GENETIC STUDIES ON HIGH TEMPERATURE TOLERANCE AT POST ANTHESIS IN WHEAT (*Triticum aestivum* L. em. Thell.)

THESIS

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1. INTRODUCTION

Bread wheat (Triticum *aestivum* L. em. Thell.), an important cereal crop of USA, Canada, Latin America, Europe, Asia and Oceania, is consumed in various forms by more than thousand million human beings in the world and is known as the protector of man from hunger. It contains about 8-15% protein, and its unique gluten content makes it very essential for bakery industries. Wheat, rice and corn together contribute about 75 % of the world's grain production and besides staple food for human beings; its Stover is used for large population of cattle in India and some developing countries.

In India it is the second most important cereal crop after rice. It was grown over an area of 26.60 million hectares with the production of 72.06 million tonnes and productivity of 2707 kg ha^{-1} in the year 2003-04 (Anonymous, 2005-06). The major wheat growing states of India are UP, MP, Punjab, Haryana, Rajasthan, Bihar, Gujrat and Maharastra. In Rajasthan, the area under wheat cultivation is 2.10 million hectares with the production of 5.87 million tonnes and productivity of 2794 kg ha^{-1} in the year 2003-04 (Anonymous, 2005). The major wheat producing districts in Rajasthan are Sriganganagar, Jaipur, Alwar, Bharatpur, Kota, Bundi, SawaiMadhopur, Bhilwara, Chittor and Udaipur.

The wheat plant is an annual cereal belonging to the family gramineae. The majority of cultivated wheat varieties in India belong to *Triticum aestivum* L. em. Thell. (86%). The other two species are *T.* t*urgidum* var. *durum* (macaroni wheat) and *T. dicoccum* (Emmer wheat).

In habit, Indian wheats correspond to the spring wheats of Europe and America. It is a C_3 crop and it's not well adapted to tropical or semitropical conditions, although day length insensitive wheat cultivars developed by CIMMYT are thriving well within 20^0 of the equator (Stoskopf, 1985).

In India, wheat is generally grown during winter spring season (mid November- mid April) after the harvesting of kharif crops. Any delay in monsoon and subsequently delay in the harvesting of wet season crops like scented rice, groundnut, toria, pigeon pea, cotton, sugarcane etc. forces wheat to be sown late upto middle of January (Aslam *et al.*, 1989). Wheat crop grown in Northern India under late sown conditions is exposed to very low temperature upto booting stage, but at later stages it has to face warm temperature, that enables grain development under high temperature conditions leading to poor grain yield. As a result the reproductive (spike initiation to anthesis) and ripening (anthesis to maturity) growth phases of late sown wheat crop is generally exposed to high temperature stress during the months of March and April where temperature remains around 35- 40^0 C.

Each genotype within a plant species has an optimum range of temperature for its normal growth and development and different stages of growth have different optima such as 20-25^0C for germination, 16-20^0C for tillering and 20-23^0C for grain formation in case of wheat. Wheat is especially sensitive to temperature that exceeds 90^0 F for any significant period, plants can be injured at seedling emergence, reproductive development, and stem elongation, heading and flowering by high temperature.

Recently an increasing attention has been paid to the development of short duration varieties with heat tolerance during grain formation stage. Breeding for heat tolerance is an integral component of wheat breeding programmes at both national and international levels (Acevedo *et al.*, 1990). These programmes will help in spreading wheat cultivation to non-traditional warm areas besides optimizing wheat yield in tropical environments under the present situation of multiple cropping systems. Both of these goals require significant breeding efforts to improve high temperature tolerance of cereals for yield and quality.

Wheat improvement for heat tolerance depends on intensive hybridization using heat tolerant donors and high yielding commercial cultivars. To evolve an effective hybridization programme combining ability analysis is used to test the performance of parents in different cross combinations and characterize the nature and magnitude of gene effects in the expression of various heat tolerant parameters.

Though several new varieties are released for commercial cultivation in recent years, most of the cultivars currently recommended were never intended for late planting. A time has come when breeders can no longer ignore this reality. The available scientific information on breeding aspects for high temperature tolerance is very little. The present study is modest attempt to fill in this gap by identifying the parents with high combining ability and their crosses on the basis of their general and specific heat tolerance parameters under normal and post anthesis heat stress environments. The present study was undertaken with the following objectives:

- To estimate the combining ability variances and their effects for grain yield, its components and heat tolerance parameters under normal and heat stress environments in diallel set of crosses in wheat.

- To estimate the extent of heterobeltiosis for grain yield, its components and heat tolerance parameters under normal and heat stress environments

- To estimate association between yield and its component characters under normal and heat stress environments.

- To identify promising parents and the cross combinations for improvement in grain yield under post anthesis heat stress.

- To suggest suitable strategy of breeding for heat tolerance in wheat.

2.REIVEW OF LITERATURE

Different types of environmental stresses often limit the yield of crop plants. One such stress is heat stress. In case of heat stress, there are a number of attributes in plants that confer both survival and production potential at various stages of life cycle. The present investigation was conducted to estimate the heterosis, combining ability and character association for high temperature tolerance and yield contributing characters in bread wheat. The information related to present investigation has been reviewed under the following heads:

2.1 Effect of heat stress

2.2 Heterosis

2.3 Combining ability

2.4 Correlation

2.1 Effect of heat stress

Heat affects survival, growth and development, and the physiological processes. The nature and extent of the effects depend mainly on the temperature, the plant species and the process in question. The different stages of growth and development differ in their sensitivity to heat stress. For example, the period of spike initiation to flowering in wheat is very sensitive to high temperature and acceleration of this phase seems to be the main cause of yield reduction under hot condition. Besides these, temperature affects several physiological processes such as respiration, photosynthetic translocation, protein denaturation, membrane composition and stability etc.

Chaudhary and Wardlaw (1978) reported that high temperature stress during grain filling period was a major constraint to increase productivity when average temperature was more than 15^0 C during this period. Wardlaw (1994) reported that the mean temperature greater than $15\text{-}18^0$ C, following anthesis could result in decrease in grain weight at maturity.

Zhong- Hu and Rajaram (1994) reported that yield, grains/spike, biomass and plant height are more thermo-sensitive than spike number/m^2, and 1000-grain weight. The grain filling rate was more temperature sensitive than days to anthesis and duration of grain filling. Grains/spike, biomass, harvest index and test weight could be considered potential selection criteria for yield under high temperature. Abdelghani *et al.* (1994) observed that grain yield, spike number/m^2 and 1000- grain weight were reduced due to late sowing while number of grains was increased.

According to stone *et al.* (1995) high temperature stress could be a single significant factor in reducing yield and quality of wheat.Chaudhary *et al.* (1996) observed that 1000- grain weight was also an important yield contributor under high temperature conditions. Viswanathan and Chopra (1996) reported that heat shock proteins might play a vital role in thermo-tolerance in order to maintain productivity under heat stress.

Radmehr et *al.* (1996) reported that very late sowing (20^{th} January) accelerated the growth and development of plants, but shortened the duration of other developmental stages and resulted in a decrease in plant height due to high temperature. Further decrease in mean yield was observed in the 21^{st} December sowing and 20^{th} January sowing to 21% and 37% respectively compared to the 21^{st} November sowing. The reduction in 1000- grain weight and number of grains/ spike were the most important.

Chaudhary *et al.* (1996) observed that in late sown wheat i.e. in IV^{th} week of December, high ambient temperature adversely affected the yield of the delayed sown crop. Kernel weight was highly correlated with heat tolerance. Other characters which significantly contributed to the yield under higher temperature were tiller number and reduced height. Alteration of the phenological phases of the plant to give a ratio of 2: 1 between the vegetative and reproductive phases was suggested as a method of enhancing crop yield under late sowing, together with increased heat tolerance.

Singh *et al.* (1997) studied the effect of high temperature on wheat varieties (HI 977, HD 2329, HD 2402, HD 2270, HD 2285 and Sonalika) that were sown in two dates (Normal: 15 November and date: 15 January). Variety HI 977, HD 2270 and HD 2285 exhibited higher photosynthetic rate and stomatal conductance, a lower rise in canopy temperature and higher grain yield under late sown conditions than the other varieties. Sairam *et al. (*1997) reported that under elevated temperature conditions, sensitive cultivar Raj 3077 showed decreased chlorophyll content and heat tolerant genotype HD 2285 showed higher chlorophyll content.

Sharma and Tandon (1997a) reported that in a study under two dates of sowing i.e. 25th Oct. and 1st Dec., 1989, days to appearance of first node, number of tillers/ plant and number of spikelets/plant were adversely affected. Similarly duration from anthesis to maturity, 1000-grain weight and grain yield/ plant were adversely affected by heat stress during grain filling. Sharma and Tandon (1997b) reported that reduction in period from anthesis to maturity and yield ranged from 18.0-32.0% and 19.5 to 37.0% respectively, due to effect of high temperature during the grain filling period.

Singh and Ahmad (1997) reported that increased temperature significantly reduced the days to anthesis, maturity duration and flag leaf area. Like wise higher post anthesis temperature i.e., 26.6^0- 30.6^0 C, contributed to decline in productive ears, biological yield, 1000- grain weight and grain yield under late sowing compared with normal sowing.

Ashraf and Bhatti (1998) reported that chlorophyll content and leaf area decreased with late sowing. Shah (1998) reported that biological yield and 100- grain weight were the traits identified for selection with high temperature. Sangam *et al.* (1998) concluded that high yield potential and earliness of a genotype were found to be desirable parameters to select for heat tolerance.

Chopra and Viswanathan (1999) evaluated 32 non-cultivated and cultivated genotypes belonging to diploid, tetraploid and hexaploid wheat species for heat tolerance in the field under full irrigation, which were sown in two dates of sowing, November (normal) and January (late) at New Delhi. Wide variability was observed for grain yield stability under heat stress, as the heat susceptibility index ranged from 0.13-2.08. Hexaploidy conferred productive and adaptive advantages as it combined high yield and stability when compared to the tetraploid and diploid groups.

Gibson (1999) reported that in a green house trial, wheat grain yield was reduced by 78%, kernel number by 63% and kernel weight by 29% at 35^0/20^0 C compared with $20^0/20^0$ C day/ night temperature from 10 days after anthesis. High temperature applied 15 days after anthesis reduced grain yield by 18%. Since kernel number was set by this time, the loss was exclusively due to decreased kernel weight. High temperature from 20 days after anthesis decreased kernel weight by 18%.

Sikdar *et al.* (2001) observed that tolerant and sensitive cultivars sown late had lower grain yield than sown during the optimum sowing time. The grain number, 1000- grain weight and main shoot weight were higher in heat tolerant cultivars as compared to sensitive cultivars. Results suggested that relative grain number/ ear and 1000- grain weight and main shoot weight could be used to determine heat tolerance of wheat under late sowing conditions. Sarkar *et al.* (2001) studied the effect of high temperature on various morpho-physiological yield attributes under three dates of sowing viz., early, normal and late. They reported that early maturing genotypes like HD 2285, UP 2338, Lok 1, Sonalika, C 306 and HD 2307 showed better performance under high temperature stress conditions with less reduction in grain yield and had relatively higher grain growth rates with more tolerance to heat stress for most of the yield attributing characters (i.e. low heat susceptibility index).

Nagarajan and Rane (2002) reported that days to anthesis, days to maturity, grain growth duration, grain weight/ spike and grain growth rate (g/ day) showed reduction in crop sown on 24^{th} December as compared to 20^{th} November with exception of harvest index, which registered an increase indicating that vegetative growth was less..

Hafsi *et al.* (2003) reported that under heat stress flag leaf carbon content at anthesis was positively associated with grain yield. Zahedi *et al.* (2003) observed that compared with growth at $20/15^0$ C (day/night), exposure of wheat plants to moderately high temperature ($30/25^0$ C) significantly decreased grain weight through shortening the duration of grain filling. Yadav and Singh (2003) observed that mean for grain protein content was highest under very late sown as indicated in the order as 12.4% (4 Jan), 11.5% (21 Dec), 11.3% (17 Nov) and 9.6% (24 Oct). Mohanty (2003) reported that under late sowing there was a marked reduction in chlorophyll and carotenoid pigmentation. The photo-oxidative pigment loss due to warmer growth conditions in late sown plants could lead to a reduction in flag leaf photosynthesis and contribute to poor yield.

Rashid *et al.* (2004) reported that plant height, number of grains/ ear, straw yield was greater with sowing on 15 Dec than sowing on 30 Dec, the number of effective tillers/plant and grain yield were not significantly affected by date of sowing.

Vivek Raj and Bhardwaj (2004) reported that significantly higher chlorophyll content at 5 days after anthesis was recorded in 19^{th} November sown crops than sown on 19^{th} December. Higher temperature during later stage might have caused water stress resulting in low relative water content (RWC). Better physiological activities were observed in normal sown crop than late sown crop. Varieties PBW 226, HD 2329, HD 2402, UP 2238 and Raj 3765 are good wheat cultivars for growing under late sown conditions for getting higher yield by minimizing the environmental stress due to higher temperature.

2.2 Heterosis

Heterosis is a genetic expression of beneficial effects of hybridization. The term "heterosis" was coined by Shull (1914) to explain its manifestation effect as hybrid vigour. The phenomenon of heterosis has been explained to be associated with some factors like heterozygosity (Shull, 1911 a & b and East, 1936), accumulation in the heterozygotes of the favourable dominant genes from each parent (Jones, 1917; Collins, 1921 and Rickey, 1945), allelic interaction (East, 1936) and non allelic interaction or epistasis (Jones, 1945; Castle, 1946 and Jinks, 1955). Fonseca and Patterson (1968) coined a new term heterobeltiosis to describe the improvement of F_1 hybrid in relation to better parent. Mackey (1976) described genetic principles of expression of heterosis (Superior to the better parent) that may result from one or more of the following situations:

a) The accumulation of favourable dominant or semi dominant genes dispersed amongst two parents i.e. dominance.

b) The complementary action of additive genes (dominant or recessive) at different loci i.e. non allelic interaction or epistasis.

Favourable interaction between two alleles at the same locus i.e. intra locus or inter-allelic interactions referred to as over dominance. The superiority of hybrid over better parent (heterobeltiosis) is more important in determining the feasibility of commercial exploitation of heterosis and also indicating the parental combinations capable of producing the highest level of transgressive seggregants.

Heterosis represents percentage increase or decrease in the mean value of the F_1 hybrids over their mid-parental value. Heterobeltiosis represents percentage increase or decrease in the mean value of F_1 hybrid over the better parent.

In the early period, plant breeders extensively explored and utilized heterosis mainly in allogamous crops. Wheat being a self-pollinated crop, scope for utilization of heterosis will depend on the direction and magnitude of heterosis, biological feasibility of the crop and nature of gene action. Further, it must be emphasized that until hybrid wheat production is achieved on a commercial scale, the wheat breeder has to concentrate his attention upon the conservation of additive component of genetic variance and those epistatic interactions, which can be exploited in homozygous state.

Heterosis in the yield of wheat has been observed for many years, although, its level of expression is highly variable. Heterosis varies with the parental and the environmental conditions under which the hybrids are grown (Phoelman, 1987). A critical prerequisite for the successful production of hybrid cultivars is the availability of sufficient heterosis if available through specific parental combinations. With the discovery of cytoplasmic male sterility (Kihara, 1951) and male fertility restorer line (Wilson and Ross, 1962) in wheat, there has been a renewed interest in the exploitation of heterosis through the use of hybrid varieties. The results obtained by several researchers on degree of heterosis during last twenty years in bread wheat are reviewed here.

Kim (1985) in a multilocation testing observed that grain yield showed higher heterosis than the yield components. Bhatti *et al.* (1986) recorded high heterosis for grain yield per plant (82.0% over mid parent and 32.4% over better parent) followed by 1000- grain weight (41.6% over mid parent and 24.6% over better parent). Dudhal *et al.* (1986) reported high heterosis for grain yield to the extent of 64.37% over mid parent and 54.63% over better parent. Patwary *et al.* (1986) evaluated 42 hybrids for grain yield and seven related characters and revealed that all the traits except days to flowering showed positive heterosis.

Borghi *et al.* (1988) observed heterobeltiosis for grain yield and plant height in 10 crosses evaluated at three locations. Saleem and Hussein (1988) estimated heterosis in 6x6 diallel set and found that four crosses out yielded the better parent for number of grains per spike, five F_1 s excelled the mid parental value, eight excelled the better parent, while all the crosses performed better than mid parental and better parental value for 1000- grain weight.

Singh (1989) assessed six yield components of wheat under salt stress conditions and reported that heterosis is either absent or low for most of the characters in all the crosses. Singh *et al.* (1989) studied heterosis in 9x9 diallel and observed the highest heterosis 33.65% and 25.83% for grain yield over better parent in normal and stress environments, respectively. They also reported that the hybrids revealed significant heterosis for grain yield as well as for number of tillers per plant and total biomass.

Atale and Vitkare (1990) studied heterosis in a set of 15x15 diallel in wheat and reported that crosses NI 5439 x UP 215 and Kalyansona x HD 2189 showed highly significant heterosis and heterobeltiosis for tillers per plant and ears per plant. Sadeque *et al.* (1991) in an eight parental full diallel observed 141.70% heterobeltiosis for number of spikes per plant and 24.40% for spike length. The heterobeltiosis ranged from 182.90 to 215.40 % for grain yield per plant. Krishna and Ahmad (1992) obtained highest mean heterosis for grain weight per spike (26.78%), 1000- grain weight (14.60%), grain yield (12.52%) and harvest index (9.72%). Tiwari and Chakraborty (1992) studied 10 genetically diverse genotypes used as lines, six testers and their 60 F_1s for six characters and observed heterosis for grains per ear and 1000- grain weight.

Kumar and Ganguli (1993) observed that the heterosis over the better parent was low except for harvest index. Significant heterosis was found for harvest index in HUW-220 x HD-2315. Walia *et al.* (1993) noted significant heterosis over better parent for grain yield per plant, number of spikelets per ear and number of ears per plant in the crosses PAN 1922 x RL 7 and HS 223 x JSWYT 9. Murlia (1993) studied seven wheat genotypes in half- diallel set and reported that Kalyansona x KRL 1-4, Kharchia 65 x Raj 1114 and Kharchia 65 x Kalyansona in normal environment and Kalyansona x WJ 222, WJ 222 x WJ 245 and Kalyansona x KRL 1-4 in saline environment possessed high heterobeltiosis for grain yield. This was mainly contributed by number of productive tillers, biological yield and number of grains per spike and grain weight per spike in both the environments. Sharma and Tandon (1993) reported that under heat stress, heterosis declined for most traits except for duration of the anthesis to maturity period and 1000- grain weight.

Chakarborty and Tiwari (1995) estimated heterosis in sixty bread wheat crosses and observed high heterotic effect for 1000- grain weight, while heterosis was low for tillers per plant. Budak and Yildirim (1996) observed that high heterosis was found for harvest index and yield in the cross Orsa x AK-702, which has the best SCA. Hennaway (1996) observed mid parent and better parent heterosis ranging from - 70.82% to 72.75% and from - 79.24 to 61.34%, respectively for grain yield in an 8 x 8 diallel set of crosses. Sharma and Tandon (1996) observed significant SCA effects as well as significant heterosis for tillers per plant. Thus for this character in 75% crosses SCA effects were indicative of heterotic potential. Among the other characters tested, SCA effects correlated with heterotic potential. Sharma and Menon (1996) reported significant and positive heterosis for grain yield (39.70 to 89.10%) in 23 out of 45 crosses of bread wheat involving 10 diverse parents. However, the magnitude of heterosis was not high for the yield components.

Prasad *et al.* (1998) observed the extent of heterosis over better parent and over standard variety for yield and yield contributing characters including some of physiological traits. The maximum heterosis over better parent for grain yield per plant was observed to be 59.70%. The crosses showing heterosis for grain yield were not heterotic for all the characters.

Deshpande and Nayeem (1999) found significant heterosis over the better parent for grain yield per plant. The cross Hindi 62 x Ajantha exhibited high heterosis over mid parent for grain yield. Munir *et al.* (1999) reported higher heterosis and heterobeltiosis for days to 50% heading and grain weight per main spike in the cross between L 4-26 x Mutant-1; for plant height, grains/spike and grain yield per plant in hybrid of C- 271 x Pirsbak-85, and for 1000- grain weight in hybrid of a cross between Barani-70 x C-271.

Budak (2001) studied heterosis for certain quantitative traits in 8 x 8 diallel of durum wheat and reported that heterosis values for heading date was highest (11.80%) in Kunduru x 97 mbvd-5 with a heading date of 128 days and lowest (4.90%) in Sorgul x Kunduru with a heading date of 122 days. Heterosis values for plant height were high for the tallest cross populations while the heterosis value for grain yield was highest (87.00%) in Akbas x 97 mbvd-5.

Dubey *et al.* (2001) determined the nature and extent of heterosis for eight characters in thirty six hybrids and their parental lines of wheat under normal and saline environments. The cross Raj 3077 x K 65, Raj 3765 x Raj 3880 and K 65 x Raj 3880 exhibited desirable heterobeltiosis under normal condition while Job 666 x K 65, Job 666 x Raj 3880 and K 65 x Raj 3880 exhibited desirable heterobeltiosis for grain yield under salinity. The heterotic crosses for yield were found to be heterotic for 1000- grain weight and harvest index. The heterosis for grain yield per plant of superior crosses in saline conditions was mainly contributed by number of productive tillers and harvest index.

Salgotra *et al.* (2002) determined heterosis in the F_1 hybrids between 13 winter wheat and 4 diverse testers of spring wheat for grain yield and nine other traits. Two crosses showed significant heterosis over the better parent for grain yield, grains per spike and harvest index, whereas, one cross showed high heterosis over standard check variety.

Subhani *et al.* (2002) in a 6 x 6 diallel set of crosses, observed that there were significant mid and better parent heterosis values in certain single crosses for flag leaf area, tillers/ plant, plant height, grains/ spike, 1000- grain weight, biomass per plant and grain yield per plant under irrigated and drought stress conditions. The high heterosis of 36.39, 15.71 and 12.54% was noted for grain yield per plant, tillers per plant and spike length respectively in cross LU 265 x Roh. 90 under irrigated conditions, whereas cross combination Inq.91 x 4072 manifested maximum heterosis and heterobeltiosis for 1000- grain weight under irrigated and drought stress conditions.

Joshi et *al.* (2003) calculated the magnitude of heterosis over mid parent and better parent, in a 10 x 10 diallel set of common wheat for quantitative and qualitative traits under varying environmental conditions i.e. early sowing (25 October) normal sowing (20 November) and late sowing (20 December) in Rajasthan. Twenty nine crosses showed significant positive heterobeltiosis for grain yield in all 3 environments. Under early, normal and late sowing environments, maximum heterobeltiosis for grain yield was 13.30% (Sonalika x WH 157), 44.30% (CPAN 3004 x Durgapura 65) and 36.37% (Sonalika x HD 2285), respectively. The cross CPAN 3004 x Raj 1972 exhibited significant positive heterbeltiosis for grain yield in all environments. Heterobeltiosis for protein content ranged from 13.81-19.61% over all environments. The hybrid, HD 2428 x HD 2329 displayed stability for higher protein content in all environments.

2.3 Combining Ability:

Combining ability is the ability of parents to combine well and to produce promising segregants in succeeding generations, and it is an important criterion in selecting parents for a successful hybridization programme. As combining ability often depends upon complex interaction among genes, certain combinations nick well to produce superior offsprings, whereas other involving equally promising parents, produce disappointing progenies.

In 1927, Davis recognized the importance of estimating combining ability of S_2 lines using inbred variety cross method. Jenkins and Brunson (1932) advocated the use of open pollinated variety as a tester for preliminary evaluation of lines. However, the concept of combining ability was developed by Sprague and Tatum (1942) working on maize. According to them general combining ability (GCA) was the average performance of a line in a series of hybrid combinations. Specific combining ability (SCA) was the performance of a parent in a specific cross i.e. SCA refers to the deviation in the performance of a particular cross from the value expected on the basis of the GCA of the parents involved.

The general combining ability is primarily due to additive as well as additive x additive type of non allele interaction. The specific combining ability is mainly a function of non-additive effects of genes i.e. dominance variances.

