

**Inheritance in Bread Wheat
(*Triticum aestivum* (L.) em. Thell)**

$xgyn[1/1Vde, 1/1Vbe \frac{1}{4} y-\frac{1}{2}b, e- Fky]$ eaoåkuçfr

Chhagan Lal

THESIS

**Master of Science in Agriculture
(Plant Breeding & Genetics)**



2011

**DEPARTMENT OF PLANT BREEDING AND GENETICS
RAJASTHAN COLLEGE OF AGRICULTURE
MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND
TECHNOLOGY, UDAIPUR**

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THESIS

Submitted to

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For the Degree of

Master of Science in Agriculture

(*Plant Breeding & Genetics*)



By

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2011

**Maharana Pratap University of Agriculture and Technology
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CERTIFICATE – I

Dated: / /2011

This is to certify that **Mr. Chhagan Lal** has successfully completed the Comprehensive/Preliminary Examination held on 20 April, 2009 as required under the regulation for degree of **Master of Science in Agriculture**.

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This is to certify that **Mr. Chhagan Lal**, student of **Department of Plant Breeding & Genetics**, Rajasthan College of Agriculture, Udaipur has made all the corrections/modifications in the thesis entitled **“Inheritance in Bread Wheat [*Triticum aestivum* (L.) em. Thell]”**, which were suggested by the external examiner and the advisory committee in the oral examination held on / / . The final copies of the thesis duly bound and corrected were submitted on / / , are enclosed herewith for approval.

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Place: Udaipur

(Chhagan Lal)

Date:

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1. INTRODUCTION

Wheat belongs to the tribe *triticeae* and family *Poaceae*. Though different wheat species are cultivated for food grain production, but among them, the hexaploid wheat, *Triticum aestivum* (L.) [$2n = 6x = 42 = AABBDD$] is widely grown and consumed food grains all over the world.

Wheat is the second most important crop after rice in India and occupies approximately 28.5 mha area. In India, wheat is grown under diverse environment from 11° to 30° N, from sea level to 4000 m elevation as rainfed to an irrigated crop, with soil pH of 5.5-9.0 and having a growth period of 150-170 days. It is grown during November to April and the seeding time depends on annual crop cycle followed by the farmers under timely sown conditions. The wheat production in India has touched a new height, annual production of wheat in India during 2010-11 was 80.5 million tonnes (Anonymous, 2010 a) which is tremendous improvement over the production level due to the rapid growth in irrigated area and popularization of high yielding varieties. About 91.5 per cent of the wheat produced in six states *viz.* Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan and Bihar. Out of this, Rajasthan shares about 10 per cent both in terms of area and production at the national level. The area and production of wheat in the state during 2010-11 was recorded as 2.29 mha and 7.29 million tonnes, respectively with an average productivity of 31.83 q ha⁻¹ (Anonymous, 2010 b).

After the quantum leap of the green revolution, wheat yields have been rising by only 1.1 percent per year, a level that falls far short of the demand of a population that is growing 1.5 percent or more annually. Now-a-days, climate change and increase in temperature are being used synonyms to seek other. The major cause of temperature increase is associated with higher emission of CO₂ primarily from burning fossil fuel and increase in green house gases like methane, nitrous oxide etc. in the environment. Based on series of observation and studies, an increase has been recorded in earth's temperature by 0.74°C between 1906 and 2005. Changing climate especially predicted increases in the frequency and severity of drought and heat, highlight the importance of abiotic (climate and soil) stresses affecting crop production. Changing climate is also likely to affect other abiotic stresses (FAO 2000).

Wheat [*Triticum aestivum* (L.) em. Thell] is a thermo-sensitive crop. It is especially sensitive to temperature that exceeds 32⁰C for any significant period. In this crop, plants can be injured at seedling emergence, reproductive development, stem elongation, heading and flowering by high temperature. 1⁰C increment in temperature reduces 8 to 10 per cent grain yield (Abrol and Ingram, 1996). This occurs at the grain filling stage in wheat resulting in the development of shriveled grain which reduces yield and decreases quality.

