl. (mg/g)} = [20.2(OD645) + 8.02\ (OD663)] \times V/1000 \times W$$

Where

V = Volume of the acetone used in extract (ml)

W = Weight of fresh leaf tissue (g)

A645 = Absorbance of the extract at 645 nm

A663 = Absorbance of the extract at 663 nm

3.4 Statistical Analysis

3.4.1 Analysis of variance

Analysis of variance for individual characters was carried out on the basis of mean value per entry per replication as suggested by Panse and Sukhatme (1967) for randomized block design (RBD). Analysis was required to test whether the genotypes differed significantly among themselves or not.

Source	**Df**	**SS**	**MSS**	**F-ratio**
Treatments	(t-1)	TSS	Mt	Mt/E
Replication	(r-1)	RSS	Mr	Mr/E
Error	(r-1) (t-1)	ESS	E	

Where,

r = number of replications

t = number of genotypes

Significance of the treatments was tested at 5 and 1 per cent level of probability.

3.4.2 Estimation of genetic variability parameters

i) Phenotypic and genotypic variances

Phenotypic and genotypic components of variance were estimated by applying the formula suggested by Cochran and Cox (1957).

$$\text{Genotypic Variance } (\sigma^2_g) = \frac{\text{MSS due to genotypes (adj)} - \text{MSS due to error (intra block)}}{r}$$

Phenotypic variance (σ^2_p) = $\sigma^2_g + \sigma^2_e$ (MSS due to error)

ii) Phenotypic and genotypic co-efficient of variation

The co-efficient of variability both at phenotypic and genotypic levels for all the characters were computed by applying the formula suggested by Burton and

De Vane (1953).

Phenotypic coefficient of variation (PCV)

$$\text{PCV (\%)} = \frac{\text{Phenotypic standard deviation}}{\overline{X}} \times 100$$

Genotypic coefficient of variation (GCV)

$$\text{GCV (\%)} = \frac{\text{Genotypic standard deviation}}{\overline{X}} \times 100$$

Where, $\overline{X}$ = General mean

GCV and PCV were classified as low (0-10 %), moderate (10-20 %) and High (>20%) as suggested by Sivasubramanian and Menon (1979).

iii) Heritability (h^2)

Heritability in broad sense for all the characters was computed as suggested by Lush (1949).

$$h^2 = \frac{\sigma^2_g}{\sigma^2_p} \times 100$$

Where,

h^2 = Broad sense heritability

σ^2_g = Genotypic variance

σ^2_p = Phenotypic variance

Heritability was classified in to low (0-30 %), moderate (30-60 %) and high (>60 %) as suggested by Robinson *et al.* (1949).

iv) Genetic advance

Genetic advance for each character was predicted by the formula given by Johnson *et al.* (1955).

$$GA = h^2 \times \sigma_p \times K$$

The expected GA as per cent of mean (GA) was estimated as given below

$$\text{Expected genetic advance as a per cent of mean} = \frac{GA}{\bar{X}} \times 100$$

Where,

h^2 = Heritability (Broad sense)

σp = Phenotypic standard deviation

K = Standard selection differential (2.06)

GA = Genetic advance

$\bar{X}$ = General mean

The genetic advance as per cent of mean was categorized into low (0-10%), moderate (10-20%) and high (> 20%) as suggested by Johnson *et al.* (1955).

3.4.3 Correlation co-efficient analysis

To determine the degree of association of characters with yield and also among the yield components, the correlation coefficients were calculated. Both genotypic and phenotypic coefficients of correlation between two characters were determined by using variance and covariance components as suggested by Al-Jibouri *et al.* (1958).

$$r_g(xy) = \frac{Cov_g(xy)}{\sqrt{\sigma 2\, g(x) \times \sigma 2 g(y)}}, \qquad r_p(xy) = \frac{Cov_p(xy)}{\sqrt{\sigma 2\, p(x) \times \sigma 2\, p(y)}}$$

Where,

r_g (xy) = Genotypic correlation coefficient

r_p (xy) = Phenotypic correlation coefficient

Cov_g (xy) = Genotypic co-variances of xy

Cov_p (xy) = Phenotypic co-variances of xy.

The calculated value of 'r' was compared with table value with n-2 degrees of freedom at 5% and 1% level of significance.

3.4.4 Path coefficient analysis

Path coefficient is a standardized partial regression coefficient and as such it is a measure of direct and indirect effects of a set of variables (component characters) on dependent variable such as grain yield. Direct and indirect effects of component characters on grain yield were computed using appropriate correlation coefficient of different component characters as suggested by Wright (1921) and elaborated by Dewey and Lu (1959). Thus, the correlation coefficient of any character with grain yield was split into the direct and indirect effects adopting the standard formula.

$$r_{iy}= r_{li}P_1+ r_{2i}P_2 + rz_iP3 +\ldots\ldots\ldots + r_{ni}P_n + \ldots\ldots\ldots\ldots r_{ii}P_I$$

Where,

r_{iy} = Correlation of i^{th} character on grain yield

r_{i1} = Indirect effect of i^{th} character on grain yield through first character

$r_{ni}P_n$ = Correlation between n^{th} character and i^{th} character

n = Number of independent variables

P_i = Direct effect of i^{th} character on grain yield

Direct effects of component characters on grain yield were obtained by solving the following equations.

$r_{iy} = (P_{iy}) (r_{ij})$ which can also be rearranged as

$(P_i) = (r_{ij}) – 1 (r_{ij})$

The direct and indirect effects are rated as given below following the method of Lenka and Mishra (1973).

Negligible = 0.00 - 0.09; Low = 0.10 - 0.19; Moderate = 0.20 - 0.29;

High = 0.30 - 1.00; Very High = > 1.00.

Experimental Results

IV. EXPERIMENTAL RESULTS

The present investigation entitled ‘Evaluation of maize inbred lines and hybrids for heat stress tolerance’ was conducted during early summer (January-2014 sowing) and late summer (March-2014 sowing) to identify the heat stress tolerant inbred lines and hybrids and to study the association of grain yield with morpho-physiological traits under high temperature.

The field evaluation of genotypes under optimum temperature as well as heat stress conditions was done to screen the genotypes for heat tolerance. The material for comprised 32 inbred lines and 11 commercial hybrids. The results of the present investigation are presented in the following headings.

4.1 Analysis of variance for morpho-physiological and yield characters in inbreds and hybrids under optimum and heat stress conditions.

4.2 Performance of maize inbred lines and hybrids for morpho-physiological and yield characters under optimum and heat stress conditions.

4.3 Genetic components of variation for morpho-physiological and yield characters in inbred and hybrids under optimum and heat stress conditions.

4.4 Phenotypic and genotypic correlation coefficient between selected characters and grain yield in inbreds and hybrids under optimum and heat stress conditions.

4.5 Direct and indirect effects of selected characters on grain yield at phenotypic and genotypic level in inbreds and hybrids under optimum and heat stress conditions.

4.1 Analysis of variance for morpho-physiological and yield characters in inbreds and hybrids under optimum and heat stress condition

The ANOVA in respect of all the characters studied on inbreds and hybrids under optimum and heat stress situations are presented in Table 2 and 3.

It revealed that the variation due to genotype was significant for all the traits except ASI and canopy temperature under optimum and heat stress conditions, for inbred lines and hybrids respectively, indicating the presence of enough genotypic variation among the inbred lines and hybrids selected for the study.

Table 2. Analysis of variance for morpho-physiological and yield characters in inbreds under optimum and heat stress conditions

Characters/ df	**Mean Sum of Square (MSS)**					
	Optimum temperature			**Heat Stress**		
	Source of variation			**Source of variation**		
	Replications	**Genotype**	**Error**	**Replications**	**Genotype**	**Error**
Degrees of freedom	1	34	34	1	32	32
Days to 50% anthesis	185.65	13.21**	5.56	78.65	4.69*	2.57
Days to 50% silking	182.41	16.12**	6.85	58.14	4.59*	3.85
ASI	0.01	1.03	0.89	1.56	0.90	0.91
EPSD	128.92	15.05*	7.07	60.06	4.21*	4.09
75% BHM	0.35	7.04**	2.29	8.26	8.64*	5.39
Plant-height (cm)	134.41	1189.14**	42.73	489.51	967.72**	16.70
Ear height (cm)	300.35	437.56**	24.35	819.39	392.09**	9.51
Leaf firing %	0.35	136.26**	4.76	0.46	1326.46**	6.95
Tassel blast %	12.01	132.11**	10.42	0.26	1518.68**	6.84
Silk length (cm)	0.12	11.89**	2.04	39.06	8.70*	7.09
Cob length (cm)	9.65	6.53**	2.62	0.39	7.03**	2.00
Cob girth (cm)	5.15	3.95**	1.62	8.26	4.41**	1.36
NKC	2568.22	11843.4**	2028.9	1764	15241.30**	579.51
Shelling %	49.72	19.65**	4.19	5.832	46.77**	11.71
100 Grain weight (g)	0.05	6.50**	2.05	34.51	6.25**	1.90
Grain yield per plant (g)	128.92	196.06**	25.69	264.06	620.03**	28.32
Grain yield (kg ha^{-1})	261948.9	5921161.2**	117609.2	36288.00	1473146**	66640.0
Physiological parameters at 60 Days after sowing						
Chlorophyll a	0.37	0.05**	0.01	0.15	0.04**	0.007
Chlorophyll b	0.01	0.25**	0.01	0.19	0.17**	0.06
Total Chlorophyll	0.23	0.45**	0.03	0.002	0.269**	0.061
Canopy temperature	0.84	6.00*	1.54	2.02	1.44*	1.33
NDVI	0.058	0.008**	0.001	0.06	0.007*	0.004
Physiological parameters at 90 Days after sowing						
Chlorophyll a	0.002	0.014**	0.003	0.001	0.010**	0.004
Chlorophyll b	0.015	0.024**	0.09	0.003	0.030**	0.002
Total Chlorophyll	0.02	0.05**	0.01	0.002	0.072**	0.002
Canopy temperature	9.23	4.95*	3.22	0.32	3.35**	1.25
NDVI	0.050	0.010**	0.001	0.060	0.007**	0.004

* and ** - Significant at 0.05 and 0.01 level of probability, respectively; ASI: Anthesis to silking interval; EPSD: End of pollen shed duration; 75%BHM: Brown husk maturity; NDVI: Normalized difference vegetative index; NKC: Number of kernels per cob.

Table 3. Analysis of variance for morpho-physiological and yield characters in hybrids under optimum and heat stress conditions

Characters/ df	Mean Sum of Square (MSS)					
	Optimum temperature			Heat Stress		
	Source of variation			Source of variation		
	Replications	Genotype	Error	Replications	Genotype	Error
Degrees of freedom	2	11	22	2	10	20
Days to 50% anthesis	2.58	12.90*	5.58	4.48	9.00**	1.18
Days to 50% silking	0.58	14.73*	5.06	4.45	11.52**	1.32
ASI	0.75	1.28*	0.50	0.12	1.82**	0.38
EPSD	2.02	13.78*	6.36	6.57	10.18**	1.20
75% BHM	3.58	8.12*	4.82	6.75	23.09**	6.22
Plant-height (cm)	18.25	413.15**	14.97	132.03	267.63**	17.43
Ear height (cm)	36.11	158.71**	10.05	30.21	59.08**	4.51
Silk length	12.11	10.75*	3.59	27.63	6.47*	2.73
Ear length (cm)	12.86	15.54**	2.04	1.30	5.00*	2.06
Cob girth (cm)	1.00	4.06*	1.51	2.54	3.09*	1.34
NKC	7934.69	7834.51**	726.93	1856.39	11359.72**	1875.79
Shelling%	7.75	13.03**	3.14	0.16	23.71*	10.16
100 Grain weight (g)	4.52	20.77**	4.25	0.63	12.1**	1.90
Grain yield per plant (g)	75.00	292.91**	61.57	82.03	141.58*	84.09
Grain yield (kg ha^{-1})	276269.70	8560690.48**	192109.07	993650.30	8950732**	458933.59
Physiological parameters at 60 Days after sowing						
Chlorophyll a	0.006	8.98**	0.30	0.065	0.162**	0.041
Chlorophyll b	1.82	13.35**	0.58	0.009	0.145*	0.125
Total Chlorophyll	1.91	41.38**	0.95	0.025	0.32*	0.149
Canopy temperature	3.50	2.67	2.71	4.33	0.52	0.50
NDVI	0.0003	0.0010**	0.0003	0.0014	0.0019*	0.0014
Physiological parameters at 90 Days after sowing						
Chlorophyll a	0.011	0.300**	0.009	0.0009	0.019**	0.003
Chlorophyll b	0.155	1.180**	0.130	0.013	0.079**	0.017
Total Chlorophyll	0.21	2.65**	0.14	0.009	0.173**	0.030
Canopy temperature	1.78	1.20	1.33	16.67	2.25	1.10
NDVI	0.0002	0.0099**	0.0010	0.0012	0.0038**	0.0009

* and ** - Significant at 0.05 and 0.01 level of probability, respectively; ASI: Anthesis to silking interval; EPSD: End of pollen shed duration; 75%BHM: Brown husk maturity; NDVI: Normalized difference vegetative index; NKC: Number of kernels per cob.

4.2 Performance of maize inbred lines and hybrids for morpho-physiological and yield characters under optimum and heat stress situations

The relative performance of a genotype for heat related traits and in turn grain yield will give an idea of heat tolerance ability of the genotype. The performance of inbreds and commercial hybrids under optimum and heat stress are presented in Table 4 to 9.

4.2.1 Morphological characters

4.2.1.1 Days to 50% anthesis

The days to 50% anthesis for inbreds ranged from 60.50 (CI-4) to 67.50 days (R-92, R-95 and R-134) with an overall mean of 63.28 days under optimum conditions. Whereas, under heat stress conditions, it ranged from 50 (P-28, P-40, P-51, CML446, HS-4 and HS-7) to 56 days (R-84) with an overall mean of 52.51 days.

The anthesis for hybrids ranged from 62 (GH-0727) to 68.33 days (DMH 117) with an overall mean of 64.66 days under optimum condition. Whereas, under heat stress it ranged from 51 (DKC9135) to 57 days (MRM -3845) with an overall mean of 54.33 days.

4.2.1.2 Days to 50% silking

The range for silking in the inbreds was from 63.50 (YP-67) to 72 days (R-92) with an overall mean of 67.12 days, under optimum condition. Under heat stress, days to 50% silking ranged from 52.5 (HS-7) to 58 days (R-84) with an overall mean of 55.48.

The days to 50% silking range in hybrids was from 64.66 (Arjun) to 72 days (DMH-117) with an overall mean of 68.08 days, under optimum condition. However, under heat stress condition, silking ranged from 53.66 (DKC9135 and GH-0727) to 59.66 days (MRM 3845) with an overall mean of 56.72 days.

4.2.1.3 Anthesis to silking interval (ASI)

In inbreds ASI ranged from 2.5 (P-25, NEI-9208B) to 5 days (HS-17, CM-111) with an overall mean of 3.72 days under optimum condition. However, it ranged from 2 (P-25, R-84, and HS-15) to 4.5 days (R-92) with an overall mean of 2.96 days under heat stress situation.

Table 4. Performance of maize inbred lines for important morphological traits under optimum and heat stress conditions

Inbred lines	Days to 50% anthesis		Days to 50% silking		Anthesis to silking interval		End of pollen shed duration		75% Brown husk maturity	
	OC	HSC	OC	HSC	OC	HSC	OC	HSC	OC	HSC
CI-4	60.50	53.50	64.50	55.50	4.00	2.00	65.50	59.00	97.00	79.00
CM-111	62.00	51.00	67.50	55.00	5.00	4.00	69.50	56.50	96.50	85.00
CML-446	65.50	50.00	70.00	53.50	4.50	3.50	72.00	54.00	95.00	85.50
HS-2	66.00	53.00	71.00	56.00	5.00	3.50	72.00	57.00	95.00	80.00
HS-4	64.50	50.00	67.50	53.00	3.00	3.00	69.50	55.00	98.50	84.00
HS-7	59.00	50.00	62.50	52.50	3.50	2.50	64.00	54.50	92.00	79.50
HS-15	65.50	53.50	69.50	55.50	4.00	2.00	71.00	57.50	98.00	83.00
HS-17	65.00	55.00	70.00	58.00	5.00	3.00	71.00	57.50	97.00	81.00
KDMI-15	62.50	51.50	67.00	54.00	4.50	2.50	68.50	56.00	95.00	83.00
NEI-9202B	61.00	51.50	64.50	54.00	3.50	2.50	66.50	55.50	92.50	86.50
NEI-9208B	63.00	52.50	66.00	55.50	2.50	3.00	67.00	56.00	96.50	83.00
P-2	63.50	53.50	66.50	57.50	3.00	4.00	67.00	58.50	94.00	83.50
P-16	63.00	53.50	67.00	56.00	4.00	2.50	68.50	57.50	94.50	83.00
P-21	60.50	52.00	64.50	54.50	4.00	2.50	67.00	57.50	94.00	80.00
P-24	63.50	52.00	66.50	54.50	3.00	2.50	68.00	56.50	98.50	85.00
P-25	65.50	53.50	69.00	55.50	2.50	2.00	69.50	56.50	98.00	83.00
P-26	62.50	53.50	66.00	57.00	3.50	3.50	67.50	56.50	97.50	80.00
P-28	62.00	50.00	66.50	53.00	4.50	3.00	68.00	54.50	96.00	81.50
P-40	60.00	50.00	64.00	53.00	4.00	3.00	64.50	54.00	94.00	81.50
P-41	62.00	53.50	66.00	56.50	4.50	3.00	65.50	57.50	93.50	80.00
P-51	66.00	50.00	70.00	53.00	4.00	3.00	71.50	56.50	93.50	85.00
R-84	67.00	56.00	70.50	58.00	3.50	2.00	72.00	60.00	97.00	83.50
R-92	67.50	53.00	72.00	57.50	4.50	4.50	73.00	57.50	94.00	82.50
R-95	67.50	53.00	71.50	55.50	4.00	2.50	72.50	58.00	93.00	85.00
R-96	60.50	52.00	64.00	55.00	3.50	3.00	66.00	57.50	94.00	81.00
R-134	67.50	54.50	71.50	57.50	4.00	3.00	72.50	58.50	97.00	83.50
R-111	63.00	53.50	67.00	57.00	4.00	3.50	69.00	58.00	96.50	82.50
YP-52	65.50	53.50	70.00	56.00	4.50	2.50	71.00	57.50	96.50	84.00
YP-58	61.00	52.50	64.00	55.50	3.50	3.00	66.00	56.50	97.00	86.00
YP-67	60.50	52.50	63.50	55.00	3.00	2.50	65.00	56.50	97.00	84.00
YP-70	62.00	54.00	65.50	57.00	3.50	3.00	67.50	58.50	93.00	84.50
YP-75	65.50	51.50	69.50	54.00	4.00	2.50	71.00	55.50	95.00	79.00
LSD (0.05)	4.81	3.28	5.34	4.00	1.93	1.95	5.43	4.13	3.09	4.74
S.Em±	1.66	1.13	1.85	1.38	0.66	0.67	1.88	1.43	1.07	1.64
Mean	63.2	52.51	67.1	55.48	3.72	2.96	68.50	56.81	95.35	82.76

OC: Optimum condition; HSC: Heat stress condition.

Table 4. Contd…..

Inbred lines	Plant height (cm)		Ear height (cm)		Leaf firing (%)		Tassel blast (%)		Silk length (cm)	
	OC	HSC	OC	HSC	OC	HSC	OC	HSC	OC	HSC
CI-4	161.00	149.50	85.00	78.00	0.00 (2.86)	0.00 (2.865)	0.00 (2.865)	0.00 (2.865)	30.00	27.00
CM-111	160.50	144.00	85.50	76.00	0.00 (2.86)	0 .00(2.865)	0 .00(2.865)	0.000(2.865)	32.00	30.50
CML-446	132.50	116.00	74.00	58.00	0.00 (2.86)	24.69 (29.74)	0.00 (2.865)	26.11 (30.77)	25.50	27.00
HS-2	133.00	87.50	70.50	42.50	0 .00(2.86)	36.71 (37.26)	0.00 (2.865)	46.57 (43.01)	27.50	26.50
HS-4	173.00	140.50	104.00	60.50	0. 00(2.86)	57.15 (49.09)	0.00 (2.865)	58.57 (49.91)	27.50	25.00
HS-7	131.50	97.50	76.50	56.50	0 .00(2.86)	19.57(26.19)	0 .00(2.865)	26.46 (30.92)	30.00	29.50
HS-15	178.50	126.50	81.50	80.50	0.00 (2.86)	25.88 (30.54)	0.00 (2.865)	0 .00(2.865)	30.00	31.00
HS-17	138.50	97.00	81.00	39.00	0.00 (2.86)	0.00 (2.865)	0 .00(2.865)	52.67 (46.51)	32.50	29.50
KDMI-15	171.00	128.00	90.50	83.50	0 .00(2.86)	32.47 (34.70)	0 .00(2.865)	46.06 (42.72)	33.50	31.50
NEI-9202B	166.00	99.50	86.50	57.00	0 .00(2.86)	38.16 (38.13)	0 .00(2.865)	36.66 (37.23)	30.50	29.50
NEI-9208B	168.00	81.50	89.00	46.50	0 .00(2.86)	31.93 (34.38)	0.00 (2.865)	0.00 (2.865)	32.00	29.50
P-2	188.50	119.00	88.50	66.00	0.00 (2.86)	30.32 (33.38)	0.00 (2.865)	46.37 (42.89)	34.50	31.00
P-16	174.00	115.50	87.00	67.00	0 .00(2.86)	46.36 (42.89)	0 .00(2.865)	30.89 (33.73)	33.50	27.00
P-21	98.00	82.00	40.00	39.50	0.00 (2.86)	30.55 (33.52)	0.00 (2.865)	16.35 (23.80)	26.50	26.50
P-24	179.00	128.00	101.00	79.50	0.00 (2.86)	31.73 (34.25)	0 .00(2.865)	26.94 (31.24)	32.00	28.00
P-25	160.00	127.00	86.00	64.50	0.00 (2.86)	0 .00(2.865)	0.00 (2.865)	0.00 (2.865)	32.00	27.50
P-26	171.00	107.00	99.50	62.00	0 .00(2.86)	30.35 (33.38)	0.00 (2.865)	31.37 (34.04)	32.00	28.50
P-28	184.00	131.00	99.00	74.50	0 .00(2.86)	29.91 (33.13)	0 .00(2.865)	41.34 (39.98)	29.50	25.50
P-40	186.50	140.00	81.50	77.00	0.00 (2.86)	51.88 (46.06)	0 .00(2.865)	60.31 (50.93)	30.50	27.00
P-41	126.00	89.00	66.50	49.00	26.00 (30.54)	99.75 (87.09)	28.5 (31.57)	99.75 (87.09)	27.50	24.00
P-51	199.50	143.00	103.00	58.50	0 .00(2.86)	23.57 (29.02)	0.00 (2.865)	24.48 (29.64)	31.00	26.50
R-84	169.00	142.50	90.00	71.50	0.00 (2.86)	0.00 (2.865)	0.00 (2.865)	0.00 (2.865)	33.00	30.50
R-92	150.50	113.00	89.00	65.00	0.00 (2.86)	10.24 (18.57)	0.00 (2.865)	23.70 (29.65)	30.00	26.00
R-95	132.50	85.50	76.00	44.50	36.50 (40.61)	99.75 (87.09)	35.5 (39.21)	99.75 (87.09)	28.50	26.50
R-96	130.00	72.00	54.50	23.50	0 .00(2.86)	16.74 (24.12)	0.00 (2.865)	0.00 (2.865)	29.00	27.00
R-134	135.00	118.00	81.00	66.00	0.00 (2.86)	0.00 (2.865)	0 .00(2.865)	29.16 (32.65)	31.00	30.50
R-111	166.00	135.50	96.50	71.00	0.00 (2.86)	0.00 (2.865)	0 .00(2.865)	0.00 (2.865)	28.50	26.50
YP-52	206.50	138.50	106.50	78.50	0.00 (2.86)	21.54 (28.65)	0.00 (2.865)	0 .00(2.865)	28.00	24.00
YP-58	193.50	146.00	96.50	65.50	0 .00(2.86)	0 .00(2.865)	0.00 (2.865)	0.00 (2.865)	33.50	29.50
YP-67	181.00	141.50	88.00	60.00	0 .00(2.86)	0.00 (2.86)	0.00 (2.865)	0 .00(2.865)	34.50	30.00
YP-70	161.00	118.50	74.00	67.50	0 .00(2.86)	13.89 (21.77)	0 .00(2.865)	0.00 (2.865)	31.00	27.00
YP-75	157.50	125.00	79.50	55.00	0.00 (2.86)	19.11 (25.90)	0 .00(2.865)	22.15 (28.65)	29.50	26.50
LSD (0.05)	13.34	8.34	10.07	6.30	4.45	5.38	6.59	5.37	2.91	5.43
S.Em±	4.62	2.89	3.48	2.18	1.54	1.86	2.28	1.85	1.01	1.88
Mean	160.38	118.04	83.12	61.76	2.19	25.09	2.19	26.47	30.72	27.87