Rojas and Sprague (1952) and Cockerham (1954) observed that estimate of relative magnitude of GCA and SCA variance from individual experiment might be of a limited value. The utility increased when such estimates were obtained by repeating them over a number of locations or years. Jinks (1954) explained GCA as the result of additive effect while SCA was considered to be composed of non allelic interactions i.e. non-additive effect of genes.

Griffing (1956) presented statistical concept of general and specific combining ability. The GCA involved both additive as well as additive x additive interaction whereas SCA involved dominance, dominance x dominance and additive x dominance interactions.

Hayman (1957) reported that in the absence of epistasis general combining ability was composed of both additive and a proportion of dominance, while specific combining ability involved dominance only. However, when epistasis was present both general combining ability and specific combining ability contained epistatic portion also.

It has also been realized that high yielding lines may not necessarily be able to transmit their superiority to their hybrids (Allard, 1960). Hence, an estimate of GCA and SCA effects may be more reliable test rather than their *per se* performance.

Kempthorne (1957) precisely defined the GCA and SCA variances in terms of covariances of half sibs (H.S.) and full sibs (F.S.), where GCA = Cov. (H.S.) and SCA = Cov. (F.S.) –2 Cov (H.S.)

Different statistical methods have been established for analyzing gene action, such as top cross technique proposed by Jenkins and Brunson (1932), poly cross by Tysdal *et al.* (1942), North Carolina Design by Comstock and Robinson (1952), line x tester by Kempthorne (1957), triallel cross by Rawlings and Cockerham (1962) and analysis of generation means by Mather and Jinks (1971). The theory of diallel analysis was developed by Jinks and Hayman (1953), Jinks (1954, 1956) and Hayman (1954a, 1954b, 1957 and 1958). The recent developments about this technique have been described in detail by Mather and Jinks (1971) and a worked example has been given by Aksel and Johnson (1963). Hull (1945) was the first to analyse data from diallel crosses of homozygous lines using regression techniques. Yates (1947) defined diallel analysis as set of all possible combinations among in genotypes.

Diallel analysis is based on the assumptions (Hayman, 1954) of normal diploid segregation, homozygosity of parents, lack of maternal effects, absence of multiple allelism, absence of linkage among genes affecting the characters, lack of epistasis and random mating.

Mainly there are two approaches for diallel analysis, first Hayman's approach (1954) and second is Griffing's approach (1956). Hayman's approach is based on estimation of components of variation. Griffing's approach is based on the estimation of GCA and SCA variances and effects.

Griffing's (1956) has given four methods of diallel depending on the materials involved in the analysis.

(i) Parents, F_1 s and reciprocals (Method I)

(ii) Parents and one set of F_1 s (Method II)

(iii) F_1 s and reciprocals (Method III)

(iv) One set of F_1 s only (Method IV)

For each of the above method, two models namely random and fixed effect models were also proposed. He further suggested that GCA involved additive and additive x additive interactions, while SCA measured dominance and dominance x dominance, additive x dominance and higher order interactions. Some of the pertinent studies during last twenty years regarding general and specific combining ability in wheat have been reviewed below:

Singh *et al.* (1987) studied combining ability over environments in wheat and found that GCA and SCA effects were significant for all the traits studied. Further, GCA x environment effect was also significant for all the traits, as so were SCA x environment interactions, except in case of days to heading. Prabhu and Sharma (1987) reported that variance for GCA and SCA was highly significant for flag leaf area and the former being predominant. The mean performance of the parents was directly related with their GCA effects in all parents except HUW 81 and K 68. The crosses showing positive and significant SCA effects involved one good and other poor as well as both poor general combiners in the cross.

Bhullar *et al.* (1988) observed that mean squares for GCA and SCA were significant for grain yield per plant, 1000- grain weight, grains per spike and spike length. They also identified six good general combiners for yield and other related traits as well as eight promising F1's. Malik *et al.* (1988) estimated general and specific combining ability in spring wheat. They found that GCA and SCA variances were highly significant for plant height and grain yield. GCA mean squares were larger than those for SCA for most of the characters. They also reported significant genotype x environment interactions.

Gupta *et al.* (1989) examined combining ability effects in an 8 x 8 diallel set of crosses in wheat and observed that mean performance of the crosses agreed well with the overall status of the specific combining ability effects. They concluded that selection of the crosses based on heterotic response is equally effective. On the other hand, high x high, high x low and low x low general combiners could cause heterosis in the best crosses.

Yadav and Iqbal (1989) determined combining ability over environments in spring wheat in an 8 x 8 diallel set of crosses. They reported that GCA x environment and SCA x environment interactions were significant for all the traits studied except for 1000- grain weight. They also found that HD 2285 had the highest GCA effect for yield and its components. The crosses HD 2285 x CPAN 1907, HD 2285 x WH 291 and WH 283 x CPAN 1907showed high SCA effects for yield and some components.

Mohammed (1990) performed diallel cross in durum wheat and it was evident that the SCA variance was greater than GCA variance for all the characters studied except that for flag leaf area and grain yield where the GCA variances were greater than the SCA variances for both. Sharma and Singh (1990) observed significant GCA effects for all the traits except harvest index and also observed significant SCA effects for all the traits except spike length, spikelets per spike and harvest index. Stupar and Borojevic (1990) reported that both additive and non-additive components were important for seed protein content. Mandal and Maity (1990) reported that additive genetic components were predominant for crude protein and grains per spike.

Bebykin and Starichkova (1991) reported that protein content was controlled by genes with additive and dominance effects. Values for protein content in the F_1 progeny were generally intermediate between those of the parents.

Mishra *et al.* (1991) in a diallel set of bread wheat grown under normal and late sown conditions reported that none of the parents was the good general combiner for all the characters studied. However, K-68 and Carazinho were found good general combiner for grain yield per plant and 100- grain weight and cross combinations, namely, Carazinho x K 68 and Toabaxi 66 x K 68 were promising for grain yield per plant.

Singh *et al.* (1991) reported that heat resistant wheat variety WH- 147 M showed significant positive GCA for grain yield per plant after late sowing. Bessonova *et al.* (1991) concluded that heat resistance was intermediate in the F_1 hybrids tested though closer to the parent with the higher value and was conditioned by additive gene effects. Li *et al.* (1991) reported that the GCA variance for seeds/spike, plant height 1000- grain weight, seed weight per spike, spike length and protein content were significant higher than their SCA effects suggesting that these characters were controlled by additive gene action. The SCA variance for spike/ plant and seed weight/ plant was greater than those of their GCA variances, suggesting the two characters were mainly controlled by non-additive generation.

Yadav and Mishra (1992) reported that some lines of late sown wheat showed significant negative GCA for plant height. Six crosses exhibited good SCA effects for grain yield/ plant, grains/ ear, spikelets/ spike, ear length and height. Both additive and non-additive gene actions were involved in the expression of different characters and additive x additive and additive x dominance epistasis was observed in some crosses.

Kheiralla and Sherif (1992) carried out genetic analysis of heading date, 1000- grain weight and grain yield/ plant by performing a half diallel cross among 6 cultivars sown at normal and late dates (favourable and heat stressed conditions) in 1990-91. For all the three characters, mean differences among genotypes, environments and G x E interaction were highly significant. Late sowing decreased time to heading date and significantly reduced 1000- grain weight and grain yield per plant by 8.7% and 22.8%, respectively. For the two sowing dates, partial dominance was estimated for all traits except grain yield/ plant under normal sowing date conditions.

Asad *et al.* (1992) reported that additive effects were more important for yield per plant, spike length and number of kernels per spike. However, gene action was non-additive for protein content, number of spikes per plant and 1000-kernel weight. Prodanovic (1993) reported that tiller number, grains/ spike, 1000- grain weight and grain yield were conditioned mainly by dominance gene effects. Over dominance was found for some traits such as grain growth duration, grain number/ spike and grain yield.

Menon and Sharma (1994) while studying combining ability in bread wheat over environments observed that Raj 1482 and HD 2204 were good general combiners for grain yield as well as for most of the other important characters.

Mishra *et al.* (1994 a) reported that under late sown, irrigated and high fertility conditions additive gene effects were generally more important than non-additive gene effects for grain yield and some of its attributes in bread wheat. Mishra *et al.* (1994 b) evaluated a 10 x 10 diallel set of crosses in timely sown bread wheat and observed the predominant role of additive gene action for the expression of all the characters under study except leaf area, biological yield and harvest index. The variance owing to SCA was significant for days to flowering, plant height, days to maturity and yield/plant indicating that non-additive gene effects were also important.

Babu and Kumar (1995) evaluated an 8 x 8 diallel set of wheat in normal and stress environments and observed that WL 711, K 68 and HD 2009 were good general combiners for grain yield in stress environments, while WL 711, WH 157, K 68 were good general combiners under normal environments. The crosses HD 2009 x K 68, WL 711 x K 68 and HD 2009 x WH 157 was desirable for grain yield in all the environments. These crosses involved at least one parent as good combiner.

Kathiria and Sharma (1996) performed combining ability analysis for earliness in bread wheat under normal and salt affected soils and reported that GCA x environment and SCA x environment interaction variances were highly significant for days to flowering and maturity. The parents HW 452, LOK 1 and Raj 1972 were good general combiners for earliness under all the environments and amongst all the crosses, Kharchia 65 x Raj 1972 was most promising for earliness in each environment.

Taleei and Beigi (1996) reported that variance components attributed to both GCA and SCA for plant height and grain yield per plant were highly significant, but GCA mean squares were larger than SCA mean squares for plant height. GCA mean square were significant for harvest index, days to heading, 1000-

grain weight and grain protein content, indicating the importance of additive and non-additive genetic variation were pronounced.

Mishra *et al.* (1996) recorded information on genetic variance derived from data on 13 yield related traits in 10 wheat parents and their 45 F_1 and 45 F_2 hybrids grown under late sown irrigated conditions. Significant additive and non-additive gene actions were found for the expression of plant height, ear length, days to maturity, number of ears/ plant, grains/ ear and 1000- grain weight, where as days to flowering, spikelets/ear, yield/plant and harvest index showed non allelic interaction. Kraljevic (1996) observed that there was a preponderance of non-additive gene action for grain protein content.

Sharma and Tondon (1997 b) reported that there was a preponderance of additive gene effects in general when 28 crosses obtained from diallel set were evaluated for chlorophyll content, leaf area/ plant, plant height and dry matter yield in heat tolerance experiments performed in growth chambers.

Arun and Raghavaiah (1998) carried out combining ability analysis by using 12 lines and 4 testers in wheat and found that parent P 932 was good general combiner for many yield components. Further, the cross HD 2329 x P 1035 was found to be best cross with desirable SCA effects for number of tillers per plant, spikelets per spike, spike length, grains per spike, 1000- grain weight and grain yield per plant.

Ali and Khan (1998) studied combining ability effects for flag leaf area, tillers/ plant, grains/ spike, 1000- grain weight and grain yield/ plant. SCA was highly significant for 1000- grain weight and tillers/plant. All the traits showed additive type of gene action.

Singh (1998) determined combining ability by using 9 x 9 diallel set of crosses of wheat in normal and stress environments for different traits and revealed that PBW 272 was a good general combiner for grain yield in both the environments, while for component traits the parent K-65 (tiller number), WL 711 and PBW 222 (grains/spike) and HD 2285, Raj 1972 and HD 2428 (1000- grain weight) were good general combiners in both environments.

Celliers *et al.* (1999) made full diallel cross with five spring wheat cultivars. One set of parents and their F_1 hybrid progenies were grown under high temperature (31^0 C/ 25^0 C day/night) and a second set under control temperature (22^0 C/ 16^0 C). Data were collected for 8 yield related traits. Additive gene action was predominant for all the characteristics measured at both temperature levels. Additive gene action was significantly lower at the temperature conditions for most characteristics. Parent with the higher GCA effects at one set of temperature tended to have the highest GCA effects for he other temperature level as well. SCA effects were significantly different at the higher temperatures. High SCA effects for a characteristic at one temperature level were often paralleled by low or negative SCA effects at the other temperature level. This indicated that specific hybrid combinations selected in an optimum environment would probably not perform in a similar manner under high temperature conditions.

Rajora (1999) carried out heterosis and combining ability analysis by using 12 lines and 5 testers for grain yield and its components. The estimates of GCA effects showed that UP 301 and Raj 3077 were good general combiners for all the traits studied. Among the females, WL 711 was the best for grain yield, grains per spike and 100- grain weight.

Sheikh and Singh (2000) found significant differences for GCA and SCA in both the environments for harvest index and related traits. Among parents WH 542, UP 2338, Raj 3765 and PBW 343 were found to be good general combiners. The crosses UP 2338 x Raj 3765 and WH 147 x PBW 373 in the normal environment and WH 542 x PBW 343 in the stress environment were observed to be good cross combinations for both grain yield per plant and the harvest index. Ghimiray *et al.* (2000) observed that both GCA and SCA variances were significant for protein content in boron deficient as well as in boron supplemented conditions. Additive as well as non-additive gene effects were important for protein content.

Ishlam *et al.* (2001) revealed that genetic studies based on combining ability analysis, the non-additive genetic components of variation were more important than additive components in most of the traits studied except for number of grains per ear and 1000- grain weight. Souza *et al.* (2001) in a partial diallel study, observed that there were differences of heat tolerance among parents and hybrid populations for grain yield and both additive and non-additive gene effects were important in the genetic control of grain yield in the presence or absence of heat.

Arshad & Chowdhry (2002) did combining ability analysis in bread wheat and revealed that GCA mean squares were significant for flag leaf area, plant height and 1000- grain weight in irrigated as well as in drought stress conditions while it was significant for grains per spike under normal and for tillers/ plant under drought stress condition. It also revealed that additive effects were more important than the dominance effects for almost all the characters under both sowing conditions which indicated the importance of additive variation for the in heritance of these characters.

Manmohan *et al.* (2003) revealed significance of both GCA and SCA variances in normal as well as heat stress environments for spikes/ plant, grains/ spike, spikelets/spike, grain yield and 1000- grain weight except SCA for grains/ spike in heat stress environment.

Joshi *et al.* (2003) reported that the GCA and SCA components of variance were significant for all the traits. However, the GCA component of variance was predominant. Among the parents HD 2329, Raj 1972, HD 2285 and HD 2428 were good general combiners for grain yield. The desirable specific crosses for grain yield were CPAN 3004 x Durgapura 65, Sonalika x HD 2329, Raj 3077 x CPAN 3004, Raj 3077 x HD 2428 and HD 2428 x WH 157. The parent Raj 1972 was the best general combiner for grain yield and protein content. The most suitable specific crosses for protein content were HD 2329 x HD 2285, HD 2428 x Raj 1972 and CPAN 3004 x WH 157.

2.4 Correlation

The knowledge regarding association between the yield and its component characters is of paramount importance in identifying the real component characters that could be used as selection parameter for effective improvement through selection.

Correlation coefficient is a statistical measure, which is used to find out the degree (strength) and direction of relationship between two or more variables. It is represented by r. A positive value of r shows that the changes of two variables are in the same direction i.e. high value of one variable are associated with high values of other and vice versa. When r is negative, the movements are in opposite directions, i.e. high values of one variable are associated with low values of other.

Most of the agronomic characters in crop plants are quantitative in nature. Yield is one such character and is governed by the actions and interactions of various component characters. It is also widely recognized that genetic architecture of yield can be resolved better by studying its component characters. This enables the plant breeder to breed high yielding genotypes with desirable combination of traits.

The degree of correlation between two observable characters based on phenotypic values of the traits is known as simple correlation or total correlation. It includes both genotypic and environmental effects and therefore, differs under varying environmental conditions. The inherent or heritable association between two variables is known as genotypic correlation. Environmental correlation is entirely due to environmental effects. In other words, this is due to error variance. It is not heritable and stable. The results obtained by several workers on correlation studies during last twenty years are reviewed here:

Rajora (1987) observed that under saline condition, grain yield per plant was positively correlated with number of tillers per plant, number of grains per ear, plant height, ear length and 1000- grain weight at genotypic and phenotypic levels. Prabhu and Sharma (1987) found that there was high positive association between flag leaf area and grain yield.

Zhong-hu and Rajaram(1994) observed that grain yield was highly and positively correlated with grains/ spike, biomass and harvest index, independent of season and genotype under high temperature. Grains/ spike, biomass and harvest index and test weight could be considered potential selection criteria for yield under high temperature. Analysis of yield under normal and late sowing conditions failed to reveal any association between the yield potential in normal sowing date and the performance of varieties under high temperature. Ibrahim (1994) observed significant positive correlation of grain yield per plant with fertility, number of grains per ear, 1000- grain weight and harvest index at both the genotypic and phenotypic levels. Chowdhary *et al.* (1996) reported that wheat kernel weight was highly correlated with heat tolerance. Other characters, which significantly contributed to yield under high temperature, were tiller number and reduced height.

Rahman *et al.* (1997) reported that grain yield was positively associated with biomass, harvest index, 1000- grain weight and chlorophyll content and negatively correlated with days to anthesis. Singh and Ahmad(1997) reported that coefficient of correlation of grain yield showed significant positive corelation with effective ear number, biological yield and 1000- grain weight indicating their involvement in heat tolerance of wheat under late sowing conditions. Singh and Redhu (1997) found that under normal and stress (rainfed) environments, grain yields were significantly and positively associated with tiller number, total biomass and harvest index. Significant positive correlations were also observed between biomass and grain yields and tiller number. Jaglam *et al.* (1997) found that yield was highly, significantly and positively correlated with plant height, number of tillers per plant and grain weight. The interrelationships among these traits were also found positive and highly significant.

Shah (1998) reported that in case of late planting days to flowering was negatively correlated with 1000- grain weight. Path analysis showed that biological yield/ plant was directly influenced by days to maturity, number of spikelets/ spike, 1000- grain weight in favourable direction, while in late sown planting biological yield was direct contribution of 1000- grain weight, grain weight/ spike, spike length and spikelets/spike. The findings revealed that 1000- grain weight and biological yield could be improved upon simultaneously for better yield in heat stress environment. Prakash and Sastry (1999) observed significant positive association of grain yield per plant with grain yield per ear and 1000- grain weight in wheat under moderate salinity (8.9 d sm^{-1}). The grain yield per ear was positively associated with plant height, grains per ear and 1000- grain weight.

Dhonde *et al.* (2000) observed high positive association of grain yield with grain weight per ear, plant height and days to 50% flowering under normal condition. Amongst other traits, 1000- grain weight had significant positive association with grain weight per ear and negative association with grains per ear, productive tillers per plant and days to 50% flowering.

Subhani (2000) observed positive and significant correlation between Grain yield/ plant and flag leaf area, tillers/ plant, grains/ spike, 1000- grain weight, biomass/ plant and harvest index. Negative and significant correlation was noted for days to heading and grain yield/ plant. In case of drought stress conditions, grain yield was positively and significantly correlated with flag leaf area, plant height, grains/ spike, 1000- grain weight, biomass / plant and harvest index. Similar to irrigated conditions, days to heading also has negative and significant correlation with grain yield.

Muhammad and Ihsan (2004) reported that plant height, grains/ spike and 1000- grain weight were positively and significantly correlated with grain yield at the genetic level and highly and significantly associated with grain yield at phenotypic level. Flag leaf area was positively but non-significantly associated with grain yield, whereas the number of fertile tillers/ plant was negatively and non-significantly correlated with grain yield. Ashok kumar and Verma (2004) found that flag leaf area exhibited a positive correlation with 1000- grain weight and negative correlation with grain number and grain weight/ spike. The number of days taken to anthesis was positively correlated with biomass yield, grain number and grain weight/ spike.

3. MATERIALS AND METHODS

The present investigation entitled "Genetic studies on high temperature tolerance at post anthesis in wheat (*Triticum aestivum* L. em. Thell.)" was carried out during *winter* 2003-04 at Agronomy Farm of SKN College of Agriculture, Jobner (RAU, Bikaner). Jobner is situated at an elevation of 420 meters above mean sea level at a latitude of 20^0 6' North and 75^0 28' East. Meteorological data during the period of crop production are given in Annexure I.

3.1 Experimental material

The experimental material consisted of 8 diverse parents viz. Raj 3765, HD 2285, Raj 3777, HD 2687, HD 2329, UP 2238, Raj 3077 and Lok 1, their all possible F_1s (excluding reciprocals) and F_2 s. The parents were selected on the basis of their different maturity duration and suitability for either timely or late sowing. The details of parents are given in table 3.2

Crosses were attempted in a diallel mating design (excluding reciprocals) during *winter* 2002-03 at Agronomy Farm of SKN College of Agriculture, Jobner. The resultant F_1 seeds of each cross were raised at wheat breeding regional station (IARI), Wellington, Nilgiris (Tamil Nadu) to obtain F_2 seeds of each cross in off season nursery in *summer* 2003.

3.2 Experimental procedure

Heat stress environment in the field conditions was created by manipulating the dates of sowing. The experimental material consisting of 8 parents, 28 F_1 s and 28 F_2 s was planted during Rabi 2003-04 in Randomized Complete Block Design with three replications under normal and heat stress environments. In each replication, each of the homogenous generation i.e. parents and F_1 s was sown in a plot of single row and the F_2 s in a plot of two rows of 2 m length. Row to row distance was kept 30 cm and 10 cm distance was maintained between plants in all the plots under both the environments. Non experimental rows were planted all around the experimental material to avoid any possible border effects. Sowing was done by dibbling the seeds in the soil. Recommended agronomic practices were followed for raising the crop in both the environments.

TABLE: 3.2 CHARACTERISTICS OF THE PARENTAL VARIETIES OF WHEAT

S. No.	Genotypes/ varieties	ORIGIN	Parentage	Salient features
1.	Raj 3765	RAU (Durgapura)	HD 2002 x VI 639	Recommended for **normal and late sown irrigated conditions**. Amber colour grain, medium bold, hard grain, medium- early maturity, medium ear
2.	HD 2285	IARI, New Delhi	(HD 1912-HD 1592/3 /HD 1962/E 4870/K65)/6 /(HD 2160/HD 2186)	Double dwarf, **late sown, irrigated conditions**, amber colour, semi hard, oblong, medium bold grains, medium-early maturity, medium ear
3.	Raj 3777	RAU (Durgapura)	Raj 3160 x HD 2449	Suitable for **very late sown conditions**, 105-110 days to maturity
4.	HD 2687	IARI, New Delhi	CPAN 2009 x HD 2329	Suitable for **timely sown irrigated conditions**
5.	HD 2329	IARI, New Delhi	HD 1962/E4870/3/ K65/ 5/SKA /6 / UP 262	**Timely sown irrigated conditions**, double dwarf, medium maturity. Amber color, semi hard, ovate, medium sized grains, high yielder, good for high fertility, brown ear and awn, medium ear
6.	UP 2338	GBPUAT, Pantnagar	UP 368 / VL 421 / UP 262	Recommended for **timely/late sown irrigated conditions**. Amber colour, hard, oblong, medium grains, medium late maturity class, long ear
7.	Raj 3077	RAU (Durgapura)	HD 2267/ Raj-1482 /Raj 1802	Double dwarf, **normal/late sown irrigated conditions**, amber colour semi hard, oblong, medium grains. Very widely adapted to various stresses, specially salinity/alkalinity tolerant, medium early

8.	Lok 1	Lok Bharti, Sansora, Gujarat	S 308 X S 331	Suitable for **timely, late sown irrigated conditions**, medium maturity class, amber, semi hard, oblong, bold grains having 40-55 g test weight

3.3 Details of the environments

To create post anthesis heat stress environment in the field conditions the material was sown about two weeks later than the normal sowing time. Thus late sowing created post anthesis heat stress environment as it exposed the crop to heat stress after anthesis i.e. about 3 months after sowing. The details of each environment were as follows:

Environment	Date of sowing
E_1 (Normal)	05.12.2003
E_2 (Heat stress)	22.12.2003

Although normal sowing time of wheat in this region is IInd - IIIrd week of November but the selected genotypes were late sown responsive and the required temperature for normal sowing was achieved in the Ist week of December, therefore, sowing on 05.12.2003 actually represents the environment of normal temperature.