Many studies (Rawson, 1986, Wardlaw *et al.*, 1989, Al-Khatib and Paulsen, 1984, Reynolds *et al.*, 1994) have shown that genetic variability for heat tolerance exists in germplasm lines and varieties. They have also suggested use of landraces in conventional breeding of wheat to incorporate genes for heat tolerance. The other approach is to use wild species *viz.* *Aegilops* and *Triticum* species with same genomes as cultivated wheat.

The success of any breeding programme depends primarily upon the proper selection of parents, mating system employed and finally the breeder's keen judgment in selecting superior genotypes from more abundant and less desirable plants within the segregating populations. Improvement for heat tolerance depends on hybridization using heat tolerant donors and high yielding commercial cultivars. The study of heterosis, inbreeding depression associated with study of gene effects in most of the crops including wheat population is an important tool in interpreting genetic parameters. The nature and magnitude of gene effect governing the inheritance of quantitative characters could play a vital role for the plant breeder in formulating the appropriate breeding procedure.

Therefore, keeping in view the aforesaid conditions, an attempt was made to evaluate important biometrical character in six generations (P₁, P₂, F₁, F₂, BC₁ and BC₂) of wheat crosses involving four diverse parents to study:

- i. To estimate the gene effects for grain yield and its attributes, and
- ii. To estimate the magnitude of heterosis and inbreeding depression, and

On the basis of the above study, superior parents and crosses were identified for improving the productivity of wheat under irrigated conditions. Based on findings, appropriate breeding strategies have been suggested for wheat improvement.

2. REVIEW OF LITERATURE

Wheat is life line for food and nutritional security in India. The research backup for this important staple food crop has always responded to endure food demand of the ever growing population.

Plant breeders are primarily concerned with the improvement of those traits which are directly or indirectly related to economic value. Such traits are generally quantitative in nature and governed by several number of genes each having small effects acting in a cumulative manner. Such genes are called polygene. Knowledge of the genetic architecture of grain yield, yield components, grain protein, and heat tolerance traits is essential for adopting the suitable breeding methodology for genetic improvement in wheat.

In order to diversify the workable gene pool wheat researchers are exploring all possible and feasible efforts for creating and harnessing the genetic diversity and trait specific variability for economic traits particularly yield attributes.

The objective of present investigations, therefore, is to elicit more information on the genetic parameters in wheat on various agronomic/morphological and quality traits. Research work of relevance to present study in wheat is reviewed under the following heads:

- 2.1 Heterosis and inbreeding depression
- 2.2 Gene action studies, and
- 2.3 Heat tolerance

2.1 HETEROSIS AND INBREEDING DEPRESSION

The Superiority of hybrid over parents is called heterosis (Shull, 1914). This phenomenon has been exploited widely to develop high yielding hybrid varieties of crop plant. Also, potential crosses for breeding are often identified on the basis of F_1 heterosis or residual heterosis (Fasoulas, 1981).

Two main hypothesis help to explain genetic basis of heterosis. The dominance hypothesis advanced by Bruce (1910), Keeble and Pellew (1910) and others considers that heterosis is primarily due to accumulation or complementary

action of dominant favorable genes present dispersed in the parents. In contrast, the over dominance hypothesis expounded by Shull (1908), East (1908) and others considers it to be due to the superiority of heterozygous loci over the homozygous ones, or over dominance. The relative significance of this gene action is however not clear as true over dominance is difficult to prove. Heterosis is usually measured as percentage deviation of F_1 hybrid family mean from the mid-parent value, or from mean of better parent, when it is called heterobeltiosis.

Wheat being a highly self pollinated crop, scope for exploitation of hybrid vigour will depend on the direction and magnitude of heterosis, biological feasibility of crop and nature of gene action. Freeman (1919) recorded heterosis in wheat for the first time. Later on it was observed by Engledow and Pal (1934), Briggles (1963), Jhonson *et al.* (1966), Bitzer *et al.* (1967) Meredith and Bridge (1972) and Sadeeque *et al.* (1991) for many characters including yield and its components. However, relevant and salient findings are reported here as follows:

Chakraborty and Tiwari (1995) studied heterosis in 60 wheat crosses over mid parent and better parent and found that high heterotic effect for 1000-grain weight while low for tillers per plant. The crosses with the highest heterosis over mid parent and better parent were the same for all characters studied. Manifestation of heterosis for grain yield was mainly due the test weight, grains per ear and biological yield per plant.