OC: Optimum condition; HSC: Heat stress condition. The values in parenthesis are arcsine

Table 5. Performance of maize inbred lines for important physiological traits under optimum and heat stress conditions

Inbred lines	Chl a (mg/g FW) 60 DAS		Chl a (mg/g FW) 90 DAS		Chl b (mg/g FW) 60 DAS		Chl b (mg/g FW) 90 DAS		Total Chl (mg/g FW) 60DAS	
	OC	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**
CI-4	1.43	1.00	0.40	0.18	2.33	1.60	0.86	0.40	3.76	2.61
CM-111	1.38	1.10	0.43	0.20	2.69	2.29	0.89	0.44	4.07	3.39
CML-446	1.34	1.13	0.36	0.21	2.33	1.92	0.75	0.48	3.68	3.05
HS-2	1.36	1.12	0.40	0.15	2.47	1.85	0.83	0.33	3.83	2.98
HS-4	1.50	1.19	0.40	0.21	2.34	1.94	0.82	0.49	3.84	3.13
HS-7	1.30	0.98	0.49	0.10	1.64	1.36	0.81	0.33	2.95	2.34
HS-15	1.44	1.16	0.38	0.23	2.32	1.61	0.78	0.47	3.76	2.77
HS-17	1.47	1.11	0.41	0.26	2.34	1.72	0.83	0.56	3.81	2.84
KDMI-15	1.67	1.23	0.60	0.31	2.98	1.71	1.20	0.63	4.66	2.94
NEI-9202B	1.66	1.27	0.47	0.26	3.02	1.68	0.95	0.60	4.69	2.96
NEI-9208B	1.18	1.08	0.47	0.17	1.67	1.30	0.97	0.49	2.86	2.38
P-2	1.38	1.18	0.46	0.19	2.59	2.16	0.90	0.44	3.98	3.34
P-16	1.55	1.22	0.43	0.19	2.54	1.70	0.87	0.45	4.10	2.93
P-21	1.27	1.17	0.45	0.15	2.37	1.75	0.97	0.35	3.64	2.92
P-24	1.31	1.11	0.42	0.14	2.38	1.96	0.86	0.33	3.69	3.07
P-25	1.23	0.99	0.44	0.22	2.44	2.12	0.90	0.30	3.67	3.12
P-26	1.61	0.82	0.29	0.19	3.11	1.37	1.55	0.39	4.73	2.19
P-28	1.61	1.34	0.61	0.19	2.92	1.57	1.22	0.42	4.54	2.91
P-40	1.34	1.18	0.77	0.47	2.35	2.10	0.84	0.69	3.69	3.28
P-41	0.99	0.83	0.29	0.18	2.10	1.56	0.76	0.29	3.10	2.39
P-51	1.73	1.49	0.42	0.22	2.38	1.87	0.87	0.48	4.12	3.37
R-84	1.50	1.20	0.42	0.23	2.47	1.42	0.92	0.48	3.97	2.62
R-92	1.28	1.06	0.37	0.17	2.36	1.88	1.02	0.30	3.65	2.95
R-95	1.09	0.80	0.43	0.09	1.38	1.07	0.88	0.16	2.48	1.87
R-96	1.38	1.14	0.50	0.21	2.47	1.72	1.01	0.44	3.86	2.86
R-134	1.36	1.19	0.42	0.22	2.38	1.99	0.85	0.42	3.75	3.19
R-111	1.30	0.95	0.41	0.15	2.75	2.38	0.83	0.42	4.05	3.34
YP-52	1.53	1.26	0.49	0.26	2.54	2.03	0.99	0.54	4.07	3.30
YP-58	1.41	1.18	0.45	0.22	2.66	1.71	0.92	0.50	4.07	2.89
YP-67	1.25	1.13	0.46	0.21	2.44	2.12	0.92	0.48	3.70	3.25
YP-70	1.57	1.14	0.51	0.38	2.77	2.06	1.04	0.81	4.35	3.20
YP-75	1.29	1.13	0.49	0.23	2.52	1.75	0.95	0.50	3.82	2.89
LSD (0.05)	0.24	0.17	0.11	0.04	0.27	0.53	0.20	0.09	0.39	0.53
S.Em±	0.08	0.06	0.04	0.01	0.09	0.18	0.06	0.03	0.13	0.18
Mean	1.39	1.12	0.45	0.21	2.44	1.79	0.92	0.45	3.84	2.92

OC: Optimum condition; HSC: Heat stress condition.

Table 5. Contd…..

Inbred lines	**Total chl (mg/g FW) 90 DAS**		**Canopy temperature (^{o}c) 60 DAS**		**Canopy temperature (^{o}c)90 DAS**		**NDVI 60 DAS**		**NDVI 90 DAS**	
	OC	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**
CI-4	1.27	0.58	28.39	33.02	33.84	35.05	0.76	0.62	0.60	0.43
CM-111	1.32	0.65	28.81	31.46	32.44	33.47	0.74	0.59	0.56	0.40
CML-446	1.12	0.70	27.60	32.03	32.70	35.04	0.66	0.57	0.51	0.38
HS-2	1.24	0.48	26.69	33.13	33.46	35.18	0.65	0.59	0.49	0.40
HS-4	1.22	0.71	29.11	32.37	33.53	36.33	0.76	0.49	0.52	0.30
HS-7	1.30	0.43	32.24	34.52	36.14	37.56	0.55	0.45	0.40	0.26
HS-15	1.17	0.70	27.87	32.49	33.72	35.44	0.74	0.54	0.62	0.35
HS-17	1.24	0.82	27.67	31.86	32.60	35.84	0.67	0.40	0.56	0.21
KDMI-15	1.80	0.95	28.24	33.88	34.76	37.85	0.74	0.65	0.56	0.46
NEI-9202B	1.43	0.86	29.48	33.50	34.59	36.52	0.72	0.54	0.55	0.35
NEI-9208B	1.45	0.67	32.00	34.73	35.12	37.76	0.57	0.51	0.36	0.32
P-2	1.36	0.64	26.77	33.73	33.50	35.76	0.75	0.54	0.65	0.35
P-16	1.31	0.65	28.09	32.88	34.78	36.12	0.79	0.54	0.67	0.35
P-21	1.42	0.51	27.36	32.93	34.39	36.25	0.68	0.43	0.59	0.24
P-24	1.29	0.48	27.86	33.62	37.84	39.32	0.72	0.59	0.58	0.40
P-25	1.34	0.59	25.68	33.62	33.30	35.71	0.74	0.53	0.53	0.34
P-26	1.45	0.96	28.24	33.16	34.27	35.18	0.79	0.49	0.70	0.30
P-28	1.84	0.62	27.15	33.45	33.30	35.42	0.76	0.55	0.61	0.36
P-40	1.62	1.17	28.72	33.91	31.92	35.93	0.78	0.53	0.68	0.34
P-41	1.06	0.47	32.80	34.91	35.27	38.94	0.59	0.48	0.47	0.29
P-51	1.30	0.71	28.01	33.18	33.20	35.19	0.77	0.58	0.67	0.39
R-84	1.34	0.72	26.26	34.36	36.85	38.38	0.75	0.53	0.55	0.34
R-92	1.39	0.48	29.00	32.87	36.47	38.29	0.71	0.55	0.63	0.36
R-95	1.31	0.25	32.67	33.73	35.61	37.74	0.60	0.58	0.49	0.39
R-96	1.52	0.65	25.43	32.06	34.92	36.08	0.61	0.45	0.49	0.26
R-134	1.27	0.65	27.74	34.02	34.42	36.03	0.73	0.53	0.56	0.34
R-111	1.24	0.57	29.45	32.30	33.23	35.33	0.76	0.62	0.62	0.43
YP-52	1.49	0.81	28.86	33.39	31.72	35.37	0.72	0.59	0.49	0.40
YP-58	1.37	0.73	28.22	32.42	32.74	34.45	0.76	0.61	0.68	0.42
YP-67	1.38	0.69	27.54	33.87	35.25	35.88	0.74	0.62	0.58	0.43
YP-70	1.56	1.19	28.34	33.38	36.55	38.39	0.71	0.53	0.53	0.34
YP-75	1.44	0.74	28.37	32	34.83	35.78	0.71	0.50	0.57	0.31
LSD (0.05)	0.28	0.10	2.53	2.35	3.36	2.28	0.06	0.13	0.07	0.13
S.Em±	0.09	0.03	0.87	0.81	1.44	0.79	0.02	0.04	0.02	0.04
Mean	1.37	0.67	28.45	33.23	34.44	36.18	0.71	0.54	0.56	0.35

OC: Optimum condition; HSC: Heat stress condition. Chl: Chlorophyll; NDVI: Normalized

Table 6. Performance of maize inbred lines for important yield attributing traits under optimum and heat stress conditions

Inbred lines	Cob length (cm)		Cob girth (cm)		No of kernels per cob		Shelling %	
	OC	HSC	OC	HSC	OC	HSC	OC	HSC
CI-4	13.00	14.50	12.00	12.00	351.00	317.50	82.50	77.25
CM-111	11.50	10.50	12.00	9.00	390.00	189.00	83.00	67.65
CML-446	11.50	7.50	13.00	5.50	309.50	83.50	81.00	67.92
HS-2	11.00	9.00	10.50	7.50	283.50	88.50	82.50	58.42
HS-4	13.50	12.50	13.50	11.00	355.50	301.50	83.00	66.44
HS-7	12.50	11.00	10.00	8.50	367.50	178.50	77.50	65.02
HS-15	14.00	13.50	12.00	11.00	425.50	222.00	83.00	61.89
HS-17	11.00	8.50	10.00	7.50	364.50	97.50	79.00	68.19
KDMI-15	15.00	12.00	13.00	9.50	376.00	179.00	81.50	77.21
NEI-9202B	13.50	11.00	12.50	9.00	367.00	113.00	79.50	65.35
NEI-9208B	13.50	14.00	12.00	11.50	300.00	298.00	80.50	60.51
P-2	14.50	11.50	15.00	8.50	336.50	128.00	84.00	69.68
P-16	14.00	13.00	12.00	11.00	446.50	200.00	80.00	74.75
P-21	12.00	8.00	10.50	8.00	333.00	224.00	80.00	68.64
P-24	15.50	14.00	14.50	8.50	458.50	101.00	76.50	54.44
P-25	16.50	12.00	14.50	10.00	405.00	277.50	75.50	75.15
P-26	15.50	11.50	13.00	9.50	448.50	150.00	83.00	71.75
P-28	13.00	10.00	12.00	9.00	368.50	132.00	80.00	67.66
P-40	16.00	8.00	13.00	8.50	569.50	70.00	80.00	69.57
P-41	10.50	9.00	9.50	7.00	373.50	38.00	74.00	70.15
P-51	13.50	11.00	12.50	8.50	427.00	155.00	79.50	67.45
R-84	13.00	12.00	11.00	10.00	397.00	218.00	77.00	64.23
R-92	13.00	12.00	12.00	9.00	426.50	53.00	81.00	62.46
R-95	10.50	9.50	9.50	8.00	226.50	63.00	71.50	65.94
R-96	10.50	8.00	11.00	8.00	276.50	59.50	78.50	62.91
R-134	11.50	10.00	11.50	7.50	391.00	95.00	81.00	67.88
R-111	13.00	12.50	12.50	11.50	432.00	282.50	78.50	66.49
YP-52	13.00	12.00	13.50	10.50	405.00	247.00	79.50	70.76
YP-58	14.50	13.50	13.50	11.50	489.50	404.00	80.50	76.91
YP-67	12.50	11.50	12.50	10.00	405.50	189.50	77.00	66.50
YP-70	12.00	10.50	11.50	10.50	367.50	151.50	77.00	63.77
YP-75	12.50	12.50	11.50	9.50	391.50	228.00	82.50	62.33
LSD (0.05)	3.31	2.89	2.60	2.38	91.97	49.15	4.18	6.98
S.Em±	1.14	1.00	0.90	0.82	31.85	17.00	1.44	2.42
Mean	12.80	11.07	11.98	9.23	378.62	169.87	79.24	66.79

OC: Optimum condition; HSC: Heat stress condition.

Table 6. Contd…..

Inbred lines	Grain yield per plant (g)		100 Grain weight (g)		Grain yield (kg ha^{-1})	
	OC	**HSC**	**OC**	**HSC**	**OC**	**HSC**
CI-4	106.50	75.50	23.50	20.50	4296.86	3330.01
CM-111	90.00	36.50	18.00	18.50	5456.47	3294.84
CML-446	85.50	16.00	19.00	17.00	4987.49	760.66
HS-2	82.50	19.00	17.50	15.50	3972.21	1031.61
HS-4	93.00	49.50	19.00	15.00	4194.18	2249.53
HS-7	82.00	28.50	17.50	15.50	3467.75	1269.98
HS-15	91.00	39.00	21.00	19.00	1911.68	1644.04
HS-17	85.00	26.50	20.50	17.00	1828.70	1296.48
KDMI-15	86.50	40.50	18.00	17.00	2839.28	2131.35
NEI-9202B	93.50	31.50	17.50	17.00	4030.20	1282.75
NEI-9208B	85.50	71.00	18.50	19.50	3959.77	1260.65
P-2	89.50	23.00	21.50	19.00	5852.76	1016.22
P-16	87.50	36.50	21.00	15.00	5481.47	1459.95
P-21	84.50	57.50	20.00	17.00	2574.06	1108.40
P-24	92.00	15.50	22.50	19.50	4816.65	779.83
P-25	104.00	46.50	21.00	20.50	4683.78	2446.57
P-26	82.00	42.50	18.50	17.00	7396.97	934.24
P-28	91.00	29.00	19.00	17.00	7277.76	1550.54
P-40	85.00	23.00	18.50	15.50	6870.35	742.82
P-41	49.00	11.00	16.00	12.50	1430.32	712.53
P-51	75.00	36.50	20.00	16.00	4379.85	1370.18
R-84	90.00	56.50	19.00	17.00	2798.37	2793.56
R-92	81.00	18.50	21.00	16.50	3937.49	683.18
R-95	66.50	21.50	15.50	15.00	804.80	429.31
R-96	101.50	16.50	19.00	16.00	1898.89	1195.97
R-134	76.50	27.50	18.00	17.00	3328.11	1414.28
R-111	91.50	48.50	19.50	19.00	5324.17	3255.65
YP-52	96.00	69.50	20.50	19.50	2962.84	2930.29
YP-58	99.50	76.50	22.50	19.00	6261.09	2940.30
YP-67	86.00	52.50	20.50	18.00	3867.81	2788.27
YP-70	79.00	42.50	20.00	18.00	1737.84	1312.03
YP-75	87.00	51.50	19.00	17.00	4688.35	2094.16
LSD (0.05)	2.92	10.86	10.35	2.81	700.28	534.00
S.Em±	1.01	3.76	3.58	0.97	242.49	185.22
Mean	86.18	38.12	19.31	17.23	3883.54	1662.82

OC: Optimum condition; HSC: Heat stress condition.

Table 7. Performance of maize hybrids for important morphological traits under optimum and heat stress conditions

Hybrids	Days to 50% anthesis		Days to 50% Silking		Anthesis to silking interval		End of pollen shed duration		75% Brown husk maturity		Plant height (cm)		Ear height (cm)		Silk length (cm)	
	OC	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**
Arjun	61.33	53.00	64.66	55.66	3.66	2.66	66.00	56.33	94.00	78.33	157.66	147.00	77.33	75.66	34.00	29.00
CP-818	67.66	56.33	71.00	58.00	3.33	1.66	71.00	59.33	97.33	78.66	164.00	148.66	80.33	73.33	35.00	33.00
DKC-9135	65.00	51.00	68.33	53.66	3.66	2.00	70.00	55.66	96.66	76.66	183.33	158.66	80.33	75.33	33.66	29.33
DMH-117	68.33	54.00	72.00	59.00	4.33	4.33	74.00	60.00	99.66	85.00	178.33	168.00	96.00	85.00	31.66	28.33
GH-0727	62.00	52.00	65.00	53.66	3.00	1.66	66.33	56.00	97.00	78.00	151.33	147.00	81.66	74.33	34.66	30.33
GK-3059	64.66	54.00	69.00	57.00	4.33	3.00	69.66	58.33	99.66	81.66	167.00	162.33	88.00	74.66	33.00	29.66
GK-3140	64.66	55.33	38.33	57.33	3.66	2.00	69.00	59.00	95.33	81.33	173.66	163.66	88.00	83.33	30.00	29.00
MRM3845	66.00	57.00	69.33	59.66	3.33	2.66	70.66	61.33	98.66	84.33	176.33	171.33	95.66	78.66	32.66	30.00
NK6240	63.33	54.00	67.33	56.00	4.00	2.00	68.66	57.33	97.33	78.66	166.00	149.66	83.33	80.33	35.33	32.66
P-3441	65.00	53.66	68.33	56.00	2.66	2.33	69.00	57.33	96.33	78.33	188.66	169.33	91.66	82.33	32.66	29.66
900M-G	65.00	55.66	67.33	58.66	3.00	2.00	69.66	59.66	98.00	82.33	175.33	152.00	92.33	84.66	31.66	30.00
LSD (0.05)	4.00	1.80	3.81	1.95	1.20	1.06	4.27	1.81	3.72	4.24	6.55	7.11	5.36	3.61	3.21	2.73
S.Em±	1.36	0.61	1.29	0.66	0.41	0.35	1.45	0.63	1.26	1.44	2.23	2.41	1.83	1.22	1.09	0.92
Mean	64.66	54.33	68.08	56.72	3.41	2.48	69.30	58.21	97.25	80.30	169.58	157.96	85.72	78.87	32.80	30.09

OC: Optimum condition; HSC: Heat stress condition

Table 8. Performance of maize hybrids for important physiological traits under optimum and heat stress conditions

Hybrids	Chl a (mg/gFW) 60 DAS		Chl a (mg/g FW) 90 DAS		Chl b (mg/g FW) 60 DAS		Chl b (mg/g FW) 90 DAS		Total Chl (mg/g FW) 60 DAS		Total Chl (mg/g FW) 90 DAS		Canopy temperature (^{0}C) 60 DAS		Canopy temperature (^{0}C) 90 DAS		NDVI 60 DAS		NDVI 90 DAS	
	OC	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**
Arjun	2.00	1.35	1.33	0.53	2.45	1.90	2.05	0.98	3.45	3.25	3.10	1.51	28.52	31.86	34.32	36.92	0.74	0.57	0.51	0.44
CP-818	2.10	1.63	1.35	0.54	2.36	1.89	2.16	1.05	4.46	3.52	3.51	1.59	29.36	32.39	33.32	35.78	0.75	0.64	0.55	0.43
DKC-9135	2.01	1.94	1.46	0.56	2.43	2.15	2.18	1.17	4.44	4.10	3.63	1.73	28.06	31.39	33.91	37.34	0.77	0.64	0.66	0.38
DMH-117	1.30	1.45	1.38	0.57	2.83	1.68	1.65	1.01	3.13	3.13	3.03	1.58	26.96	31.38	34.59	37.58	0.76	0.63	0.66	0.37
GH-0727	1.66	1.52	1.42	0.59	1.92	1.77	1.85	1.17	3.58	3.29	3.27	1.76	29.75	32.38	34.78	36.74	0.737	0.64	0.55	0.37
GK-3059	2.96	1.98	1.66	0.78	3.58	2.17	2.58	1.52	6.53	4.13	4.24	2.30	28.75	32.08	33.60	34.87	0.763	0.59	0.63	0.45
GK-3140	2.07	1.67	1.30	0.71	2.42	1.96	1.56	1.36	4.49	3.63	2.86	2.07	29.21	31.61	33.93	36.82	0.773	0.61	0.62	0.43
MRM-3845	1.51	1.25	1.41	0.60	1.88	1.66	1.68	1.19	3.39	2.91	3.09	1.79	28.30	31.96	35.56	35.74	0.77	0.63	0.64	0.38
NK-6240	1.60	1.42	1.40	0.58	1.99	1.77	1.57	1.17	3.59	3.19	2.96	1.75	29.66	31.34	33.71	36.97	0.77	0.64	0.63	0.37
P-3441	1.95	1.56	1.27	0.63	2.15	1.84	1.79	1.25	4.10	3.34	3.06	1.88	28.68	31.19	33.77	37.32	0.767	0.66	0.63	0.43
900M-G	2.04	1.63	1.35	0.52	2.49	1.72	1.84	1.03	2.53	3.35	3.19	1.55	27.1	31.80	34.67	37.52	0.76	0.61	0.51	0.46
LSD (0.05)	0.93	0.34	0.16	0.09	1.29	0.60	0.62	0.22	1.65	0.65	0.65	0.29	2.79	1.20	1.95	1.78	0.03	0.06	0.05	0.05
S.Em±	0.31	0.11	0.05	0.03	0.31	0.20	0.21	0.07	0.56	0.22	0.22	0.10	0.95	0.40	0.66	0.60	0.01	0.02	0.01	0.01
Mean	1.88	1.58	1.28	0.60	2.20	1.88	1.52	1.17	3.91	3.44	3.24	1.77	28.67	31.76	34.16	36.69	0.75	0.62	0.59	0.41

OC: Optimum condition; HSC: Heat stress condition; Chl: Chlorophyll; NDVI: Normalized difference vegetative index

Table 9. Performance of maize hybrids for important yield traits under optimum and heat stress conditions

Hybrids	**Cob length (cm)**		**Cob girth (cm)**		**No of kernels per cob**		**Shelling %**		**Grain yield per plant (g)**		**100 Grain weight (g)**		**Grain yield (kg ha^{-1})**	
	OC	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**
Arjun	16.00	13.66	13.66	13.00	410.33	318.33	80.33	78.14	103.55	91	20.66	18.33	6587.64	2529.44
CP- 818	21.67	14.66	17.00	11.33	533.33	263.66	84.00	79.57	109.66	101.33	21.33	19.33	9158.31	5885.20
DKC-9135	16.66	13.33	14.00	12.00	503.33	454.66	81.00	78.33	98.55	86.33	17.00	15.66	8316.85	6174.02
DMH-117	15.33	12.33	13.33	12.00	415.00	234.00	79.66	69.43	110.66	85.33	23.66	21.33	6233.16	4050.52
GH-0727	15.33	12.33	13.66	12.00	493.00	317.33	79.33	77.97	101.33	89.66	22.66	21.33	4462.49	4846.16
GK-3059	17.00	16.00	15.33	14.66	390.33	379.00	81.00	78.28	108.12	104.33	26.66	22.33	8842.70	9376.80
GK-3140	15.66	14.33	14.33	13.66	412.67	341.67	77.00	74.68	109.33	87.66	20.66	18.33	8187.17	4953.35
MRM-3845	16.33	15.33	14.66	12.66	439.66	310.33	80.00	75.03	109.88	82.66	24.33	20.66	6098.75	3673.62
NK-6240	16.00	14.33	13.66	13.33	446.33	295.00	80.00	76.13	114.44	94.66	23.66	20.66	7351.83	5590.86
P-3441	18.00	14.66	16.00	12.33	422.33	271.33	81.00	80.10	106.22	85.00	21.00	20.66	7462.48	6355.67
900M-G	19.33	12.66	16.00	14	542.00	367.00	85.33	81.04	136.77	92.33	25.33	22.33	9461.70	6303.72
LSD (0.05)	2.42	12.29	2.08	1.97	45.65	73.76	3.00	6.98	3.49	15.61	13.28	2.34	742.22	1153.83
SE(m)	0.82	4.16	0.71	0.66	15.56	25.00	1.02	2.36	1.19	5.29	4.53	0.79	253.05	391.12
Mean	16.69	13.75	14.66	12.81	453.80	322.93	80.06	76.84	109.58	90.93	22.27	20.09	7287.49	5395.68

OC: Optimum condition; HSC: Heat stress condition

Under optimum condition, the ASI of hybrids ranged from 2.6 (P-3441) to 4.3 days (GK 3059, DMH-117) with an overall mean of 3.41 days. While under heat stress, it was ranged from 1.66 (CP-818, GH-0727) to 4.33 days (DMH-117) with an overall mean of 2.48 days.