3.4 Observations recorded

The observations on 10 morphological traits were recorded on a sample of 5 randomly selected competitive plants for each parent and F_1s and 10 plants in F_2 generation in each replication and environment. Three characters/ parameters were not directly observed but derived. Single plants were tagged before completion of flowering for unbiased plant selection. Every care was taken to select only competitive plants and border plants were avoided. A random sample of flag leaf and grain was also obtained from each plot / parent / F_1/ F_2 / replication in each environment for the estimation of chlorophyll content in flag leaf and protein content in grain. Thus, in all 15 parameters were considered. The procedure followed for recording data on different characters are described below:

3.4.1 Morphological characters:

3.4.1.1 Number of tillers per plant Number of total tillers of each sampled plant at maturity was counted.

3.4.1.2 Number of effective tillers per plant Spike bearing tillers were counted on the selected plants and averaged.

3.4.1.3 Plant height (cm) Plant height was measured in centimeters from the base (ground level) to the tip of the main spike (excluding awns). Observations were recorded on all selected plants at the time of maturity.

3.4.1.4 Flag leaf area (cm^2) Length and breadth in cm of the flag leaf on the main tillers of the selected plants were measured and mean length and breadth was calculated. The area was obtained by the following formula (Simpson, 1968);

Leaf area (cm^2) = Length x Breadth (maximum) x 0.79

3.4.1.5 Days to anthesis The days taken from the date of sowing to the date of anthesis i.e. appearance of yellow coloured dehiscent anthers on the spike on plot basis.

3.4.1.6 Duration from anthesis to maturity The days taken from the date of anthesis to the date of maturity on plot basis.

3.4.1.7 Days to maturity The days taken from the date of sowing to the date of spikes turning yellow on plot basis.

3.4.1.8 Number of grains per spike Total number of grains per main spike of the sampled plant was counted after threshing and averaged.

3.4.1.9 1000- grain weight (g) A sample of 100 grains was drawn from the pooled yield of the selected plants and its weight was recorded in grams, which was multiplied by 10 to obtain 1000-grain weight.

3.4.1.10 Biological yield per plant (g) Total weight of selected single plants along with its ears after sun drying for two weeks was taken and then averaged.

3.4.1.11 Grain yield per plant (g) The total grain produced by selected plants in each plot was weighed and mean value per plant was calculated.

3.4.1.12 Straw yield per plant (g) Weight of total grains produced by single plant was subtracted from the biological yield of concerned single plant and averaged.

3.4.1.13 Harvest Index It is the ratio of grain yield to biological yield expressed in percentage. It was calculated as per formula suggested by Singh and Stoskopf (1971).

$$\text{Harvest Index (\%)} = \frac{\text{Grain yield per plant}}{\text{Biological yield per plant}} \times 100$$

3.4.2 Biochemical parameters/ characters:

3.4.2.1 Chlorophyll content (mg/g fresh weight) Total chlorophyll content was estimated 5 days after anthesis from a sample of fully expanded flag leaf of each treatment in each replication. The chlorophyll content was estimated colorimetrically by the method suggested by HisCox and Israelstam (1979) i.e. DMSO method.

3.4.2.2 Grain protein content (%): The grains of the sampled plants from each plot in each replication were dried and pooled. These grains were then ground in a mechanical grinder. Nitrogen content was determined by colorimetric method as suggested by Snell and Snell (1949). Protein content was worked out by multiplying the percent nitrogen content in grain with a factor

6.25 (A.O.A.C., 1960). The results were expressed as percent on dry weight basis.

3.5 Statistical Procedures

3.5.1 Analysis of variance

The mean values of parents, F_1s and F_2 s for all the characters were subjected to analysis of variance separately for individual environment as well as for pooled data, to determine the significance of differences among genotypes, environments and genotype x environment interaction (Panse and Sukhatme, 1967). The ANOVA was conducted for P +F_1 and P+F_2 separately. The structure of the analysis of variance (ANOVA) is presented in tables 3.3 and 3.4.

Table: 3.3 ANOVA form for pooled analysis for Parents + F_1

Source	d f	Mean Sum of squares
Environments	(e-1)	M_e
Replications	e. (r-1)	M_r
Environment x Replications	(e-1) (r-1)	M_{re}
Genotypes	$\left(\frac{p\,(p+1)}{2} - 1\right)$	M_g
Genotypes x environments	$\left(\frac{p\,(p+1)}{2} - 1\right)$.(e-1)	M_{ge}
Error	$\left(\frac{p\,(p+1)}{2} - 1\right)$. (r-1). e	M_e

The same structure was prepared for Parents + F_2 also. Where, e= number of environments, r = number of replications and p = number of parents.

Table: 3.4 ANOVA form for individual environment Parents + F_1

Source	d f	Mean sum of squares	Expected mean sum of squares

Replications	(r-1)	M_r	$\sigma^2_e + g\,\sigma^2_r$
Genotypes	$\left(\frac{p\,(p+1)}{2} - 1\right)$	M_g	$\sigma^2_e + r\,\sigma^2_g$
Parents	(p-1)		
F_1	$\left(\frac{p\,(p-1)}{2} - 1\right)$		
Parents Vs F_1	1		
Error	$\left(\frac{p\,(p+1)}{2} - 1\right).(r-1)$	M_e	σ^2_e

The same structure was prepared for Parents + F_2, where F_1 was replaced by F_2.

Where, r and p are the number of replications and parents, respectively.

σ^2_g = genotypic variance

σ^2_r = variance due to replications

σ^2_e = environmental variance

$\sigma^2_{g\,e}$ = variance due to genotype x environment

The standard error (SEm) of mean, critical differences (CD) and coefficient of variation (CV) were estimated as under:

$$S\,Em = \sqrt{\frac{Me}{r}}\,, \quad CD = \sqrt{\frac{2\,Me}{r}} \times t_{(r-1)\,(g-1)} \text{ at 5\% level of significance}$$

$$CV\,\% = \frac{\sqrt{Me}}{\bar{X}} \times 100$$

Where Me= error mean square

r= number of replications

$\bar{X}$= over all mean of the traits

To compare means of any two genotypes in two different environment

$$CD = \sqrt{\frac{2\ Me\ (pooled)}{r}} \times t_{(g-1)\ (r-1)} \text{ at 5\% level of significance}$$

Where

Me (Pooled) = error mean square from pooled analysis

e = number of environments

r = number of replications

3.5.2 Combining ability analysis

When pooled analysis of variance indicated significant variation due to genotype x environment for in (Parents $+F_1$) and (Parents $+F_2$) analysis, ANOVA for combining ability was done environment wise following Griffing's (1956) Method II, Model I. The statistical model for the analysis as given by Griffing is:

$$x_{ijk} = \mu + g_i + g_i + s_{ij} + e_{ijk}/b$$

Where,

x_{ijk} = an observation of the phenotype of a cross i^{th} and j^{th} parents in k^{th} block.

μ= Population mean

g_i = general combining ability effect of i^{th} parent

g_j = general combining ability effect of j^{th} parent

s_{ij} = specific combining ability effect of the cross between i^{th} parent and j^{th} parent such that $s_{ii} = s_{ji}$

b = number of blocks and

e_{ijk} = environmental effects associated with i j k^{th} observation

The usual restrictions such as gi= 0 and sij + sji = 0 (for each i) are imposed on combining ability elements. The structure of ANOVA of combining ability is given below:

Table 3.5: ANOVA form for combining ability for pooled data

Source	**d.f.**	**M**	**Expectation of mean squares**
GCA	(p-1)		$\sigma^2 e + \frac{(p+2)e \Sigma_i}{(p-1)} g^2_i$
SCA	p(p-1)/2		$\sigma^2 e + \frac{2e}{p (p-1)} \Sigma_{i \leq} \Sigma_j s^2_{ij}$
Environment.	(e-1)		$\sigma^2 e + \frac{p (p+1)}{2(e-1)} \Sigma_k e^2_k$
GCA x	(p-1) (e-	M(g	$\sigma^2 e + \frac{(p+2)}{2} \Sigma_k \Sigma_i (g\ e)^2_{ik}$
SCA x	[p (p-	M(s	$\sigma^2 e + \text{---------------} \Sigma_k \Sigma_i \Sigma j\ (se)^2_{ij}$
Error	e(t-1) (r-1)	M_e	$\sigma^2 e$

Where, r, p, t and e are the number of replications, parents, genotypes and environments respectively.

TABLE: 3.6 ANOVA FORM FOR COMBINING ABILITY IN INDIVIDUAL ENVIRONMENT

Source	**d f**	**Mean sum of squares**	**Expectations of mean squares**
GCA	p-1	M_g	$\sigma^2_e + (p+2/p-1)\ \Sigma\ g^2_i$
SCA	p (p-1)/2	M_s	$\sigma^2_e + 2/[p(p+1)]\ \Sigma\ \Sigma\ s^2_{ij}$
Error	$P\ \{\ \frac{(p+1)}{2}\ \} -1\ \ (r-1)$	M_e	σ^2_e

Where,

Components due to GCA=1/ p-1 $\sum_i g^2_i = (M_g - M_e)/\ p+2$

Components due to SCA=2/[p(p-1)] $\sum_{i \leq j} \Sigma\ s^2_{ij} = M_s - M_e$

Ratio of GCA variance to SCA variance was calculated as follows-

$$\text{GCA / SCA} = \frac{1}{(p-1)} \Sigma\ g^2_i \ / \ [2/p\ (p-1)]\ \ \sum_{i \leq j} \Sigma\ s^2_{ij}$$

GCA / SCA variance ratio might directly be calculated as follows:-

$$\text{GCA / SCA variance ratio} = \frac{(M_g - M_e)}{(M_s - M_e)} \times \frac{1}{(p+2)}$$

M_e = the error mean squares for the separate data of parents and F_1s and parents and F_2 s of individual environment.

The estimates of GCA and SCA effects for the data of individual environment were obtained as follows-

$$\text{Population mean} = \mu = \frac{2}{p(p+1)} x_{..}$$

$$\text{GCA effects of } i^{th} \text{ parents} = \hat{g}i = \frac{1}{(p+2)}\left[(x_{i.} + x_{ii}) - \frac{2}{p} x_{..}\right]$$

$$\text{SCA effects of } ij^{th} \text{ cross} = \hat{S}_{ij} = x_{ij} - \frac{1}{(p+2)}(x_{i.} + x_{ii} + x_{.j} + x_{jj}) + \frac{2}{(p+1)(p+2)} x_{..}$$

Where,

p = number of parents

g_i = general combining ability effect of i^{th} parent

s_{ij} = specific combining ability effects of cross involving i^{th} and j^{th} parents.

$x_{i.}$ = total of array involving i^{th} parents

$x_{.j}$ = total of array involving j^{th} parent

x_{ii} = parental value of the i^{th} parent

x_{jj} = parental value of the j^{th} parent

$x..$ = total of all $p(p+1)/2$ items in the diallel table.

$$\text{Var } g_i = \frac{p-1}{p(p+2)}\sigma_e^2, \qquad \text{Var } s_{ij} = \frac{(p^2+p+2)}{(p+1)(p+2)}\sigma_e^2$$

$$\text{Var } s_{ij} - s_{ik} = \frac{2(p+1)}{(p+2)}\sigma_e^2, \qquad \text{Var } g_i - g_j = \frac{2}{p+2}\sigma_e^2$$

$$\text{Var } s_{ij} - s_{kl} = \frac{2p}{(p+2)}\sigma_e^2$$

$\sigma^2 e = M_e$ (as detailed above)

Significance of general and specific combining ability estimates and the standard error of difference between the two estimates was computed by applying the “t” test, where the SE of the estimate was the square root of respective variance.

3.5.3 Estimation of heterobeltiosis

Per cent heterobeltiosis of a cross was calculated by the following formula as suggested by Fonseca and Patterson (1968),

$$\text{Heterobeltiosis} = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

Where,

F_1 is the mean over replications of hybrid between i^{th} and j^{th} parents. BP is the mean over replications of the better parent between i^{th} and j^{th} parents.

Test of significance of heterobeltiosis

The significance of the heterobeltiosis was done using‘t’ test. The SE for testing the significance of heterobeltiosis was calculated by the following formula,

$$SE_{(F1-BP)} = (2\ M_e / r)^{½}$$

The‘t’ value was estimated by the following formula,

$$t_{(r-1)(g-1)} = (F_1 - BP)/\ SE_{(F1-BP)}$$

Where,

F_1 = mean value of hybrid

BP = mean value of the better parent over replications

r = number of replications

g = number of genotypes / hybrids

M_e =error mean square from analysis

The calculated‘t’ value was compared with table value at error degree of freedom i.e. (r-1) (g-1)

To calculate heterobeltiosis, parent with higher mean values were considered desirable for all the characters except for plant height, days to anthesis, duration from anthesis to maturity, days to maturity where negative direction was considered desirable.

3.5.4 Correlation analysis

Correlation coefficients were worked out between different pairs of characters as well as with yield as per the method described below.

For computing phenotypic and genotypic correlation coefficients analysis of covariance was carried out in all possible paired combinations of characters. The structure of the analysis of covariance is presented in following table:

TABLE 3.7 ANALYSIS OF COVARIANCE AND EXPECTATIONS OF MEAN SUM OF CROSS PRODUCTS BETWEEN CHARACTERS X AND Y

Source	d f	Mean sum of products	Expected mean sum of products
Replications	(r-1)	MSP_r	
Genotypes	(g-1)	MSP_g	Cov e_{xy} + r.Cov g_{xy}
Error	(r-1). (g-1)	MSP_e	Cov e_{xy}

From the above table the expected mean sum of products were estimated as given below:

Error covariance (Cov e_{xy}) = MSP_e

Genotypic covariance (Cov g_{xy}) = $(MSP_g - MSP_e)$ /r

Phenotypic covariance (Cov p_{xy}) = Cov g_{xy} + Cov e_{xy}

The phenotypic and genotypic correlation coefficients were calculated from the phenotypic and genotypic and components of variances and covariances as described by Singh and Choudhary (1995) as per formulae given by Johnson *et al*. (1955)

Genotypic correlation (r_g) between characters x and y

$$r_g = \frac{Cov\ g_{xy}}{\sqrt{\sigma^2_g \text{ of x X } \sigma^2_g \text{ of y}}}$$

Phenotypic correlation (r_p)between characters x and y

$$r_p = \frac{Cov\ p_{xy}}{\sqrt{\sigma^2_p \text{ of x X } \sigma^2_p \text{ of y}}}$$

Where, σ^2_g and σ^2_p represent the genotypic and phenotypic variances. The estimates of correlations were compared with the r values given in the 'r' Table (Fisher and Yates, 1938) at error degrees of freedom.

3.5.5 Heat Susceptibility Index (HSI)

A heat susceptibility index (Fisher and Maurer, 1978) was calculated by using the following formula

$$HSI = \frac{1 - (Yij / Y_{ic})}{D}$$

$$D = 1 - (Yj / Y_c)$$

Where,

D = Heat Stress Intensity

Y_{ij} = Grain yield of i^{th} genotype in the heat stress environment

Y_{ic} =Grain yield of i^{th} genotype in the normal environment

Y_j =Mean grain yield of all the genotypes in the heat stress environment

Y_c = Mean grain yield of all the genotypes in the normal environment

4. EXPERIMENTAL RESULTS

The data obtained in the present investigation for different characters on parents, F_1's and F_2's of an 8-parent diallel set (excluding reciprocals) evaluated in *rabi* 2003-04 under normal and post anthesis heat stress environments, were analyzed using appropriate statistical methods. The results obtained are presented under the following heads:

4.1 Analysis of variance for experimental design

4.2 Mean and range of various characters in parents, F_1's and F_2's

4.3 Combining ability analysis

4.3.1. Analysis of variance for combining ability

4.3.2. Estimation of combining ability effects

4.4 Estimation of heterobeltiosis and

4.5 Estimation of correlation between yield and yield related attributes

4.1 Analysis of variance

Pooled analysis of variance revealed that significant differences existed between genotypes in both the generations for all the characters studied (Table ….). Significant differences between the environments were also observed, indicating the effects of environment on the expression of all the characters. The genotype X environment interaction was found significant for all the characters studied except for flag leaf area and for grain protein content in both the generations and for days to maturity, grains per spike and grain yield per plant in F_1 generation and for tillers per plant and effective tillers per plant in F_2 generation. Significant genotype X environment interaction for different characters indicated a non linear response of genotypes to the change in the environment. Since genotype X environment interaction was found significant for most of the characters studied, further analyses were done for the individual environment separately.

Analysis of variance based on individual environments (Table ……...) indicated significant differences between the genotypes for all the characters in normal as well as in heat stress environment in both the generations. Further partitioning of mean sum of squares into parents, hybrids and parents v/s hybrids indicated that significant differences existed among the parents, F_1's and F_2's for all the characters studied in both the environments. Parents v/s F_1 was found significant for all the characters studied except for plant height, duration from anthesis to maturity, grains per spike, chlorophyll content and grain protein content in normal environment and for effective tillers per plant, days to anthesis, grains per spike, 1000- grain weight, biological yield per plant, grain yield per plant, straw yield per plant, harvest index and grain protein content in heat stress environment.

Similarly parents v/s F_2 was found significant for all the characters studied except for effective tillers per plant, flag leaf area, days to anthesis, grains per spike, 1000- grain weight, biological yield per plant, grain yield per plant, harvest index in normal environment and effective tillers per plant, flag leaf area, days to anthesis, grains per spike in heat stress environment.

4.2 Mean and range of various characters in parents, F_1's and F_2's

The general mean and range of variation for each character over the environments are given in table---------. In general all the characters and in both the environments, the mean of the F_1's exceeded that of parental mean indicating existence of heterosis, similarly the F_2's mean was less in comparison to F_1's indicating existence of inbreeding depression. Further, the mean of most of the characters decreased under heat stress environment (Table ……). The mean of different characters over generations and environments are given in Table---------and are presented below:-

4.2.1 Number of tillers per plant

Among the parents, number of tillers per plant ranged from 7.87 (HD 2687) to 9.40 (Raj 3777) with the mean value of 8.61 in the normal environment whereas under heat stress it ranged from 6.47 (HD 2687) to 8.27

(Raj 3765) with the mean value of 7.36. The mean value of F_1's was 9.07 with a range from 7.67 (UP 2338 X Lok 1) to 10.73 (Raj 3765 X UP 2338) under normal whereas in heat stress environment, the mean was 7.70 with a range from 6.33 (HD 2687 X Lok 1) to 8.80 (Raj 3777 X HD 2687).

In F_2's the mean was 8.33 with a range from 6.47 (UP 2338 X Lok 1) to 9.87 (Raj 3777 X HD 2687) in normal whereas in heat stress environment, the mean was 7.14 with a range from 5.67 (UP 2338 X Lok 1) to 8.40 (HD 2285 X UP 2338).Performance across the environments indicated that under heat stress environment the number of tillers per plant was reduced by 14.52, 15.10 and 14.29 per cent among the parents, F_1's and F_2's, respectively.

4.2.2 Number of effective tillers per plant

Among the parents, number of effective tillers per plant ranged from 5.87 (HD 2285) to 7.67 (Raj 3777) with the mean value of 6.98 in the normal environment whereas under heat stress it ranged from 5.07 (HD 2285) to 6.87 (Raj 3777) with the mean value of 6.19. The mean value of F_1's was 7.30 with a range from 5.40 (HD 2285 X UP 2338) to 8.53 (Raj 3765 X UP 2338) under normal whereas in heat stress environment, the mean was 6.21 with a range from 4.73 (HD 2329 X UP 2338) to 7.33 (Raj 3777 X HD 2687).

In F_2's the mean was 6.83 with a range from 5.37 (Raj 3765 X HD 2329) to 8.40 (Raj 3777 X HD 2687) in normal whereas in heat stress environment, the mean was 6.05 with a range from 4.83 (Raj 3765 X HD 2329) to 7.47 (Raj 3777 X HD 2687).Performance across the environments indicated that under heat stress environment the number of effective tillers per plant was reduced by 11.32, 14.93 and 11.42 per cent among the parents, F_1's and F_2's, respectively.

4.2.3 Plant height (cm)

Among the parents, Plant height ranged from 61.80 cm (HD 2687) to 83.00 cm (Raj 3077) with the mean value of 74.31 cm in the normal environment whereas under heat stress it ranged from 51.13 cm (HD 2687) to

66.93 cm (Raj 3765) with the mean value of 57.80 cm. The mean value of F_1's was 73.53 cm with a range from 59.67 cm (Raj 3765 X HD 2687) to 85.47 cm (HD 2329 X Raj 3077) under normal whereas in heat stress environment, the mean was 62.74 cm with a range from 54.40 cm (Raj 3765 X Raj 3077) to 71.27 cm (HD 2329 X Raj 3077).

In F_2's the mean was 71.22 cm with a range from 58.93 cm (HD 2687 X HD - 2329) to 81.60 cm (Raj 3765 X Raj 3777) in normal whereas in heat stress environment, the mean was 63.22 cm with a range from 55.17 cm (HD 2687 X HD 2329) to 71.70 cm (Raj 3765 X HD 2687).Performance across the environments indicated that under heat stress environment the plant height was reduced by 22.22, 14.67 and 11.23 per cent among the parents, F_1's and F_2's, respectively.

4.2.4 Flag leaf area (cm^2)

Among the parents, flag leaf area ranged from 21.88 cm^2 (HD 2687) to 34.46 cm^2 (Lok 1) with the mean value of 27.04 cm^2 in the normal environment whereas under heat stress it ranged from17.46 cm^2 (Raj 3777) to 28.98 cm^2 (Lok 1) with the mean value of 22.34 cm^2. The mean value of F_1's was 28.69 cm^2 with a range from 23.15 cm^2 (HD 2687 X Lok 1) to 37.12 cm^2 (HD 2285 X Raj 3077) under normal whereas in heat stress environment, the mean was 23.83 cm^2 with a range from 18.31 cm^2 (HD 2687 X Lok 1) to 29.71 cm^2 (HD 2285 X Raj 3077).

In F_2's the mean was 27.28 cm^2 with a range from 18.94 cm^2 (Raj 3765 X Raj 3077) to 33.08 cm^2 (HD 2285 X Raj 3077) in normal whereas in heat stress environment, the mean was 21.91 cm^2 with a range from 16.98 cm^2 (Raj 3765 X Raj 3077) to 27.37 cm^2 (HD 2285 X Raj 3077).Performance across the environments indicated that under heat stress environment the flag leaf area was reduced by 17.38, 16.94 and 19.68 per cent among the parents, F_1's and F_2's, respectively.

4.2.5 Days to anthesis

Among the parents, days to anthesis ranged from 77.33 days (Lok 1) to 87.33 days (HD 2687) with the mean value of 82.50 days in the normal environment whereas under heat stress it ranged from 67.00 days (Lok 1) to 77.00 days (UP 2338) with the mean value of 71.96 days. The mean value of F_1's was 83.81 days with a range from 77.67 days (HD 2285 X Lok 1) to 88.00 days (Raj 3777 X UP 2338) under normal whereas in heat stress environment, the mean was 71.83 days with a range from 68.33 days (HD 2329 X Raj 3077) to 75.33 days (Raj 3777 X UP 2338).

In F_2's the mean was 82.65 days with a range from 78.33 days (HD 2329 X Raj 3077) to 87.33 days (Raj 3765 X Raj 3077) in normal whereas in heat stress environment, the mean was 71.69 days with a range from 66.67 days (HD 2285 X Lok 1) to 75.33 days (HD 2687 X UP 2338).Performance across the environments indicated that under heat stress environment the days to anthesis was reduced by 12.78, 14.29 and 13.26 per cent among the parents, F_1's and F_2's, respectively.

4.2.6 Duration from anthesis to maturity

Among the parents, duration from anthesis to maturity ranged from 29.00 days (UP 2338) to 38.33 days (HD 2285) with the mean value of 33.83 days in the normal environment whereas under heat stress it ranged from 24.00 days (HD 2687) to 30.33 days (HD 2285) with the mean value of 26.79 days. The mean value of F_1's was 33.89 days with a range from 28.00 days (HD 2687 X Raj 3077) to 41.00 days (HD 2329 X Raj 3077) under normal whereas in heat stress environment, the mean was 28.63 days with a range from 24.33 days (Raj 3765 X HD 2329) to 33.67 days (HD 2329 X Raj 3077).