Khan and Khan (1996) observed that number of tillers showed maximum heterosis over the mid parent (31.91%) followed by grain yield per plant (19.41%), 1000-grain weight (17.32%), grains per spike (11.37%) and plant height (5.23%).

Prasad *et al.* (1998) observed maximum heterosis over the better parent for grain yield per plant (59.7%) while maximum heterosis over the standard parent was 27.3 per cent. Crosses KS 19 x KS 34, KS 34 x HD 2402 and HUW 206 x KS 19 exhibited significant heterosis over better parent for grain yield per plant and biological yield. Heterosis for number of grains per ear and 1000-grain weight was generally independently associated with heterosis for grain yield per plant.

Sharma and Tandon (1998) studied effect of heat stress on heterosis for some physiological characters in 8 x 8 diallel crosses of wheat and observed that heat stress

(increasing the temperature from 20 to 30°C) reduced mean heterosis for plant height, leaf area per plant and chlorophyll content and increased it for dry weight.

Deshpande and Nayeem (1999) found significant heterosis over better parent for grain yield, heat injury, chlorophyll content and stomatal frequency. However, moderately negative (desirable) heterosis over better parent was observed in crosses Hindi 62 x Ajantha (-1.1%), Hindi x Kalyansona (-16.91%) and Hindi 62 x CC 464 (-14.9%) for plant height. The highly significant and positive heterosis over best parent for number of grains per spike was observed in Ajantha x CC 464 (37.4%) and Hindi 62 x Ajantha (20.2%). For 1000-grain weight, significant heterosis was observed in Kalyansona x CC 416 (10.9%).

Larik *et al.* (1999) reported that in a 6 x 6 diallel set of common bread wheat, grain yield per plant displayed maximum observed and predicted inbreeding depression ranging from 25.25 to 88.71 per cent and 10.16 to 19.85 per cent, respectively.

Yadav and Narsinghani (2000) evaluated twelve genotypes of *T. aestivum* and *T. durum* crosses and P₁, P₂, F₁ and F₂ generations of seven crosses were evaluated for nine yield components during *rabi*, 1995-96 for information on heterosis and inbreeding depression. The significant negative heterosis followed by negative inbreeding depression was observed for days to heading and grain yield per plant in cross JWI 2914 x HI 1077 indicating the occurrence of additive gene effects which would result in the appearance of transgressive segregants in F₂ and subsequent generations, hence the isolation of superior yielding genotypes may be possible by isolating desirable segregants from the segregating population of this cross.

Singh and Parsad (2001) studied the magnitude and direction of heterosis in wheat in L x T involving 10 lines and 4 testers. They observed that the cross combination Lok 1 x HD 2285, PBW 351 x HD 2307 and Lok 1 x K 8020 showed heterobeltiosis for grain yield per plant and also exhibited heterosis for some important yield components. Heterosis for yield per plant varied from 8.79 to 41.14 per cent.

Ijaz *et al.* (2002) observed heterosis over mid parent in different wheat genotypes and found that grain yield per plant had the highest heterosis (31.56 per cent) followed by number of grains per spike (15.56 per cent), spike length (7.42 per

cent), number of spikelets per spike (7.29 per cent), 1000-grain weight and number of tillers (- 2.14 per cent).

Joshi *et al.* (2003) reported that significant negative inbreeding depression for yield and yield contributing traits indicating that the F₂ was superior to the F₁. The study demonstrated the potential of isolating pure lines among the progenies of heterotic F₁s improvement of yield potential in bread wheat.

Prakash and Joshi (2003) observed significant inbreeding depression in 2 crosses of spring wheat for days to heading, days to maturity, plant height, grains per spike and grain yield per spike under normal and late sowing conditions.