4.2.1.4 End of pollen shed duration (EPSD)

The duration of pollen shed for inbreds was from 64 (HS-7) to 73 days (R-92) with an overall mean of 68.50 days under optimum condition. While under heat stress, it ranged from 54 (P-40, CML-446) to 60 days (R-84) with an overall mean of 56.81 days.

However, for hybrids pollen shed duration was from 66 (Arjun) to 74 days (DMH-117) with an overall mean of 69.30 days under optimum condition. While under heat stress condition, it ranged from 55.66 (DKC-9135) to 61.33 days (MRM-3845) with an overall mean of 58.21 days.

4.2.1.5 75% Brown husk maturity (BHM)

The husk maturity for inbreds ranged from 92 (HS-7) to 98.5 days (HS-4, P-24) with an overall mean of 95.35 days, under optimum condition. While under heat stress, the range was from 79 (YP-75) to 86.5 days (NEI9202-B) with an overall mean of 82.76 days.

The husk maturity for hybrids ranged from 94 (Arjun) to 99.6 days (GK-3059, DMH-117) with an overall mean of 97.25 days under optimum condition. While, under heat stress, husk maturity it ranged from 76.66 (DKC-9135) to 85 days (DMH-117) to with an overall mean of 80.30 days.

4.2.1.6 Plant height (cm)

The plant height of inbreds ranged from 98 (P-21) to 206.5 cm (YP-52) with an overall mean of 160.38 cm under optimum condition. While, under heat stress it ranged from 72 (R-96) to 146 cm (YP-58) with an overall mean of 118.04 cm.

However, for hybrids plant height under optimum conditions ranged from 151.33 (GH-0727) to 188.6 cm (P-3441) with an overall mean of 169.58 cm. Whereas, under heat stress it ranged from 147 (Arjun, GH-0727) to 171.33 cm (MRM-3835) with an overall mean of 157.96 cm.

4.2.1.7 Ear height (cm)

The ear height for inbreds ranged from 40 (P-21) to 106.5 cm (YP-52) with an overall mean of 83.12 cm under optimum condition. While under heat stress, it ranged from 23.5 (R-96) to 83.5 cm (KDMI-15) with an overall mean of 61.76 cm.

Whereas, under optimum condition ear height of hybrids ranged from 77.33 (Arjun) to 96 cm (DMH-117) with an overall mean of 85.72 cm. While under heat stress, ear height ranged from 73.33(CP-818) to 85 cm (DMH-117) with an overall mean of 78.87 cm.

4.2.1.8 Leaf firing (%)

Leaf firing is one of the prominent indicators of the heat stress susceptibility. The leaf firing percentage was nil in most of the inbreds but for two inbreds *viz.,* R-95 (36.5%) and P-41(26%) recorded the leaf firing under optimum situation.

Whereas, the leaf firing under heat stress condition rose in many inbred lines *viz.,* P-41 (99.75%), R-95 (99.75%), HS-4 (57.15%) with an overall mean of 25.09. The inbreds *viz.,* P-25, YP-58, YP-67, R-84, R-111, CI-4 and CM-111 did not record any leaf firing symptoms.

4.2.1.9 Tassel blast (%)

It is also one of the important indicators of the heat susceptibility. Whereas tassel blast percentage was nil in most of the inbreds except R-95 (35.5%) and P-41 (28.5%) under optimum situation.

Whereas, the tassel blast under heat stress condition rose in many inbred lines, 99.75% (P-41), 99.75% (R-95) 58.57% (HS-4) with an overall mean of 26.47.Whereas, the inbreds *viz.,* P-25, YP-58, YP-67, R-84, R-111, CI-4 and CM-111 did not record any tassel blast symptoms.

4.2.1.10 Silk length (cm)

The silk length in inbreds ranged from 26.5 (P-21) to 34.5 cm (P-2, YP-67) with an overall mean of 30.72 cm under optimum condition. Whereas under heat stress, it ranged from 24 (P-41, YP-52) to 31.5 cm (KDMI-15) with an overall mean of 27.87 cm.

In hybrids silk length ranged from 30 (GK-3140) to 35.33 cm (NK-6240) with an overall mean of 32.80 cm under optimum condition. However, in stress condition the lowest silk length was observed in Arjun and GK3140 (29 cm) and the highest in CP-818 (33 cm) with an overall mean of 30.09 cm.

4.2.2 Physiological characters

4.2.2.1 Chlorophyll a content

The chlorophyll a content at 60 DAS for inbreds ranged from 0.99 (P-41) to 1.73 mg/g FW (P-51) with an overall mean of 1.39 mg/g FW under optimum condition. Whereas, under heat stress, chlorophyll a content ranged from 0.80 (R-95) to 1.49 (P-51) mg/g FW with an overall mean of 1.12 mg/g FW.

However, the chlorophyll a content at 60 DAS for hybrids ranged from 1.30 (DMH-117) to 2.96 mg/g FW (GK-3059) with an overall mean of 1.88 mg/g FW under optimum condition. While under heat stress condition, chlorophyll a content ranged from 1.25 (MRM-3835) to 1.98 mg/g FW (GK-3059) with an overall mean of 1.58 mg/g FW.

At 90 DAS chlorophyll a content among inbreds ranged from 0.29 to 0.77 mg/g FW (P-40, P-41 and P-26) with an overall mean of 0.45 mg/g FW under optimum condition. Whereas under heat stress situation, it ranged from 0.09 (R-95) to 0.47 mg/g FW (P-40) with an overall mean of 0.21 mg/g FW.

Under optimum situation, chlorophyll a content among the hybrids at 90 DAS ranged from 1.27 (P-3441) to 1.66 mg/g FW (GK-3059) with an overall mean of 1.28 mg/g FW. Under heat stress, it ranged from 0.52 (900 M-G) to 0.78 mg/g FW (GK-3059) with an overall mean of 0.60 mg/g FW.

4.2.2.2 Chlorophyll b content.

The chlorophyll b content at 60 DAS among inbreds under optimum situation ranged from 1.38 (R-95) to 3.11 mg/g FW (P-26) with an overall mean of 2.44 mg/g FW. Whereas under heat stress, it ranged from 1.07 (R-95) to 2.38 mg/g FW (R-111) with an overall mean of 1.79 mg/g FW.

The chlorophyll b content of hybrid at 60 DAS ranged from 1.88 (MRM-3845) to 3.58 mg/g FW (GK-3059) with an overall mean of 2.20 mg/g FW under optimum condition. While under heat stress, it ranged from 1.66 (MRM-3845) to mg/g FW (GK-3059) with an overall mean of 1.88 mg/g FW.

Under optimum condition, the chlorophyll b content of inbred lines at 90 DAS ranged from 0.75 (CML-446) to 1.55 mg/g FW (P-26) with an overall mean of 0.92 mg/g FW.Whereas, under heat stress situation it ranged from 0.16 (R-95) to 0.81 mg/g FW (YP-70) with an overall mean of 0.45 mg/g FW.

At 90 DAS the chlorophyll b content of hybrids ranged from 1.56 (GK-3140) to 2.58 mg/g FW (GK-3059) with an overall mean of 1.52 mg/g FW under optimum condition. While it ranged from 0.98 (Arjun) to 1.52 mg/g FW (GK-3059) with an overall mean of 1.17 mg/g FW under heat stress condition.

4.2.2.3 Total chlorophyll content

The total chlorophyll content of inbreds at 60 DAS ranged from 2.48 (R-95) to 4.73 mg/g FW (P-26) with an overall mean of 3.84 mg/g FW under optimum condition. Under heat stress it ranged from 1.87 (R-95) to 3.39 mg/g FW (CM-111) with an overall mean of 2.92 mg/g FW.

The total chlorophyll content of hybrids at 60 DAS ranged from 2.53 (900-M-G) to 6.53 mg/g FW (GK-3059) with an overall mean of 3.91 mg/g FW under optimum condition. Under stress condition, it ranged from 2.91 (MRM-3845) to 4.13 mg/g FW (GK-3059) with an overall mean of 3.44 mg/g FW.

Under optimum condition, the total chlorophyll content of hybrids at 90 DAS ranged from 1.06 (P-41) to 1.84 mg/g FW (P-28) with an overall mean of 1.37 mg/g FW. Whereas under heat stress condition, it ranged from 0.25 (R-95) to 1.19 mg/g FW (YP-70) with an overall mean of 0.67 mg/g FW.

The total chlorophyll content at 90 DAS for hybrids ranged from 2.86 (GK-3140) to 4.24 mg/g FW (GK-3059) with an overall mean of 3.24 mg/g FW under optimum situation. While under heat stress condition, it ranged from 1.51 (Arjun) to 2.37 mg mg/g FW (GK-3059) to with an overall mean of 1.77 mg/g FW.

4.2.2.4 Canopy temperature

The canopy temperature of inbreds recorded at 60 DAS ranged from 25.43 ^{0}C (R-96) to 32.80 ^{0}C (P-41) with an overall mean of 28.45 ^{0}C under optimum condition. Under heat stress condition, canopy temperature ranged from 31.46 ^{0}C (R-95) to 34.91^{0}C (P-41) with an overall mean of 33.23 ^{0}C.

The canopy temperature of hybrids ranged from 26.96 ^{0}C (DMH-117) to 29.75^{0}C (GH-0727) with an overall mean of 28.67 ^{0}C under optimum condition. While under heat stress, it ranged from 31.19 ^{0}C (P3441) to 32.39 ^{0}C (CP-818) with an overall mean of 31.76 ^{0}C

The canopy temperature of inbreds at 90 DAS ranged from 32.80 ^{0}C (P-41) to 37.84 ^{0}C (R-24) with an overall mean of 34.44 ^{0}C under optimum condition. Whereas under heat stress, it ranged from 34.45 ^{0}C (YP-58) to 39.32 ^{0}C (P-24) to with an overall mean of 36.18 ^{0}C recorded.

The canopy temperature of hybrids at 90 DAS ranged from 33.71 ^{0}C (NK-6240) to 35.56 ^{0}C (MRM-3845) with an overall mean of 34.16 ^{0}C under optimum condition. Under heat stress, it ranged from 34.87 ^{0}C (GK-3059) to 37.58 ^{0}C (DMH-117) with an overall mean of 36.69 ^{0}C.

Lower canopy temperature indicates higher transpiration rate and there by indirectly suggesting carbon dioxide exchange capacity of leaves and effect on grain yield of plant.

4.2.2.5 Normalized difference vegetative index (NDVI)

The NDVI recorded at 60 DAS for inbreds ranged from 0.55 (HS-7) to 0.79 (P-16) with an overall mean of 0.71 under optimum condition. Under heat stress, it ranged was from 0.40 (HS-17) to 0.62 (YP-67) with an overall mean of 0.54.

The NDVI recorded at 60 DAS for hybrids under optimum condition ranged from 0.73 (GH-0727) to 0.77 (GK-3140, DKC-9135, NK-6240) with an overall mean of 0.75. Under heat stress condition it ranged from 0.57 (Arjun) to 0.66 (P-3441) with an overall mean of 0.62.

The NDVI recorded at 90 DAS for inbreds ranged from 0.40 (HS-7) to 0.68 (P-40, YP-58) with an overall mean of 0.56 under optimum condition. Under heat stress, it ranged from 0.34 C^0 (YP-58) to 0.43 (R-111, CI-4, YP-67) with an overall mean of 0.35.

Under optimum condition, the NDVI of hybrids at 90 DAS ranged from 0.51 (900 M-G, Arjun) to 0.66 (DMH117, DKC9135) with an overall mean of 0.59.Whereas under heat stress, it ranged from 0.37 (GH-0727, NK-6240, DMH-117) to 0.46 (900 M-G) with an overall mean of 0.41.

4.2.3 Yield attributing characters

4.2.3.1 Cob length (cm)

Among the inbred lines P-41 (10.5 cm) recorded the least cob length and P-25 (16.5 cm.) recorded the highest cob length with an overall mean of 12.80 cm under optimum condition. Under heat stress conditions, cob length ranged from 8 cm (P-21, P-40, and R-96) to 14 cm (P-24, NEI9208-B) with an overall mean of 11.07 cm.

Among the hybrids, variation for this trait ranged from 15.33 cm (DMH-117) to 21.67 cm (CP-818) with an overall mean of 16.69 cm under optimum condition. Under heat stress, DMH-117 recorded lowest (12.33 cm) and GK-3059 recorded the highest (16 cm) cob length respectively with an overall mean of 13.75 cm.

4.2.3.2 Cob girth (cm)

Among the inbred lines, P-41, R-92 (9.5 cm) and P-2 (15 cm) recorded lowest and highest cob girth respectively with an overall mean of 11.9 cm under optimum condition. Under heat stress, it ranged from 7 cm (P-41) to 11.5 cm (YP-28, R-111) with an overall mean of 9.23 cm.

The range for this trait among the hybrids was from 13.33 cm (DMH-117) to 17 cm (CP-818) with an overall mean of 14.66 cm under optimum conditions. Under heat stress, DMH-117 (11.33 cm) recorded the lowest and GK-3059 (14.66 cm) recorded the highest cob girth, respectively with an overall mean of 12.81 cm.

4.2.3.3 Number of kernels per cob

Among inbreds, R-95 (142.5) recorded the least and P-40 (569.58) recorded the highest number of kernels per cob with an overall mean of 378.62 under optimum condition. Under heat stress, it ranged from 38 (P-41) to 404 (YP-58) with an overall mean of 169.87.

Among the hybrids, Arjun (410) and 900M-G (542) recorded lowest and highest number of kernels per cob, respectively with an overall mean of 453.80 under optimum condition. Under heat stress situation, it ranged was from 234 (DMH-117) to 454.66 (DKC-9135) with an overall mean of 322.93.

4.2.3.4 Shelling percentage

Among the inbreds, shelling percentage ranged from 71.5% (R-96) to 84% (P-2) with an overall mean of 79.24% under optimum condition. Under heat stress situation, it ranged was from 54.44% (P-24) to 77.21% (KDMI-15) with an overall mean of 66.79%.

The range for this trait among the hybrids was from 77% (GK-3140) to 85.33% (900M-G) with an overall mean of 80.66% under optimum condition. Under heat stress, the range was from 69.43% (DMH-117) to 81.04% (900M-G) with an overall mean of 76.84%.

4.2.3.5. Grain yield per plant (g)

Among the inbreds lines, P-41 (49 g) and P-25 (104 g) recorded lowest and highest grain yield per plant, respectively with an overall mean of 86.18 g under optimum condition. Under heat stress, it ranged from 11 g (P-41) to 76.5 g (YP-58) with an overall mean of 38.12 g.

The grain yield per plant among hybrids ranged from 98.55 g (DKC-9135) to 136.77 g (900M-G) with an overall mean of 109.58 g under optimum condition. Under heat stress, it ranged from 82.66 g (MRM-3845) to 104.33 g (GK-3059) with an overall mean of 90.93 g was noticed.

4.2.3.6. 100 grain weight (g)

Mean values for the trait among the inbred lines varied from 15.5 g (R-95) to 23.5 g (CI-4) with an overall mean of 19.31 g under optimum condition. Under heat stress, it ranged from 12.5 g (P-41) to 20.5 g (P-25) with an overall mean of 17.23 g.

Among the hybrids, DKC-9135 (17.00 g) and GK-3059 (26.66 g) recorded lowest and highest 100 grain weight, respectively with an overall mean of 22.27 g under optimum condition. Under heat stress, mean value ranged from 15.66 g (DKC-9135) to 22.33 g (900M-G) with an overall mean of 20.09 g.

4.2.3.7 Grain yield (kg ha^{-1})

Among the inbred lines, R-95 (804.80 kg ha^{-1}) recorded the least and P-28 (7277.76 kg ha^{-1}) recorded highest grain yield kg ha^{-1} respectively with an overall mean of 3883.54 kg ha^{-1} under optimum condition. Under heat stress, mean value ranged from 683.18 kg ha^{-1} (R-92) to 3294.84 kg ha^{-1} (CM-111) with an overall mean of 1662.82 kg ha^{-1}.

Among the hybrids, GH-0727 (4462.49 kg ha^{-1}) and 900M-G (9461.70 kg ha^{-1}) recorded lowest and highest grain yield kg ha^{-1}, respectively with an overall mean of 7287.49 kg ha^{-1} under optimum condition. Under heat stress situation, Arjun (2529.44 kg ha^{-1}) and GK-3059 (9376.80 kg ha^{-1}) recorded lowest and highest grain yield kg ha^{-1}, respectively with an overall mean of 5395.68 kg ha^{-1}.

4.3 Genetic components of variation for morpho-physiological and yield characters in inbreds and hybrids under optimum and heat stress condition

Variability is very important for improvement of any trait. The nature and magnitude of variation for different traits apart from mean performance decides the worth of the genotypes.

The variability parameters such as genotypic co-efficient of variation (GCV), phenotypic co-efficient of variation (PCV), heritability in broad sense (h^2_{BS}) and genetic advance (GA) were computed for inbreds and hybrids for all the characters and are presented in Table 10 and 11.

4.3.1 Morphological characters

4.3.1.1 Days to 50% anthesis

Under optimum condition, the inbreds recorded low PCV (4.06%), GCV (3.08%) and GA (4.84%). But the estimate of heritability was moderate (57%). Similar trend was observed for the trait under heat stress condition.

Whereas, hybrids under optimum conditions showed low PCV (3.20%), GCV (2.41%) and GA (3.75%) but moderate heritability (56%). Similarly, under heat stress

Table 10. Genetic components of variation for morpho-physiological and yield attributing characters in inbreds under optimum and heat stress conditions

Sl. No.	Characters	Optimum temperature				Heat stress			
		PCV (%)	GCV (%)	h^2_{BS}	GA (%)	PCV (%)	GCV (%)	h^2_{BS}	GAM (%)
1.	**Days to 50% anthesis**	4.06	3.08	57	4.84	2.91	1.96	45	2.75
2.	**Days to 50% silking**	4.23	3.20	57	5.01	2.73	1.10	16	0.91
3.	**Anthesis to silking interval**	19.33	7.16	13	5.47	22.61	3.02	01	0.83
4.	**End of pollen shed duration**	4.00	2.91	29	4.37	2.55	0.43	02	0.15
5.	**75% Brown husk maturity**	1.96	1.61	57	2.73	2.51	1.54	37	1.94
6.	**Plant height (cm)**	15.20	14.92	96	30.19	18.63	18.47	98	37.72
7.	**Ear height (cm)**	17.79	17.29	94	34.61	22.66	22.39	97	45.56
8.	**Leaf firing%**	96.00	80.00	96	98.00	90.00	78.00	99	98.50
9.	**Tassel blast%**	90.00	75.00	92	98.00	88.00	73.00	99	98.50
10.	**Silk length (cm)**	8.58	7.22	82	13.54	7.48	3.22	78	2.85
11.	**Cob length (cm)**	14.12	10.92	61	20.29	16.93	14.31	71	24.94
12.	**Cob girth (cm)**	11.73	9.00	60	20..22	16.09	13.38	69	22.93
13.	**Number of kernals per cob**	20.32	18.50	82	34.69	51.38	50.40	96	95.50
14.	**Shelling%**	3.95	3.50	78	6.40	7.24	6.26	75	11.17
15.	**100 Grain weight**	9.33	7.71	68	13.14	10.26	8.56	66	14.71
16.	**Grain yield per plant**	11.31	10.51	86	20.15	46.18	45.11	95	90.79
17.	**Grain yield (kg ha^{-1})**	44.30	43.86	98	89.45	51.61	50.39	95	98.50
Physiological parameters at 60 Days after sowing									
18.	**Chlorophyll a**	11.71	10.94	72	20.40	12.82	11.57	81	21.51
19.	**Chlorophyll b**	14.51	13.99	92	27.78	16.71	13.11	61	21.18
20.	**Total Chlorophyll**	12.42	11.90	91	23.45	12.56	10.83	74	20.25
21.	**Canopy temperature**	6.09	5.24	74	9.31	2.55	0.69	07	0.38
22.	**NDVI**	9.04	8.43	86	16.19	10.98	7.19	42	9.71
Physiological parameters at 90 Days after sowing									
23.	**Chlorophyll a**	19.03	16.80	78	30.80	33.73	33.96	95	66.35
24.	**Chlorophyll b**	12.02	10.34	60	14.99	26.88	25.95	93	51.61
25.	**Total Chlorophyll**	11.71	10.33	62	15.26	28.28	27.81	96	56.34
26.	**Canopy temperature**	4.56	2.69	34	3.27	3.58	2.83	62	4.62
27.	**NDVI**	14.22	13.47	89	26.28	16.87	11.05	42	14.92

PCV: Phenotypic Coefficient of Variation; GCV: Genotypic Coefficient of Variation; h^2_{BS}: Heritability in broad sense; GAM: Genetic advance as per cent of mean.