In F_2's the mean was 34.95 days with a range from 29.33 days (Raj 3765 X Raj 3077) to 38.67 days (HD 2285 X Lok 1) in normal whereas in heat stress environment, the mean was 28.07 days with a range from 24.00 days

(Raj 3765 X HD 2687) to 31.00 days (Raj 3777 X UP 2338).Performance across the environments indicated that under heat stress environment the duration from anthesis to maturity was reduced by 14.52, 15.10 and 14.29 per cent among the parents, F_1's and F_2's, respectively

4.2.7 Days to maturity

Among the parents, days to maturity ranged from 112.67 days (Lok 1) to 122.67 days (HD 2687) with the mean value of 116.34 days in the normal whereas under heat stress environment it ranged from 96.00 days (Lok 1) to 101.00 days (UP 2338) with the mean value of 98.75 days. The mean value of F_1's was 117.70 days with a range from 113.67 days (Raj 3765 X Raj 3077) to 121.00 days (UP 2338 X Lok 1 and Raj 3077 X Lok 1) under normal whereas in heat stress environment, the mean was 100.46 days with a range from 96.00 days (Raj 3765 X HD 2329) to 103.33 days (Raj 3777 X HD 2329).

In F_2's the mean was 117.61 days with a range from 113.67 days (HD 2687 X Lok -1) to 121.33 days (Raj 3777 X UP 2338) in normal whereas in heat stress environment, the mean was 99.76 days with a range from 96.33 days (Raj 3765 X UP 2338) to 104.33 days (Raj 3777 X UP 2338).Performance across the environments indicated that under heat stress environment the days to maturity was reduced by 15.12, 14.65 and 15.18 per cent among the parents, F_1's and F_2's, respectively.

4.2.8 Grains per spike

Among the parents, number of grains per spike ranged from 38.33 (HD 2329) to 48.20 (UP 2338) with the mean value of 44.25 in the normal environment whereas under heat stress it ranged from 35.20 (HD 2329) to 41.73 (UP 2338) with the mean value of 39.14. The mean value of F_1's was 45.39 with a range from 39.40 (Raj 3765 X HD 2329) to 53.27 (UP 2338 X Raj 3077) under normal whereas in heat stress environment, the mean was 40.06 with a range from 34.40 (HD 2285 X HD 2687) to 47.53 (UP 2338 X Raj 3077).

In F_2's the mean was 43.73 with a range from 36.23 (HD 2285 X Raj 3077) to 54.10 (HD 2329 X Lok 1) in normal whereas in heat stress environment, the mean was 38.85 with a range from 33.07 Raj 3765 X UP 2338) to 48.73 (HD 2329 X Lok 1).Performance across the environments indicated that under heat stress environment the grains per spike was reduced by 11.55, 11.74 and 11.16 per cent among the parents, F_1's and F_2's, respectively.

4.2.9 1000- grain weight (g)

Among the parents, 1000- grain weight ranged from 35.21 g (HD 2687) to 48.77 g (Lok 1) with the mean value of 41.61 g in the normal environment whereas under heat stress it ranged from 30.12 g (HD 2687) to 43.02 g (Lok 1) with the mean value of 37.01 g. The mean value of F_1's was 43.74 g with a range from 35.73 g (HD 2285 X UP 2338) to 49.48 g (HD 2329 X Lok 1) under normal whereas in heat stress environment, the mean was 37.00 g with a range from 30.22 g (HD 2285 X UP 2338) to 41.21 g (HD 2285 X Lok 1).

In F_2's the mean was 41.09 g with a range from 33.32 g (HD 2285 X UP 2338) to 46.81 g (HD 2285 X Lok 1 and HD 2329 X Lok 1) in normal whereas in heat stress environment, the mean was 35.37 g with a range from 29.17 g (HD 2285 X UP 2338) to 40.32 g (HD 2329 X Lok 1).Performance across the environments indicated that under heat stress environment the 1000-grain weight was reduced by 11.06, 15.41 and 13.94 per cent among the parents, F_1's and F_2's, respectively.

4.2.10 Biological yield per plant (g)

Among the parents, biological yield per plant ranged from 24.50 g (HD 2285) to 35.73 g (Lok 1) with the mean value of 30.38 g in the normal environment whereas under heat stress it ranged from 16.54 g (HD 2687) to 25.50 g (UP 2338) with the mean value of 22.76 g. The mean value of F_1's was 33.30 g with a range from 26.36 g (HD 2285 X UP 2338) to 43.11 g (Raj 3077 X Lok 1) under normal whereas in heat stress environment, the mean was

23.16 g with a range from 17.46 g (Raj 3765 X HD 2687) to 32.04 g (UP 2338 X Raj 3077).

In F_2's the mean was 31.09 g with a range from 22.43 g (Raj 3777 X Raj 3077) to 44.17 g (Raj 3777 X HD 2687) in normal whereas in heat stress environment, the mean was 21.62 g with a range from 15.15 g (Raj 3777 X Lok 1) to 31.93 g (Raj 3777 X HD 2687).Performance across the environments indicated that under heat stress environment the biological yield per plant was reduced by 25.08, 30.42 and 30.46 per cent among the parents, F_1's and F_2's, respectively.

4.2.11 Grain yield per plant (g)

Among the parents, grain yield per plant ranged from 9.98 g (HD 2285) to 14.59 g (Lok 1) with the mean value of 12.03 g in the normal environment whereas under heat stress it ranged from 7.07 g (HD 2687) to 10.43 g (Lok 1) with the mean value of 9.24 g. The mean value of F_1's was 13.78 g with a range from 11.25 g (HD 2285 X HD 2329) to 17.16 g (Raj 3077 X Lok 1) under normal whereas in heat stress environment, the mean was 9.43 g with a range from 7.02 g (Raj 3765 X HD 2687) to 12.80 g (UP 2338 X Raj 3077).

In F_2's the mean was 12.23 g with a range from 9.07 g (Raj 3777 X Raj 3077) to 16.45 g (HD 2329 X Lok 1) in normal whereas in heat stress environment, the mean was 8.60 g with a range from 6.57 g (Raj 3777 X Lok 1) to 11.26 g (Raj 3777 X HD 2687).Performance across the environments indicated that under heat stress environment the grain yield per plant was reduced by 23.19, 31.57 and 29.68 per cent among the parents, F_1's and F_2's, respectively.

4.2.12 Straw yield per plant (g)

Among the parents, straw yield per plant ranged from 14.51 g (HD 2285) to 22.82 g (Raj 3077) with the mean value of 18.35 g in the normal environment whereas under heat stress it ranged from 9.47 g (HD 2687) to 15.68 g (UP 2338) with the mean value of 13.52 g. The mean value of F_1's was 19.45 g with a range from 14.52 g (HD 2285 X UP 2338) to 25.95 g (Raj 3077 X Lok 1) under normal whereas in heat stress environment, the mean was 13.72 g with a range from 10.10 g (HD 2329 X UP 2338) to 19.23 g (UP 2338 X Raj 3077).

In F_2's the mean was 18.91 g with a range from 13.35 g (Raj 3765 X HD 2329) to 28.36 g (Raj 3765 X Raj 3777) in normal whereas in heat stress environment, the mean was 13.02 g with a range from 8.58 g (Raj 3777 X Lok 1) to 20.67 g (Raj 3777 X HD 2687).Performance across the environments indicated that under heat stress environment the straw yield per plant was reduced by 26.32, 29.46 and 31.15 per cent among the parents, F_1's and F_2's, respectively.

4.2.13 Harvest Index (%)

Among the parents, harvest index ranged from 34.45 % (Raj 3077) to 43.43 % (Raj 3765) with the mean value of 39.74 % in the normal environment whereas under heat stress it ranged from 36.77 % (Raj 3077) to 42.71 % (HD 2687) with the mean value of 40.67 %. The mean value of F_1's was 41.43 % with a range from 37.80 % (Raj 3777 X Lok 1) to 44.82 % (HD 2285 X UP 2338) under normal whereas in heat stress environment, the mean was 40.70 % with a range from 36.45 % (Raj 3777 X Lok 1) to 44.15 % (HD 2329 X Raj 3077).

In F_2's the mean was 39.57 % with a range from 27.15 % (Raj 3765 X Raj 3777) to 43.23 % (UP 2338 X Raj 3077) in normal whereas in heat stress environment, the mean was 40.07 % with a range from 31.19 % (Raj 3765 X HD 2687) to 44.37 % (Raj 3765 X HD 2329).Performance across the environments indicated that there was no marked reduction in harvest index under heat stress, though a slight increase was observed. Among the parents and F_2's, harvest index had increased by 2.34 and 1.26 per cent, respectively and among F_1's it was reduced by 1.74 per cent as compared to normal.

4.2.14 Chlorophyll Content (mg/ g fresh weight)

Among the parents, chlorophyll content ranged from 1.42 mg (Raj 3077) to 2.31 mg (Lok 1) with the mean value of 1.77 mg in the normal environment whereas under heat stress it ranged from 1.31 mg (Raj 3077) to 2.06 mg (Lok 1) with the mean value of 1.61 mg. The mean value of F_1's was 1.74 mg with a range from 1.34 mg (Raj 3777 X Raj 3077) to 2.31 mg (UP 2338 X Raj 3077) under normal whereas in heat stress environment, the mean was 1.47 mg with a range from 1.02 mg (HD 2285 X Raj 3077) to 2.22 mg (UP 2338 X Raj 3077).

In F_2's the mean was 1.67 mg with a range from 1.28 mg (Raj 3777 X Lok 1) to 2.09 mg (Raj 3765 X Raj 3077) in normal whereas in heat stress environment, the mean was 1.44 mg with a range from 1.06 mg (HD 2687 X HD 2329) to 1.89 mg (Raj 3765 X Raj 3077).Performance across the environments indicated that under heat stress environment the chlorophyll content was reduced by 9.04, 15.52 and 13.77 per cent among the parents, F_1's and F_2's, respectively.

4.2.15 Grain Protein Content (%)

Among the parents, grain protein content ranged from 10.20 % (HD 2687) to 14.27 % (Raj 3077) with the mean value of 11.90 % in the normal environment whereas under heat stress it ranged from 10.83 % (HD 2687) to 14.79 % (Raj 3077) with the mean value of 12.42 %. The mean value of F_1's was 12.01 % with a range from 10.52 % (HD 2285 X HD 2329) to 13.85 % (Raj 3077 X Lok 1) under normal whereas in heat stress environment, the mean was 12.54 % with a range from 10.73 % (HD 2285 X HD 2329) to 14.58 % (Raj 3077 X Lok 1).

In F_2's the mean was 11.48 % with a range from 10.31 % (HD 2285 X Raj 3777) to 13.23 % (Raj 3077 X Lok 1) in normal whereas in heat stress environment, the mean was 12.01 % with a range from 10.73 % (HD 2285 X HD 2329) to 13.54 % (Raj 3077 X Lok 1).Performance across the environments indicated that under heat stress environment the chlorophyll content was reduced by 4.37, 4.41 and 4.62 per cent among the parents, F_1's and F_2's, respectively.

4.3 Combining ability analysis

4.3.1 Analysis of variance for combining ability

The results of combining ability analysis pooled over both the environments revealed that the mean squares due to general and specific combining ability were significant for all the characters in both the generations (Table…….). This indicated that both additive and non additive gene effects were involved in the inheritance of the characters under study. The mean squares due to environments were also significant for all the characters, indicating strong influence of environment in the expression of characters studied.

The mean squares due to GCA X environment were significant for all the characters except for total number of tillers per plant, effective tillers per plant, flag leaf area, grains per spike and grain protein content in both the generations; and for days to maturity, and grain yield per plant in F_1 generation and for 1000- grain weight in F_2 generation.

Similarly, the mean squares due to SCA X environment were also significant for all the characters except for flag leaf area and grain protein content in both the generations; and for days to maturity, grains per spike, biological yield per plant, grain yield per plant and straw yield per plant in F_1 generation and for tillers per plant and effective tillers per plant in F_2 generation.

Analysis of variance showed that genotype X environment interaction was significant for most of the characters in both the generations; hence, the combining ability analysis was carried out for each of the environment separately.

Environment wise mean squares due to GCA and SCA for different characters in F_1 and F_2 generations are presented in Table (……). The analysis of variance for combining ability in F_1 and F_2 generations showed that mean squares due to GCA and SCA were highly significant for all the characters in normal as well as in heat stress environment. The significant GCA and SCA mean sum of squares indicated the importance of both additive as well as non additive gene effects in the inheritance of the traits. The GCA/ SCA variance ratio indicated preponderance of additive gene action in F_1 generation for days to anthesis under normal environment and for grain protein content in both the environments. For rest of the traits preponderance of non additive gene action was observed in both the generations and in both the environments.

4.3.2 Estimation of combining ability effects

The combining ability effects were computed to obtain information on selection of suitable parents and crosses for their further use in breeding programmes for tangible advancement of bread wheat. Since GCA X E and SCA X E were significant for most of the characters studied, the combining ability effects were estimated on individual environment basis separately, otherwise pooled combining ability effects were estimated. Estimates of general combining ability effects of the crosses in both F_1 and F_2 generations in both the environments are presented in Table ……..and are described below for each character separately.

4.3.2.1 Tillers per plant

The positive GCA and SCA effects are desirable for this trait. Under normal environment, 4 parents in F_1 and 5 parents in F_2 generation exhibited significant GCA effects out of which two parents viz., Raj 3765 and Raj 3777 showed high positive GCA effects under normal environment in both the generations. Under heat stress environment, 4 parents exhibited significant GCA effects in F_1 generation, out of which 2 parents viz., Raj 3765 and HD 2285 showed high positive GCA effects whereas based on F_2 analysis, 5 parents exhibited significant GCA effects, out of which 3 parents viz., Raj

3765, Raj 3777 and HD 2329 showed high positive GCA effects. Raj 3765 exhibited the highest positive GCA effect under heat stress in both the generation. Raj 3765 in F_1 and Raj 3765 and Raj 3777 in F_2 showed high positive desirable GCA effects in normal as well as in heat stress environments. In general, Raj 3765 and Raj 3777 exhibited high positive desirable GCA effects in both the environments.

In F_1 generation, 14 crosses exhibited significant SCA effects in normal environment, out of which 9 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3765 X UP 2338, Raj 3777 X HD 2687, HD 2687 X HD 2329 and HD 2285 X HD 2687. Under heat stress environment, 17 crosses exhibited significant SCA effects, out of which 9 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2687, HD 2285 X UP 2338, Raj 3765 X Raj 3077 and HD 2285 X HD 2687. In general, Raj 3777 X HD 2687 and HD 2285 X HD 2687 exhibited high positive desirable SCA effects in both the environments.

In F_2 generation, 14 crosses exhibited significant SCA effects in normal environment, out of which 6 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2687, HD 2285 X UP 2338 and Raj 3077 X Lok 1. Under heat stress environment, 14 crosses exhibited significant SCA effects, out of which 6 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2687, HD 2285 X UP 2338 and Raj 3077 X Lok 1. In general, Raj 3777 X HD 2687 and HD 2285 X UP 2338 exhibited high positive desirable SCA effects in both the environments.

Evaluation across the environments indicated that Raj 3777 X HD 2687 and HD 2285 X UP 2338 exhibited high positive desirable SCA effects in both the environments.

4.3.2 Effective tillers per plant

The positive GCA and SCA effects are desirable for this trait. Under normal environment, 6 parents exhibited significant GCA effects in F_1 generation, out of which 3 parents viz., Raj 3077, Raj 3777 and Raj 3765 showed high positive GCA effects whereas based on F_2 analysis, 3 parents exhibited significant GCA effects, out of which Raj 3077 showed the highest positive GCA effect. Raj 3077 exhibited the highest positive GCA effect under normal environment in both the generations. Under heat stress environment, 4 parents exhibited significant GCA effects in F_1 generation out of which 2 parents viz., Raj 3077 and Raj 3777 showed high positive GCA effects whereas based on F_2 analysis, 5 parents exhibited significant GCA effects, out of which three parents viz., Raj 3077, Raj 3777 and Raj 3765 showed high positive GCA effects. Raj 3077 and Raj 3777 exhibited high positive GCA effects under heat stress in both the generations. Raj 3077 and Raj 3777 in F_1 and Raj 3077 in F_2 showed high positive desirable GCA effects in normal as well as in heat stress environments. In general, Raj 3077 and Raj 3777 exhibited high positive desirable GCA effects in both the environments.

In F_1 generation, 14 crosses exhibited significant SCA effects in normal environment, out of which 9 crosses showed positive SCA effects. Higher positive SCA effects were observed in HD 2285 X Lok 1, Raj 3765 X UP 2338, UP 2338 X Raj 3077 and Raj 3777 X HD 2687. Under heat stress environment, 13 crosses exhibited significant SCA effects, out of which 6 crosses showed positive SCA effects. Higher positive SCA effects were observed in UP 2338 X Raj 3077, Raj 3777 X HD 2687, and HD 2285 X Lok 1. In general, UP 2338 X Raj 3077 and Raj 3777 X HD 2687 exhibited high positive desirable GCA effects in both the environments.

In F_2 generation, 18 crosses exhibited significant SCA effects in normal environment, out of which 9 crosses showed positive SCA effects. Higher positive SCA effects were observed in HD 2285 X HD 2329, Raj 3777 X HD 26787 and Raj 3765 X Raj 3077. Under heat stress environment, 18 crosses exhibited significant SCA effects, out of which 9 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2687, HD 2285 X HD 2329 and Raj 3765 X Raj 3077. In general, HD 2285 X HD 2329 and Raj 3777 X HD 2687 showed high positive desirable SCA effects in both the environments.

Evaluation across the environments indicated that cross Raj 3777 X HD 2687 exhibited high positive desirable SCA effect in both the environments.

4.3.2.3 Plant height (cm)

The negative GCA and SCA effects are desirable for this trait. Under normal environment, 5 parents exhibited significant GCA effects in F_1 generation, out of which 2 parents viz., HD 2687 and Raj 3765 showed high negative GCA effects whereas based on F_2 analysis, 6 parents exhibited significant GCA effects, out of which 3 parents viz., HD 2687,HD 2329 and UP 2338 showed high negative GCA effects. HD 2687 exhibited the highest negative GCA effect under normal environment in both the generations. Under heat stress environment, 4 parents exhibited significant GCA effects in F_1 generation, out of which 2 parents viz., HD 2687 and Raj 3765 showed high negative GCA effects whereas based on F_2 analysis, 5 parents exhibited significant GCA effects, out of which 3 parents viz., HD 2329, UP 2338 and HD 2687 showed high negative GCA effects. HD 2687 exhibited high negative GCA effect under heat stress in both the generations. HD 2687 and Raj 3765 in F_1 and HD 2687, HD 2329 and UP 2338 in F_2 showed high negative desirable GCA effects in normal as well as in heat stress environments. In general, HD 2687 exhibited high negative desirable GCA effects in both the environments.

In F_1 generation, 13 crosses exhibited significant SCA effects in normal environment, out of which 7 crosses showed negative SCA effects. Higher negative SCA effect were observed in Raj 3765 X Raj 3077 ,Raj 3765 X HD 2687, Raj 3765 X HD 2329 and Raj 3777 X Raj 3077. Under heat stress environment, 16 crosses exhibited significant SCA effects, out of which 5 crosses showed negative SCA effects. Higher negative SCA effect were observed in Raj 3765 X Raj 3077, Raj 3765 X HD 2285and Raj 3777 X Raj

3077. In general, Raj 3765 X Raj 3077 and Raj 3777 X Raj 3077 showed high negative desirable SCA effects in both the environments.

In F_2 generation, 17 crosses exhibited significant SCA effects in normal environment, out of which 9 crosses showed negative SCA effects. Higher negative SCA effects were observed in Raj 3777 X Raj 3077, HD 2687 X HD 2329 and UP 2338 X Lok 1 . Under heat stress environment, 19 crosses exhibited significant SCA effects, out of which 6 crosses showed negative SCA effects. Higher negative SCA effects were observed in Raj 3765 X UP 2338, Raj 3777 X Raj 3077 and HD 2687 X HD 2329.

Evaluation across the environments indicated that Raj 3777 X Raj 3077 and Raj 3765 X Raj 3077 exhibited high negative desirable SCA effects in both the environments.

4.3.2.4 Flag leaf area (cm^2)

The positive GCA and SCA effects are desirable for this trait. Under normal environment, 6 parents exhibited significant GCA effects in F_1 generation, out of which 3 parents viz., HD 2285, Raj 3077, and HD 2329 showed high positive GCA effects whereas based on F_2 analysis, 2 parents exhibited significant GCA effects, out of which only one parent HD 2285 showed the highest positive GCA effect. HD 2285 exhibited the highest positive GCA effect under normal environment in both the generations. Under heat stress environment, 5 parents exhibited significant GCA effects in F_1 generation, out of which 3 parents viz., HD 2329, HD 2285 and Raj 3765 showed high positive GCA effects whereas based on F_2 analysis, 2 parents exhibited significant GCA effects, out of which only one parent HD 2329 showed high positive GCA effect. HD 2285 and HD 2329 in F_1 and none in F_2 showed high positive desirable GCA effects in normal as well as in heat stress environments. In general, HD 2285 and HD 2329 exhibited high positive desirable GCA effects in both the environments.

In F_1 generation, 12 crosses exhibited significant SCA effects in normal environment, out of which 7 crosses showed positive SCA effects. Higher positive SCA effects were observed in HD 2285 X Raj 3077, Raj 3777 X UP 2338 and HD 2285 X Raj 3777. Under heat stress environment, 11 crosses exhibited significant SCA effects, out of which 5 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X UP 2338, HD 2285 X HD 2687 and HD 2285 X Raj 3077. In general, Raj 3777 X UD 2338 and HD 2285 X Raj 3077 exhibited high positive desirable SCA effects in both the environments.

In F_2 generation, 13 crosses exhibited significant SCA effects in normal environment, out of which 6 crosses showed positive SCA effects. Higher positive SCA effects were observed in HD 2285 X Raj 3077, HD 2285 X UP 2338 and HD 2687 X UP 2338. Under heat stress environment, 12 crosses exhibited significant SCA effects, out of which 4 crosses showed positive SCA effects. Higher positive SCA effects were observed in HD 2285 X Raj 3077, HD 2285 X UD 2338 and Raj 3777 X UP 2338. In general, HD 2285 X Raj 3077 and HD 2285 X UD 2338 showed the high positive desirable SCA effects.

Evaluation across the environments indicated that HD 2285 X Raj 3077 and Raj 3777 X UP 2338 exhibited the high positive desirable SCA effects in both the environments.

4.3.2.5 Days to anthesis

The negative GCA and SCA effects are desirable for this trait. Under normal environment, 8 parents in F_1 and 7 parents in F_2 exhibited significant GCA effects out of which 4 parents in F_1 and 3 parents in F_2 showed negative desirable GCA effects. Three parents viz., Lok 1, HD 2329 and HD 2285 showed high negative GCA effects under normal environment in both the generations. Under heat stress environment, 5 parents exhibited significant GCA effects in F_1 generation, out of which 3 parents viz., Lok 1, HD 2285 and HD 2329 showed high negative GCA effects whereas based on F_2 analysis, 5 parents exhibited significant GCA effects, out of which 2 parents viz., Lok 1 and HD 2285 showed high negative GCA effects. Lok 1 and HD 2285 exhibited high negative GCA effects under heat stress in both the generations. In general, Lok 1, HD 2285 and HD 2329 exhibited high negative desirable GCA effects in both the environments.

In F_1 generation, 10 crosses exhibited significant SCA effects in normal environment, out of which 4 crosses showed negative SCA effects. Higher negative SCA effects were observed in HD 2329 X Raj 3077, HD 2285 X Lok 1 and HD 2687 X UP 2338. Under heat stress environment, 9 crosses exhibited significant SCA effects, out of which 5 crosses showed negative SCA effects. Higher negative SCA effect were observed in HD 2329 X Raj 3077, Raj 3765 X Raj 3777 and Raj 3765 X UP 2338/ HD 2285 X HD 2687. In general, HD 2329 X Raj 3077 showed the highest negative desirable SCA effect in both the environments.