Singh (2003) evaluated P₁, P₂, F₁, F₂, BC₁ and BC₂ populations of 3 bread wheat crosses and reported that inbreeding depression in segregating populations was observed for most of the characters except for number of days to heading in some crosses. He also studied heterosis for yield and its components in wheat and observed positive and significant heterosis for most of the traits except plant height and grain yield in UP 301 x Raj 3077, plant height in CPAN 3044 x HD 2329 and plant height and grain yield per plant in HD 2428 x Raj 1482.

Baric *et al.* (2004) reported that all the combinations gave average heterosis (MP, BP) for 1000-grain weight (14.38 per cent, 6.12 per cent) and grain weight per spike (11.47 per cent, 3.68 per cent). The highest heterosis (MP, BP) was found for 1000-grain weight (35.27 per cent, 28.42 per cent) in the hybrid Remus x Sivka.

Hussain *et al.* (2004) reported that positive and significant heterotic effects were as 11.61, 61.90, 30.67, 2.30, 51.89, 126.64, 111.71 and 45.91 per cent from crosses SA 42 x Nacozari, MH 97 x Crow, Parula x Chenab 70, Crow x Nacozari, Crow x Chenab 70, SA 42 x Nacozari, MH 97 x SA 42 and Nacozari x Chenab for plant height, tillers per plant, grains per spike, spikelets per spike, grain weight, grain yield, biological yield per plant and harvest index, respectively.

Jahanzeb and Khaliq (2004) reported that the 1000-grain weight had maximum heterosis over the mid parent (20.96 per cent), followed by number of grains per spike (13.97 per cent), plant height (-7.00 per cent), grain yield per plant (23.70 per cent) and number of tillers per plant (-31.22 per cent).

Sharma *et al.* (2004) determined the magnitude of inbreeding depression from F₁ to F₂ in a 10 x 10 diallel set of durum wheat for grain yield and its component

traits. The study revealed that there were good scopes for potential isolation of pure lines among the progenies of heterotic F_1 s for improvement of yield levels in durum wheat.

Singh *et al.* (2004) reported significant positive heterobeltiosis by 55 crosses in two sowing dates (20 November and 10 December), however, only 20 crosses showed consistent heterobeltiosis over two environments for grain yield. The maximum heterobeltiosis for grain yield per plant was 121.08 (PBW 373 x HD 2329) and 93.96 per cent (PBW 373 x HD 2329) under normal and late sowing conditions, respectively. They also estimated inbreeding depression for quantitative and qualitative traits in a 10 x 10 diallel set in bread wheat under 3 different environments. Significant inbreeding depression was recorded for yield and yield contributing traits. However, in a few traits significantly negative inbreeding depression was observed indicated that F_2 was superior to F_1 considered desirable combination for traits.

Chowdhry *et al.* (2005) reported that grain yield per plant had maximum significant heterosis over the mid parent (44.19 and 29.65 per cent, respectively) followed by flag leaf area (28.72 per cent), tillers per plant (18.83 per cent) and spike length (18.79 per cent).

El-Sayed and Moshref (2005) indicated that heterosis was significant for most studied characters in the F_1 and F_2 . Compared with better parent, the highest heterosis effect was registered by the crosses Giza 170 x Sakha 93 for plant height, flag leaf area, number of spikes per plant, straw yield per plant and grain yield per plant.

Punia *et al.* (2005) reported that the cross Raj 3077 x Kailash and C 306 x PBN 451 exhibit significant standard heterosis in more than one environment for grain yield and heat tolerance traits.

Prakash *et al.* (2006) observed heterosis and its components and inbreeding depression for grain yield and its components in generation mean analysis in 4 wheat crosses i.e. Raj 1482 x HD 2329, PBW 373 x Raj 3077, HD 2329 x Raj 3777 and HD 2285 x WH 542. The components of heterosis showed that dominance gene action contributed the most to the expression of heterosis for the traits examined, although additive x additive, additive x dominance and additive gene action also contributed to the expression of heterosis. Inbreeding depression was due to the dissipation of heterotic effects in the F_2 generation.

Sharma *et al.* (2006) reported significant inbreeding depression for peduncle length in some crosses of durum wheat due to the epistatic effects involving dominance in the F₂ generation.