Table 11. Genetic components of variation for morpho- physiological and yield attributing characters in hybrids under optimum and heat stress conditions

Sl. No.	**Characters**	**Optimum temperature**				**Heat stress**			
		PCV (%)	**GCV (%)**	**h^2_{BS}**	**GA (%)**	**PCV (%)**	**GCV (%)**	**$h^2_{BS\ (\%)}$**	**GAM (%)**
1.	**Days to 50% anthesis**	3.20	2.41	56	3.75	3.18	2.98	87	5.75
2.	**Days to 50% silking**	3.25	2.63	65	4.39	3.45	3.25	88	6.30
3.	**Anthesis to silking interval**	19.12	14.8	59	23.77	31.38	27.84	78	50.90
4.	**End of pollen shed duration.**	3.09	2.27	53	3.40	3.13	2.94	87	5.68
5.	**75% Brown husk maturity**	1.69	1.07	40	1.40	3.45	2.95	73	5.19
6.	**Plant height (cm)**	6.92	6.79	96	13.73	5.97	5.78	93	11.51
7.	**Ear height (cm)**	8.48	8.21	93	16.37	5.62	5.40	92	10.70
8.	**Silk length (cm)**	5.77	4.70	66	7.91	4.88	3.70	57	5.80
9.	**Cob length (cm)**	13.63	12.70	86	24.39	9.39	7.19	60	11.34
10.	**Cob girth (cm)**	7.93	6.28	64	11.24	7.91	5.95	60	10.21
11.	**Number of kernals per cob**	11.26	10.72	90	21.04	19.05	17.41	83	32.77
12.	**Shelling%**	2.58	2.25	75	4.03	10.01	9.19	84	4.30
13.	**100 Grain weight (g)**	11.81	10.53	75	19.35	7.55	4.81	40	17.39
14.	**Grain yield per plant (g)**	9.01	8.01	79	14.67	3.65	2.76	57	6.31
15.	**Grain yield (kg ha^{-1})**	23.18	22.91	97	46.67	32.01	31.18	94	62.56
Physiological parameters at 60 Days after sowing									
16.	**Chlorophyll a**	42.84	42.10	96	85.25	13.22	11.41	74	20.30
17.	**Chlorophyll b**	27.16	26.57	95	53.52	7.04	2.61	13	1.99
18.	**Total Chlorophyll**	31.45	31.08	97	63.29	6.72	4.95	53	7.41
19.	**Canopy temperature**	3.29	0.39	01	0.48	1.31	0.27	04	0.12
20.	**NDVI**	2.78	2.41	75	4.32	4.09	2.07	25	2.17
Physiological parameters at 90 Days after sowing									
21.	**Chlorophyll a**	24.20	23.84	97	48.39	13.27	12.20	84	23.10
22.	**Chlorophyll b**	24.69	23.24	88	45.08	13.80	12.22	18	22.30
23.	**Total Chlorophyll**	24.40	23.10	94	47.43	13.49	12.25	82	22.91
24.	**Canopy temperature**	1.85	0.60	10	0.68	2.36	1.69	51	2.49
25.	**NDVI**	9.70	9.17	89	17.92	8.61	7.39	73	13.08

PCV: Phenotypic Coefficient of Variation; GCV: Genotypic Coefficient of Variation; h^2_{BS}: Heritability in broad sense; GA: Genetic advance as per cent of mean.

conditions, the hybrids recorded low PCV (3.18%), GCV (2.98%), and GA (5.75%) with high heritability (87%).

4.3.1.2 Days to 50% silking

Under optimum condition, the inbreds showed low PCV (4.23%), GCV (3.20%) and GA (5.01%) but estimate of heritability was moderate (57%). Under heat stress condition, it showed low PCV (2.73%), GCV (1.10%), GAM (0.91%) and heritability (16%).

Similar observations were recorded for hybrids under heat stress and optimum conditions.

4.3.1.3 Anthesis to silking interval (ASI)

Inbred lines under optimum condition revealed moderate PCV (19.33%) and low GCV (7.16%) for ASI with low estimates of heritability (13%) and GA (5.47%). Under heat stress condition, the moderate PCV (22.61%) and low GCV (3.02%), heritability (1%) and GA (0.83%) were recorded.

Under optimum condition, the hybrids showed the moderate PCV (19.12%) GCV (14.80%) and heritability (60%) but GA was high (23.77%). Under heat stress condition, they showed the high PCV (31.38%), GCV (27.84%), heritability (78%) and GA (50.90%).

4.3.1.4 End of pollen shed duration (EPSD)

Under optimum condition, the inbreds showed the low PCV (4%) and GCV (2.91%). The estimate of heritability was moderate (53%) while GA (4.37%) was low. Whereas, under heat stress condition, inbreds showed low PCV (2.55%) GCV (0.43%), heritability (2%) and GA (0.15%) for the trait.

The hybrids under optimum condition recorded low PCV (3.09%), GCV (2.27%) and GA (3.4%) with moderate heritability (53%). Under heat stress condition, they exhibited similar trend with high heritability.

4.3.1.5 75% Brown husk maturity (BHM)

Inbreds showed low PCV (1.96%), GCV (1.61%) and low GA (2.73%) high heritability (67%) under optimum and heat stress condition.

However, hybrids under optimum condition showed low PCV (1.69%), GCV (1.07%) and GA (1.4%) with moderate heritability (40%). Under heat stress condition, similar trend was noticed with high heritability.

4.3.1.6 Plant height (cm)

Plant height, an important component of yield revealed moderate PCV (15.20%) and GCV (14.92%) under optimum condition. The estimates of heritability (96%) and GA were high (30.19%). Similar trend was also observed for trait under heat stress condition.

However, under optimum condition, the hybrids showed low PCV (6.92%) and GCV (6.79%). The estimate of heritability was high (96%) with moderate GA (13.73%). Under heat stress condition, the trend of the variability parameters for the trait was similar as that of optimum condition.

4.3.1.7 Ear height (cm)

Under optimum condition, the inbreds showed moderate PCV (17.79%) and GCV (17.79%) for ear height. The estimates of heritability (94%) and GA (34.61%) were high. Under heat stress condition, it showed the high PCV (22.66%), GCV (22.39%), heritability (97%) and GAM (45.56%).

Whereas, under optimum condition, the hybrids recorded low PCV (8.48%) and GCV (8.21%). The estimate of heritability was high (93%) moderate GA (16.37%). Under heat stress condition, hybrids showed the low PCV (5.62%) and GCV (5.40%). The estimate of heritability was high (92%) with moderate GA (10.70%).

4. 3.1.8 Leaf firing (%)

The inbreds recorded high PCV (96%), GCV (80%), heritability (96%) and GA (99%) under optimum condition. Whereas, under heat stress condition, inbreds revealed higher values for all the genetic components *viz*., PCV (90%), GCV (78%), heritability (98%) and GA (99%).

4.3.1.9 Tassel blast%

Under optimum condition, the inbreds recorded the high PCV (90%), GCV (75%), heritability (96%) and GA (94%). Similarly, under heat stress condition, it recorded the high PCV (88%), GCV (73%), heritability (99%) and GA (98%).

4.3.1.10 Silk length (cm)

The inbreds showed the low PCV (8.58%) and GCV (7.22%), heritability was high (82%) and GA moderate (13.54%) under optimum conditions. Contrarily, under heat stress condition, silk length showed the low PCV (7.48%) and GCV (3.42%) besides low heritability (18%) and GA (2.85%).

Under optimum condition, the hybrids exhibited the low PCV (5.77%), GCV (4.70%) and GA (7.91%) but heritability was high (66%). Under heat stress condition, it showed low PCV (4.88%), GCV (3.70%) and GA (5.80%) with moderate heritability (57%).

4.3.2 Physiological characters

4.3.2.1 Chlorophyll a content

Chlorophyll a content of inbreds at 60 DAS under optimum condition showed moderate PCV (11.71%) and low GCV (9.94%) with high heritability (72%) and GA (20.40%). Whereas, under heat stress condition even though inbreds revealed the moderate PCV (12.82%) and GCV (11.57%), they revealed high heritability (81%) and GA (21.51%).

Whereas Chlorophyll a content under optimum condition at 90 DAS for inbreds, exhibited the moderate PCV (19.03%) and low GCV (16.80%) with high heritability (78%) and GA (30.80%). Under stress condition, it showed the high PCV (33.73%), GCV (33.96%) heritability (95%) and GA (66.35%).

Under optimum condition at 60DAS, the hybrids recorded high PCV (42.84%), GCV (42.10%), heritability (96%) and high GA (45.56%). Under heat stress condition, the character exhibited moderate PCV (13.22%) and GCV (11.40%) with high heritability (74%) and GA (20.30%).

Whereas Chlorophyll a content under optimum condition at 90 DAS for hybrids, showed high PCV (24.20%), GCV (23.84%), heritability (97%) and GA (48.39%). Under heat stress condition, it showed the moderate PCV (13.27%) and GCV (12.20%) with high heritability (84%) and GA (23.10%).

4.3.2.2 Chlorophyll b content

The Chlorophyll b content recorded under optimum conditions at 60 DAS for the inbreds, showed moderate PCV (14.51%) and GCV (13.99%) with high heritability (92%) and GA (27.78%). Similar trend was also seen for the variability parameters, under heat stress condition.

The Chlorophyll b content recorded under optimum condition at 90DAS for the inbreds, showed the moderate PCV (12.02%) and low GCV (9.34%) with high heritability (60%) and moderate GA (14.99%). However, under heat stress condition, it recorded the high PCV (26.88%) and low GCV (9.34%) with high heritability (93%) and GA (51.61%).

Contrarily, the PCV (27.16%) and GCV (26.57%) values for hybrids were high under optimum condition at 60 DAS besides high heritability (95%) and GA (53.52%). While, under heat stress condition, all the genetic components *viz.,* PCV (7.04%), GCV (2.61%), heritability (13%) and GA (1.99%) were low for the trait.

Under optimum condition at 90 DAS, the hybrids exhibited high PCV (24.69%), GCV (23.24%) with high heritability (88%) and GA (45.08%) for the trait. While under heat stress condition, it recorded the moderate PCV (13.80%) and GCV (12.20%) with low heritability (18%) and high GA (22.30%).

4.3.2.3 Total chlorophyll content

The total chlorophyll content under optimum condition at 60DAS, the inbreds exhibited moderate PCV (12.42%) and GCV (11.90%) with high heritability (91%) and GA (23.45%). But under heat stress condition, the trait showed moderate PCV (12.56%) and GCV (10.83%) high heritability (74%) and moderate GA (19.25%).

Total chlorophyll content under optimum condition at 90DAS, the inbreds showed moderate PCV (11.71%) and low GCV (9.33%) with high heritability (62%) and moderate GA (15.26%). But under heat stress condition, the trait exhibited the high PCV (28.28%), GCV (27.81%), heritability (96%) and GA (56.34%).

Under optimum condition at 60DAS, the hybrids recorded high PCV (31.45%), GCV (31.08%), heritability (97%) and GA (63.29%) for the trait. However under heat stress condition, the trait showed the low PCV (6.72%) and GCV (4.95%). The estimate of heritability was moderate (53%) with low GA (7.47%).

Under optimum condition at 90 DAS, the hybrids recorded high PCV (24.40%), GCV (23.10%) heritability (94%) and GA (47.43%) for the trait. Under heat stress condition, it showed moderate PCV (13.49%) and GCV (12.25%). The estimates of heritability (82%) and GA (22.91%) were high.

4.3.2.4 Canopy temperature

Canopy temperature recorded under optimum condition at 60 DAS for inbreds revealed low PCV (6.09%) and GCV (5.24%). The estimate of heritability was high (74%) with low GA (9.31%). While under heat stress condition, it exhibited low PCV (2.55%), GCV (0.69%), heritability (7.00%) and GA (0.38%).

Whereas under optimum condition at 90DAS, the inbreds exhibited moderate PCV (4.56%) and low GCV (2.69%) with high heritability (34%) and moderate GA (3.27%) for the trait. While under heat stress condition, the trait showed the low PCV (3.58%) and GCV (2.83%) with high heritability (62%) and low GA (4.62%).

Under optimum condition at 60DAS, the hybrids recorded low PCV (1.85%) GCV (0.60%), heritability (10%) and GA (0.48%) for the trait .Whereas under heat stress condition, the trait showed the low PCV (2.36%) and GCV (1.69%) with moderate heritability (51%) and low GA (0.12%).

Canopy temperature recorded under optimum condition at 90 DAS for hybrids, showed low PCV (1.85%), GCV (0.60%), heritability (10%) and GA (0.68%).Similar picture was noticed for the trait under heat stress condition.

4.3.2.5 Normalized difference vegetative index (NDVI)

NDVI recorded under optimum condition at 60 DAS for the inbreds, revealed low PCV (9.04%) and GCV (8.43%). But estimates of heritability (86%) and GA (26.28%) were high for the trait. However, under heat stress condition, the trait exhibited the moderate PCV (10.98%) and low GCV (7.19%) with moderate heritability (42%) and GA (14.92%).

The NDVI recorded at 90DAS for the inbreds under optimum condition revealed moderate PCV (14.22%) and low GCV (13.47%). The estimates of heritability (89%) and GA were high (26.28%) for the trait under optimum condition. But the trait showed the moderate PCV (16.87%), GCV (11.05%), heritability (42%) and GA (14.92%) under heat stress condition.

Under optimum condition at 60DAS, the hybrids showed low PCV (2.78%) and GCV (2.41%) with high heritability (75%) and moderate GA (17.92%) for the trait .Whereas under heat stress condition, the trait showed low PCV (4.09%) and GCV (2.07%) with moderate heritability (25%) and low GA (2.49%).

Under optimum condition at 90 DAS under optimum condition, the hybrids exhibited low PCV (9.70%) and GCV (9.17%) with high heritability (89%) and moderate GA (17.92%) for the trait. Similar trend was also observed for the variability parameters under heat stress condition.

4.3.3 Yield characters

4.3.3.1 Cob length (cm)

Both the inbreds as well as hybrids revealed moderate PCV (14.12% and 13.63%) and GCV (10.92% and12.70%), under optimum conditions. The heritability (59%) and GA (17.39%) were moderate for inbreds, but hybrids recorded higher heritability and GA (86% and 24.39%, respectively). However, under heat stress condition, inbreds recorded moderate PCV (16.93%) and GCV (14.31%), even though the estimates of heritability (71%) and GA were high (24.94%). Under same environmental conditions hybrids showed low PCV (9.39%) and GCV (7.19%) with moderate heritability (58%) and GA (11.34%).

4.2.3.2 Cob girth (cm)

Cob girth of inbreds showed moderate PCV (11.73%) low GCV (9%) with moderate heritability (58%) and GA (14.22%) under optimum condition. Whereas under heat stress condition, it recorded moderate PCV (16.93%), GCV (13.38%) and heritability (69%) with high GA (22.93%).

Under optimum condition, the hybrids showed low PCV (7.93%) and GCV (6.28%). The estimate of heritability was high (62%) with moderate GA (10.24%). While under heat stress condition, it recorded low PCV (7.91%) and GCV (5.95%) with moderate heritability (56%) and low GA (9.21%).

4.2.3.3 Number of kernels per cob

Number of kernels per cob in inbreds exhibited moderate PCV (20.32%) and GCV (18.50%) with high heritability (82%) high GA (34.69%).Whereas, under stress condition, it showed the high PCV (51.38%), GCV (50.40%), heritability (96%) and GA (95.5%).

Whereas, hybrids showed the moderate PCV (11.26%) and GCV (10.72%) with high heritability (90%) and high GA (21.04%) under optimum condition. Under heat stress condition, it recorded the moderate PCV (19.05%) and GCV (17.41%) with high heritability (83%) and high GA (32.77%).

4.2.3.4 Shelling percentage

The inbreds showed low PCV (3.95%) and GCV (3.50%) with high heritability (78%) and low GA (6.40%) under optimum condition. However under heat stress condition, it recorded low PCV (7.24%) and GCV (6.26%) with high heritability (75%) and moderate GA (11.17%).

Shelling percentage of hybrids showed low PCV (2.58%) and GCV (25%). The estimate of heritability was high (75%) with low GA (4.03%) under optimum condition. But under heat stress condition, it recorded moderate PCV (10.01%) and GCV low (9.19%) with high heritability (84%) and low GA (4.30%).

4.2.3.5 Grain Yield per plant (g)

Grain yield per plant of the inbreds recorded moderate PCV (11.31%) and GCV (10.51%) with high heritability (86%) and high GA (20.15%).Whereas, under stress condition, it showed the high PCV (46.18%), GCV (45.11%), heritability (95%) and GA (90.79%).

Under optimum condition, the hybrids showed low PCV (9.01%) and GCV (8.01%) with high heritability (79%) and moderate GA (14.67%). While under heat stress condition, it showed low PCV (3.65%) and GCV (2.76%) with moderate heritability (57%) and low GA (6.31%).

4.2.3.6 100 grain weight (g)

The inbreds showed low PCV (9.33%) and GCV (7.71%) with high heritability (68%) and moderate GA (13.14%) under optimum condition. Whereas under heat stress condition, the trait recorded moderate PCV (10.26%) and low GCV (8.56%) with high heritability (66%) and moderate GA (14.71%).

Hundred grain weight of hybrids showed moderate PCV (11.81%) and GCV (10.53%) with high heritability (75%) and moderate GA (19.35%) under optimum condition. Whereas under heat stress condition, it recorded low PCV (7.55%) and GCV (4.81%) with moderate heritability (40%) and moderate GA (17.39%).

4.2.3.7 Grain yield (kg ha^{-1})

Grain yield of the inbreds under optimum condition recorded high PCV (44.30%), GCV (43.86%), heritability (98%) and GA (89.45%). While under heat stress condition, it recorded the high PCV (51.61%), GCV (50.39%), heritability (95%) and GA (98.5%).

Similarly, hybrids also recorded high PCV, GCV with high heritability and GA under optimum and heat stress conditions.

4.4 Phenotypic and genotypic correlation coefficients between grain yield and its selected attributing traits in inbreds and hybrids under optimum and heat stress conditions

To aid the selection process, it is always essential to have the information on nature of association of characters with economic yield. Hence, the correlation co-efficient between the characters were computed at phenotypic level and genotypic level. The associations among different characters are presented in the fallowing headings.

4.4.1 Phenotypic and genotypic correlation coefficients between grain yield and its attributing traits in inbreds under optimum condition

The phenotypic and genotypic correlations estimated for 14 characters to determine their nature of relationship with yield under optimum condition are presented in Table 12. Generally, the genotypic correlation coefficients were higher than phenotypic

Table 12. Phenotypic and genotypic correlation coefficients between grain yield and its attributing traits in inbreds under optimum temperature condition

Characters		50% A	50% S	ASI	75% BHM	PH	SL	LF %	TB %	Chl a 1	Chl b 1	NDVI 1	NKC	100 GW	GYP
50% A	**P**	**1.000**	0.960**	0.209	0.268	-0.009	0.083	0.180	0.137	-0.043	-0.151	-0.049	0.030	0.066	-0.136
	G	**1.000**	0.970**	0.705**	0.444**	-0.050	0.147	0.245	0.274	-0.021	-0.167	0.329	0.024	0.126	-0.040
50% S	**P**		**1.000**	0.445**	0.260	-0.055	-0.129	0.190	0.157	0.061	-0.131	0.065	-0.030	-0.101	-0.192
	G		**1.000**	0.589**	0.314	-0.029	-0.214	0.258	0.280	0.054	-0.132	0.284	-0.013	-0.034	-0.090
ASI	**P**			**1.000**	-0.046	-0.263	-0.216	0.121	0.139	0.067	0.054	-0.133	-0.100	-0.138	-0.229
	G			**1.000**	-0.505**	-0.906**	-0.674**	0.391*	0.367*	0.379*	0.389*	-0.247	-0.696**	-0.443**	-0.466**
75% BHM	**P**				**1.000**	0.276	0.116	-0.263	-0.268	0.014	0.148	0.307	0.253	0.368*	0.374*
	G				**1.000**	0.421*	0.282	-0.312	-0.308	0.234	0.168	0.588**	0.376*	0.661**	0.493**
PH	**P**					**1.000**	0.406*	-0.292	-0.281	0.392*	0.362*	0.624**	0.358*	0.320	0.329*
	G					**1.000**	0.540**	-0.312	-0.340*	0.603**	0.407*	0.692**	0.380*	0.562**	0.393*
SL	**P**						**1.000**	-0.250	-0.263	0.235	0.206	0.316	0.115	0.232	0.199
	G						**1.000**	-0.271	-0.273	0.227	0.219	0.447**	0.216	0.208	0.288
LF%	**P**							**1.000**	0.969**	-0.445**	-0.521**	-0.411*	-0.283	-0.402*	-0.607**
	G							**1.000**	0.980**	-0.586**	-0.553**	-0.464**	-0.330	-0.621**	-0.712**
TB%	**P**								**1.000**	-0.473**	-0.535**	-0.414**	-0.248	-0.392*	-0.632**
	G								**1.000**	-0.579**	-0.515**	-0.477**	-0.346*	-0.652**	-0.742**
Chl a 1	**P**									**1.000**	0.568**	0.487**	0.172	0.173	0.281
	G									**1.000**	0.754**	0.730**	0.326	0.281	0.460**
Chl b 1	**P**										**1.000**	0.661**	0.248	0.165	0.352*
	G										**1.000**	0.738**	0.256	0.305	0.437**
NDVI 1	**P**											**1.000**	0.407*	0.372*	0.354*
	G											**1.000**	0.517**	0.621**	0.413**
NKC	**P**												**1.000**	0.312	0.151
	G												**1.000**	0.548**	0.210
100 GW	**P**													**1.000**	0.473**
	G													**1.000**	0.538**
GYP	**P**														**1.000**
	G														**1.000**

* and ** - Significant at 0.05 and 0.01 level of probability, respectively; 50% A: Days to 50% anthesis; 50% S: Days to 50% silking; ASI: Anthesis to silking interval; 75%BHM: 75% Brown husk maturity; PH: Plant-height; SL: Silk length; LF% : Leaf firing %; TB%: Tassel blast %; Chl a 1: Chlorophyll a 60 DAS; Chl b 1: Chlorophyll b 60 DAS; NDVI 1: Normalized difference vegetative index 60 DAS; NKC: Number of kernels per cob; 100 GW: 100 Grain weight; GYP: Grain yield per plant.

correlation coefficients indicating the importance of genotypic difference in determining the association.

The grain yield per plant exhibited significant positive association with 100 grain weight (0.473, 0.538), 75% BHM (0.374, 0.493), NDVI (0.354, 0.413), Chl b (0.352, 0.437) and plant height (0.329, 0.393) at both phenotypic and genotypic levels. Whereas, grain yield showed significant negative association with tassel blast per cent (-0.632, -0.742) and leaf firing per cent (-0.607, -0.712) at both phenotypic and genotypic levels. However, it recorded significant positive association with Chl a (0.460) and significant negative correlation with ASI (-0.466) only at genotypic level.

Days to 50 per cent anthesis exhibited significant positive association with days to 50 per cent silking (0.960, 0.970); days to 50 per cent silking with ASI (0.445, 589) ; 75 per cent BHM with 100 grain weight (0.368, 0.661); plant height with silk length (0.406, 0.540), Chl a (0.392, 0.603), Chl b (0.362, 0.407), NDVI (0.624, 0.692) and number of kernels per cob (0.358, 0.380); leaf firing percent with tassel blast percent (0.969, 0.980); Chl a with Chl b (0.568, 0.754) and NDVI (0.487, 0.730); Chl b with NDVI (0.661 0.738); NDVI with number of kernels per cob (0.407, 0.517) and 100 grain weight (0.372, 0.621) at both phenotypic and genotypic levels. However, days to 50 per cent anthesis showed significant positive association with ASI (0.705) and 75 per cent BHM (0.444) ; ASI with leaf firing percent (0.391), tassel blast per cent (0.367), Chl a (0.379) and Chl b (0.389); 75 per cent BHM with plant height (0.421), NDVI (0.588) and number of kernels per cob (0.376) and number of kernels per cob with 100 grain weight (0.548) at genotypic level.

Contrary to this, leaf firing per cent exhibited significant negative association with Chl a (-0.445, -0.586), Chl b (-0.521, -0.553), NDVI(-0.411, -0.464) and 100 grain weight (-0.402, -0.621) and tassel blast per cent with Chl a (-0.473, -0.579), Chl b (-0.535, -0.575), NDVI(-0.414, -0.477) and 100 grain weight (-0.392, -0.652) at both phenotypic and genotypic levels. However, ASI showed significant negative association with 75 per cent BHM (-0.505), plant height (-0.906), silk length (-0.674), number of kernels per cob (-0.696), and 100 grain weight (-0.443); plant height with tassel blast per cent (-0.340); tassel blast per cent with number of kernels per cob (-0.346) at genotypic level only.

4.4.2 Phenotypic and genotypic correlation coefficients between grain yield and its attributing traits in inbreds under heat stress condition

The 14 selected characters were used for studying the phenotypic and genotypic association between grain yield and its attributing traits in inbreds under heat stress condition and the results were presented in Table 13. The grain yield per plant exhibited significant positive association with plant height (0.365, 0.393), number of kernels per cob (0.905, 0.882) and 100 grain weight (0.482, 0.598), and negative significant correlation exhibited with the leaf firing (-0.423, -0.445) and tassel blast%(-0.569,-0.607) at both phenotypic and genotypic levels. The character ASI exhibited significant negative correlation at genotypic level.