In F_2 generation, 10 crosses exhibited significant SCA effects in normal environment, out of which 4 crosses showed negative SCA effects. Higher negative SCA effects were observed in Raj 3765 X UP 2338, HD 2329 X Raj 3077 and HD 2329 X UP 2338. Under heat stress environment, 12 crosses exhibited significant SCA effects, out of which 6 crosses showed negative SCA effects. Higher negative SCA effect were observed in Raj 3765 X UP 2338, HD 2329 X UP 2338 and Raj 3777 X HD 2687. In general, Raj 3765 X UP 2338, HD 2329 X UP 2338 showed the highest negative desirable SCA effects in both the environments.

Evaluation across the environments indicated that Raj 3765 X UP 2338 and HD 2329 X Raj 3077 exhibited high negative desirable SCA effects in both the environments.

4.3.2.6 Duration from anthesis to maturity

The positive GCA and SCA effects are desirable for this trait. Under normal environment, 8 parents in F_1 and 7 parents in F_2 exhibited significant GCA effects out of which 4 parents in F_1 and 3 parents in F_2 showed positive desirable GCA effects. Under heat stress environment, 7 parents exhibited significant GCA effects in each generation out of which 4 parents in F_1 and 3 parents in F_2 showed positive desirable GCA effects. Three parents viz., Lok 1, HD 2285 and HD 2329 showed high positive GCA effects in both the generations in normal as well as in heat stress environments.

In F_1 generation, 24 crosses exhibited significant SCA effects in normal environment out of which 13 crosses showed positive SCA effects. Higher positive SCA effects were observed in HD 2329 x Raj 3077, Raj 3077 x Lok1, UP 2338 X Raj 3077 and HD 2329 X UP 2338. Under heat stress environment, 25 crosses exhibited significant SCA effects out of which 16 crosses showed positive SCA effects. Higher positive SCA effects were observed in HD 2329 x Raj 3077, HD 2329 x UP 2338, and HD 2285 X Raj 3777. In general, HD-2329 x Raj-3077 and HD 2329 x UP 2338showed high positive SCA effect in both the environments.

In F_2 generation, 22 crosses exhibited significant SCA effects in normal environment out of which 14 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3765 x UP 2338, Raj 3777 x UP2338 and HD 2329 X UP 2338/ Raj 3777 X HD 2329. Under heat stress environment, 18 crosses exhibited significant SCA effects was observed in Raj 3777 x UP 2338, HD 2329 x UP 2338 and HD 2687 X Lok 1. In general Raj3777 x Raj 2338 and HD 2329 X UP 2338 showed the positive SCA effects in both the environments.

Evaluation across the environments indicated that HD 2329 x UP 2338 showed positive SCA effects in both the environments.

4.3.2.7 Days to maturity

The negative GCA and SCA effects are desirable for this trait. Under normal environment, 3 parents exhibited significant GCA effects in F_1

generation, out of which Raj 3765 showed the highest negative GCA effect whereas based on F_2 analysis, 5 parents exhibited significant GCA effects, out of which 3 parents viz., Lok 1, HD 2329 and Raj 3765 showed high negative GCA effects. Raj 3765 exhibited high negative GCA effect under normal environment in both the generations. Under heat stress environment, 3 parents exhibited significant GCA effects in each generation out of which Raj 3765 in F_1 and Raj 3077 in F_2 showed the highest negative desirable GCA effect. Raj 3765 in F_1 and none in F_2 showed the highest negative desirable GCA effect in normal as well as in heat stress environments. In general, Raj 3765 exhibited high negative desirable GCA effect in both the environments.

In F_1 generation, 11 crosses exhibited significant SCA effects in normal environment, out of which 4 crosses showed negative SCA effects. Higher negative SCA effect were observed in HD 2687 X Raj 3077 ,HD 2687 X UP 2338 and Raj 3765 X UP 2338/ Raj 3765 X Raj 3077. Under heat stress environment, 9 crosses exhibited significant SCA effects, out of which 2 crosses showed negative SCA effects. Higher negative SCA effects were observed in HD 2687 X Raj 3077 and Raj 3765 X HD 2329. In general HD 2687 X Raj 3077 showed the highest negative SCA effect in both the environments.

In F_2 generation, 13 crosses exhibited significant SCA effects in normal environment, out of which 4 crosses showed negative SCA effects. Higher negative SCA effects were observed in HD 2687 X Lok 1, HD 2687 X UP 2338 and HD 2285 X UP 2338. Under heat stress environment, 8 crosses exhibited significant SCA effects, out of which 3 crosses showed negative SCA effects. Higher negative SCA effects were observed in Raj 3765 X UP 2338, and HD 2285 X HD 2687.

Evaluation across the environments indicated that HD 2687 X Raj 3077 showed negative desirable SCA effect in both the environments except in F_2 generation.

4.3.2.8 Grains per spike

The positive GCA and SCA effects are desirable for this trait. Under normal environment, 5 parents exhibited significant GCA effects in F_1 generation, out of which 3 parents viz., UP 2338, Raj 3077 and Lok 1 showed high positive GCA effects whereas based on F_2 analysis, 4 parents exhibited significant GCA effects, out of which 2 parents viz., Lok 1 and Raj 3777 showed high positive GCA effects. Lok 1 exhibited high positive GCA effect under normal environment in both the generations. Under heat stress environment, 3 parents exhibited significant GCA effects in F_1 generation, out of which only one parent UP 2338 showed high positive GCA effect whereas based on F_2 analysis, 4 parents exhibited significant GCA effects, out of which 2 parents viz., Lok 1 and HD 2687 showed high positive GCA effects. UP 2338 in F_1 and Lok 1 in F_2 showed high positive desirable GCA effects in normal as well as in heat stress environments. In general, Lok 1 and UP 2338 exhibited high positive desirable GCA effects in both the environments.

In F_1 generation, 11 crosses exhibited significant SCA effects in normal environment, out of which 6 crosses showed positive SCA effects. Higher positive SCA effects were observed in UP 2338 X Raj 3077 ,HD 2329 X Lok 1 and HD 2285 X Lok 1. Under heat stress environment, 10 crosses exhibited significant SCA effects, out of which 7 crosses showed positive SCA effects. Higher positive SCA effects were observed in UP 2338 X Raj 3077 ,HD 2687 X HD 2329, HD 2687 X Raj 3077 and HD 2285 X Lok 1. In general UP 2338 X Raj 3077 and HD 2285 X Lok 1 showed high positive SCA effects respectively in both the environments.

In F_2 generation, 19 crosses exhibited significant SCA effects in normal environment, out of which 9 crosses showed positive SCA effects. Higher positive SCA effects were observed in HD 2329 X Lok 1, HD 2285 X Lok 1, Raj 3765 X Lok 1 and Raj 3777 X Raj 3077. Under heat stress environment, 17 crosses exhibited significant SCA effects, out of which 6 crosses showed positive SCA effects. Higher positive SCA effects were observed in HD 2329 X Lok 1, HD 2687 X Raj 3077, Raj 3765 X Lok 1 and Raj 3777 X Raj 3077. In general HD 2329 X Lok 1, Raj 3765 X Lok 1 and Raj 3777 X Raj 3077 exhibited high positive SCA effects in both environments.

Evaluation across the environments indicated that HD 2329 X Lok 1, and HD 2285 X Lok 1 showed positive desirable SCA effects in both the environments.

4.3.2.9 1000- grain weight (g)

The positive GCA and SCA effects are desirable for this trait. Under normal environment, 6 parents in F_1 and 7 parents in F_2 generation exhibited significant GCA effects out of which 3 parents exhibited positive GCA effects in each generation. Under heat stress environment, 8 parents in F_1 and 5 parents in F_2 exhibited significant GCA effects, out of which 5 parents in F_1 and 2 parents in F_2 exhibited positive GCA effects. In general, Lok 1, HD 2329 and HD 2285 exhibited high positive desirable GCA effects in both the environments and in both the generations except for HD 2285 in F_2 under heat stress.

In F_1 generation, 21 crosses exhibited significant SCA effects in normal environment, out of which 13 crosses showed positive SCA effects. Higher positive SCA effects were observed in UP 2338 X Raj 3077, Raj 3765 X Raj 3777, HD 2329 X UP 2338 and HD 2285 X HD 2687. Under heat stress environment, 19 crosses exhibited significant SCA effects, out of which 11 crosses showed positive SCA effects. Higher positive SCA effects were observed in HD 2285 X HD 2687, HD 2329 X UP 2338 and Raj 3765 X UP 2338. In general, HD 2329 X UP 2338, HD 2285 X HD 2687 and Raj 3765 X UP 2338 exhibited high positive SCA effects in both the environments.

In F_2 generation, 17 crosses exhibited significant SCA effects in normal environment, out of which 10 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2329, HD 2329 X UP 2338, UP 2338 X Raj 3077 and HD 2285 X HD 2687. Under heat stress environment, 18 crosses exhibited significant SCA effect out of which 10 crosses showed positive SCA effects. Higher positive GCA effects were observed in Raj 3777 X UP 2338, HD 2285 X HD 2687, HD 2329 X UP 2338 and HD 2687 X Raj 3077. In general, HD 2285 X HD 2687 and HD 2329 X UP 2338 showed high positive desirable SCA effects in both the environments.

Evaluation across the environments indicated that HD 2285 X HD 2687 and HD 2329 X UP 2338 showed positive desirable SCA effects in both the environments.

4.3.2.10 Biological yield per plant (g)

The positive GCA and SCA effects are desirable for this trait. Under normal environment, 6 parents exhibited significant GCA effects in F_1 generation, out of which 3 parents viz., Raj 3077, Lok 1 and Raj 3777 and Raj 3777 showed high positive GCA effects whereas based on F_2 analysis, 5 parents exhibited significant GCA effects, out of which 2 parents viz., Lok 1 and Raj 3777 showed high positive GCA effects. Lok 1 and Raj 3777 exhibited high positive GCA effects under normal environment in both the generations. Under heat stress environment, 7 parents exhibited significant GCA effects in F_1 generation, out of which 3 parents viz., Raj 3077, Raj 3777 and Lok 1 showed high positive GCA effects whereas based on F_2 analysis, 5 parents exhibited significant GCA effects, out of which 2 parents viz., Lok 1 and Raj 3765 showed high positive GCA effects. Lok 1 exhibited high positive GCA effect under heat stress in both the generations. Raj 3077, Raj 3777 and Lok 1 in F_1 and Lok 1 in F_2 showed high positive desirable GCA effects in normal as well as in heat stress environments. In general, Lok 1 and Raj 3777 exhibited high positive desirable GCA effects in both the environments.

In F_1 generation, 14 crosses exhibited significant SCA effects in normal environment, out of which 8 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2687, Raj 3765 X HD 2285 and UP 2338 X Raj 3077/ Raj 3077 X Lok 1. Under heat stress environment, 18 crosses exhibited significant SCA effects, out of which 9 crosses showed positive SCA effects. Higher positive SCA effects were observed in UP 2338 X Raj 3077, Raj 3077 X Lok 1 and HD 2285 X HD 2687.

In general, UP 2338 X Raj 3077 and Raj 3077 X Lok 1 showed high positive SCA effects in both the environments.

In F_2 generation, 18 crosses exhibited significant SCA effects in normal environment, out of which 9 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2687, HD 2285 X Lok 1 and Raj 3765 X Raj 3777. Under heat stress environment, 21 crosses exhibited significant SCA effects, out of which 8 crosses showed positive negative SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2687, HD 2285 X Lok 1 and Raj 3765 X HD 2285. In general, Raj 3777 X HD 2687 and HD 2285 X Lok 1 showed positive SCA effects in both the environments.

Evaluation across the environments indicated that Raj 3777 X HD 2687 and UP 2338 X Raj 3077 showed high positive desirable SCA effects in both environments.

4.3.2.11 Grain yield per plant (g)

The positive GCA and SCA effects are desirable for this trait. Under normal environment, 2 parents in F_1 and three parents in F_2 generation exhibited significant GCA effects. One parent Lok 1 only showed positive GCA effect in both the generations i.e. Lok 1 exhibited the highest positive GCA effect under normal environment in both the generations. Under heat stress environment, 5 parents exhibited significant GCA effects in F_1 generation, out of which only 2 parents viz., Raj 3077 and Raj 3777 showed high positive GCA effects whereas based on F_2 analysis, 4 parents exhibited significant GCA effects, out of which only 2 parents viz., Lok 1 and Raj 3777 showed high positive GCA effects. Raj 3777 exhibited high positive GCA effects under heat stress in both the generations. In general, Lok 1 exhibited high positive desirable GCA effect in both the environments.

In F_1 generation, 12 crosses exhibited significant SCA effects in normal environment, out of which 8 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2687, UP 2338 X Raj 3077, HD 2687 X UP 2338 and Raj 3077 X Lok 1. Under heat stress environment, 19 crosses exhibited significant SCA effects, out of which 10 crosses showed positive SCA effects. Higher positive SCA effects were observed in UP 2338 X Raj 3077, HD 2285 X HD 2687, Raj 3077 X Lok 1 and Raj 3777 X HD 2687. In general, UP-2328X Raj 3077 and Raj 3777 X HD 2687 showed positive SCA effects in both the environments.

In F_2 generation, 18 crosses exhibited significant SCA effects in normal environment, out of which 9 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2687, UP 2338 X Raj 3077, HD 2329 X Lok 1 and Raj 3777 X HD 2329. Under heat stress environment, 21 crosses exhibited significant SCA effects, out of which 9 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2687, HD 2329 X Lok 1,UP 2338 X Raj 3077 and Raj 3777 X HD 2329. In general, Raj 3777 X HD 2687, HD 2338 X Raj 3077 and HD 2329 X Lok 1 showed positive SCA effects in both the environments.

Evaluation across the environments indicated that Raj 3777 X HD 2687 and UP 2338 X Raj 3077 showed the positive desirable SCA effects in both environments.

4.3.2.12 Straw yield per plant (g)

The positive GCA and SCA effects are desirable for this trait. Under normal environment, 6 parents exhibited significant GCA effects in each generation, out of which 3 parents showed positive GCA effects in each generation. Three parents viz., Raj 3077, Lok 1 and Raj 3777 showed high positive GCA effects in F_1 whereas based on F_2 analysis, 3 parents viz., Lok 1, Raj 3777 and Raj 3765 showed high positive GCA effects. Lok 1 and Raj 3777 exhibited high positive GCA effects under normal environment in both the generations. Under heat stress environment, 7 parents exhibited significant GCA effects in F_1 generation, out of which 3 parents viz., Raj 3077, Raj 3777 and Lok 1 showed high positive GCA effects whereas based on F_2 analysis, 5 parents exhibited significant GCA effects, out of which 3 parents viz., Lok 1, Raj 3765, and HD 2285 showed high positive GCA effects. Lok 1 exhibited high positive

GCA effect under heat stress in both the generations. Raj 3077, Raj 3777 and Lok 1 in F_1 and Lok 1 in F_2 showed high positive desirable GCA effects in normal as well as in heat stress environments. In general, Lok 1 and Raj 3777 exhibited high positive desirable GCA effects in both the environments.

In F_1 generation, 18 crosses exhibited significant SCA effects in normal environment, out of which 11 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2687, Raj 3765 X HD 2285, Raj 3077 X Lok 1 and UP 2338 X Raj 3077. Under heat stress environment, 20 crosses exhibited significant SCA effects, out of which 10 crosses showed positive SCA effects. Higher positive SCA effects were observed in UP 2338 X Raj 3077, Raj 3077 X Lok 1, HD 2285 X HD 2687 and Raj 3777 X HD 2687. In general, Raj 3777 X HD 2687, UP 2338 X Raj 3077 and Raj 3077 X Lok 1 showed high positive SCA effects in both the environments.

In F_2 generation, 22 crosses exhibited significant SCA effects in normal environment, out of which 10 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3765 X Raj 3777, Raj 3777 X HD 2687 and HD 2285 X Lok 1. Under heat stress environment, 24 crosses exhibited significant SCA effects, out of which 10 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3777 X HD 2687, Raj 3765 X HD 2285 and HD 2285 X Lok 1. In general, Raj 3777 X HD 2687 and HD 2285 X Lok 1 showed positive SCA effects in both the environments.

Evaluation across the environments indicated that Raj 3777 X HD 2687 exhibited positive SCA effects in both environments.

4.3.2.13 Harvest Index (%)

The positive GCA and SCA effects are desirable for this trait. Under normal environment, 7 parents exhibited significant GCA effects in F_1 generation, out of which 3 parents viz., HD 2329, Raj 3765 and HD 2285 showed high positive GCA effects whereas based on F_2 analysis, 6 parents exhibited significant GCA effects, out of which HD 2329 and Lok 1 showed high positive GCA effects. HD 2329 exhibited the highest positive GCA effect under normal environment in both the generations. Under heat stress environment, 4 parents exhibited significant GCA effects in F_1 generation, out of which one parent HD 2329 only showed positive GCA effect whereas based on F_2 analysis, 6 parents exhibited significant GCA effects, out of which 3 parents viz., HD 2329, Raj 3777 and UP 2338 showed high positive GCA effects. Similar to F_1 generation, HD 2329 exhibited high positive GCA effect under heat stress in both the generations. In general, HD 2329 exhibited high positive desirable GCA effects in both the environments and in both the generations.

In F_1 generation, 10 crosses exhibited significant SCA effects in normal environment, out of which 7 crosses showed positive SCA effects. Higher positive SCA effects were observed in HD 2329 X Raj 3077, HD 2285 X UP 2338, HD 2687 X UP 2338 and Raj 3765 X Raj 3777. Under heat stress environment, 15 crosses exhibited significant SCA effects, out of which 8 crosses showed positive SCA effects. Higher positive SCA effects were observed in HD 2329 X Raj 3077, HD 2285 X Raj 3077, HD 2329 X UP 2338 and HD 2285 X UP 2338. In general, HD 2329 X Raj 3077 and HD 2285 X UP 2338 showed the highest positive SCA effects respectively in both the environments.

In F_2 generation, 21 crosses exhibited significant SCA effects in normal environment, out of which 14 crosses showed positive SCA effects. Higher positive SCA effects were observed in UP 2338 X Raj 3077, Raj 3765 X UP 2338, HD 2285 X Raj 3777, HD 2285 X HD 2687 and Raj 3077 X Lok 1. Under heat stress environment also 21 crosses exhibited significant SCA effects, out of which 12 crosses showed positive showed negative SCA effects. Higher positive SCA effects were observed in Raj 3765 X HD 2329, HD 2687 X Raj 3077, HD 2687 X UP 2338, Raj 3077 X Lok 1 and HD 2285 X Raj

3777. In general, Raj 3077 X Lok 1 and HD 2285 X Raj 3777 showed positive desirable SCA effects in both environments.

4.3.2.14 Chlorophyll content (mg/g fr.wt)

The negative GCA and SCA effects are desirable for this trait under post anthesis heat stress while positive effects are desirable under normal environment. Under normal environment, 7 parents in F_1 and all the 8 parents in F_2 exhibited significant GCA effects. Two parents only viz., Lok 1 and Raj 3765 showed high positive GCA effects under normal environment in both the generations. Under heat stress environment, 7 parents exhibited significant GCA effects in F_1 generation, out of which 4 parents viz., HD 2285, HD 2329, Raj 3077 and HD 2687 showed high negative GCA effects whereas based on F_2 analysis, 5 parents exhibited significant GCA effects, out of which 3 parents viz., HD 2329, Raj 3077 and HD 2285 showed high negative GCA effects. These 3 parents exhibited high negative GCA effects under heat stress in both the generations.

In F_1 generation, 17 crosses exhibited significant SCA effects in normal environment, out of which 7 crosses showed positive SCA effects. Higher positive SCA effects were observed in UP 2338 X Raj 3077, Raj 3765 X HD 2329 and Raj 3765 X Raj 3777. Under heat stress environment, 23 crosses exhibited significant SCA effects, out of which 15 crosses showed negative SCA effects. Higher negative SCA effects were observed in Raj 3765 X Lok 1, HD 2687 X HD 2329, HD 2285 X Raj 3077 and HD 2285 X Lok 1.

In F_2 generation, 22 crosses exhibited significant SCA effects in normal environment, out of which 10 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3765 X Raj 3077, HD 2285 X UP 2338, UP 2338 X Lok 1 and Raj 3777 X HD 2687. Under heat stress environment also, 24 crosses exhibited significant SCA effects, out of which 14 crosses showed negative SCA effects. Higher negative SCA effect were observed in Raj 3765 X Lok 1, Raj 3777 X Lok 1, HD 2285 X Raj 3077 and HD 2285 X Lok 1/ HD 2687 X HD 2329.

4.3.2.15 Grain protein content (%)

The positive GCA and SCA effects are desirable for this trait. Under normal environment, 6 parents exhibited significant GCA effects in both the generations. Under heat stress environment, 5 parents in F_1 and 6 parents in F_2 exhibited significant GCA effects. In general, three parents viz., Raj 3077, UP 2338 and Raj 3765 only exhibited high positive desirable GCA effects in both the environments and in both the generations.

In F_1 generation, 5 crosses exhibited significant SCA effects in normal environment, out of which 2 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3765 X Raj 3777, Raj 3077 X Lok 1 and HD 2285 X HD 2687. Under heat stress environment, 9 crosses exhibited significant SCA effects, out of which 4 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3077 X Lok 1/ Raj 3765 X Raj 3777, HD 2687 X HD 2329 and HD 2285 X UP 2338. In general Raj 3765 X Raj 3777 and Raj 3077 X Lok 1 showed the highest positive SCA effects in both the environments.

In F_2 generation, 10 crosses exhibited significant SCA effects in normal environment, out of which 5 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3765 X Raj 3777, Raj 3077 X Lok 1 and Raj 3765 X Lok 1. Under heat stress environment, 13 crosses exhibited significant SCA effects, out of which 3 crosses showed positive SCA effects. Higher positive SCA effects were observed in Raj 3765 X Raj 3777, HD 2285 X UP 2338 and Raj 3077 X Lok 1. In general, Raj 3765 X Raj 3777 and Raj 3077 X Lok 1 showed high positive SCA effects in both the environments.

Evaluation across the environments indicated that Raj 3765 X Raj 3777 and Raj 3077 X Lok 1 showed positive desirable SCA effects in both environments.

4.4 Estimation of heterobeltiosis

Heterobeltiosis was measured as per cent increase (+) or decrease (-) in F_1 over better parent for all the characters in both the environments. The character wise results are present in Table ……. and discussed below:

4.4.1 Tillers per plant

The higher positive magnitude of this trait is desirable. Heterobeltiosis ranged from –12.88 (UP 2338 X Lok 1) to 17.65 (HD 2285 X HD 2687) in normal and from –16.22 (UP 2338 X Lok 1) to 14.81 (HD 2285 X Raj 3077) in heat stress environment. Under normal environment, 10 crosses exhibited significant heterobeltiosis, out of which 6 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2285 X HD 2687, Raj 3765 X UP 2338 and HD 2329 X Raj 3077. Under heat stress environment, 16 crosses exhibited significant heterobeltiosis, out of which 8 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2285 X Raj 3077, HD 2285 X UP 2338 and HD 2285 X HD 2687. Evaluation across the environments indicated that the HD 2285 X HD 2687 showed high positive desirable heterobeltiosis in both the environments.

4.4.2 Effective tillers per plant

The higher positive magnitude of this trait is desirable. Heterobeltiosis ranged from –23.36 (HD 2329 X UP 2338) to 18.27 (HD 2285 X Lok 1) in normal and from –26.04 (HD 2329 X UP 2338) to 12.50 (HD 2285 X Lok 1) in heat stress environment. Under normal environment, 11 crosses exhibited significant heterobeltiosis, out of which 6 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2285 X Lok 1, Raj 3765 X UP 2338 and UP 2338 X Raj 3077. Under heat stress environment, 12 crosses exhibited significant heterobeltiosis, out of which 4 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2285 X Lok 1, HD 2285 X HD 2687, and HD 2329 X Raj 3077/ UP 2338 X Raj 3077. Evaluation across the environments indicated that the HD 2285 X Lok 1 and UP 2338 X Raj 3077 showed high positive desirable heterobeltiosis in both the environments.