Days to 50 percent anthesis recorded significant positive association with days to 50 per cent silking (0.887, 0.890); days 50 per cent silking with ASI (0.383, 0.394); plant height with Chl a (0.347, 0.416), Chl b (0.416, 0.614), NDVI (0.480,0.858), number of kernels per cob (0.423, 0.450) and 100 grain weight (0.346, 0.460); Leaf firing per cent with tassel blast per cent (0.841 0.845); number of kernels per cob with 100 grain weight (0.472, 0.610) at both phenotypic and genotypic levels. However, days to 50 per cent anthesis showed significant positive association with 75 per cent BHM (0.562), leaf firing per cent (0.382), and 100 grain weight (0.405); days to 50 per cent silking showed significant positive association with 75 per cent BHM (0.846) and Chl b (0.470); ASI with tassel blast per cent (0.943); 75% BHM with Chl b (0.864) followed by plant height (0.632), Chl a (0.499) and NDVI (0.392); silk length with number of kernels per cob (0.406); Chl a with Chl b (0.463) and NDVI (0.413); Chl b with NDVI (0.611) and 100 grain weight (0.550) and NDVI with 100 grain weight (0.507) at genotypic level only.

On the contrary, leaf firing percent exhibited significant negative association with Chl b (-0.356, -0.577), number of kernels per cob (-0388, -0.399) and 100 grain weight (-0.580 -0.840) and tassel blast per cent with number of kernels per cob (-0542, -0.567) and 100 grain weight (-0.628, -0.881) at both phenotypic and genotypic levels. However, days 50 per cent silking exhibited significant negative association with leaf firing per cent (-0.642) and Chl a (-0.629); ASI with 75 per cent BHM (-0.696) and plant height (-0.916); silk length with leaf firing per cent (-0.780) and tassel blast per cent (-0.626) and tassel blast per cent with Chl b (-0.397) at genotypic level only.

Table 13. Phenotypic and genotypic correlation coefficients between grain yield and its attributing traits in inbreds under heat stress conditions

Characters		**50% A**	**50% S**	**ASI**	**75% BHM**	**PH**	**SL**	**LF %**	**TB %**	**Chl a 1**	**Chl b 1**	**NDVI 1**	**NKC**	**100 GW**	**GYP**
50% A	**P**	**1.000**	0.887**	0.088	0.093	-0.062	0.176	0.180	0.120	-0.199	-0.060	-0.018	0.031	0.140	0.112
	G	**1.000**	0.890**	0.104	0.562**	-0.102	0.273	0.382*	0.265	-0.355	-0.095	0.271	0.043	0.405*	0.309
50% S	**P**		**1.000**	0.383*	0.072	-0.090	0.122	-0.153	-0.062	-0.163	0.021	0.080	-0.095	0.091	-0.021
	G		**1.000**	0.394*	0.846**	-0.307	0.242	-0.642**	-0.308	-0.629**	0.470**	0.087	-0.385	0.285	-0.007
ASI	**P**			**1.000**	-0.031	-0.070	-0.091	0.030	0.107	0.048	0.164	0.137	-0.266	-0.082	-0.270
	G			**1.000**	-0.696**	-0.916**	-0.121	0.012	0.943**	0.209	0.289	0.184	-0.115	-0.059	-0.341*
75% BHM	**P**				**1.000**	0.270	0.111	-0.052	-0.110	0.303	0.058	0.267	0.131	0.239	0.074
	G				**1.000**	0.632**	0.086	-0.110	-0.215	0.499**	0.864**	0.392*	0.199	0.451	0.142
PH	**P**					**1.000**	0.089	-0.422*	-0.334	0.347*	0.416*	0.480**	0.423*	0.346	0.365*
	G					**1.000**	0.202	-0.431	-0.341	0.416**	0.614**	0.858**	0.450**	0.460**	0.393*
SL	**P**						**1.000**	-0.285	-0.209	0.075	0.080	0.168	0.065	0.108	0.034
	G						**1.000**	-0.780**	-0.626**	0.229	0.142	0.308	0.406**	0.154	0.346
LF%	**P**							**1.000**	0.841**	-0.270	-0.356*	-0.115	-0.388*	-0.580**	-0.423*
	G							**1.000**	0.845**	-0.321	-0.577**	-0.223	-0.399*	-0.840**	-0.445*
TB%	**P**								**1.000**	-0.228	-0.262	-0.152	-0.542**	-0.628**	-0.569**
	G								**1.000**	-0.280	-0.397*	-0.275	-0.567**	-0.881**	-0.607**
Chl a 1	**P**									**1.000**	0.187	0.043	0.121	0.069	0.135
	G									**1.000**	0.463**	0.413*	0.134	0.148	0.157
Chl b 1	**P**										**1.000**	0.180	0.061	0.242	-0.036
	G										**1.000**	0.611**	0.112	0.550**	-0.020
NDVI 1	**P**											**1.000**	0.165	0.315	0.144
	G											**1.000**	0.219	0.507**	0.263
NKC	**P**												**1.000**	0.472**	0.882**
	G												**1.000**	0.610**	0.905**
100 GW	**P**													**1.000**	0.482**
	G													**1.000**	0.598**
GYP	**P**														**1.000**
	G														**1.000**

* and** - Significant at 0.05 and 0.01 level of probability, respectively; 50% A: Days to 50% anthesis; 50% S: Days to 50% silking; ASI: Anthesis to silking interval; 75%BHM: 75% Brown husk maturity; PH: Plant-height; SL: Silk length; LF% : Leaf firing %; TB%: Tassel blast %; Chl a 1: Chlorophyll a 60 DAS; Chl b 1: Chlorophyll b 60 DAS; NDVI 1: Normalized difference vegetative index 60 DAS; NKC: Number of kernels per cob; 100 GW: 100 Grain weight; GYP: Grain yield per plant.

4.4.3 Phenotypic and genotypic correlation coefficients between grain yield and its attributing traits in hybrids under optimum condition

The phenotypic and genotypic correlations estimated among 14 characters to determine their nature of relationship with yield under optimum condition are presented in Table 14. The grain yield per plant exhibited significant positive association with 75% BHM (0.776) followed by 100 grain weight (0.751) only at genotypic level.

Days to 50 per cent anthesis recorded significant positive association with days to 50 per cent silking (0.958, 0.977); plant height with Chl a (0.595, 0.662), Chl b (0.581, 0.703) and NDVI (0.590, 0.882); Chl a with Chl b (0.812, 0.901) and Chl b with NDVI (0.598, 0.836) at both phenotypic and genotypic levels. However, days to 50 per cent anthesis recorded significant positive association with 75 percent BHM (0.911), planth height (0.854), Chl a (0.678) and NDVI (0.720); Days to 50 per cent silking with the 75% BHM (0.865), followed by NDVI (0.842), plant height (0.808) and Chl a (0.673); ASI with NDVI (0.666) and Chl a with NDVI (0.686) only at genotypic level.

ASI exhibited significant negative association with silk length (-0.693) and number of kernels per cob (-0684) only at genotypic level.

4.4.4 Phenotypic and genotypic correlation coefficients between grain yield and its attributing traits in hybrids under heat stress condition

The 14 selected characters were used for studying the phenotypic and genotypic association with grain yield in hybrids under heat stress condition and the results are presented in Table 15. The grain yield exhibited significant genotypic positive and negative association with silk length (0.920) and plant height (-0.748), respectively.

Days to 50 percent anthesis recorded significant positive association with days to 50 per cent silking (0.899, 0.934) and days to 50 per cent silking with 75% BHM (0.617, 0.715) at both phenotypic and genotypic level. However, days to 50 per cent silking recorded significant positive association with ASI (0.605); 75% BHM with plant height (0.705), followed by 100 grain weight (0.671) and Chl a (0.603); silk length with NDVI (0.941) and Chl b with NDVI (0.611) at only genotypic level.

ASI exhibited significant negative association with silk length (-0.850) and plant height with silk length (-0.718) at only genotypic level.

Table 14. Phenotypic and genotypic correlation coefficients between grain yield and its attributing traits in hybrids under optimum temperature condition

Characters		**50% A**	**50%S**	**ASI**	**75% BHM**	**PH**	**SL**	**Chl a 1**	**Chl b 1**	**NDVI 1**	**NKC**	**100 GW**	**GYP**
50% A	**P**	**1.000**	0.958**	0.132	0.459	0.355	0.228	0.418	0.280	0.201	0.144	0.052	0.170
	G	**1.000**	0.977**	0.349	0.911**	0.854**	0.076	0.678*	0.478	0.720**	0.193	0.293	0.412
50% S	**P**		**1.000**	0.349	0.515	0.384	-0.235	0.453	0.318	0.255	0.062	0.077	0.182
	G		**1.000**	0.403	0.865**	0.808**	0.210	0.673*	0.489	0.842**	-0.043	0.402	0.324
ASI	**P**			**1.000**	0.317	0.001	-0.072	0.327	0.253	0.172	-0.361	0.085	-0.113
	G			**1.000**	0.157	0.097	-0.693*	0.486	0.360	0.666**	-0.684**	0.422	-0.527
75% BHM	**P**				**1.000**	0.089	-0.123	0.071	0.122	0.100	0.058	0.234	0.095
	G				**1.000**	0.365	0.108	0.239	0.016	0.339	0.025	0.319	0.776**
PH	**P**					**1.000**	0.085	0.595*	0.581*	0.590*	-0.071	-0.026	0.116
	G					**1.000**	0.184	0.662*	0.703*	0.882**	-0.005	-0.119	0.170
SL	**P**						**1.000**	-0.152	0.112	0.237	0.242	-0.006	-0.149
	G						**1.000**	-0.106	0.177	0.286	0.379	0.106	-0.064
Chl a 1	**P**							**1.000**	0.812**	0.436	-0.172	-0.110	-0.072
	G							**1.000**	0.901**	0.686*	-0.222	-0.107	-0.074
Chl b 1	**P**								**1.000**	0.598*	0.016	-0.119	-0.079
	G								**1.000**	0.836**	0.074	-0.053	-0.054
NDVI 1	**P**									**1.000**	-0.003	0.227	0.125
	G									**1.000**	-0.081	0.155	0.303
NKC	**P**										**1.000**	-0.105	0.267
	G										**1.000**	-0.177	0.568
100 GW	**P**											**1.000**	0.458
	G											**1.000**	0.751**
GYP	**P**												**1.000**
	G												**1.000**

* and ** - Significant at 0.05 and 0.01 level of probability, respectively; 50% A: Days to 50% anthesis; 50% S: Days to 50% silking; ASI: Anthesis to silking interval; 75%BHM: 75% Brown husk maturity; PH: Plant-height; SL: Silk length; Chl a 1: Chlorophyll a 60 DAS; Chl b 1: Chlorophyll b 60 DAS; NDVI 1: Normalized difference vegetative index 60 DAS; NKC: Number of kernels per cob; 100 GW: 100 Grain weight; GYP: Grain yield per plant.

Table 15. Phenotypic and genotypic correlation coefficients between grain yield and its attributing traits in hybrids under heat stress condition

Characters		**50% A**	**50%S**	**ASI**	**75% BHM**	**PH**	**SL**	**Chl a 1**	**Chl b 1**	**NDVI 1**	**NKC**	**100 GW**	**GYP**
50% A	**P**	**1.000**	0.899**	0.103	0.487	0.283	0.176	0.020	0.024	0.035	-0.249	0.251	0.093
	G	**1.000**	0.934**	0.304	0.848	0.303	0.328	0.020	0.356	0.159	-0.466	0.431	0.069
50% S	**P**		**1.000**	0.491	0.617*	0.414	0.009	0.187	-0.120	0.065	-0.364	0.361	-0.027
	G		**1.000**	0.605*	0.715*	0.517	0.030	0.281	-0.300	0.492	-0.532	0.471	-0.053
ASI	**P**			**1.000**	0.505	0.293	-0.359	0.367	-0.317	0.020	-0.265	0.418	-0.135
	G			**1.000**	0.529	0.589	-0.850**	0.593	-0.011	0.027	-0.217	0.427	-0.224
75% BHM	**P**				**1.000**	0.431	-0.322	0.459	0.036	-0.130	-0.262	0.386	-0.096
	G				**1.000**	0.705**	-0.393	0.603*	0.072	-0.400	-0.318	0.671*	-0.327
PH	**P**					**1.000**	-0.330	0.466	0.229	0.180	-0.024	0.076	-0.356
	G					**1.000**	-0.718**	0.593	0.200	0.462	-0.150	0.107	-0.748**
SL	**P**						**1.000**	-0.147	0.074	0.166	-0.008	0.114	0.353
	G						**1.000**	-0.526	0.068	0.941**	-0.492	0.101	0.920**
Chl a 1	**P**							**1.000**	0.026	0.140	0.034	0.183	-0.038
	G							**1.000**	0.352	0.464	0.110	0.159	-0.424
Chl b 1	**P**								**1.000**	0.195	0.060	0.153	-0.114
	G								**1.000**	0.661*	0.347	0.182	-0.269
NDVI 1	**P**									**1.000**	-0.246	0.057	-0.093
	G									**1.000**	-0.532	0.106	-0.112
NKC	**P**										**1.000**	-0.338	0.038
	G										**1.000**	-0.468	0.263
100 GW	**P**											**1.000**	0.240
	G											**1.000**	0.333
GYP	**P**												**1.000**
	G												**1.000**

* and ** - Significant at 0.05 and 0.01 level of probability, respectively; 50% A: Days to 50% anthesis; 50% S: Days to 50% silking; ASI: Anthesis to silking interval; 75%BHM: 75% Brown husk maturity; PH: Plant-height; SL: Silk length; Chl a 1: Chlorophyll a 60 DAS; Chl b 1: Chlorophyll b 60 DAS; NDVI 1: Normalized difference vegetative index 60 DAS; NKC: Number of kernels per cob; 100 GW: 100 Grain weight; GYP: Grain yield per plant.

4.5 Direct and indirect effects of selected characters on grain yield at phenotypic and genotypic level in inbreds under optimum and heat stress condition

To get the idea about the actual effects of a character on the yield, path analysis was employed. When a dependent character like yield is to be improved, it is governed by many independent characters through direct or indirect effects via other characters. Hence, sometimes even character showing significant correlation with the yield may not be considered for improvement as its correlation with yield may be due to the indirect effects of the trait through other characters. Under these circumstances, it is always more appropriate to split the correlation value into direct and indirect effects through path coefficient analysis. It will facilitate for weightage to be given while considering a character for selection to improve economic yield.

4.5.1 Direct and indirect effects of selected characters on grain yield at phenotypic level in inbreds under optimum condition

Path coefficient phenotypic values for direct and indirect effects of different traits on grain yield are presented in Table 16.

4.5.1.1 Direct effects of selected characters on grain yield

Eight out of 14 characters exhibited positive and direct effect on grain yield at phenotypic level. The character days to 50 per cent anthesis (0.478) recorded highest positive direct effect on grain yield followed by 75% BHM (0.224), 100 grain weight (0.201) and plant height (0.117).

4.5.1.2 Indirect effects of selected characters on grain yield

High indirect positive effect on grain yield was exhibited by days to 50 per cent silking through days to 50 per cent anthesis (0.459); Chl b via tassel blast per cent (0.336). However, Chl a via tassel blast per cent (0.297); NDVI through tassel blast per cent (0.260) and 100 grain weight via tassel blast per cent (0.246) exhibited moderate indirect positive influence on grain yield.

Whereas low indirect positive effect on grain yield was exhibited by days to 50 per cent anthesis through 75 percent BHM (0.060), leaf firing percent (0.032), ASI (0.008), and silk length (0.006); days to 50 per cent silking via 75 per cent BHM (0.058), ASI (0.018) and leaf firing% (0.033); 75 percent BHM through tassel blast per cent

Table 16. Direct and indirect effects between selected characters and grain yield at phenotypic level in inbred under optimum condition

Characters	**50% A**	**50% S**	**ASI**	**75% BHM**	**PH**	**SL**	**LF%**	**TB%**	**Chl a 1**	**Chl b 1**	**NDVI 1**	**NKC**	**100 GW**	**‘r’ with GYP**
50% A	**0.478**	-0.622	0.008	0.060	0.001	0.006	0.032	-0.086	0.001	-0.005	0.002	0.004	-0.013	-0.136
50% S	0.459	**-0.647**	0.018	0.058	-0.006	0.009	0.033	-0.098	0.002	-0.004	0.002	0.003	-0.020	-0.192
ASI	0.100	-0.288	**0.040**	0.010	-0.031	0.015	0.021	-0.087	0.002	0.002	0.004	0.011	-0.028	-0.229
75% BHM	0.128	-0.169	0.002	**0.224**	0.032	-0.008	-0.046	0.169	0.001	0.005	-0.010	-0.027	0.074	0.374*
PH	0.001	0.035	-0.010	0.062	**0.117**	-0.027	-0.051	0.177	0.011	0.011	-0.020	-0.039	0.064	0.329
SL	-0.04	0.084	-0.009	0.026	0.047	**-0.067**	-0.044	0.165	0.006	0.007	-0.010	-0.013	0.047	0.199
LF%	0.086	-0.123	0.005	-0.059	-0.034	0.017	**0.175**	-0.609	-0.012	-0.016	0.013	0.031	-0.081	-0.607**
TB%	0.066	-0.101	0.006	-0.060	-0.033	0.018	0.170	**-0.628**	-0.013	-0.017	0.014	0.027	-0.079	-0.632**
Chl a 1	0.021	-0.039	0.003	0.003	0.046	-0.016	-0.078	0.297	**0.027**	0.018	-0.016	-0.019	0.035	0.281
Chl b 1	-0.072	0.085	0.002	0.033	0.042	-0.014	-0.091	0.336	0.015	**0.031**	-0.022	-0.027	0.033	0.352*
NDVI 1	-0.024	0.042	-0.005	0.069	0.073	-0.021	-0.072	0.260	0.013	0.021	**-0.033**	-0.044	0.075	0.354*
NKC	-0.016	0.019	-0.004	0.057	0.042	-0.008	-0.050	0.156	0.005	0.008	-0.013	**-0.108**	0.063	0.151
100 GW	-0.032	0.065	-0.005	0.083	0.037	-0.016	-0.071	0.246	0.005	0.005	-0.012	-0.034	**0.201**	0.473**

50% A: Days to 50% anthesis; 50% S: Days to 50% silking; ASI: Anthesis to silking interval; 75%BHM: 75% Brown husk maturity; PH: Plant-height; SL: Silk length; LF% : Leaf firing %; TB%: Tassel blast %; Chl a 1: Chlorophyll a 60 DAS; Chl b 1: Chlorophyll b 60 DAS; NDVI 1: Normalized difference vegetative index 60 DAS; NKC: Number of kernels per cob; 100 GW: 100 Grain weight; GYP: Grain yield per plant

(0.169), days to 50 per cent anthesis (0.128), plant height (0.032); plant height through tassel blast per cent (0.177), 100 grain weight (0.064) and 75% BHM (0.062); silk length via tassel blast per cent (0.165), days to 50 per cent anthesis (0.084) and plant height (0.047); leaf firing per cent through days to 50 per cent anthesis (0.086) ,number of kernels per cob (0.031) and silk length (0.017); tassel blast% via leaf firing% (0.170) and days to 50 per cent anthesis (0.066); Chl a through days to 50 per cent anthesis (0.021), plant height(0.046) and 100 grain weight (0.035). Chl b via days to 50 per cent silking (0.085), 75% BHM (0.033), plant height (0.042) and 100 grain weight (0.033); NDVI through 100 grain weight (0.075) and plant height (0.073) and 75% BHM (0.069); Number of kernels per cob through tassel blast% (0.156), 75% BHM (0.159) and100 grain weight (0.063); and 100 grain weight via days to 50 per cent silking (0.065), plant height (0.037) and 75% BHM (0.083).

4.5.2 Direct and indirect effects of selected characters on grain yield at genotypic level in inbreds under optimum condition

Path coefficient genotypic values for direct and indirect effects of different traits on grain yield are presented in Table 17.

4.5.2.1 Direct effects of various characters on grain yield

Eight out of 14 characters recorded positive and direct effect on grain yield at genotypic level. The characters that had low positive direct effect on grain yield were number of kernels per cob (0.082) followed by silk length (0.051) and ASI (0.027).Whereas high positive direct effect on grain yield were tassel blast per cent (0.633) followed by Chl b (0.595) ,plant height (0.592), 75% BHM(0.423) and days to 50 per cent anthesis (0.412).

4.5.2.2 Indirect effects of various characters on grain yield

The indirect high positive effect on grain yield was exhibited by days to 50 per cent silking through days to 50 per cent anthesis (0.417); 75 per cent BHM through leaf firing per cent (0.471); plant height via leaf firing per cent (0.471); silk length via leaf firing per cent (0.409) followed by plant height (0.302); leaf firing per cent through tassel blast per cent (0.652) followed by NDVI (0.420); tassel blast per cent via NDVI (0.432) and Chl a (0.169); Chl a through leaf firing per cent (0.884) followed by Chl b (0.448)

Table 17. Direct and indirect effects between selected characters and grain yield at genotypic level in inbred under optimum condition

Characters	50% A	50% S	ASI	75% BHM	PH	SL	LF%	TB%	Chl a 1	Chl b 1	NDVI 1	NKC	100 GW	'r' with GYP
50% A	**0.412**	-0.055	0.019	0.188	0.030	-0.008	-0.370	0.173	-0.006	-0.099	-0.298	0.002	-0.029	-0.040
50% S	0.417	**-0.054**	0.016	0.133	-0.017	-0.011	-0.389	0.177	-0.016	-0.078	-0.258	-0.001	-0.008	-0.09
ASI	0.291	-0.032	**0.027**	-0.214	-0.536	-0.035	-0.590	0.233	-0.110	0.231	0.224	-0.057	0.102	-0.466**
75% BHM	0.183	-0.017	-0.014	**0.423**	0.249	0.015	0.471	-0.195	-0.068	0.100	-0.532	0.031	-0.152	0.493**
PH	0.021	0.002	-0.025	0.178	**0.592**	0.028	0.471	-0.215	-0.176	0.242	-0.627	0.031	-0.129	0.393**
SL	-0.061	0.012	-0.018	0.119	0.302	**0.051**	0.409	-0.173	-0.066	0.130	-0.405	0.018	-0.048	0.288
LF%	0.101	-0.014	0.011	-0.132	-0.185	-0.014	**-1.508**	0.652	0.171	-0.329	0.420	-0.027	0.143	-0.712**
TB%	0.113	-0.015	0.010	-0.130	-0.201	-0.014	-1.553	**0.633**	0.169	-0.306	0.432	-0.028	0.15	-0.742**
Chl a 1	0.009	-0.003	0.010	0.099	0.357	0.012	0.884	-0.366	**-0.291**	0.448	-0.661	0.027	-0.065	0.460**
Chl b 1	-0.069	0.007	0.011	0.071	0.241	0.011	0.834	-0.326	-0.220	**0.595**	-0.669	0.021	-0.07	0.437**
NDVI 1	0.136	-0.015	-0.007	0.249	0.41	0.023	0.700	-0.302	-0.212	0.439	**-0.906**	0.042	-0.143	0.413*
NKC	0.010	0.001	-0.019	0.159	0.225	0.011	0.498	-0.219	-0.095	0.152	-0.469	**0.082**	-0.126	0.210
100 GW	0.052	-0.002	-0.012	0.280	0.333	0.011	0.937	-0.413	-0.082	0.181	-0.562	0.045	**-0.23**	0.538**

50% A: Days to 50% anthesis; 50% S: Days to 50% silking; ASI: Anthesis to silking interval; 75%BHM: 75% Brown husk maturity; PH: Plant-height; SL: Silk length; LF% : Leaf firing %; TB%: Tassel blast %; Chl a 1: Chlorophyll a 60 DAS; Chl b 1: Chlorophyll b 60 DAS; NDVI 1: Normalized difference vegetative index 60 DAS; NKC: Number of kernels per cob; 100 GW: 100 Grain weight; GYP: Grain yield per plant.

and plant height (0.357); Chl b via leaf firing per cent (0.834); NDVI through leaf firing% (0.700) followed by Chl b (0.439) and plant height (0.410); the number of kernels per cob via leaf firing% (0.700) and 100 grain weight through leaf firing per cent (0.937), followed by plant height (0.333). ASI through days to 50 per cent anthesis (0.291) and tassel blast per cent (0.233); 75% BHM through plant height (0.249); plant height through Chl b (0.242); Chl b via plant height (0.241); NDVI through 75 per cent BHM (0.249); number of kernels per cob through plant height (0.225); and 100 grain weight through 75% BHM (0.280) exhibited moderate indirect positive influence on grain yield.

Whereas low indirect positive effect on grain yield was exhibited by days to 50 per cent anthesis through 75 per cent BHM (0.188) followed by tassel blast per cent (0.173); days to 50 per cent silking through tassel blast per cent (0.177); ASI via 100 grain weight (0.102); 75 per cent BHM through days to 50 per cent anthesis (0.183), Chl b (0.100); plant height through 75 per cent BHM (0.178); silk length through 75 per cent BHM (0.119); leaf firing% through Chl a (0.171) and 100 grain weight (0.143); tassel blast per cent via and Chl a (0.169) and grain weight (0.150); Chl a via 75 per cent BHM (0.099); Chl b through 75 per cent BHM (0.099); NDVI through days to 50 per cent anthesis (0.136); number of kernels per cob via 75 per cent BHM (0.159) and 100 grain weight through Chl b (0.181).

4.5.3 Direct and indirect effects of selected characters on grain yield at phenotypic level in inbreds under heat stress condition

Path coefficient phenotypic values for direct and indirect effects of different traits on grain yield are presented in Table 18.

4.5.3.1 Direct effects of selected characters on grain yield

Seven out of 14 characters recorded positive and direct effect on grain yield at phenotypic level. The character that showed high positive direct effect on grain yield was number of kernels per cob (0.771) followed by days to 50 per cent anthesis (0.214). While Chl a (0.075) followed by 100 grain weight (0.060), ASI (0.034), plant height (0.030) and NDVI (0.028) showed low positive direct effect on grain yield.

Table 18. Direct and indirect effects between selected characters and grain yield at phenotypic level in inbred under heat stress condition

Characters	50% A	50% S	ASI	75% BHM	PH	SL	LF%	TB%	Chl a 1	Chl b 1	NDVI 1	NKC	100 GW	'r' with GYP
50% A	**0.214**	-0.119	-0.003	-0.008	-0.002	-0.016	0.004	0.014	-0.015	0.010	0.001	0.024	0.008	0.112
50% S	0.190	**-0.134**	0.013	-0.006	-0.003	-0.011	0.004	0.007	-0.012	-0.003	0.002	-0.074	0.006	-0.021
ASI	-0.019	-0.051	**0.034**	0.003	-0.002	0.008	-0.001	-0.013	0.004	-0.026	0.004	-0.206	-0.005	-0.270
75% BHM	0.020	-0.010	-0.001	**-0.085**	0.008	-0.010	0.001	0.013	0.023	-0.009	0.008	0.102	0.014	0.074
PH	-0.013	0.012	-0.002	-0.023	**0.030**	-0.008	0.010	0.039	0.026	-0.067	0.014	0.326	0.021	0.365*
SL	0.038	-0.016	-0.003	-0.009	0.003	**-0.089**	0.007	0.025	0.006	0.013	0.005	0.050	0.007	0.034
LF%	-0.039	0.021	0.001	0.004	-0.013	0.025	**-0.023**	-0.099	-0.020	0.057	-0.003	-0.299	-0.035	-0.423*
TB%	-0.026	0.008	0.004	0.009	-0.010	0.019	-0.019	**-0.118**	-0.017	0.042	-0.004	-0.418	-0.038	-0.569**
Chl a 1	-0.043	0.022	0.002	-0.026	0.010	-0.007	0.006	0.027	**0.075**	-0.030	0.001	0.093	0.004	0.135
Chl b 1	-0.013	-0.003	0.006	-0.005	0.013	0.007	0.008	0.031	0.014	**-0.16**	0.005	0.047	0.015	-0.036
NDVI 1	0.004	-0.011	0.005	-0.023	0.014	-0.015	0.003	0.018	0.003	-0.029	**0.028**	0.127	0.019	0.144
NKC	0.007	0.013	-0.009	-0.011	0.013	-0.006	0.009	0.064	0.009	-0.010	0.005	**0.771**	0.028	0.882**
100 GW	0.030	-0.012	-0.003	-0.020	0.010	-0.010	0.013	0.074	0.005	-0.039	0.009	0.364	**0.060**	0.482**

50% A: Days to 50% anthesis; 50% S: Days to 50% silking; ASI: Anthesis to silking interval; 75%BHM: 75% Brown husk maturity; PH: Plant-height; SL: Silk length; LF% : Leaf firing %; TB%: Tassel blast %; Chl a 1: Chlorophyll a 60 DAS; Chl b 1: Chlorophyll b 60 DAS; NDVI 1: Normalized difference vegetative index 60 DAS; NKC: Number of kernels per cob; 100 GW: 100 Grain weight; GYP: Grain yield per plant.

4.5.3.2 Indirect effects of selected characters on grain yield

The indirect high positive effect on grain yield was exhibited by plant height through number of kernels per cob (0.326) and100 grain weight through number of kernels per cob (0.364)

The low indirect positive effect on grain yield was exhibited by days to 50 per cent anthesis through number of kernels per cob (0.024), tassel blast per cent (0.014); days to 50 per cent silking via days to 50 per cent anthesis (0.190), ASI (0.013); ASI through silk length (0.008), Chl a (0.004) and NDVI (0.004); 75 per cent BHM through number of kernels per cob (0.102), Chl a (0.023) and days to 50 per cent anthesis (0.020); plant height through number of kernels per cob (0.326), tassel blast per cent (0.039) and Chl a (0.026); silk length via number of kernels per cob (0.050), tassel blast per cent (0.025) and days to 50 per cent anthesis (0.038); leaf firing per cent through Chl b (0.057), silk length (0.025) and days to 50 per cent silking (0.021); tassel blast per cent via Chl a (0.042), days to 50 per cent silking (0.008) followed by 75% BHM; Chl a via number of kernels per cob (0.093), tassel blast per cent (0.027) and days to 50 per cent silking (0.022); Chl b through number of kernels per cob (0.047), tassel blast per cent (0.031) and leaf firing per cent (0.008); NDVI via number of kernels per cob (0.127) tassel blast per cent (0.018), plant height (0.014); number of kernels per cob through tassel blast per cent (0.064), 100 grain weight (0.028) and plant height (0.013); 100 grain weight via tassel blast% (0.074) and days to 50 per cent anthesis (0.030).

4.5.4 Direct and indirect effects of selected characters on grain yield at genotypic level in inbreds under heat stress condition

Path coefficient genotypic values for direct and indirect effects of different selected traits on grain yield are presented in the Table 19.

4.5.4.1 Direct effects of selected characters on grain yield

Seven out of 14 characters showed positive and direct effect on grain yield at genotypic level. The character that exhibited high positive direct effect on grain yield was number of kernels per cob (0.752) followed by days to 50 per cent anthesis (0.427). Whereas 100 grain weight (0.287) followed by NDVI (0.194), Chl a (0.146) tassel blast% (0.045), leaf firing% (0.005) and plant height (0.030) recorded low positive direct effect

Table 19. Direct and indirect effects between selected characters and grain yield at genotypic level in inbred under heat stress condition

Characters	50% A	50% S	ASI	75% BHM	PH	SL	LF%	TB%	Chl a 1	Chl b 1	NDVI 1	NKC	100 GW	'r' with GYP
50% A	**0.427**	-0.267	0.000	0.137	0.018	-0.030	-0.002	-0.012	-0.052	-0.005	-0.052	0.033	0.116	0.309
50% S	0.489	**-0.233**	0.000	0.206	0.053	-0.027	-0.003	-0.014	-0.092	0.026	-0.205	-0.289	0.082	-0.007
ASI	0.567	-1.478	**0.000**	0.170	-0.157	-0.166	0.000	-0.043	0.031	-0.235	0.791	0.342	0.775	0.597**
75% BHM	-0.240	0.197	0.000	**-0.244**	-0.109	-0.121	-0.001	-0.010	0.073	0.047	0.270	0.149	0.130	0.142
PH	-0.044	0.071	0.000	-0.154	**-0.172**	-0.023	-0.002	-0.015	0.061	0.034	0.166	0.338	0.132	0.393*
SL	0.116	-0.056	0.000	-0.265	-0.035	**-0.111**	-0.004	-0.028	0.034	0.008	-0.060	0.305	0.442	0.346*
LF%	-0.163	0.150	0.000	0.027	0.074	0.087	**0.005**	0.038	-0.047	-0.032	-0.043	-0.300	-0.241	-0.445**
TB%	-0.113	0.072	0.000	0.052	0.059	0.070	0.004	**0.045**	-0.041	-0.022	-0.053	-0.426	-0.253	-0.607**
Chl a 1	-0.151	0.147	0.000	-0.122	-0.071	-0.026	-0.001	-0.013	**0.146**	0.025	0.080	0.101	0.043	0.157
Chl b 1	-0.041	-0.110	0.000	-0.211	-0.105	-0.016	-0.003	-0.018	0.068	**0.055**	0.118	0.084	0.158	-0.020
NDVI 1	-0.115	0.246	0.000	-0.340	-0.147	0.034	-0.001	-0.012	0.060	0.034	**0.194**	0.165	0.146	0.263
NKC	0.019	0.090	0.000	-0.048	-0.077	-0.045	-0.002	-0.026	0.020	0.006	0.043	**0.752**	0.175	0.905**
100 GW	0.173	-0.067	0.000	-0.110	-0.079	-0.172	-0.004	-0.040	0.022	0.030	0.098	0.459	**0.287**	0.598**

50% A: Days to 50% anthesis; 50% S: Days to 50% silking; ASI: Anthesis to silking interval; 75%BHM: 75% Brown husk maturity; PH: Plant-height; SL: Silk length; LF% : Leaf firing %; TB%: Tassel blast %; Chl a 1: Chlorophyll a 60 DAS; Chl b 1: Chlorophyll b 60 DAS; NDVI 1: Normalized difference vegetative index 60 DAS; NKC: Number of kernels per cob; 100 GW: 100 Grain weight; GYP: Grain yield per plan.

on grain yield.

4.5.4.2 Indirect effects of selected characters on grain yield

The high indirect positive effect on grain yield was exhibited by days to 50 per cent silking through days to 50 per cent anthesis (0.427); ASI via days to 50 per cent anthesis (0.567), NDVI (0.791), number of kernels per cob (0.342) and 100 grain weight (0.775); plant height via number of kernels per cob (0.338); silk length via number of kernels per cob (0.305) and100 grain weight (0.442) and 100 grain weight through number of kernels per cob (0.459).

The indirect low positive effect on grain yield was exhibited by days to 50 per cent anthesis through 75 per cent BHM (0.137), 100 grain weight (0.116) and number of kernels per cob (0.033); days to 50 per cent silking through days to 50 per cent anthesis (0.489), 75 per cent BHM (0.206) and 100 grain weight (0.082); ASI through 75 per cent BHM (0.170); 75 per cent BHM through NDVI (0.270), days to 50 per cent silking (0.197), number of kernels per cob (0.149) and 100 grain weight (0.130); plant height through NDVI (0.166) and100 grain weight (0.132); silk length via Chl a (0.034); leaf firing per cent through days to 50 per cent silking (0.150), silk length (0.087) and plant height (0.074). Tassel blast per cent via days to 50 per cent silking (0.072), silk length (0.070) and plant height (0.059). Chl a through days to 50 per cent silking (0.147), NDVI (0.080) and 100 grain weight (0.043); Chl b via 100 grain weight (0.158), NDVI (0.118) and Chl a (0.068); NDVI via days to 50 per cent silking (0.246), number of kernels per cob (0.165) and 100 grain weight (0.146); number of kernels per cob through 100 grain weight (0.175), days to 50 per cent silking (0.090) and Chl a (0.020); 100 grain weight through number of kernels per cob (0.459) followed by days to 50 per cent anthesis (0.173) and NDVI (0.098).

Discussion

V. DISCUSSION

Maize is an important cereal crop of the world as well as India. Yield potential of maize crop is always at risk due to biotic and abiotic stresses. Abiotic stresses are integral part of any agro ecosystem, which may vary with space and time because of several factors that determine the severity and impact of abiotic stresses, like temperature, relative humidity, precipitation etc, and their uncertainty of occurrence and magnitude.

High temperature stress at critical developmental stages of maize plants causes significant yield loss. Plants become susceptible to high temperature after reaching eight-leaf stage (Chen *et al*., 2010). It has been estimated that 2^{o}C increase in temperature above 30^{o}C reduces the maize yields by 13 per cent as compared to 20 per cent intra seasonal variation in the rainfall, which reduces the maize yields by 4.5 per cent (Lobell *et al.*, 2011).

Response of the maize crop to climate depends on the genetic and physiological make-up of the hybrid/variety being grown and interactions with prevailing climatic condition. Yield differences are the result of the genetic composition of the hybrid, the environmental conditions under which the crop is grown. Transitory or constantly high temperatures cause an array of morpho- physiological, anatomical and biochemical changes in plants, which eventually affect plant growth and development and lead to a drastic reduction in biological and economic yield (Badu-Apraku *et al*., 1983; Commuri and Jones, 2001).

With this view in mind, screening of selected inbred lines and leading commercial hybrids was carried at Agriculture College Farm, Bheemarayanagudi during early summer (January-sowing), and late summer (March-sowing) -2014. The results obtained during the investigation are discussed under the following headings.

5.1 Analysis of variance for morpho-physiological and yield related traits of inbred lines and commercial hybrids under optimum and heat stress conditions

5.2 Mean performance of inbred lines and hybrids for important morpho-physiological and yield traits under optimum and heat stress conditions

5.3 Genetic variability parameters in inbreds and hybrids under optimum and heat stress conditions

5.4 Association of grain yield and its attributing traits in inbred lines and hybrids under optimum and heat stress conditions

5.5 Path coefficient analysis for grain yield and its attributing traits in inbred lines under optimum and heat stress conditions

5.1. Analysis of variance for morpho-physiological and yield related traits of inbred lines and commercial hybrids under optimum and heat stress conditions

Plant breeders have debated the question of optimum environment (the environment that improves efficiency and effectiveness of the breeding programme) for selecting the genotypes for yield. The optimum environment for selection is one, which maximizes the genetic variation and hence, the responses to selection in the target environment. Three strategies have been considered (Byrne *et al.*, 1995) for selecting the material for drought tolerance. The first strategy is based on the assumption that when the growing conditions are optimum, high yielding cultivars selected under optimal growing conditions will perform well under all conditions. The second strategy assumes that the optimum environment for selection should be as representative as possible of the target environments. The third strategy involves the use of both optimum and stressed conditions for selecting the genotypes that yield well in both the situations. The third strategy is important because the selected inbred line / hybrid would have stress resilience, as well as high yielding ability under optimum condition.

In an attempt to verify the role of different morphological, yield and yield related traits, inbred lines and commercial hybrids were evaluated under optimum and heat stress environments by assuming the principles of third strategy.

The extent of variability for various quantitative traits available to the breeder determines the success that can be achieved in genetic improvement of that species. The analysis of variance revealed that the variation due to genotype was significant for all the traits except anthesis to silking interval (ASI) in inbred lines and except canopy temperature in hybrids under optimum and heat stress condition, indicating the presence of enough genotypic variation among the inbred lines and hybrids selected for the study.

5.2 Mean performance of inbred lines and hybrids for important morpho-physiological and yield traits under optimum and heat stress condition

Under heat stress condition plant height, ear height, silk length, Chl a, Chl b and yield per plant were severally affected in inbred lines and hybrids as compare to optimum condition and few inbred lines *viz.,* P 41 and R 95 showed the leaf firing and tassel blast symptoms under heat stress and optimum conditions and produced the low yield. Warrington *et al*. (1983), Bonhomme *et al*. (1994) and Rupinder Kaur and Saxena (2011) also reported the adverse effect of heat stress on the plant growth, ASI and events involved in the growth and development of reproductive organs, such as tassel initiation, time of flowering, pollination, fertilization and susceptible plants showed the leaf firing and tassel blast symptoms leading to drastic reduction in yield of maize genotypes.

The *per se* performance of selected inbred lines in terms of per cent yield reduction indicated that quantum of yield reduction was very high in inbred lines *viz.,* 67.66 % and 77.5 % in P-41 and R-95, respectively. Whereas, the inbred lines *viz.,* YP-58 (23.11 %), CI-4 (29.17 %), R-111 (46.99 %) and CM-111 (59.44 %) exhibited minimal yield loss (Table 20). Based on yield and other secondary traits, these inbred lines *viz.,* CI-4, CM-111, R-111 and YP-58 were identified as heat stress resilience (plates 1 and 2). Among inbred lines, P-41 and R-95 produced highest leaf firing and tassel blast symptoms with low plant height, ear height, Chl a, Chl b, NDVI, number of kernels per cob and grain yield per plant under heat stress condition and were identified as heat susceptible inbred lines (Plate 3).

Among 11 hybrids evaluated under heat stress condition, the hybrid, GK-3059 was superior for cob length, cob girth, grain yield per plant and grain yield per hectare followed by P-3341, 900-M-Gold, DKC-9135 and CP-818. Whereas, four hybrids *viz.,* CP-818, 900-M-Gold, GK-3059 and DKC-9135 showed better performance for yield under both the conditions. However, none of the hybrids expressed any leaf firing and tassel blast symptoms. Comparatively, four hybrids *viz.,* Arjun, MRM-3845, DMH-117 and GH- 0727 recorded the low yield. Among these hybrids Arjun recorded the low plant height, ear height, Chl a, Chl b and 100 grain weight under heat stress condition.

The hybrids *viz.*, GK-3059, CP-818, DKC-9135, 900-M-Gold and P-3341 recorded a yield reduction of 3.50 %, 7.59 %, 14.98%, 18.92 % and 19.97%, respectively.

Table 20. The per se performance of selected inbred lines for selected characters under optimum and heat stress conditions

Inbred lines	Plant height (cm)		ASI		Leaf firing (%)		Tassel blast (%)		Total Chl (mg/g FW) 60 DAS	
	OC	HSC	OC	HSC	OC	HSC	OC	HSC	OC	HSC
Tolerant inbred lines										
CI-4	161.00	149.50	4.00	2.00	0.00 (2.86)	0.00 (2.86)	0.00 (2.86)	0.00 (2.86)	3.76	2.61
CM-111	160.50	144.00	5.00	4.00	0.00 (2.86)	0.00 (2.86)	0.00 (2.86)	0.00 (2.86)	4.07	3.39
R-111	166.00	135.50	4.00	3.50	0.00 (2.86)	0.00 (2.86)	0.00 (2.86)	0.00 (2.86)	4.05	3.34
YP-58	193.50	146.00	3.50	3.00	0.00 (2.86)	0.00 (2.86)	0.00 (2.86)	0.00 (2.86)	4.07	2.89
Susceptible inbred lines										
P-41	126.00	89.00	4.50	3.00	26.0 (30.54)	99.7 (87.09)	28.5 (31.57)	99.7 (87.09)	3.10	2.39
R-95	132.50	85.50	4.00	2.50	36.5 (40.61)	99.7(87.09)	35.5 (39.21)	99.75 (87.09)	2.48	1.87
LSD (0.05)	13.34	8.34	13.34	8.34	4.45	5.38	6.59	5.37	0.39	0.53
S.Em±	4.62	2.89	0.66	0.67	1.54	1.86	2.28	1.85	0.13	0.18
Mean	156.50	124.90	4.16	3.00	10.5	33.23	10.66	33.23	3.58	2.74

ASI: Anthesis to silking interval; NDVI: Normalized difference vegetative index; Chl: Chlorophyll; GYP: Grain yield per plant.

Table 20 Contd...

Inbred lines	Canopy temperature (^{0}C) 60 DAS		NDVI 60 DAS		Number of kernels per cob		GYP (g)		Reduction % of GYP
	OC	HSC	OC	HSC	OC	HSC	OC	HSC	
Tolerant inbred lines									
CI-4	28.39	33.02	0.76	0.62	351.00	317.50	106.50	75.50	29.10
CM-111	28.81	31.46	0.74	0.59	390.00	189.00	90.00	36.50	59.44
R-111	29.45	32.30	0.76	0.62	432.00	282.50	91.50	48.50	46.99
YP-58	28.22	32.42	0.76	0.61	489.50	404.00	99.50	76.50	23.11
Susceptible inbred lines									
P-41	32.80	34.91	0.59	0.48	373.00	38.00	49.00	11.00	67.66
R-95	32.67	33.73	0.60	0.58	226.50	63.00	66.50	21.50	77.55
LSD (0.05)	2.35	3.36	0.06	0.13	45.65	73.76	2.92	10.86	-
S.Em±	0.87	0.81	0.02	0.04	31.85	17.00	1.01	3.76	-
Mean	30.05	32.97	0.70	0.58	377.00	215.60	83.75	44.91	-

Plate 1: Morphological view of heat stress tolerance inbred lines under heat stress condition

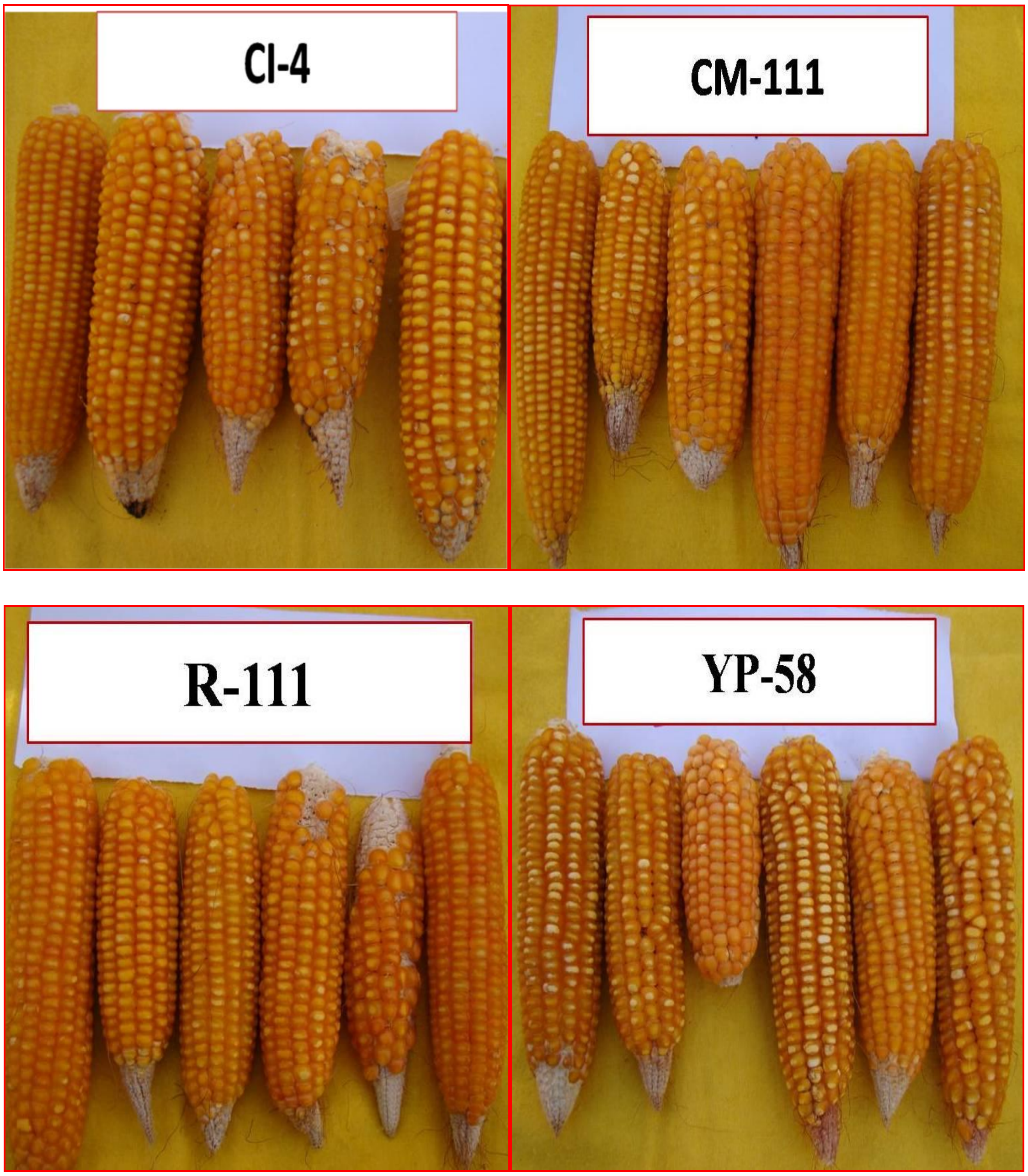

Plate 2: Cobs of heat stress tolerant inbred lines under heat stress condition

Plate 3: Morphological view of heat stress susceptible inbred lines under heat stress condition

Whereas checks *viz.,* Arjun (21.77 %) and DMH-117 (22.95 %) recorded the higher yield reduction under heat stress condition (Table 21).