4.4.3 Plant height (cm)

Dwarfness is considered to be desirable which is associated with negative heterobeltiosis. Heterobeltiosis ranged from –19.84 (Raj 3765 X Raj 3077) to 5.17 (Raj 3777 X HD 2687) in normal and from –18.73 (Raj 3765 X Raj 3077) to 27.46 (HD 2329 X Lok 1) in heat stress environment. Under normal environment, 13 crosses exhibited significant heterobeltiosis and all of which showed negative desirable heterobeltiosis. Higher negative heterobeltiosis were observed in Raj 3765 X Raj 3077, Raj 3765 X HD 2687 and Raj 3777 X Raj 3077. Under heat stress environment, 19 crosses exhibited significant heterobeltiosis, out of which 7 crosses showed negative heterobeltiosis. Higher negative heterobeltiosis were observed in Raj 3765 X Raj 3077, Raj 3765 X HD 2687 and Raj 3765 X HD 2285. Evaluation across the environments indicated that Raj 3765 X Raj 3077 and Raj 3765 X HD 2687 showed high negative desirable heterobeltiosis in both the environments.

4.4.4 Flag leaf area (cm^2)

Higher value of flag leaf area has positive effect on grain yield; hence, positive heterobeltiosis is desirable. Heterobeltiosis ranged from –32.82 (HD 2687 X Lok 1) to 31.54 (HD 2285 X Raj 3077) in normal and from –36.82 (HD 2687 X Lok 1) to 45.85 (Raj 3777 X UP 2338) in heat stress environment. Under normal environment, 15 crosses exhibited significant heterobeltiosis, out of which 6 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2285 X Raj 3077, Raj 3777 X UP 2338 and HD 2687 X UP 2338. Under heat stress environment, 14 crosses exhibited significant heterobeltiosis, out of which 5 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in Raj 3777 X UP 2338, HD 2285 X Raj 3077 and HD 2285 X HD 2687. Evaluation across the environments indicated that Raj 3777 X UP 2338 and HD 2285 X Raj 3077 showed high positive desirable heterobeltiosis in both the environments.

4.4.5 Days to anthesis

Since earliness is desirable, the crosses possessing significant negative heterobeltiosis were considered superior. Heterobeltiosis ranged from –5.43 (Raj 3777 X Lok 1) to 6.22 (HD 2285 X Raj 3077) in normal and from –7.83 (HD 2285 X HD 2687) to 2.87 (HD 2285 X Raj 3077) in heat stress environment. Under normal environment, 10 crosses exhibited significant heterobeltiosis, out of which 8 crosses showed negative desirable heterobeltiosis. Higher negative heterobeltiosis were observed in Raj 3777 X Lok 1, HD 2329 X UP 2338, UP 2338 X Raj 3077 and UP 2338 X Lok 1. Under heat stress environment, 15 crosses exhibited significant negative heterobeltiosis. Higher negative heterobeltiosis were observed in HD 2285 X HD 2687, HD 2687 X HD 2329, HD 2285 X UP 2338, Raj 3765 X HD 2687, Raj 3765 X UP 2338 and HD 2329 X UP 2338. Evaluation across the environments indicated that HD 2329 X UP 2338 showed high negative desirable heterobeltiosis in both the environments.

4.4.6 Duration from anthesis to maturity

The higher positive magnitude of this trait is desirable. Heterobeltiosis ranged from –22.94 (HD 2687 X Raj 3777) to 12.84 (HD 2329 X Raj 3077) in normal environment and from –14.29 (Raj 3765 X HD 2285) to 18.82 (HD 2329 X Raj 3077) in heat stress environment. Under normal environment, 23 crosses exhibited significant heterobeltiosis, out of which 8 crosses showed positive heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2329 X Raj 3077, HD 2329 X Lok 1, Raj 3077 X Lok 1, HD 2329 X UP 2338 and Raj 3777 X HD 2329. Under heat stress environment, 20 crosses exhibited significant heterobeltiosis, out of which 12 crosses showed positive heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2329 X Raj 3077, HD 2329 X Lok 1 and HD 2329 X UP 2338. Evaluation across the environments indicated that HD 2329 X Raj 3077, HD 2329 X Lok 1 and HD 2329 X UP 2338 showed the highest positive desirable heterobeltiosis followed by HD 2329 X Lok 1.

4.4.7 Days to maturity

The earliness is desirable which is reflected by negative heterobeltiosis. Heterobeltiosis ranged from –6.52 (HD 2687 X Raj 3077) and (Raj 3765 X HD 2687) to 4.36 (HD 2329 X Lok 1) in normal and from –3.31 (HD 2687 X Raj 3077) to 5.44 (Raj 3077 X HD 2329) in heat stress environment. Under normal environment, 16 crosses exhibited significant heterobeltiosis, out of which 8 crosses showed negative desirable heterobeltiosis. Higher negative heterobeltiosis were observed in HD 2687 X Raj 3077, Raj 3765 X HD 2687, HD 2687 X UP 2338 and HD 2687 X Lok 1. Under heat stress environment, 9 crosses exhibited significant heterobeltiosis, out of which 3 cross negative desirable heterobeltiosis. Higher negative heterobeltiosis were observed in HD 2687 X Raj 3077, Raj 3765 X HD 2687 and Raj 3765 X UP 2338. Evaluation across the environments indicated that Raj 3765 X HD 2687 and HD 2687 X Raj 3077 showed high negative desirable heterobeltiosis.

4.4.8 Grains per spike

The higher positive magnitude of this trait is desirable. Heterobeltiosis ranged from –15.91 (HD 2285 X UP 2338) to 10.51 (UP 2338 X Raj 3077) in normal and from –14.85 (HD 2285 X HD 2687) to 13.90 (UP 2338 X Raj 3077) in heat stress environment. Under normal environment, 6 crosses exhibited significant heterobeltiosis, out of which 1 cross only i.e. UP 2338 X Raj 3077 showed positive desirable heterobeltiosis. Under heat stress environment, 6 crosses exhibited significant heterobeltiosis, out of which 3 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in UP 2338 X Raj 3077, HD 2285 X HD 2329 and HD 2687 X Raj 3077. Evaluation across the environments indicated that UP 2338 X Raj 3077 showed high positive desirable heterobeltiosis in both the environments.

4.4.9 1000- grain weight (g)

The higher positive magnitude of this trait is desirable. Heterobeltiosis ranged from –22.51 (HD 2285 X UP 2338) to 21.20 (UP 2338 X Raj 3077) in normal and from –24.71 (HD 2285 X HD-2338) to 9.01 (UP-2687X UP 2338) in heat stress environment. Under normal environment, 16 crosses exhibited significant heterobeltiosis, out of which 7 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in UP 2338 X Raj 3077, Raj 3765 X Raj 3777 and HD 2687 X UP 2338. Under heat stress environment, 16 crosses exhibited significant heterobeltiosis, out of which 2 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2687 X UP 2338 and Raj 3765 X Raj 3777. Evaluation across the environments indicated that HD 2687 X UP 2338 and Raj 3765 X Raj 3777 showed positive desirable heterobeltiosis in both the environments.

4.4.10 Biological yield per plant (g)

Heterobeltiosis ranged from –19.65 (HD 2285 X UP 2338) to 36.15 (HD 2285 X HD 2687) in normal and from –30.06 (HD 2285 X UP 2338) to 33.31 (HD 2285 X HD 2687) in heat stress environment. Under normal environment, 12 crosses exhibited significant heterobeltiosis, out of which 7 crosses showed positive heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2285 X HD 2687, Raj 3777 X HD 2687 and HD 2687 X HD 2329. Under heat stress environment, 16 crosses exhibited significant heterobeltiosis, out of which 4 crosses showed positive heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2285 X HD 2687, UP 2338 X Raj 3077 and Raj 3077 X Lok 1. Evaluation across the environments indicated that HD 2285 X HD 2687 showed high positive heterobeltiosis in both the environments.

4.4.11 Grain yield per plant (g)

Higher grain yield per plant is desirable which is reflected by positive heterobeltiosis. Heterobeltiosis ranged from –15.08 (UP 2338 X Lok 1) to 40.88 (HD 2285 X HD 2687) in normal and from –32.01(Raj 3765 X HD 2687) to 32.42 (HD 2285 X HD 2687) in heat stress environment. Under normal environment, 6 crosses exhibited significant heterobeltiosis all of which showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2285 X HD 2687, UP 2338 X Raj 3077, HD 2687 X UP 2338 and Raj 3777 X HD 2687. Under heat stress environment, 18 crosses exhibited significant heterobeltiosis, out of which 5 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2285 X HD 2687, UP 2338 X Raj 3077. Evaluation across the environments indicated that HD 2285 X HD 2687, UP 2338 X Raj 3077 showed high positive heterobeltiosis in both the environments.

4.4.12 Straw yield per plant (g)

Heterobeltiosis ranged from –30.84 (HD 2285 X UP 2338) to 32.87 (HD 2285 X HD 2687) in normal and from –35.62 (HD 2329 X UP 2338) to 33.93 (HD 2285 X HD 2687) in heat stress environment. Under normal environment, 15 crosses exhibited significant heterobeltiosis, out of which 6 crosses showed positive heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2285 X HD 2687, Raj 3777 X HD 2687 and HD 2687 X HD 2329. Under heat stress environment, 21 crosses exhibited significant heterobeltiosis, out of which 5 crosses showed positive heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2285 X HD 2687, Raj 3077 X Lok 1 and UP 2338 X Raj 3077. Evaluation across the environments indicated that HD 2285 X HD 2687 showed high positive heterobeltiosis in both the environments.

4.4.13 Harvest index (%)

Higher harvest index along with higher biological yield per plant is desirable, which is associated with positive heterotic effect. Heterobeltiosis ranged from –8.55 (Raj 3765 X Raj 3077) to 14.42 (UP 2338 X Raj 3077) in normal and from –12.43 (Raj 3777 X Lok 1) to 7.86 (HD 2329 X Raj 3077) in heat stress environment. Under normal environment, 11 crosses exhibited significant heterobeltiosis, out of which 6 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in UP 2338 X Raj 3077, HD 2285 X UP 2338 and HD 2329 X Raj 3077. Under heat stress environment, 21 crosses exhibited significant heterobeltiosis, out of which 6 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in HD 2329 X Raj 3077, HD 2329 X UP 2338 and HD 2285 X Raj 3077. Evaluation across the environments indicated that HD 2329 X Raj 3077 showed high positive desirable heterobeltiosis in both the environments.

4.4.14 Chlorophyll content (mg/g fr.wt.)

Higher chlorophyll content is desirable which is associated with positive heterotic effect, but under heat stress low chlorophyll content is desirable which is reflected by negative heterobeltiosis. Heterobeltiosis ranged from –35.16 (HD 2329 X Lok 1) to 59.17 (UP 2338 X Raj 3077) in normal and from –43.04 (HD 2285 X Lok 1) to 62.44 (UP 2338 X Raj 3077) in heat stress environment. Under normal environment, 26 crosses exhibited significant heterobeltiosis, out of which 6 crosses showed positive desirable heterobeltiosis. Higher positive heterobeltiosis were observed in UP 2338 X Raj 3077, Raj 3765 X HD 2329 and Raj 3765 X Raj 3777. Under heat stress environment, 24 crosses exhibited significant heterobeltiosis, out of which 21 crosses showed negative desirable heterobeltiosis. Higher negative heterobeltiosis were observed in HD 2285 X Lok 1, HD 2687 X HD 2329 and Raj 3765 X Lok 1 and higher positive heterobeltiosis were observed in UP 2338 X Raj 3077 and Raj 3765 X Raj 3777. Evaluation across the environments indicated that UP 2338 X Raj 3077 showed high positive desirable heterobeltiosis in both the environments and HD 2285 X Lok 1 showed high negative desirable heterobeltiosis under heat stress.

4.4.15 Grain protein content (%)

Higher grain protein content is desirable. Heterobeltiosis ranged from –22.64 (HD 2285 X Raj 3077) to 5.86 (Raj 3765 X Raj 3077 and Raj 3765 X Lok 1) in normal and from –20.42 (HD 2285 X Raj 3077) to 9.13 (Raj 3077 X Raj 3777) in heat stress environment. Under normal environment, 10 crosses exhibited significant heterobeltiosis, all of which showed negative heterobeltiosis. Higher negative heterobeltiosis were observed in HD 2285 X

Raj 3077 and HD 2329 X Raj 3077. Under heat stress environment, 11 crosses exhibited significant heterobeltiosis, out of which only 1 cross i.e. Raj 3765 X Raj 3777 showed positive desirable heterobeltiosis. Evaluation across the environments indicated that none of the cross showed positive desirable heterobeltiosis, which was common in both the environment.

4.5 Estimation of correlation

Genotypic, phenotypic and environmental correlation coefficients between different pairs of characters were estimated for both the generations in both the environments and are presented in Table ……. Significance was tested at phenotypic level only.

Perusal of Table……. reveals that in F_1 generation, effective tillers per plant, plant height, days to maturity, biological yield per plant and straw yield per plant showed significant positive phenotypic correlation with grain yield per plant in normal as well as in heat stress environment. In addition to these, grains per spike and harvest index in normal environment and flag leaf area, 1000-grain weight and chlorophyll content in heat stress environment showed significant positive correlation with grain yield per plant. Among the other traits, character association observed as presented in Table ……….

Perusal of Table……. reveals that in F_2 generation, tillers per plant, effective tillers per plant, grains per spike, biological yield per plant and straw yield per plant showed significant positive correlation with grain yield per plant in normal as well as in heat stress environment. In addition to these, plant height, flag leaf area in normal environment and 1000-grain in heat stress environment showed significant positive correlation with grain yield per plant. Among the other traits, character association appeared as presented in Table ……….

Regarding magnitude of correlation coefficient, strong association of grain yield per plant was observed with straw yield per plant, biological yield per plant and effective tillers per plant in both the environments.

5. DISCUSSION

In India wheat is grown under subtropical environment during mild winter, which warms up towards grain filling stage of the crop. Howard (1924) while analyzing the factor controlling wheat production remarked that wheat production in India is a gamble with temperature. This statement is valid even today. Hexaploid wheats are of temperate origin (Harlan and Zohary, 1966) and they do not tolerate prolonged exposure to temperature exceeding 35^0C (Gusta and Chen, 1987). The present day rice wheat cropping system, keeping in view monsoonal irregularities, has compelled wheat crop to be subjected to rapidly ascending temperatures coupled with hot dry winds during the post anthesis stages, especially during grain development. These unfavourable environments terminate grain growth prematurely and reduces yield considerably. Wardlaw (1994), also reported that mean temperature greater than 15-18 ^{0}C following anthesis can result in decrease in grain weight at maturity. It has already been established that high temperature stress can be a significant factor in reducing yield and quality of wheat (Stone and Nicolas, 1995). Even during the period of present study due to high temperature during anthesis to maturity period the yield was expected to be less.

Breeding for heat tolerance has been an integral component of wheat breeding programmes at both national and international level (Acevedo *et al.*, 1990). These programmes will not only help in spreading wheat cultivation to nontraditional warm areas besides, optimizing wheat yield in more tropical environments under the present situation of multiple cropping system. Breeding for thermotolerance in wheat cultivars requires understanding of the physiological responses of wheat crop to heat stress which will help in identifying traits, to be used as selection criteria.

Improvement in grain yield is the sole aim of breeding in wheat under heat stress. In stress breeding, knowledge of genetic variability and of the type of gene action controlling yield and its components and of the expression of the genes involved are of paramount importance in the initiation of any sound breeding programme involving selection or hybridization. However, yield being the complex outcome of its components, selection based on yield alone would be misleading. Selection based on yield components would therefore, be more rewarding. This requires information on nature and magnitude of variations in the base population, inheritance, combining ability etc. Presently, the information available on these aspects in bread wheat under normal condition is abundant but under post anthesis heat stress the information on the inheritance of various characters is very meager.

The present investigation was therefore, planned and conducted to address some of these problems. The experimental material *i.e.* parents chosen for this study consisted of 4 heat tolerant genotypes viz., HD 2329, UP 2338, Raj 3777 and Raj 3765 (Table 3.2) and 4 higher yielding genotypes viz., HD 2285, HD 2687, Raj 3077 and Lok 1 which were selected on the basis of their different maturity duration and recommended suitable for either timely or late sowing. Diallel analysis helping us in identifying suitable parents and specific crosses and is based on the assumptions of normal diploid segregation, lack of maternal effects, absence of multiple allelism, homozygosity of the parents, absence of linkage, lack of epistasis and absence of lethal genes (Hayman, 1954 a). Hence, this investigation may assist in isolating specific parents and crosses for direct use in evolving the heat tolerant varieties. The chosen eight parents were crossed in a diallel fashion (excluding reciprocal crosses) to obtain 28 F_1's and their 28 F_2's. The experiment was carried out on two dates of sowing. The late sowing represented heat stress environment.

Although, bread wheat is a segmental autopolyploid, it behaves like a diploid because of control of homeologous pairing of chromosomes during meiosis. Therefore, it fulfills the assumption of diploid segregation. The parents used in the present study were selfed for several generations and thus they were homozygous. The reciprocal effects in autogamous crops like wheat are also assumed to be limited. Therefore, the three assumptions, homozygosity of parents, diploid segregation and lack of maternal effects were safely assumed to be fulfilled.

The assumptions of lack of multiple alleles, has not been considered to be of much importance (Kempthorne, 1957). Hayman (1957) also found that multiple allelism in the parents do not seriously disturb the average degree of dominance. As the wheat is an allohexaploid species, some linkage might be expected. The presence of linkage may cause some bias in the estimates of genetic parameters obtained from the F_2 and back cross generations (Vander Veen, 1959). The genetic estimates derived from homogeneous populations like parents and F_1 are usually unbalanced even in the presence of linkage. Kempthorne (1957) proved that bias due to linkage relations in the estimates of gene effects would be expected when there is epistasis especially of additive x additive and dominance x dominance types. The lethal genes were not likely to be present in the crosses as the viability was consistent for all the generations of the present study. Only negligible biasness would be expected from unequal viability of the genotypes (Gamble, 1962). The significant findings of the present investigation are being discussed here:

5.1 ANALYSIS OF VARIANCE

The parents along with segregating and nonsegregating generations obtained from the diallel crosses were evaluated for various traits in normal and post anthesis heat stress environments. In pooled analysis (Table 4.1.1 and 4.1.2), mean squares due to environment were significant for all the characters studied indicating significant effect of environments on the expression of different traits. The pooled analysis of variance revealed significant differences among genotypes/treatment indicating that the material used had enough genetic variability.

Genotype x environment interaction is a common phenomenon present in crop plant species (Allard and Bradshaw, 1964). In the present investigation, although, it did not prevail in all the characters studied in both the sets (Parents + F_1 and Parents + F_2) indicating differential response of genotypes to the environment. Mean square due to genotype x environment was found non significant for flag leaf area and grain protein content in both the generations. Sprague and Federer (1951) suggested that the biasness caused by genotype x environment interaction in the estimates of genetic parameters is of unknown magnitude and direction and it may not be same for each parameter. As such to avoid this, further analysis was done on the basis of individual environmental data because G x E interaction was found significant for most of the characters studied in this investigation.

The analysis of variance for individual environment (Table4.1.3 and 4.1.4) revealed highly significant variation for all the characters and all the genotypes, thus explained the fact that the characters exhibited the presence of adequate genetic variability among the parents, segregating and nonsegregating generations under normal as well as under heat stress environment.

Mean squares due to parents v/s F_1 was found significant for most of the characters studied (Table 4.1.3) was significant for effective tillers per plant, days to anthesis, 1000-grain weight, biological yield per plant, grain yield/plant, straw yield per plant and harvest index in normal environment but nonsignificant in heat stress environment. Similarly, for plant height, duration from anthesis to maturity and chlorophyll content it was non significant differences in normal environment but significant in heat stress environment. Significant mean squares due to parents v/s F_1 indicated the presence of heterotic effect.

Mean squares due to parents v/s F_2 was found significant for most of the characters studied (table 4.1.4). Biological yield per plant, 1000-grain weight, grain yield per plant and harvest index showed non significant differences in normal environment but significant differences under heat stress environment. Studies in *Triticum aestivum* by Srivastava *et al.*(1992), Menon and Sharma (1995), Guha Sarkar *et al.* (2001), Singh (2002) and Punia (2003) also reported significant differences between genotypes for grain yield and its attributes.

5.2 EFFECT OF HEAT STRESS ON MEAN VALUES

Range for most of the observed characters was relatively wider in the normal environment in comparison to heat stress environment. Comparison of mean values of different traits indicated that the means of various characters decreased under heat stress in comparison to normal environment except for grain protein content (Table 4.2.2). However, there was no marked reduction in harvest index. This is in agreement with Nagarajan and Rane (2002) who also registered a slight increase in harvest index under heat stress environment. In crease in grain protein content under late sown conditions was also observed by Yadav and Singh (2003). High reduction in the duration of developmental phases and in other characters of wheat crop under high temperature regime caused by late sowing has been reported by several workers (Shpiler and Blum, 1986, Zhong-hu and Rajaram, 1994, Penelia *et al.*, 1993, Abdelghani *et al.*, 1994, Reynold *et al.*, 1994, Stone *et al.*, 1995, Radmehr *et al.*, 1996, Sairam *et al.*, 1997, Sharma and Tandon 1997a, 1997b, Singh and Ahmad, 1997, Gibson, 1999, Nagarajan and Rane, 2002, Rashid *et al.*, 2004, Singh and Madanpal, 2003, and Vivek Raj and Bhardwaj, 2004).

Among the parents and F_2 the maximum decrease was observed in straw yield per plant followed by biological yield per plant and grain yield per plant and among F_1 it was observed in grain yield per plant followed by biological yield per plant and straw yield per plant. In other words it can be said that biological yield per plant, straw yield per plant and grain yield per plant were the most sensitive parameters to heat stress. It is also interesting that the extent of reduction by delayed sowing in these three traits were almost at par. Such observations agree with previous reports (Wardlaw *et al.*, 1989, Shpiler and Blum, 1991, Zhong- hu and Rajaram, 1994). Significant reduction in growth and growth characters of wheat by delayed sowing mainly resulted due to marked reduction in the growth duration caused by relatively higher temperature prevailing during the critical phases of late sown crop plants. This is in agreement with Singh and Madanpal (2003).

The mean values of grain yield per plant were reduced by 23.19%, 31.57% and 29.67 % among the parents, F_1's and F_2's, respectively under heat stress. The detrimental effect of heat stress on grain yield was maximum through reduction in duration from anthesis to maturity followed by 1000-grain weight, effective tillers per plant and grains per spike (Table 4.2.2). This is in agreement with Singh and Madanpal (2003). Low grain yield under heat stress was supposed to be due to cumulative effect of several traits and factors. Under late sown conditions, the poor grain yield of genotypes may be attributed to poor biomass production coupled with low harvest index which is in agreement with Nagarajan and Rane (2002).

The increase in yield is possible either through increase in grain number or 1000-grain weight under heat stress environment (Reynolds *et al.*, 1996). The differences between these two important yield parameters determine the yield potential of a genotype and its suitability to stress environment. The grain number is well decided during the early phases of growth and development. So, increase in 1000- grain weight remains an unexploited parameter for increasing productivity under heat stress environment (Guha Sarkar *et al.*, 2001). Longer growth duration of wheat plants under normal sowing provides an opportunity to accumulate more biomass as compared to late sown plants and henceforth manifests higher grain and biological yield per plant. In the present investigation, the maximum reduction due to heat stress environment was observed in straw yield, biological yield and grain yield per plant. Poor biological yield under late sown conditions was probably due to reduced leaf area per shoot in wheat cultivars (Singh and Madanpal, 2003). Ashraf and Bhatti (1998) reported marked reduction in photosynthetic area of wheat plants under late sown conditions. The number of tillers per plant and grains per spike together determine the total number of grains/plant (Kumar *et.al*., 1995).