5.3 Genetic variability parameters in inbreds and hybrids under optimum and heat stress conditions

5.3.1 Phenotypic and genotypic coefficient of variation in inbreds and hybrids under optimum and heat stress conditions

For comparing the variability of one character with another, coefficient of variation which is independent of unit of measurement is preferred. In the present study the phenotypic coefficient of variation and genotypic coefficient of variation were low to high for most of the characters. As expected, the PCV values were greater than the GCV values for all the characters indicating considerable influence of environment on the expression of these characters under field conditions.

Among the traits studied, leaf firing, tassel blast and grain yield (kg ha^{-1}) and number of kernel per cob showed higher variability as indicated by high PCV and GCV values of 32 inbreds under both optimum and heat stress conditions (Fig 1 and 2). However, the traits *viz*., plant height, Chl a and b, total chlorophyll, cob length, cob girth, exhibited moderate variability as showed by mean PCV and GCV values in both the conditions indicating major role of additive gene action in the inheritance of these traits and hence phenotypic selection for these traits could be effective. Remaining traits showed non-additive gene action as indicated by their low PCV and GCV values in both the situations.

Grain yield per plant and ear height showed high PCV and GCV values under stress condition, whereas under optimum condition PCV and GCV values were moderate indicating major role of additive gene action in the inheritance of these traits.

The characters *viz.,* grain yield (kg ha^{-1}) recorded higher variability and number of kernel per cob exhibited moderate variability as showed by mean PCV and GCV values in hybrids under both the conditions. Chl a, Chl b and total Chl at 60 and 90 DAS showed high PCV and GCV values under optimum condition and low under heat stress condition (Fig 3 and 4), indicating major role of additive and non additive gene action respectively in the inheritance of these traits but traits like canopy temperature and NDVI recorded low PCV and GCV under both conditions.

Table 21. The *per se* performance of selected hybrids for selected characters under optimum and heat stress conditions

Hybrids	**Plant height (cm)**		**ASI**		**Total Chl (mg/g FW) 60 DAS**		**Canopy temperature (^{0}C) 60 DAS**		**NDVI 60 DAS**		**Number of kernels per cob**		**GYP (g)**		**Reduction % of GYP**
	OC	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	**OC**	**HSC**	
Tolerant hybrids															
GK-3059	167.00	162.33	4.00	3.00	6.53	4.13	28.75	32.08	0.76	0.59	390.33	379.00	108.12	104.33	3.50
P-3341	188.66	169.33	2.66	2.33	4.10	3.34	28.68	31.19	0.76	0.66	422.33	271.33	106.22	85.00	19.97
900-M-Gold	175.00	152.00	3.00	2.00	3.35	2.53	27.10	31.80	0.76	0.61	542.00	367.00	123.77	99.33	18.92
DKC-9135	183.33	158.66	3.66	2.00	4.44	4.13	28.06	31.39	0.77	0.64	503.33	454.66	101.55	86.33	14.98
CP-818	164.00	148.66	3.33	1.66	4.46	3.52	29.36	32.39	0.75	0.64	533.33	263.66	109.66	101.33	7.59
Susceptible hybrids															
Arjun	157.66	147.00	3.66	2.66	3.45	3.25	28.52	31.86	0.74	0.57	410.00	318.00	103.55	81.00	21.77
MRM-3845	176.33	171.33	3.33	2.66	3.39	2.91	28.30	31.96	0.77	0.63	439.66	310.33	109.88	82.66	24.77
DMH-117	178.33	168.00	4.33	4.33	3.13	3.12	26.96	31.38	0.76	0.63	415.00	234.00	110.66	85.33	22.95
LSD (0.05)	6.55	7.11	1.20	1.06	1.65	0.65	2.79	1.20	0.03	0.06	45.65	73.67	3.49	15.61	-
S.Em±	2.23	2.41	0.41	0.35	0.56	0.22	0.95	0.40	0.01	0.02	15.56	25.00	1.19	5.29	-
Mean	173.78	159.66	3.49	2.58	4.10	3.36	28.21	31.75	0.75	0.62	456.99	324.74	110.80	91.03	-

ASI: Anthesis to silking interval; NDVI: Normalized difference vegetative index; Chl: Chlorophyll; GYP: Grain yield per plant.

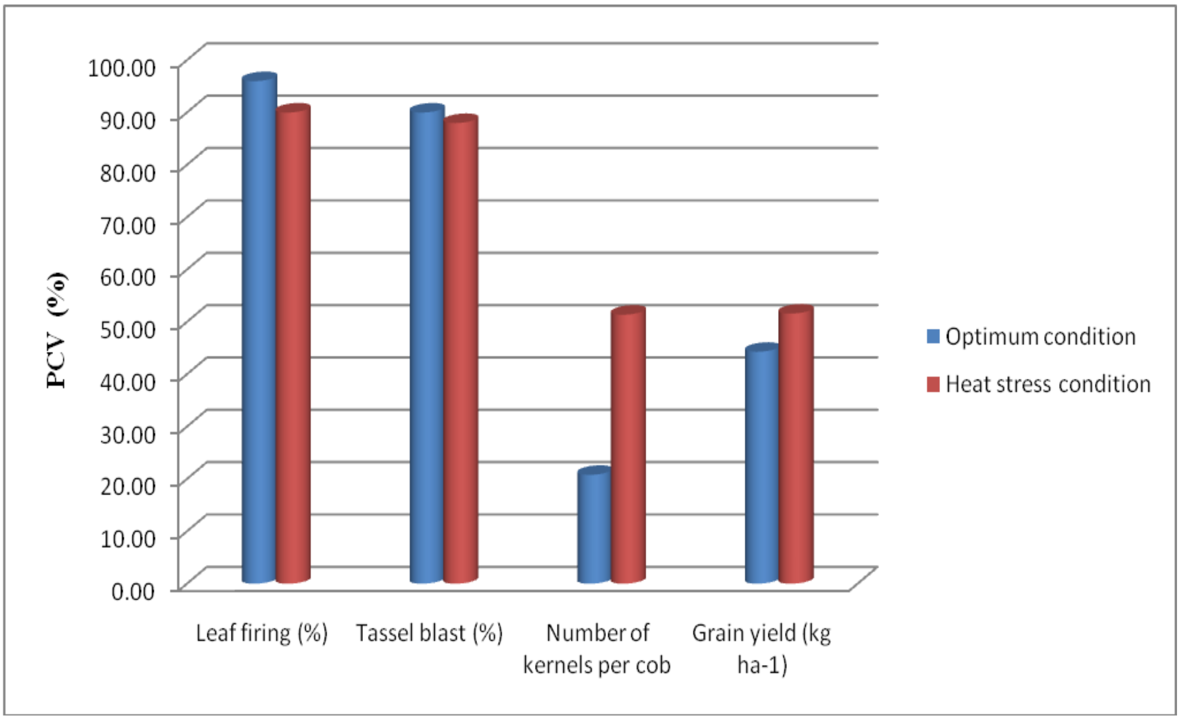

Fig. 1: Phenotypic coefficient of variation for selected characters in inbreds under optimum and heat stress conditions

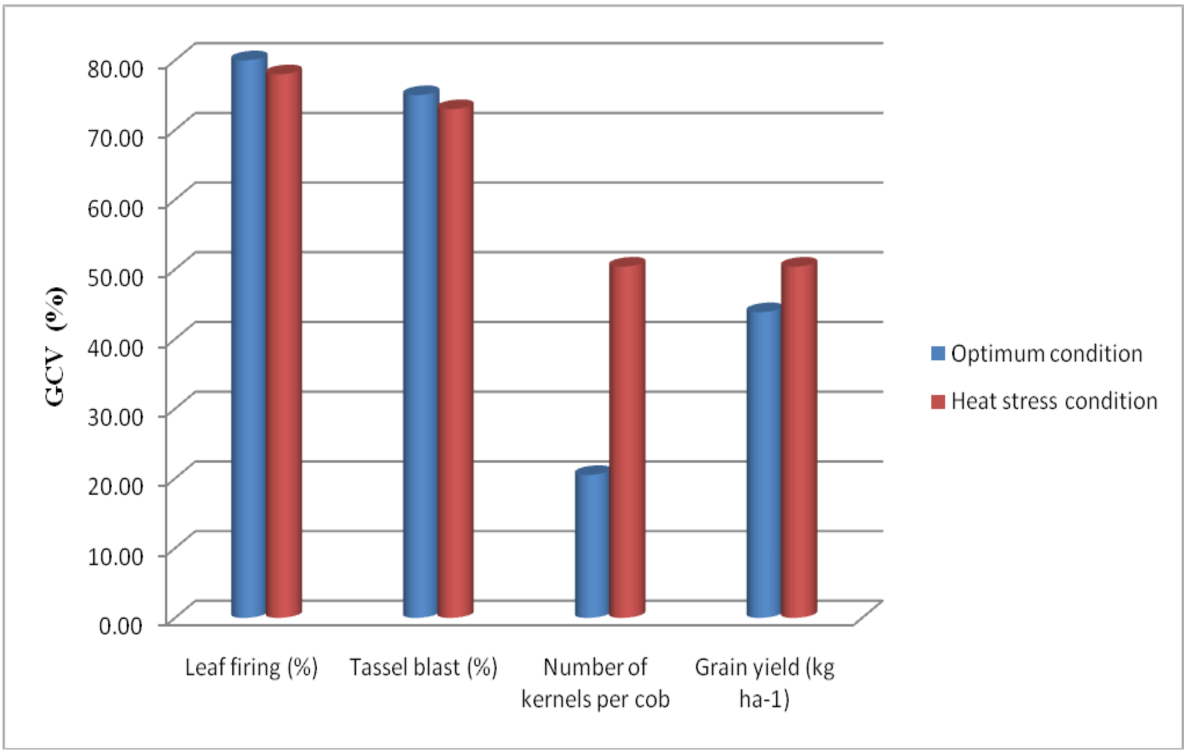

Fig. 2: Genotypic coefficient of variation for selected characters in inbreds under optimum and heat stress conditions

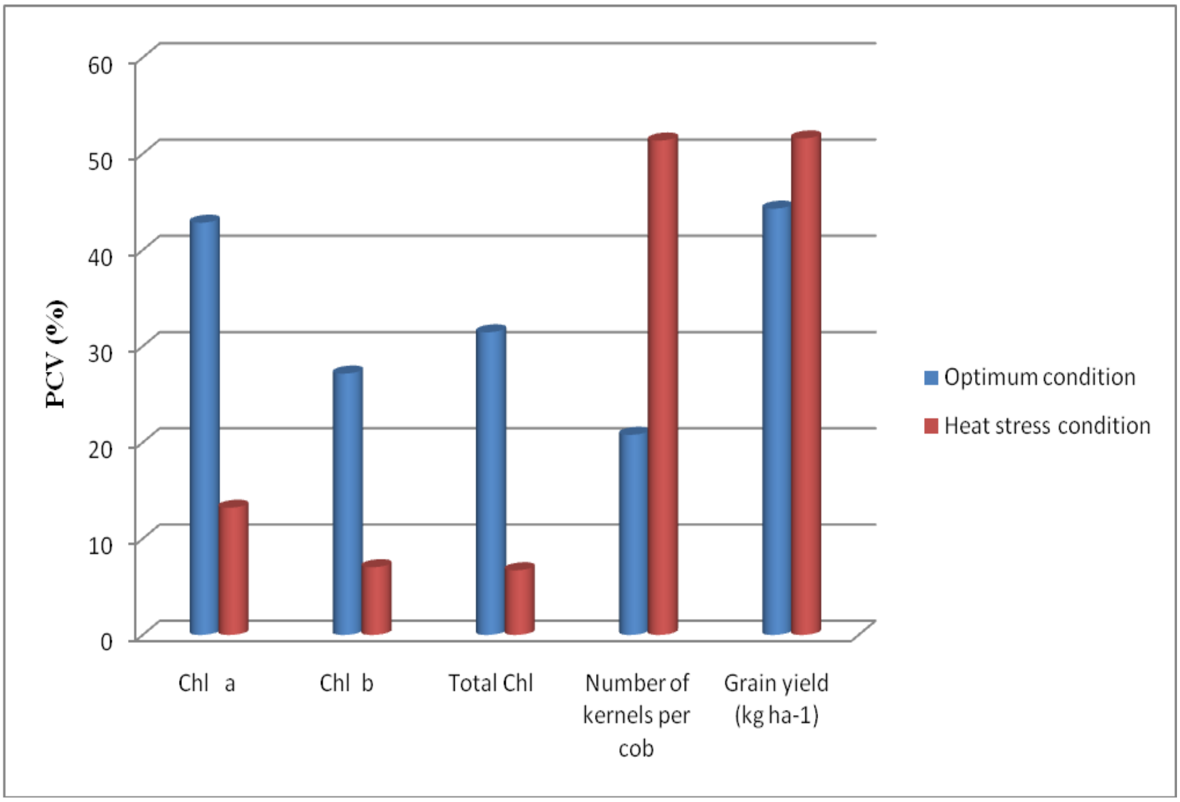

Fig. 3: **Phenotypic coefficient of variation for selected characters in hybrids under optimum and heat stress conditions**

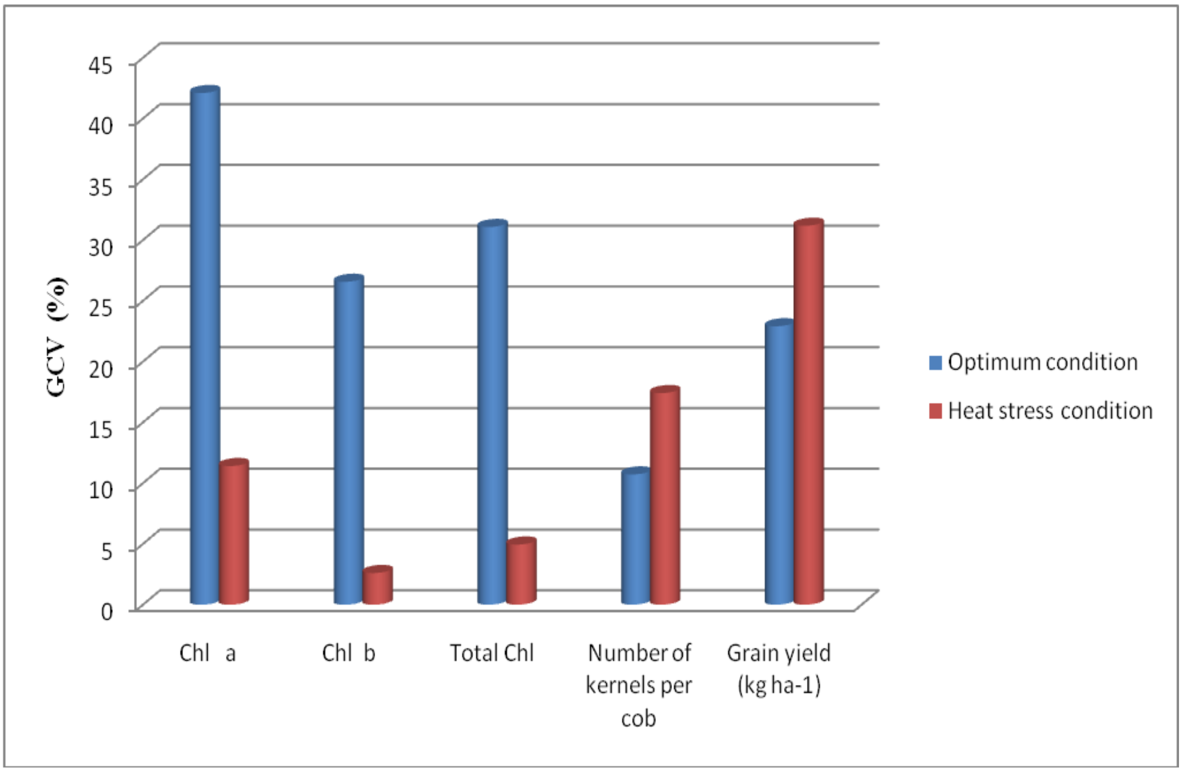

Fig. 4: **Genotypic coefficient of variation for selected characters in hybrids under optimum and heat stress conditions**

Rupinder Kaur and Saxena (2011) also reported additive and non-additive gene actions were involved in inheritance of these traits under optimum and heat stress conditions.

5.3.2 Heritability and genetic advance

The effectiveness of selection for any yield component depends not only on the magnitude of variability, but also how much of it is heritable to the next generation. The coefficient of variation indicates only the extent of variation and does not discriminate the variability into heritable and non-heritable.

Heritability value alone cannot provide information on the amount of progress that would result from selection of best individuals. Johnson *et al.* (1955) reported that heritability estimates along with genetic gain would be more useful than the former alone in predicting the effectiveness of selecting the best individuals. Therefore, it is essential to consider the predicted genetic advance along with heritability estimate as a tool in the selection programme for better efficiency in the selection.

A relative comparison of heritability values and expected genetic gain expressed as percentage of mean gives an idea about the nature of gene action governing a particular character. High heritability coupled with high genetic advance reveals the presence of lesser environmental influence and prevalence of additive gene action in their expression of traits (Panse, 1957). But lower values of genetic advance indicate the prevalence of narrow range of variability, high G × E interaction or non-additive gene action. For moderate values of genetic advance, both additive and non-additive gene actions might be responsible for the expression of traits.

High heritability coupled with high genetic advance as per cent of mean in inbred was observed for ten traits *viz*., plant height, ear height, leaf firing per cent, tassel blast per cent, Chl a at 60 and 90 DAS, Chl b, total Chl at 60 DAS, cob length, cob girth and number of kernels per cob, grain yield per plant (g) and grain yield kg ha^{-1}, suggesting that these characters are under the control of additive gene action and phenotypic selection for these traits may be effective under optimum condition and heat stress conditions. However moderate heritability with low genetic advance as per cent of mean was observed for three traits *viz*., Days to 50% anthesis, days to 50% silking and 75% brown husk maturity, suggesting that these characters are under the control of non-additive gene action under optimum condition and heat stress condition, Tassawar *et al.* (2007) also reported days to 50% anthesis, days to 50% silking and 75% brown husk maturity control by non-additive gene action under heat stress condition.

The hybrids recorded high heritability with high genetic advance as per cent of mean for three traits *viz.,* Chl a, number of kernels per cob and grain yield kg ha^{-1}. Whereas high heritability with moderate genetic advance as per cent of mean was observed for plant height, ear height, cob length and cob girth, suggesting that these characters are under the control of additive gene, phenotypic selection for these traits may be effective under optimum and heat stress conditions.

5.4 Association of grain yield and its attributing traits in inbreds and hybrids under optimum and heat stress conditions

In any crop improvement programme, it becomes necessary to have simultaneous selection of more than one character, especially in the case of complex character like yield, which is influenced by many other contributing traits. Association of characters serves as a guide and forms the basis of selection as it gives strength and direction of relationship between the characters studied. Selection for yield will be effective, only when it is considered along with its yield components rather than relying on yield alone. When a breeder applies selection pressure for a trait, it also brings about a simultaneous change in all associated characters with it. This is practically true when breeder want to value selection under stress conditions.

In the present study, association analysis for grain yield and its attributing traits was carried in inbred lines and hybrids. In inbreds, 100-grain weight showed strong positive relationship with grain yield per plant at phenotypic and genotypic levels under optimum conditions, but under heat stress condition, the grain yield per plant exhibited significant positive association with plant height (0.365, 0.393), number of kernels per cob (0.905, 0.882) and 100 grain weight (0.482, 0.598), at phenotypic and genotypic level.

In hybrids, 75% brown husk maturity and 100- grain weight under optimum and silk length under hat stress condition showed strong relationship with grain yield per plant at genotypic level only suggesting that individual plant selections could be practiced in optimum and heat stress conditions with these characters which could precisely lead to improvement in seed yield in the later generations.

The positive significant association between leaf firing and tassel blast and negative association with yield were found in present study. Rupinder Kaur *et al.* (2011) also reported similar associations between these traits.

The important yield attributing traits *viz.*, days to 50 per cent anthesis, days to 50 per cent silking, leaf firing, Chl a, Chl b and number of kernels per cob also showed significant positive correlation among themselves at phenotypic and genotypic levels. Hence, selection for any one of these traits will result in the improvement of grain yield. Hussain *et al.* (2006) also reported leaf firing strongly associated with Chl a, Chl b and number of kernels per cob.

5.5 Path coefficient analysis for grain yield and its attributing traits in inbreds under optimum and heat stress conditions

The correlation coefficient measures the relationship existing between pair of characters. A dependent character is an interaction product of many mutually associated component characters and change in any one component will disturb the whole network of cause and effect system. The path coefficient analysis, a statistical device developed by Wright (1921) takes into account the cause and effect relation between the variables which is unique in partitioning the association into direct and indirect effects through other independent variables. The path coefficient analysis also measures the relative importance of causal factors involved. This is simply a standardized partial regression analysis where in total correlation value is subdivided into causal scheme. Li (1956) emphasized the importance of path diagram which facilitates the understanding of the nature of cause and effect system. The results of path coefficient analysis from the present study are discussed below.

Path coefficient analysis in inbreds revealed that grain yield was primarily influenced by days to 50 per cent anthesis and number of kernels per cob at phenotypic and genotypic level under optimum and heat stress condition respectively, which showed maximum direct effect on grain yield per plant. These traits showed high direct effect on grain yield under both the conditions and hence it may be considered as a selection criterion.

Under optimum condition next to days to 50 per cent anthesis, 75% brown husk maturity, plant height, leaf firing (%), Chl a, Chl b and 100-grain weight exhibit positive direct effect on grain yield at phenotypic level. At genotypic level 75% brown husk maturity, plant height, tassel blast (%), Chl b, silk length and number of kernels per cob exhibit positive direct effect on grain yield.

Under heat stress condition next to number of kernels per cob, days to 50 per cent anthesis, plant height,100 grain weight, Chl a and NDVI exhibit positive direct effect on grain yield at phenotypic and genotypic level (Fig 5 to 8).

5.6 Future line of work

The highlight of the results obtained and inferences drawn from the different aspects of the study have given rise to some directions for future line of work. They are as follow

- The identified heat stress tolerant inbred lines viz., CI-4, CM-111, P-25, R-84, R-111, YP-58 and YP-67 could be used as potential donors for development of heat stress resilient hybrids / populations.
- The genetic nature of heat stress tolerance could be studied by utilizing the identified heat stress susceptible and heat stress tolerant inbred lines.
- Further specific molecular markers associated with heat stress tolerance could be identified for using reported variability for marker assisted selection.
- Also, understand the nature and mechanism of heat stress tolerance by using available information about HSPs (Heat Shock Proteins) in maize in general.

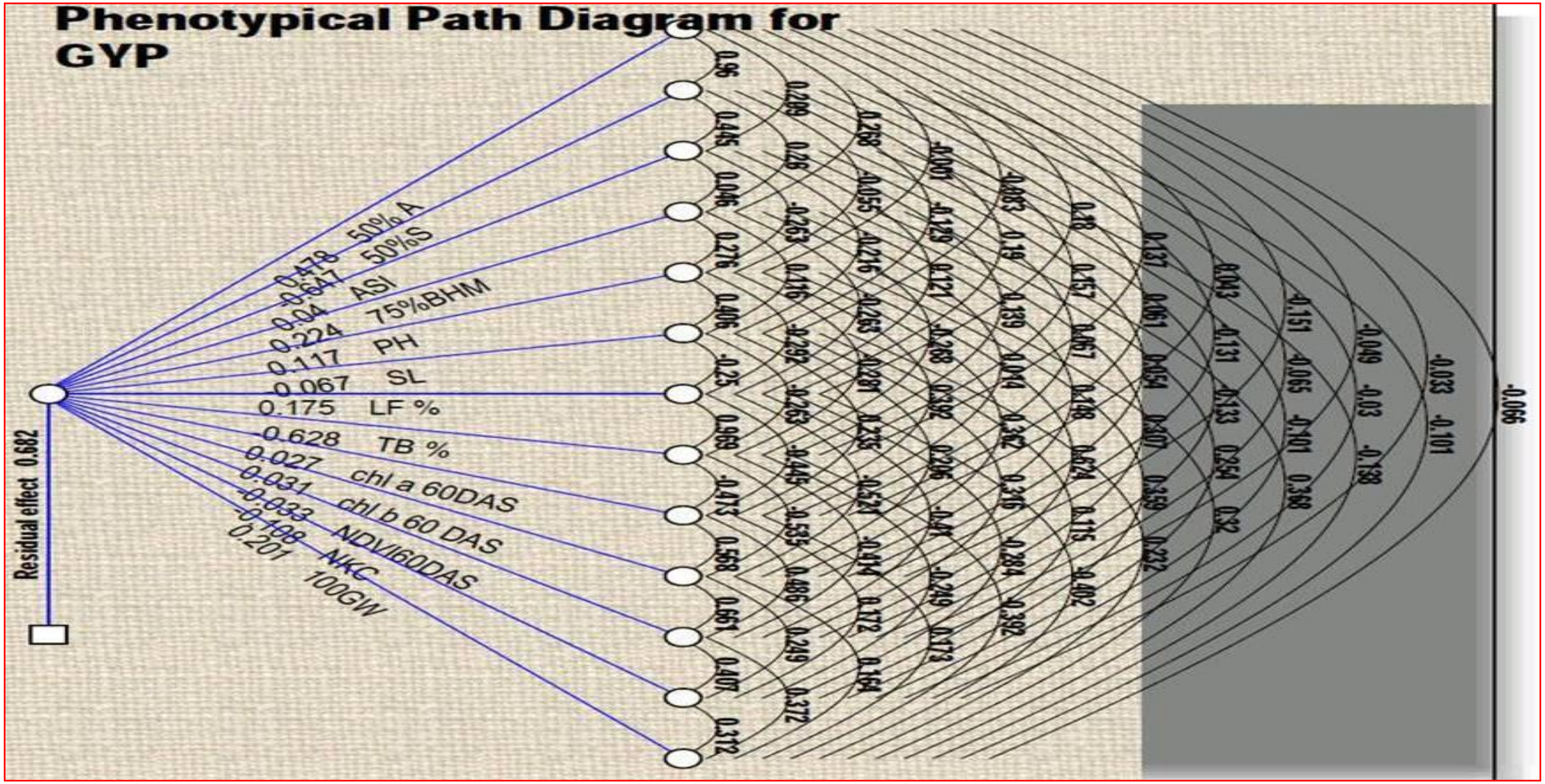

Fig. 5: Phenotypic path diagram indicating the influence of 13 major characters on grain yield per plant in 32 inbred lines under optimum condition

50% A: Days to 50% anthesis; 50% S: Days to 50% silking; ASI: Anthesis to silking interval; 75%BHM: 75% Brown husk maturity; PH: Plant-height; SL: Silk length; LF % : Leaf firing %; TB %: Tassel blast %; Chl a: Chlorophyll a ; Chl b : Chlorophyll b ; NDVI : Normalized difference vegetative index ; NKC: Number of kernels per cob; 100 GW: 100 Grain weight.

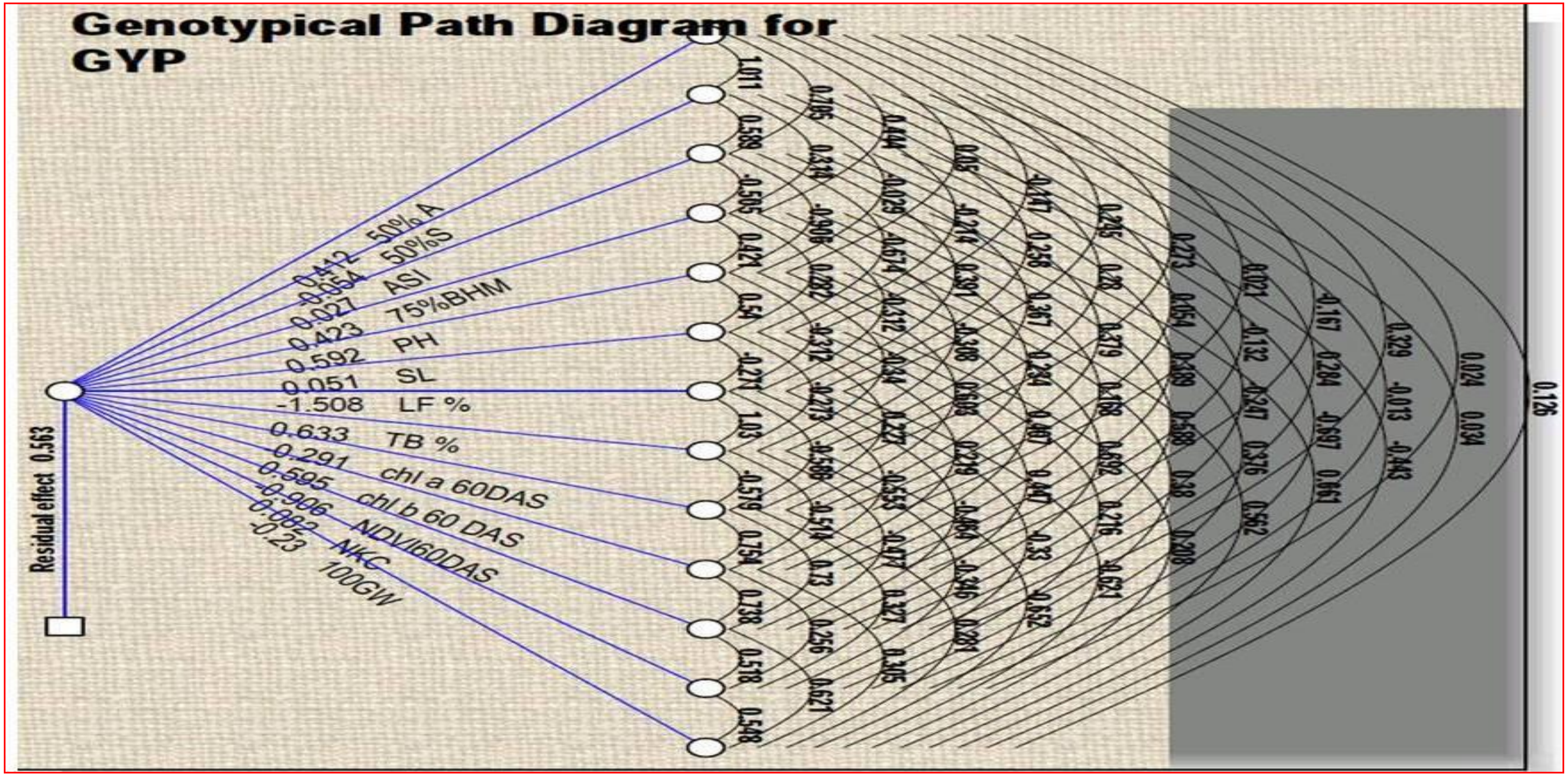

Fig. 6: Genotypic path diagram indicating the influence of 13 major characters on grain yield per plant in 32 inbred lines under optimum condition

50% A: Days to 50% anthesis; 50% S: Days to 50% silking; ASI: Anthesis to silking interval; 75%BHM: 75% Brown husk maturity; PH: Plant-height; SL: Silk length; LF % : Leaf firing %; TB %: Tassel blast %; Chl a : Chlorophyll a; Chl b : Chlorophyll b ; NDVI : Normalized difference vegetative index ; NKC: Number of kernels per cob; 100 GW: 100 Grain weight.

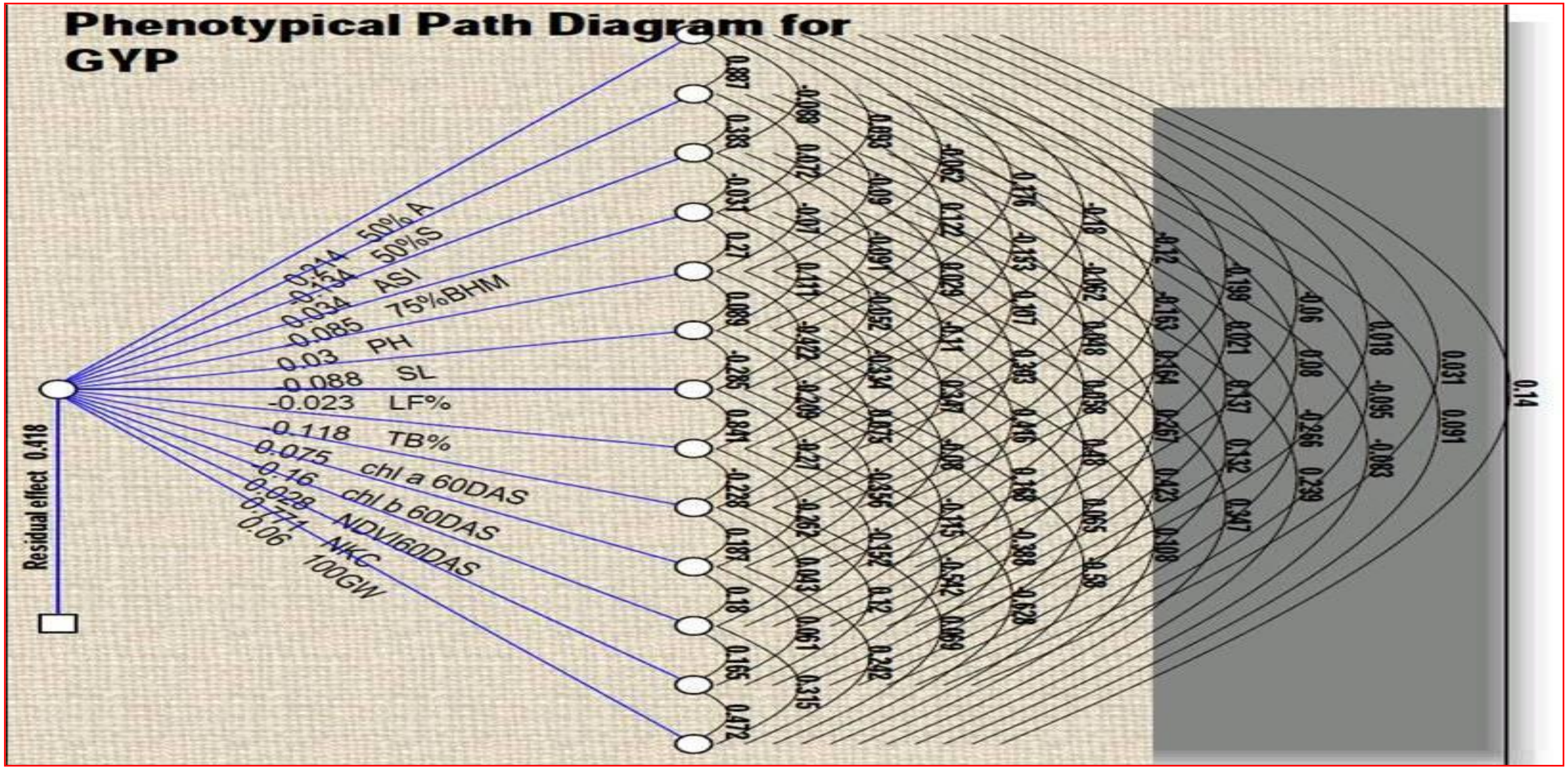

Fig. 7: Phenotypic path diagram indicating the influence of 13 major characters on grain yield per plant in 32 inbred lines under heat stress condition

50% A: Days to 50% anthesis; 50% S: Days to 50% silking; ASI: Anthesis to silking interval; 75%BHM: 75% Brown husk maturity; PH: Plant-height; SL: Silk length; LF % : Leaf firing %; TB %: Tassel blast %; Chl a : Chlorophyll a ; Chl b : Chlorophyll b ; NDVI : Normalized difference vegetative index ; NKC: Number of kernels per cob; 100 GW: 100 Grain weight

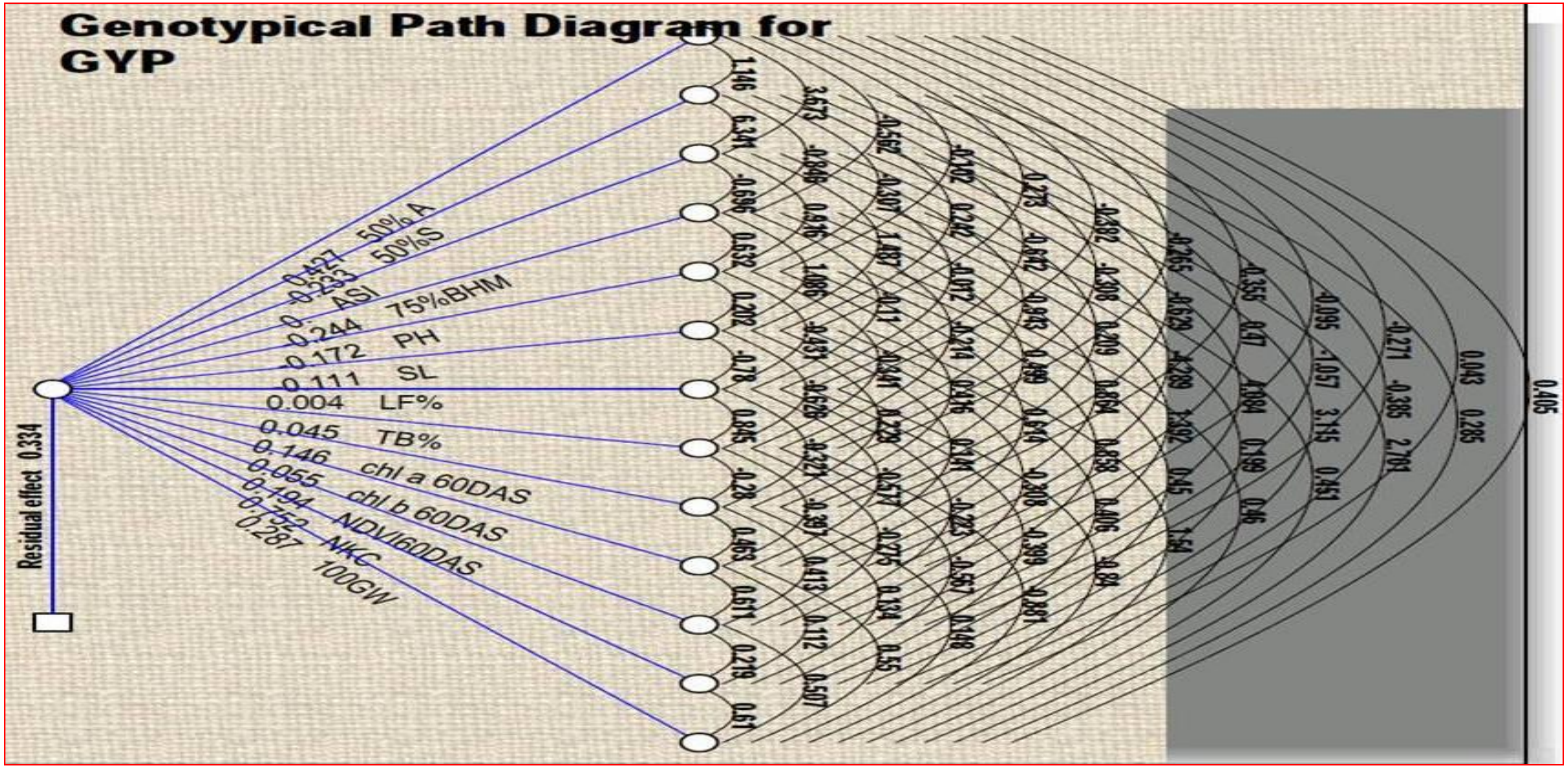

Fig. 8: Genotypic path diagram indicating the influence of 13 major characters on grain yield per plant in 32 inbred lines under heat stress condition

50% A: Days to 50% anthesis; 50% S: Days to 50% silking; ASI: Anthesis to silking interval; 75%BHM: 75% Brown husk maturity; PH: Plant-height; SL: Silk length; LF % : Leaf firing %; TB %: Tassel blast %; Chl a : Chlorophyll a ; Chl b : Chlorophyll b ; NDVI : Normalized difference vegetative index ; NKC: Number of kernels per cob; 100 GW: 100 Grain weight.

Summary and Conclusions

VI. SUMMARY AND CONCLUSIONS

The field experiments were conducted to evaluate the maize inbred lines and hybrids for heat stress tolerance. The experimental material comprising 32 inbred lines and 11 hybrids, were evaluated in a randomized block design during early summer (January-2014) and late summer (March-2014) at Agriculture College Farm Bheemarayanagudi.

The objectives of the investigation were re-screening of maize inbred lines and hybrids for heat stress tolerance and to study the association of grain yield with morpho-physiological traits under heat stress condition.

- Based on the *per se* performance of the genotypes for morpho-physiological and yield contributing characters *viz.,* plant height, leaf firing (%), tassel blast (%) total chlorophyll content, canopy temperature, NDVI, number of kernels per cob and grain yield per plant (g) four inbred lines *viz.,* CI-4, CM-111, R-111 and YP-58 were identified as heat stress tolerant and two inbred lines *viz.,* P-41 and R-95 were identified as heat stress susceptible. Further, few commercial hybrids *viz.,* GK-3059, P-3341, 900-M-Gold, CP-818 and DKC-9135 also performed well under heat stress.
- The evaluation of inbred lines and hybrids revealed that all genotypes differed significantly for all the traits indicating the presence of genetic variability for all the traits in the germplasm utilized for present study. In general, PCV were higher in magnitude than GCV for all the characters reported under study. The estimates of PCV and GCV in inbreds were high for leaf firing, tassel blast, number of kernel per cob and grain yield (kg ha^{-1}) and for number of kernel per cob and grain yield (kg ha^{-1}) in hybrids under both stress and non-stress conditions. High heritability and genetic advance expressed as per cent of mean was observed in inbred for plant height, ear height, leaf firing per cent, tassel blast per cent, Chl a, Chl b, total Chl, cob length, cob girth and number of kernels per cob, grain yield per plant and grain yield kg ha^{-1} and in hybrids Chl a , number of kernels per cob and grain yield kg per hectare, suggesting that these characters are under the control of additive genes and hence phenotypic selection for these characters could be effective.
- Correlation coefficients between grain yield and other traits revealed that in inbreds 100-grain weight under optimum conditions and number of kernels per cob under heat

stress condition showed strong positive relationship with grain yield per plant at phenotypic and genotypic levels. But in hybrids, 75% brown husk maturity and 100 grain weight under optimum and silk length under heat stress condition showed strong relationship with grain yield per plant at genotypic level only.

- Path coefficient analysis in inbreds revealed that grain yield was primarily influenced by days to 50 per cent anthesis at phenotypic and genotypic levels under optimum and heat stress conditions as it showed maximum direct effect on grain yield per plant. 75% brown husk maturity, plant height, tassel blast, Chl a, Chl b and 100-grain weight were next flowering trait days to 50 per cent anthesis to exhibit positive direct effect on grain yield, indicating the potentiality of these characters in selection for increased grain yield under both optimum and heat stress conditions.

- Evaluating maize inbreds and hybrids for tolerance to high temperature stress is an essential step towards stabilizing maize yields in tropical countries. This study gives some important clues that each genetic trait under study responded differently to temperature stress and also showed wide variation for their response to temperature stress tolerance and the information generated on commercial hybrid will help the farmers to select the hybrids for cultivation for January / March sowing.

- The identified tolerant inbred lines *viz*., CI-4, CM-111, R-111 and YP-58 could be used as potential donors for development of heat stress tolerant hybrids / population.

References

VII. REFERENCES

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Appendix

APPENDIX – I

Monthly meteorological data for the cropping period (2014) recorded at the meteorological observatory of the Agricultural Research Station, Bheemarayanagudi

Month	Rainfall (mm)	Temperature (^{o}C)		Bright Sun shine hours	Relative humidity (%)
		Maximum	Minimum		
January (2014)	0.00	30.55	14.00	7.30	58.30
February (2014)	0.00	32.55	14.80	8.83	58.87
March (2014)	14.50	35.55	20.10	8.54	57.46
April (2014)	34.00	39.33	23.40	8.69	56.90
May (2014)	42.50	38.61	24.16	8.65	62.90
June (2014)	22.50	36.90	24.50	7.61	64.73
Total	**113.50**				

EVALUATION OF MAIZE (*Zea mays* L.) INBRED LINES AND HYBRIDS FOR HEAT TOLERANCE

SHRISHAIL ANGADI **2014** **Dr. P.H.KUCHANUR**

ABSTRACT **Major Advisor**

Experiment were conducted for evaluating the selected inbreds and commercial hybrids for heat tolerance at Agriculture College Farm, Bheemarayanagudi during early summer (January- sowing) and late summer (March-sowing) 2014.

The ANOVA revealed that the variation due to genotypes was significant for all the traits except ASI in inbreds and except canopy temperature in hybrids under optimum and heat stress conditions, indicating the presence of enough genotypic variation among the inbreds and hybrids.

The traits like Leaf firing (LF), Tassel blast (TB) and grain yield (kg ha^{-1}) of the inbreds and grain yield (kg ha^{-1}) of the hybrids showed higher PCV and GCV values under both conditions. High heritability coupled with high GA in inbred was observed for plant height, LF, TB, Chl a, total Chl , GYP (g), and grain yield (kg ha^{-1}) for inbreds and hybrids under both conditions, indicating that these characters are under the control of additive gene action.

In inbreds correlation coefficient revealed that 100-grain weight under optimum conditions and NKC under heat stress condition showed strong positive relationship with GYP at phenotypic and genotypic levels. But in hybrids, 75% BHM and 100 grain weight under optimum and silk length under hat stress condition showed strong relationship with GYP at genotypic level. Path analysis of inbreds revealed that 50 % anthesis and NKC showed maximum direct effect on GYP at phenotypic and genotypic level under optimum and heat stress conditions respectively, suggesting that individual plant selections could be practiced in both conditions with these characters which could precisely lead to improvement in seed yield in the later generations.

Four inbreds *viz.,* CI-4, CM-111, R-111 and YP-58 and five hybrids *viz.,* GK-3059, P-3341, 900-M-Gold, DKC-9135 and CP-818 were identified as heat tolerant based on their mean performance for important traits *viz.,* plant height, LF, TB and yield.