Wheat is basically a long day plant but the short and cooler days of December delay heading (Evans, 1987). Temperature and day length are increased in March. There is a negative effect of high temperature after anthesis on grain weight and consequently, grain test weight. Final kernel weight is determined by rate and duration of grain filling and dry matter accumulation. Generally, lower kernel weight of heat stressed wheat is due to a reduced duration rather than reduced grain growth (Sofield *et al.*, 1997, Warrington *et al.*, 1977, Wiegand and Cuellar, 1981). The greatest effect of a stress during grain filling is expected to be on grain test weight. Heat stress during grain filling hastens maturation of the crop resulting in small shrunken grains. Grain yield is influenced by other factors that occur prior to grain filling (Evans, 1978, Fischer, 1975, Shanahan *et al.*, 1985). Higher temperature during later stages might have caused water stress resulting in low relative water content (RWC). As the duration from anthesis to maturity was shortened in the present study, the stem reserves play an important role in supply of assimilates to the developing sink. Wardlaw (1974) studied the three main components of the plant system. The three components are: (a) source- flag leaf blade; (b) sink- ear; and (c) transport pathway-peduncle. He observed that photosynthesis had a broad temperature optimum from 20-30 ^{0}C; with photosynthesis declining rapidly at temperature above 30 ^{0}C. The rate of ^{14}C assimilate movement out of the flag leaf, phloem loading was optimum around 30 ^{0}C the rate of ^{14}C assimilate movement through the stem was independent of temperature from 1-50 ^{0}C. Thus in wheat, temperature effect on translocation results indirectly from direct temperature effects on source and sink activities. In present study, the maximum average weekly temperature during March *i.e.* grain filling period was above 35 ^{0}C. Heat stress reduced grain weight. This observation supports the earlier findings that temperature effect on grain weight is direct effects rather than assimilate availability (Bremner and Rawson, 1978; Ford *et al.*, 1978; Spiertz, 1974). Furthermore, respiration effects do not appear to be the direct cause of decreased grain size in heat stress wheat (Wardlaw, 1974).

Research on the effects of brief periods of ear warming after anthesis on ear metabolism have identified differential responses of starch and nitrogen accumulation in grain of wheat cultivars (Bhullar and Jenner, 1983, 1985, 1986; Hawker and Jenner, 1993, Jenner, 1991a, b). Warming increased the rate of dry matter accumulation. Rate of increase in nitrogen accumulation was; however, higher than the increase in total dry matter. Under long-term exposure to heat stress, increased grain nitrogen concentration is almost entirely as a result of decreased starch content rather than a change in total grain quality (Bhullar and Jenner, 1985). The conversion of sucrose to starch within the endosperm is decreased by elevated temperature. Furthermore, heat stress effect on final grain weight was associated with reduced levels of soluble starch synthetase activity (Hawker and Jenner, 1993). Increased N content ultimately reflected higher grain protein content under heat stress. Besides, the late sown crop receives less photosynthetically active radiation (PAR) than its early sown counterparts, resulting in reduction of biomass and grain yield (Penelia *et al.*, 1993). Ashraf and Bhatti (1998) also reported marked reduction in photosynthetic area of wheat plant under late sown condition. Sensitivity of photosynthesis to heat mainly may be due to damage to components of photosystem II located in the thylakoid membranes of the chloroplasts and membrane properties (Al-Khatib and Paulsen, 1999). Low production could likely result from stomatal closure which simultaneously reduces CO_2 assimilation (and then photosynthetic rate) and transpiration. The decreased transpiration would then result in increased leaf temperature that may lead to chlorophyll degradation (Tardy *et al.*, 1998). Consequently, low chlorophyll content could be an adaptation to decrease leaf absorbance and reduce leaf heating effects of high light intensities by decreasing the light absorbance of leaf. Decreased leaf chlorophyll content limited the energy load from strong sunlight. Thus chlorophyll content could play an important role in leaf temperature regulation (Havaux and Tardy, 1999).

Maximum extent of reduction in grains per spike by delayed sowing may perhaps be due to reduction in days to anthesis. Shpiler and Blum (1986) also reported greater sensitivity of reproductive growth phase to high temperature stress in wheat.

Marked reduction in 1000-grain weight under late sowing was probably due to reduction in duration from anthesis to maturity due to high temperature. Similar results were obtained by Singh and Madanpal (2003).

In summary, high temperature reduction of grain yield results from: (a) reduced number of grains formed; (b) shorter duration from anthesis to maturity and (c) reduced 1000-grain weight due to inhibition of sucrose assimilation in grains.

Selection for biomass yield is one of the ways to improve the productivity in bread wheat. In the present investigation, apart from biological yield per plant, other important traits like greater number of effective tillers per plant, grains per spike, 1000-grain weight, duration from anthesis to maturity, flag leaf area and harvest index are the suitable parameters to be considered while breeding cultivars suitable for late sown conditions or heat stress environment (Prabhu and Sharma, 1987, Sharma, 1993, Zhong- hu and Rajaram, 1994, Singh and Redhu, 1997, Shah, 1998, Guha Sarkar *et.al.*, 2001, and Arshad and Chowdhary, 2002).

As under late sown conditions the assimilate supply becomes a limiting factor because of increase in temperature during grain development due to rapid senescence of the assimilatory surface. It may be emphatically felt that to allow proper assimilate supply a significant amount of biomass production, with high to medium grain growth rate and having low heat susceptibility index values, are the significant features of a high yielding genotype under high temperature stress condition and this should be given utmost consideration in the breeding programme for the selection of genotypes tolerant to heat stress environment (Guha Sarkar *et.al.*, 2001).

In order to determine the relative tolerance, a heat susceptibility index (HSI) was estimated (Table 5.1) for yield and its main attributes. Based upon the value and direction of desirability, ranking was done for both the sets (Parents + F_1 and Parents + F_2) as highly heat tolerant (HSI < 0.50), heat tolerant (HSI: 0.51-0.75), moderately heat tolerant (HSI: 0.76-1.00) and heat susceptible (HSI > 1.00).

Perusal of Table 5.1 indicated that UP 2338, Raj 3765, HD 2329 and Raj 3777 for effective tillers per plant; HD 2329, Raj 3765, Raj 3777 and Lok 1 for grains per spike; Raj 3077, Raj 3765 and Raj 3777 for 1000- grain weight (g); and HD 2329, UP

2338, HD 2285, Raj 3777 and Raj 3765 for grain yield per plant (g), were least affected by post anthesis heat stress. All these parents were bred for heat tolerance. The worst parent was HD 2687 followed by Lok 1 and Raj 3077. An overall appraisal indicated that Raj 3777 followed by Raj 3765 was the best parent based on HSI. High grain yield per plant under high temperature of late sown conditions indicates the presence of genes for heat tolerance.

Among the crosses, HD 2687 x Raj 3077, HD 2285 X Raj 3777, HD 2285 x HD 2687, Raj 3777 x UP 2338, HD 2285 x Raj 3077 and Raj 3777 x HD 2329 were having good tolerance in both the generations. The worst crosses from the tolerance point of view in both the generations were Raj 3777 x Lok 1, Raj 3765 x Raj 3077, HD 2687 x UP 2338, UP 2338 x Lok 1 and HD 2285 x UP 2338. Among the parents involved in these crosses, Raj 3777 has been recommended for very late sown, HD 2285 for late sown, Raj 3765, Raj 3077, UP 2338 and Lok 1 for timely/ late sown and HD 2687 and HD 2329 for timely sown conditions. The crosses mean also testified the conclusions reached above that the best or worst crosses had at least one parent which proved tolerant under heat stress except HD 2687 x Raj 3077 where both the parents were poor based on HSI, though Raj 3077 ranked first for 1000- grain weight (g) . The *per se* grain yield performance of HD 2687 was the worst in both the environments.

The tolerance to heat stress in present study was related to less reduction in the number of grains per spike and 1000-grain weight. These observations are in agreement with the findings of Choudhary *et al.*, (1996), Shah (1998) and Sikdar *et al.* (2001). High 1000-grain weight indicated that genotypes could maintain high grain growth rate under high temperature. The synthesis of heat shock proteins, observed in response to heat stress in many plant species (Key *et al.*, 1981), may be involved in increased membrane thermostability. A cell membrane system that remains functional during heat stress appears central to adaptation of plants to high temperature (Raison *et al.*, 1980). This is especially important during the grain filling period since grain growth is greatly reduced by environmental conditions that adversely affect assimilate supply (Evans *et al.*, 1975) or utilization (Bhullar and Jenner, 1985 and 1986).

5.3 COMBINING ABILITY ANALYSIS

The pooled analysis of variance for combining ability (Table 4.3.1.1 and 4.3.1.2) revealed that mean squares due to GCA and those due to SCA were significant for all the characters indicating that both additive and non-additive gene effects played significant role in the inheritance of these characters. Environment had significant effect on the expression of the characters studied exhibited by significant mean sum of square due to environment. The mean squares due to SCA were higher than those due to GCA in grain yield per plant in both the generations indicating the preponderance of non-additive gene effects in the genetic control of this trait. The magnitude of SCA x Environment was comparatively higher than GCA x Environment for most of the characters indicating more **susceptibility** of non-additive gene action to the environmental variations. Further, mean squares due to GCA x Environment were significant in both the generations for all the characters except for tiller/plant, effective tillers per plant , flag leaf area, grain/spike and grain protein content. Similarly, mean squares due to SCA x Environment were significant for all the characters except for flag leaf area and grain protein content. The non-significant GCA x Environment and SCA x Environment interaction indicated that these five characters/traits were stable to the environmental variations. Similar results were earlier reported by Sharma and Singh (1990), Yadav and Mishra (1992), Menon and Sharma (1994), Singh and Singh (1996), Pochaba *et al.* (1997), Singh and Chatrath (1997), Rajara (1999), Sheikh and Singh (2000), Singh (2002), Punia (2003), Yadav and Singh (1989) and Kathiria and Sharma (1990).

The combining ability analysis in the individual environment (Table 4.3.1.3 and 4.3.1.4) also revealed significant mean squares due to GCA and SCA for all the characters in both the generations and environments indicating the importance of both additive and non additive gene effects in the genetic control of the characters studied. Further, the GCA/SCA variance ratio (less than unity) indicated preponderance of non-additive gene effects in both the environments except for days to anthesis (normal, P + F_1) and grain protein content which showed higher GCA/SCA variance ratio indicating preponderance of additive gene effects for these two characters. Similar results were earlier reported by Mohammed (1990), Mandal and Maity (1990), Li *et al.* (1991), Prodanovic (1993), Mishra *et al.*, (1994b), Nayeem and Veer (2000), Sheikh and Singh

(2000), Arshad and Chowdhary (2002), Singh (2002), Punia (2003) and Manmohan *et al.* (2003) etc. Some differences in the reports occur because of the differences in the experimental material and conditions under which evaluation is done.

Nature and magnitude of combing ability effects provide an idea about the role of fixable and non-fixable gene effects in the inheritance of different characters. This in turn helps in identification of suitable parents and crosses for hybridization/exploitation of heterosis. An overall appraisal of general combing ability effects revealed that the parents had consistent GCA effects for a specific character(s) over environments for example Raj 3765 for tillers per plant, days to maturity, and chlorophyll content; HD 2285 for flag leaf area, days to anthesis and duration from anthesis to maturity; Raj 3777 for tillers per plant, effective tillers per plant, biological yield per plant, grain yield per plant, and straw yield per plant; HD 2687 for plant height; HD 2329 for plant height, 1000- grain weight, harvest index, chlorophyll content; UP 2338 for grains per spike and grain protein content; Raj 3077 for effective tillers per plant, grains per spike, biological yield per plant, straw yield per plant and grain protein content and Lok 1 for days to anthesis, duration from anthesis to maturity, 1000- grain weight, biological yield per plant, grain yield per plant, straw yield per plant and chlorophyll content. All these parents exhibited significant and desirable GCA effects for characters mentioned against each parent. Therefore, these parents have good potential and may be used in synthesizing a dynamic population with most of the favourable genes to be accumulated.

Perusal of the general combing ability effects of the parents (Table 5.2) for grain yield revealed that a good co-ordination existed between F_1 and F_2 for GCA effects in normal and heat stress environments. Perusal of Table 5.3 indicated that Raj 3777 was found to be the best combiner for Grain yield per plant (g) under heat stress environment while Lok 1 was very good under both the environments. The GCA effects of these two parents for different characters are presented in Table 5.4.

The results revealed that Lok 1 was found to be the good combiner for days to anthesis, duration from anthesis to maturity, grains per spikes, 1000-grain weight, biological yield per plant, straw yield per plant, days to maturity, chlorophyll content and harvest index in normal environment while under heat stress environment it had desirable GCA effects for all these characters except for chlorophyll content and harvest index (Table 5.2). This indicates that these traits are important yield determiners. Earlier Kathiria and Sharma (1996), Singh (1998), Rajora (1999), Dimitrijevic and Kraljevic-Balalik (1992), Rajora and Maheshwari (1996), Sudesh *et al.* (2002) and Punia (2003) provided similar information on combining ability in wheat.

The results also revealed that Raj 3777 was found to be the good combiner tillers per plant, effective tillers per plant, biological yield per plant, straw yield per plant and harvest index (Table 5.2). In all such cases where GCA effect was more pronounced for particular trait indicating preponderance of additive gene action so these genotypes should be involved in crosses to improve the specific trait. Similar to the present findings under heat stress environment, were reported by several researchers In all such cases where GCA effect was more pronounced for particular trait indicating preponderance of additive gene action so these genotypes should be involved in crosses to improve the specific trait.

Shah (1998) reported that biological yield was the trait identified for selection with high temperature. The increase in productivity under late sown condition depends on the biomass attained by a genotype at the time of anthesis (Sharma, 1993). Blum *et al.*, (1997) emphasized that selection for high biomass yield should bring about positive improvement in grain yield, effective tillers per plant and number of kernels per spike. Thus selection for biomass yield is one of the ways to improve the productivity in bread wheat. The results of present investigation are in agreement with Guha Srkar *et.al.*, 2001, Nagarajan and Rane (2002), and Punia (2003).

In self pollinated crops like wheat, SCA effects are not much important as they are mostly related to non-additive gene effects and excepting those arising from complementary gene action or linkage effects they can not be fixed in the pure line or the end product inbred line. However, if a crosses combination exhibiting high SCA as well as high *per se* performance having atleast one parent as good general combiner for a specific trait, it is expected to throw desirable transgressive segregants in later generations (Kathiria and Sharma, 1996). However, such combinations may not necessarily throw good segregants. Similarly, from a superior cross involving poor x poor combiners, very little gain is expected because high SCA effects may be due to dominance and epistatic gene effects which may dissipate with the advancement towards homozygosity. Those crosses involving good and poor general combiners indicate the additive x dominance interactions. This is one of the reasons why the discrepancy with regard to SCA effects in F_1 and F_2 generations are observed.

In the present study both GCA and SCA effects were significant for majority of the characters. The crosses which showed desirable SCA effects for grain yield, also exhibited desirable SCA effects with one or more yield contributory traits. Crosses which showed high SCA effects for grain yield per plant were Raj 3777 x HD 2687 and UP 2338 x Raj 3077 in both the environments and in both generations. In addition to these, comparison across the generations (Table 5.5) indicated that HD 2329 X Lok 1, HD 2687 x UP 2338, Raj 3077 X Lok 1 and Raj 3777 X HD 2329 were the most suitable cross combinations for normal environment and HD 2285 X HD 2687, Raj 3077 X Lok 1, HD 2329 X Lok 1 and Raj 3777 X HD 2329 for the heat stress environment. However, these crosses had high SCA effects for number of tillers per plant, effective tillers per plant, biological yield per plant and harvest index indicating the importance of these traits towards yield contribution (Table 5.2) under normal and heat stress environment.

Mani and Rao (1977) had suggested that while selecting parents for future breeding, more stress should be laid on GCA effects rather than SCA effects. In general, high SCA effects denoted high heterotic response and there was some degree of association between these two. Breeder’s interest, therefore, rests in obtaining transgressive segregants through crosses and to produce potent homozygous lines. Jinks and Jones (1958) emphasized that superiority of the hybrids might not indicate their ability to yield transgressive segregants; rather SCA would provide satisfactory criteria.

The present study indicated that parents having high mean values also possessed desirable GCA effects in both the environments. The data (Table 5.2) also indicated that under heat stress environment in general, a good cross combination had at least one parent with high and desirable GCA effects in both the generations. Most of the crosses which exhibited high SCA effects for different traits in both the generations over environments involved either the poor general combiners or a good and a poor general combiner. Similar results have been reported earlier by several researchers (Muralia and Sastry, 2001 and Dubey *et al.*, 2001).

5.4 HETEROBELTIOSIS

A feasible strategy to achieve a quantum jump in the yield of bread wheat is the commercial production of hybrid varieties. The development of new and superior varieties is an important goal of practically all breeding programmes irrespective of their use as varieties *per se* and / or as parents of a hybrid. In self pollinated crops like wheat the improvement choices are limited. It involves hybridization of superior parents and then carrying forward, the superior crosses by bulk, single seed descent and/or pedigree method for several generations to obtain genetically fixed pure line varieties. The scope for utilization of heterosis depends mainly upon the direction and magnitude of heterosis. The magnitude of heterosis provides information on the extent of genetic diversity of parents involved in a cross and helps to choose the parents in developing superior F_1 s so as to exploit hybrid vigour.

Although heterosis was observed in wheat by Freeman (1919), its commercial exploitation has not become a reality, mainly due to self pollinating nature of the crop, although F_1 hybrids of wheat are under cultivation in a limited area in Australia and United States. The use of advanced generations has been suggested to exploit residual heterosis, if present, but it is not commercially feasible to produce sufficient F_1 seeds. Several theories have been put forward to explain the genetic basis of heterosis in crop plants but the dominant linked gene hypothesis (Jones, 1917) has found favour in self-pollinated crops to explain the phenomenon.

Both additive and non-additive gene effects have been suggested to explain heterosis. If heterosis is due to epistatic gene action, particularly of additive X additive type or due to repulsion phase linked loci, exhibiting partial or complete dominance, it should be possible to fix the alleles at interacting loci to preserve the heterotic effects in the pure lines. In addition, the heterotic hybrid can also produce desirable transgressive segregants in their advance generations (Arunachalam *et al.*, 1984). Under such situation, it will be useful to observe the genetic effects in crosses involving them, which may throw desirable recombinants in later generations. However, dispersion of alleles, as one of the major causes of heterosis, cannot be ruled out as enough evidence now supports dispersion of complementary genes as the major cause of heterosis (Singh and Singh, 1984).

In the present investigation, heterobeltiosis has been estimated in order to explore the possibility of using in the production of hybrids. The superiority of hybrids particularly over better parent is more useful in determining the feasibility of commercial exploitation of heterosis and also indicating the parental combinations, capable of producing the highest level of transgressive segregants. In present investigation, the expression of heterobeltiosis, in general, was variable for different traits under both the environments. The magnitude of heterobeltiosis was maximum for grain yield per plant followed by biological yield in both the environments. The only one cross UP 2338 X Raj 3077 exhibited greatest heterobeltiosis for chlorophyll content in both the environments. Furthermore, heterobeltiosis declined for most traits under heat stress except for duration from anthesis to maturity which is in agreement with Sharma and Tandon (1993). The crosses showing heterobeltiosis for grain yield were not heterotic for all the characters. In present study, very low heterobeltiosis was observed under late planting which is in agreement with Rehaman (1978), Singh and Anand (1971), Walton (1971) and Amaya *et al.* (1972) who reported that the environment conditioned expression of heterosis.

A comparative study of three most heterobeltiotic crosses in both the environments, for grain yield per plant corresponding to other attributes are presented in Table5.6. The perusal of table revealed that the crosses involving HD 2687, Raj 3077, UP 2338 and HD 2285 were found to be heterotic for a number of traits over the environments. The cross HD 2285 X HD 2687 and UP 2338 X Raj 3077 showed very high heterobeltiosis for grain yield in both the environments. The results revealed that the heterobeltiosis for grain yield was mainly contributed by number of effective tillers per plant, tillers per plant, flag leaf area, grains per spike and biological yield per plant under heat stress environment while in normal environment; it was also contributed by 1000-grain weight in addition to these five characters (Table 5.7). The results are in agreement with the results of Borghi *et al.* (1988), Saleem and Hussain (1988), Singh *et al.* (1989), Atale and Vitkare (1990), Kumar and Ganguli (1993), Walia *et al.* (1993), Murlia (1993), Hennaway (1996), Prasad *et al.* (1998), Deshpande and Nayeem (1999), Munir *et al.* (1999), Dubey *et al.* (2001), Salgotra *et al.* (2002), Subhani *et al.* (2002), Joshi *et al.* (2003), and Punia (2003).

It is of considerable interest to know the cause of heterosis for seed yield. Grafius (1959) suggested that there could be no separate gene system for yield *per se* as yield is an end product of multiplicative interaction between its various components. Thus heterosis for yield could be determined by finding the effect of heterosis for individual yield components or alternatively by multiplicative effect of partial dominance of component characters.

In general, mechanism for the expression of heterobeltiosis for grain yield was mainly dependent upon number of tillers per plant, effective tillers per plant, biological yield per plant, 1000-grain weight, grains per spike, days to anthesis, days to maturity and duration from anthesis to maturity in varying degree.

5.5 CORRELATION

Under heat stress environment, improvement in grain yield is the sole aim of breeding in cereals, however, yield being the complex outcome of its components, selection based on the yield alone would be misleading. Selection based on the yield components would, therefore, be more rewarding. This requires study on association of yield components with yield and themselves.

Perusal of Table 4.5.1 and 4.5.4 indicated that correlations were, in general, stronger at phenotypic level in comparison to genotypic level in both the environments. The associations at phenotypic level are generally considered, as there is no tangible test for knowing the statistical significance of correlations at genotypic level (Reddy and Sharma, 1982 and Singh *et al.* 1998). Under normal environment, the grain yield per plant was positively and significantly correlated with tillers per plant, effective tillers per plant, plant height, days to maturity, grains per spike, biological yield per plant, straw yield per plant and harvest index while negatively and significantly correlated with flag leaf area (in F_2 generation only r = -0.33, Table 4.5.2- 4.5.3).

The association of grain yield per plant was significant with effective tillers per plant, plant height, flag leaf area, days to maturity, 1000-grain weight, biological yield per plant, straw yield per plant, chlorophyll content, tillers per plant and grains per spike in heat stress environment. These results corroborate the earlier findings of Prabhu and Sharma (1987), Zhong-hu and Rajaram(1994), Ibrahim (1994), Chowdhary *et al.* (1996), Jaglam *et al.* (1997), Singh and Redhu (1997), Singh and Ahmad (1997), Reynold *et al.* (1998), Dhonde *et al.* (2000), Subhani (2000) and Nagarajan and Rane (2002).

The interrelationship of tillers per plant, effective tillers per plant, plant height, duration from anthesis to maturity, grains per spike, 1000-grain weight and biological yield per plant were also observed in both the environments (Table 4.5.5- 4.5.6).

The strong association of grain yield per plant with straw yield per plant, biological yield per plant followed by effective tillers per plant in heat stress environment indicated that these characters should be considered as potential selection criteria for improvement in grain yield under high temperature conditions. Shah (1998) also identified biological yield as the trait for selection under high temperature. According to Sharma (1993) the increase in productivity under late sown condition depends on the biomass attained by a genotype at the time of anthesis. Similar results were obtained by Zhong-hu and Rajaram(1994), Chowdhary *et al.* (1996), Jaglam *et al.* (1997). Blum *et al.* (1997) emphasized that selection for high biomass yield should bring about positive improvement in grain yield, effective tillers and numbers of kernel/spike heat stress environment. Nagarajan and Rane (2002) have also emphasized that biomass/ m^2 and spikes/ m^2 are easily measurable parameters and can be used for selecting genotypes suitable for late sown conditions. Thus selection for biomass yield is one of the ways to improve the productivity in bread wheat under heat stress environment (Guha Srkar *et.al*., 2001).

PLANT BREEDING IMPLICATIONS

Wheat is a thermosensitive crop and best adapted to the temperate climate, it is predominantly produced and consumed in tropical and subtropical regions of the world, where it is exposed to high temperature stress during certain growth stages, resulting in tremendous yield losses. Wheat crop grown in Northern India under late sown conditions is exposed to very low temperature upto booting stage, but at later stages it has to face warm temperature that enables grain development under high temperature conditions leading to poor grain yield. Cultivars differ in their relative adaptation to hot environments irrespective of their yield performance in cool environments (Shpiler and Blum, 1986). For improvement with respect to heat tolerance, information on the genetic control of grain yield and associated characters under heat stress and identification of good combiner parents/crosses are the primary requirements.

Improvement in grain yield is one of the sole aims of breeding for cereals under any agroclimatic condition. Grain yield is a most complex character and is the result of interaction of many direct and indirect component traits. Genetic manipulation of yield components in wheat continues to play a vital role in yield improvement event after the break through provided by the semi dwarf varieties.

The study of morphological as well as biochemical traits in wheat in normal as well as in heat stress environment provides guidelines for selection and development of new genotype with improved yields, as the material under study has provided enough variability upon which selection could operate effectively if there is no antagonistic associations which may retard response to selection. The results of genetic variability observed in the present investigation indicated that significant amount of genetic variation was present for the characters biological yield per plant, effective tillers per plant, grains per spike, 1000- grain weight, duration from anthesis to maturity and flag leaf area. These are the cvharacters which have been reported to be critical with respect to heat tolerance (Prabhu and Sharma, 1987, Sharma, 1993, Zhong- hu and Rajaram, 1994, Singh and Redhu, 1997, Shah, 1998, Guha Sarkar *et.al.*, 2001, and Arshad and Chowdhary, 2002). Hence, these characters should be considered while selection is carried out for higher yield under heat stress environment.

The results of the present investigation revealed that the grain yield and its associated characters were very much influenced under heat stress and both additive and non-additive gene actions were responsible for controlling inheritance of all the characters studied. The GCA/SCA variance ratio indicated that non-additive gene effects were predominant in exercising the genetic control. Dominance effect itself cannot be utilized in autogamous crops like wheat. However, additive x additive gene interactions being fixable can be exploited. Most of the characters were under the control of non-additive gene action. Thus results show concurrence among different types of analysis. Some differences existed between the different types of analysis; this is a general occurrence (Muralia, 1993 and Dubey, 1997). Therefore, some sort of recurrent selection by way of intermating the most desirable segregants followed by selection (Joshi and Dhawan, 1966), diallel selective mating system (Jenson, 1978) sounds to be a good technique, which delays quick fixation of gene complexes, permits break down of linkage, general fostering of recombination and concentration of favourable genes/gene complexes, into central gene pool by a series of multiple crosses. The use of biparental mating in early segregating generations as given by Joshi and Dhawan (1966) might prove to be effective alternative approach under such situations. In crops like wheat, non-additive gene action can not be utilized in the form of hybrid vigour due to lack of feasibility to produce enough quantity of hybrid seed, it is the best approach other wise to exploit the non-additive type of gene action.

Most of the traits studied were affected by heat stress. It was therefore, essential to develop a scale for sorting parents for their relative heat tolerance. In the present study perusal of Table 5.1 indicated that in general, varieties specially developed for heat stress had better tolerance with low HSI (heat susceptibility index). HD 2329, UP 2338, HD 2285, Raj 3777 and Raj 3765 are such genotypes. Not only the parents themselves, even the crosses which involved atleast one of the above parents or both the parents from above group had higher tolerance indices (low HSI) *viz.*, HD 2687 X Raj 3077, HD 2285 X Raj 3777, HD 2285 X HD 2687, Raj 3777 x UP 2338 and HD 2285 X Raj 3077, here HD 2687 X Raj 3077 is an exception in which both the parents are poor performers. Parents HD 2687 was in general poor yield performer based on means and HSI. However, HSI is not the ultimate reliable parameter for determining relative heat tolerance. These parents and crosses should be further exploited for improvement of grain yield under heat stress environment.

On the basis of *per se* performance, GCA and HSI, parent Raj 3777 followed by Lok 1 was identified as donor parent for the development of heat tolerant varieties (Table 5.8). These parents should be used intensively in the hybridization programme aimed to develop heat tolerant genotypes. Sharma *et al*. (2004) also observed and reported Raj 3777 to be heat tolerant genotype. Lok 1 should be used as best general combiner for normal environment as well as in heat stress environment, though it had high HSI (1.23).The crosses which showed desirable SCA effects have also exhibited high *per se* performance, low HSI and have one parent as good general combiner for various traits. This suggested that intermating between selected individuals from segregating generations of these crosses followed by intensive selection would be promising to concentrate most of the desirable alleles in the lines showing transgression for yield and its components.

On the basis of *per se* performance, SCA effect, the best crosses for grain yield per plant were identified as Raj 3777 X HD 2687, UP 2338 X Raj 3077, HD 2329 x Lok 1, HD 2687 X UP 2338, Raj 3077 X Lok 1 and Raj 3777 X HD 2329 under normal environment and Raj 3777 X HD 2687, UP 2338 X Raj 3077, HD 2285 X HD 2687, Raj 3077 X Lok 1, HD 2329 X Lok 1 and Raj 3777 X HD 2329 under heat stress environment, though, their heat susceptibility indices did not give the firm decision regarding desirable or undesirable crosses (Table 5.9), because as mentioned earlier, HSI is not the ultimate reliable parameter for determining relative heat tolerance.

Estimation of heterobeltiosis in the present investigation indicated presence of high magnitude of heterobeltiosis for grain yield and its components. Thus, present results advocated the exploitation of heterobeltiosis at commercial scale in wheat, if successful technology for hybrid seed production is developed. On the basis of heterobeltiosis, HD 2285 x HD 2687 and UP 2338 x Raj 3077 were the most heterotic crosses for grain yield per plant in normal as well as in heat stress environments. These crosses were also desirable for other 2-3 yield attributing traits and HSI. These crosses may be included in multiple crossing programmes following paired crosses or diallel selective mating or intermating among selects followed by selection would be worthwhile approach. The dynamic breeding populations thus developed are expected to result in homozygous lines characterized by good plant type and high grain yield.

The character association study indicated strong positive association of grain yield per plant with straw yield per plant and biological yield per plant followed by effective tillers per plant under heat stress environment. This indicated that these traits should be considered potential selection criteria for grain yield under high temperature.

Significant influence of heat stress environment on grain yield and other traits observed in the present investigation. Thus, screening conditions and selection criteria must also be emphasized according to the targeted environments along with the breeding methods. Similarly, the choice of parents and cross should be made on the basis of *per se* performance, GCA, SCA, heterobeltiosis and type of gene action involved for the characters of interest. In the present investigation the good parents identified under heat stress were Raj 3777 and Lok 1. The good crosses were identified as UP 2338 x Raj 3077, HD 2285 x HD 2687, Raj 3077 x Lok 1 and Raj 3777 x HD 2687.

It may be concluded that for improving wheat for heat tolerance both additive and dominant gene action have to be exploited by adopting adequate breeding strategies. For this, diallel selective mating (Jensen, 1970) and reciprocal recurrent selection (Comstock *et al.*, 1949) approaches may be adopted.

6. SUMMARY

The present study entitled "Genetic studies on high temperature tolerance at post anthesis in wheat (*Triticum aestivum* L. em. Thell.)"was undertaken with the objectives of estimating the combining ability variances and their effects, magnitude of heterobeltiosis and association between yield and its component characters along with some biochemical parameters. Eight genetically diverse varieties of wheat namely, Raj 3765, HD 2285, Raj 3777, HD 2687, HD 2329, UP 2338, Raj 3077 and Lok 1 selected on the basis of their different maturity duration and recommended suitable for either timely or late sowing, were crossed in diallel fashion (excluding reciprocals) during rabi, 2002-03 at S.K.N. College of Agriculture, Jobner. Twenty F_1 seeds were planted at Wellington (T.N.) to obtain F_2's in off season nursery during *summer*, 2003.

Above 8 parents, their 28 F_1's and 28 F_2's were evaluated in randomized block design with three replications under normal and post anthesis heat stress environments at Agronomy Farm, S.K.N. College of Agriculture, Jobner during *Rabi* 2003-04. Although it was not possible to create heat stress environment but by manipulating dates of sowing it could be created in the field conditions. Post anthesis heat stress environment was created by sowing the materials on Dec.22, 2003. On both dates of sowing parents and F_1's were sown in a single row plot of 2 m in each replication, while the segregating generation *i.e.* F_2 was sown in a plot of two rows of 2 m length and 30 cm x 10 cm spacing was maintained in each plot. Non experimental rows were planted all around the experimental material to avoid any possible boarder effects. Observations were recorded tillers/plant, effective tillers/plant, plant height (cm), flag leaf area (cm^2), days to anthesis, days to maturity, grains/spike, 1000-grain weight (g), biological yield/plant (g), grain yield/plant (g), chlorophyll content (mg/g fresh weight) and grain protein content (%). Three parameters were derived namely, duration from anthesis to maturity, straw yield/plant (g) and harvest index (%). Data were recorded on a sample of 5 plants/plot in parents and F_1's and on 10 plants/plot in F_2's per replication per environment, except days to anthesis, duration from anthesis to maturity, days to maturity, chlorophyll content and grain protein content which were recorded on plot basis. The data obtained were subjected to analysis of variance conducted for F_1 and F_2 diallel separately for pooled as well as environment wise using standard statistical procedures. The diallel analysis was done as per Griffing's (1956) method II, model I to derive information on combining ability. The magnitudes of heterobeltiosis and character associations were also obtained. The results of the present investigation are summarized below:

1. Pooled analysis of variance revealed significant differences among the genotypes in both the sets (P + F_1 and P + F_2) and between the environments indicating sufficient diversity among the genotypes for all the characters studied and differential influence of environments on their expression. The genotype x environment interactions were significant for all the characters except for flag leaf area and grain protein content. Analysis of variance for environment indicated significant differences among the genotypes for all the characters revealing the existence of

sufficient genetic variability among the parents and their F_1's and F_2's for all the characters in normal as well as in heat stress environment. Partitioning of the mean sum of squares due to genotypes into parents, crosses and parents v/s crosses (*i.e.* parents, F_1 and parents v/s F_1 and parents, F_2 and parents v/s F_2) indicated that significant differences existed among parents, their segregating and non-segregating generations in both the environments. The mean sum of squares due to parents v/s crosses for both the generations were also observed significant for all the characters except for effective tillers/plant, days to anthesis and grains/ spike in heat stress environment and grains/spike in normal environment. The significant mean sum of squares among parents v/s F_1 signified the existence of heterosis.

2. Comparison of mean values revealed that the means of different traits decreased under heat stress in comparison to normal environment except grain protein content which registered a slight increase and harvest index in which no marked reduction was observed. The maximum reduction in the mean values under heat stress was observed for straw yield/plant, biological yield/plant, grain yield/plant and duration from anthesis to maturity. The detrimental effect of heat stress on grain yield was maximum through duration from anthesis to maturity, 1000-grain weight, effective tillers/ plant and grains/ spike.

3. Based on heat susceptibility index (HSI) UP 2338, Raj 3765, HD 2329 and Raj 3777 for effective tillers/ plant; HD 2329, Raj 3765, Raj 3777 and Lok 1 for grains/ spike; Raj 3077, Raj 3765 and Raj 3777 for 1000- grain weight (g); and HD 2329, UP 2338, HD 2285, Raj 3777 and Raj 3765 for grain yield/ plant (g), were least affected by post anthesis heat stress. An overall appraisal indicated that Raj 3777 followed by Raj 3765 was the best parent based on HSI.

4. The combining ability analysis based on pooled as well as individual environment revealed that mean sum of squares due to GCA and SCA were significant for all the characters, indicating the importance of additive and non-additive gene action in the inheritance of the characters studied. The GCA/SCA variance ratio indicated preponderance of non-additive gene action except for days to anthesis and grain protein content, where additive gene effects was predominant. The interaction between GCA x E and SCA x E were found significant for all the characters except for flag leaf area and grain protein content reflecting susceptibility of GCA and SCA effects of these characters to environments.

5. On the basis of GCA effects and *per se* performance parent Raj 3777 followed by Lok 1 emerged as very good general combiner for grain yield/ plant under heat stress environment and Lok 1 in normal environment. The good combiner Raj 3777 was also found to be the good combiner for tillers/plant, effective tillers/plant, biological yield and harvest index indicating the importance of these characters in the yield improvement under heat stress environment.

6. On the basis of SCA effects and *per se* performance the desirable crosses for grain yield /plant were Raj 3777 X HD 2687, UP 2338 X Raj 3077, HD 2285 X HD 2687, Raj 3077 X Lok 1, HD 2329 X Lok 1 and Raj 3777 X HD 2329 under heat stress environment and Raj 3777 X HD 2687, UP 2328 x Raj 3077, HD 2329 X Lok 1, HD 2687 X UP 2338, Raj 3077 X Lok 1 and Raj 3777 X HD 2329 under normal environment. These crosses were also desirable for important yield attributing traits and HSI. Thus these crosses hold great promise in improving the grain yield in bread wheat in normal and heat stress environments through systematic breeding programme in future.

7. Sufficient degree of heterobeltiosis was observed for all the characters. The most heterotic crosses for grain yield/plant, showing significant heterobeltiosis were HD 2285 X HD 2687, UP 2338 X Raj 3077 and Raj 3077 X Lok 1 in normal as well as heat stress environments whereas HD 2687 X UP 2338 in normal and HD 2285 X HD 2687 in heat stress environment.

8. At phenotypic level, the grain yield was positively and significantly correlated with tillers/plant, effective tillers/plant, plant height, days to maturity, grain/spike, biological yield/plant, straw yield/plant and harvest index in the normal environment. Under heat stress environment there was strong association of grain yield/plant with straw yield/plant, biological yield/plant followed by effective tillers/plants. Hence these characters should be considered for selection in breeding for post anthesis heat stress environment.

9. Both additive and non-additive gene actions controlled the expression of most of the characters and the magnitudes of non-additive gene actions were higher than additive action. Therefore, in addition to conventional breeding methods some non-conventional breeding methods such as biparental mating followed by recurrent selection, diallel selective mating, and mass selection with recurrent random mating or multiple crossing are suggested for amelioration of grain yield through its components traits in normal as well as in heat stress environments.

10. On the basis of *per se* performance, GCA and HSI parent Raj 3777 followed by Lok 1 was identified as a donor parent which may be used in hybridization programmes for the development of heat tolerant varieties.

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Kumar,

Genetic studies on high temperature tolerance at post anthesis in wheat (*Triticum aestivum* L. em. Thell.)

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Abstract**

Eight genetically diverse varieties of wheat (*Triticum aestivum* L. em. Thell.) namely Raj 3765, HD 2285, Raj 3777, HD 2687, HD 2329, UP 2338, Raj 3077 and Lok 1 were crossed in diallel fashion (excluding reciprocals). The 8 parents, their 28 F_1's and 28 F_2's were evaluated in randomized block design with three replications under both normal and post anthesis heat stress environments. Observations were recorded on tillers per plant, effective tillers per plant, plant height (cm), flag leaf area (cm^2), days to anthesis, duration from anthesis to maturity, days to maturity, grains per spike, 1000-grain weight (g), biological yield per plant (g), grain yield per plant (g), straw yield per plant (g), harvest index (%), chlorophyll content (mg/g fresh weight) in flag leaf at 5 DAA (days after anthesis) and grain protein content (%).

The data obtained were analysed in two separate sets of generations *i.e.*, parents + F_1 (P + F_1) and parents + F_2 (P + F_2) as per the standard statistical methods. The pooled analysis of variance indicated significant differences among the genotypes and the environments. The genotype x environments interaction was also found to be significant for most of the characters except for flag leaf area and grain protein content. Environmentwise analysis indicated that genotypes had significant differences for all the characters. The significant interaction between parents versus F_1's indicated presence of heterosis.

The mean grain yield/ plant (g) and heat susceptibility index (HSI) indicated that HD 2329, UP 2338, HD 2285, Raj 3777 and Raj 3765 were least affected by post anthesis heat stress. The desirable crosses (low HSI values) had either both or atleast one of the above parents. An overall appraisal indicated that Raj 3777 followed by Raj 3765 was the best parent based on HSI.

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Combining ability analysis (Griffing's Method II, Model I) indicated that both GCA and SCA mean squares were significant on pooled as well as individual environment basis for all the traits. Genotype x environment, GCA x environment and SCA x environment were also significant for most of the traits indicating the non linear response of genotypes and GCA and SCA variances to the varying environments. The GCA/SCA variance ratio indicated preponderance of non –additive gene action for most of the traits except for days to anthesis and grain protein content. There was good agreement between *per se* performance and GCA effects of the parents for various traits in both the environments. Parent Raj 3777 was found to be good general combiner for grain yield per plant under heat stress and Lok 1 was found to be good general combiner in normal as well as in heat stress environment. Parents which showed desirable GCA effects for grain yield also showed desirable GCA effects for some other yield attributing traits.

On the basis of SCA effects and *per se* performance the desirable crosses for grain yield per plant were Raj 3777 x HD 2687 and UP 2338 x Raj 3077 in normal as well as in heat stress environments. These crosses were also desirable for 2-3 yield attributing traits and HSI.

Sufficient degree of heterobeltiosis was observed for all the characters. The most heterotic crosses for grain yield per plant were HD 2285 x HD 2687 and UP 2338 x Raj 3077 in normal as well as in heat stress environments.

At phenotypic level, the grain yield per plant had positive significant correlation with effective tillers per plant, biological yield per plant, and straw yield per plant under both the environments.

Parent Raj 3777 followed by Lok 1 were identified as good donors for heat tolerance. Raj 3777 x HD 2687 and UP 2338 x Raj 3077 were identified as superior crosses in both the environments. On the basis of present investigation it was concluded that diallel selective mating or multiple crossing should be followed for amelioration of grain yield.

ANNEXURE –I

Weekly observations of key abiotic factors during the course of study (November to April, 2003-04)

Meteor-ological weeks	Period		Temperature (^oC)		Relative humidity (%)		Evapo-ration (mm)	**Rainfall (mm)**
	From	**To**	Maxi.	Mini.	Mor.	Eve.		
45 Nov.	**05/11**	**11/11**	**32.0**	**17.2**	**54**	**23**	**04.5**	**000.0**
46	**12/11**	**18/11**	**29.8**	**12.0**	**68**	**26**	**04.0**	000.0
47	**19/11**	**25/11**	**29.1**	**09.6**	**69**	**24**	**03.5**	000.0
48	**26/11**	**02/12**	**27.3**	**07.3**	**72**	**26**	**02.7**	000.0
49 Dec.	**03/12**	**09/12**	**26.8**	**06.5**	**70**	**30**	**03.2**	**000.0**
50	**10/12**	**16/12**	**27.0**	**07.1**	**65**	**31**	**03.6**	**000.0**
51	**17/12**	**23/12**	**27.4**	**06.2**	**76**	**32**	**02.6**	**000.0**
52	**24/12**	**31/12**	**20.7**	**04.0**	**84**	**48**	**02.0**	**000.0**
1 Jan.	**01/01**	**07/01**	**20.5**	**03.5**	**91**	**53**	**02.2**	000.0
2	**08/01**	**14/01**	**23.9**	**05.1**	**87**	**32**	**02.4**	000.0
3	**15/01**	**01/01**	**24.1**	**05.7**	**92**	**47**	**02.2**	000.0
4	**20/01**	**28/01**	**20.0**	**03.9**	**92**	**51**	**01.9**	000.0
5	**29/01**	**04/02**	**21.7**	**03.5**	**92**	**44**	**02.0**	000.0
6 Feb.	**05/02**	**11/02**	**24.9**	**07.7**	**80**	**32**	**03.9**	000.0
7	**12/02**	**18/02**	**26.8**	**08.3**	**78**	**33**	**03.6**	000.0
8	**19/02**	**25/02**	**29.6**	**08.4**	**80**	**26**	**03.7**	000.0
9	**26/02**	**04/03**	**31.8**	**10.7**	**74**	**25**	**04.2**	000.0
10 Mar.	**05/03**	**11/03**	**33.3**	**14.3**	**71**	**31**	**05.9**	000.0
11	**12/03**	**18/03**	**37.5**	**15.6**	**67**	**21**	**06.1**	000.0
12	**19/03**	**25/03**	**38.6**	**12.8**	**52**	**24**	**10.1**	000.0

13	**26/03**	**01/04**	**35.7**	**18.0**	**51**	**15**	**07.0**	000.0
14 Apr.	**02/04**	**08/04**	**38.8**	**27.7**	**54**	**22**	**09.2**	000.0
15	**09/04**	**15/04**	**40.0**	**24.1**	**41**	**22**	**12.6**	000.0
16	**16/04**	**20/04**	**40.2**	**23.1**	**40**	**19**	**13.8**	000.0
17	**23/04**	**29/04**	**39.1**	**20.0**	**46**	**16**	**11.4**	000.2
18	**30/04**	**06/05**	**34.9**	**27.3**	**58**	**31**	**08.3**	002.8

ANNEXURE –II

The procedure for the determination of total chlorophyll content

Total chlorophyll content was determined by using method described by Hiscox and Isrealstom (1979). Five days after anthesis (DAA), fresh flag leaf was taken from each genotype in each replication, washed under tap water and put on blotting paper to remove excessive moisture. Fifty mg flag leaf material was then taken and placed in the bottom of numbered test tubes to which 5.0 ml DMSO (Dimethyl sulfoxide) was added by pipette. These test tubes were tightly capped by aluminium foil and placed in an oven at 60 ^{0}C for 6 h.

After required heating period, the tubes were removed from the oven and cooled to room temperature. Finally, the tubes were thoroughly shaken and extracted solvent was decantated to read absorbance in spectrophotometer. The absorbance was recorded at 652 nm.

Following formula was used for calculation of total chlorophyll content:

$$\text{Total chlorophyll content (mg/g fr.wt.)} = \frac{D \times 1000}{34.5} \times \frac{V}{1000 \times W}$$

Where,

D = Optical density or absorbance

V = Final volume of the extract (ml)

W = Fresh weight of sample taken in gram

ANNEXURE –III

The procedure for the estimation of Nitrogen content

Reagents used

i. Nessler's reagent

Took 45.5 g of mercuric iodide and 35.0 g of potassium iodide, dissolved these two in 70.0 ml of distilled water, this was called solution A. In another beaker, dissolved 112.0 gm of NaOH in about 100 ml of distilled water, this was called solution B. Then, mixed solution A and B in a volumetric flask of 500 ml and made the volume. This mixed solution was kept over night and transfered the supernatant liquid in a coloured bottle and kept it in a dark place. This was called stock solution. The working solution was prepared from stock solution by taking stock solution and dissolving 4 times at the time of working.

ii. Sodium silicate 10%

Dissolved 10.0 gm of sodium silicate in 100 ml of warmed water and boiled for complete dissolution.

iii. Sodium hydroxide 10%

Dissolved 10.0 g of NaOH pellets in 100 ml of distilled water.

Procedure for digestion and nitrogen determination:

0.1 g of dried and grinded grain sample was taken in 100 ml microkjeldahl flask, about 2.0 ml of concentrated H_2SO_4 was added slowly and heated gently on the hot plate [digestion assembly] till the sample was broken down and particles were dissolved. Flask was cooled and 0.5 ml of 30 % H_2O_2 was added and heated again, repeated the process till the solution became perfectly clear and colourless. Flask was cooled again and volume was made up.

5.0 ml of digested material [aliquot] was transferred in to 50 ml volumetric flask. Some water, 2 ml of 10 % NaOH and 1 ml of 10% sodium silicate was added and stirred well. There after, added 1.6 ml of diluted working solution of Nessler's reagent, mixed thoroughly and the volume was made up to 50 ml. The colour intensity was read at 420 nm using Spectronic - 20.

Preparation of standard curve

Dissolved 0.1185 g of ammonium sulphate [Analytical Reagent Grade-I] in water and made the volume 1.0 litre in volumetric flask, this solution contained 25 ppm of nitrogen. Now from this solution, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and to 4.0 ml was taken in cubate and absorbance was measured at 420 nm. Observations were plotted on a graph *i.e.* concentration of N on X-axis and absorbance on Y-axis.

Calculation

$$\text{Dilution factor} = \frac{100}{0.1} \times \frac{50}{5} = 10000$$

$$\text{Percentage of nitrogen} = \frac{\text{ppm nitrogen}}{10000} \times \text{Dilution factor}$$

Percentage of crude protein content = Nitrogen % X 6.25