Vanpariya *et al.* (2006) reported that the crosses PBW 316 x Lok 1, DWR 202 x GW 496, K 8565 x Lok 1, DL 803-3 x GW 173 and GW 326 x GW 190 exhibited exploitable heterosis for grain yield and most of its component traits.

Ribadia *et al.* (2007) the maximum heterosis and heterobeltiosis were recorded for grain yield per plant in Flamingo's' x H-6178 (5) 6-4-5.

Singh *et al.* (2007) reported that the magnitude of better parent heterosis was high for grain yield attributing traits as spikelets per spike, grains per spike and 1000-grain weight. Similar finding that the heterosis was found to be high for the traits as panicles per plant, grains per spike and 1000-grain weight (Xinnian *et al.*, 2007).

2.2 GENE ACTION STUDIES

The modes of expression of gene are called gene action. The nature and magnitude of gene actions governing the inheritance of various characters could be of vital importance to the plant breeder in formulating the appropriate breeding procedures.

Fisher (1918) partitioned the total genetic variance into additive, dominance and epistatic components and defined these three importances as:

- (i) Additive genetic variance arising from the additive effect of genes summed at all segregating loci which gives an average heritable effect of genes.
- (ii) Dominance genetic variance arising due to the deviation from the additive scheme of gene action resulting from intra-allelic interaction of genes at segregating loci which is unfixable variation, and
- (iii) Epistatic genetic variance arising due to the deviation of a consequence of inter-allelic interaction of genes at two or more segregating loci.

Mather (1949, 1982) portioning generation means into genetic components of variation i.e. additive (d), dominance (h), and m, being mid parent value, considering epistasis being not important and gave tests to detect the presence of epistasis and these tests are familiar as A, B, C, and D scaling tests. In case, the scaling tests

indicated epistasis, transformation of data to fit to the additive-dominance model is needed.

Cavalli (1952) proposed a joint scaling test for estimating parameters, m, d and h using weighted least square technique. It also suggests about epistasis.

Several workers (Cockerham, 1954 and Kempthorne, 1957) partitioning the epistatic variance into additive x additive, additive x dominance and dominance x dominance for digenic traits and other trigenic and higher order interactions.

Hayman (1958) described genetic components *viz.*, population mean (m), additive (d), dominance (h), additive x additive (i), additive x dominance (j) and dominance x dominance (l).

Jinks and Jones (1958) proposed three parameters model to estimate genetic components using six generations.

Gardner (1963) described the following genetic parameters which are of interest to plant breeders: (i) genotypic correlation among quantitative characters, (ii) additive genetic variance ($\sigma^2 A$), (iii) dominance genetic variance ($\sigma^2 D$), (iv) epistatic variance, (v) average degree of dominance or ratio of dominance variance to additive genetic variance, and (vi) genotype x environment interactions.

Chand *et al.* (1996) reported that both additive and non-additive gene effects with predominance of later controlled the biological yield per plant and grain yield per spike, whereas reverse was true for spikelets per spike and days to flowering.

Rajara and Maheshwari (1996) indicated the importance of both additive and non-additive gene effects for grain yield per plant, days to heading, plant height, spikelets per spike and harvest index.

Khalifa *et al.* (1997) studied inheritance of some physiological traits, yield and its components in six durum wheat cultivar crosses and progenies during 1989-93. Heterosis, gene effects, heritability and inbreeding depression were recorded. Grain weight analysis demonstrated the absence of epistasis in all crosses, although dominance and additive effects were highly significant. Dominance effects played a major role in biological yield inheritance.

Nayeem and Veer (1998) reported that additive and non-additive gene effects were important for expression of heat injury, proline content, days to 50 per cent flowering, plant height, ear length, grains per spike and 1000-grain weight.

Mehla *et al.* (2000) reported that dominance and additive x additive interactions were involved in the inheritance of days to heading, spike length and spikelets/spike. However, for biological yield, grain yield and harvest index dominance, additive x additive and dominance x dominance epistasis effects were important.

Dhayal *et al.* (2003) reported that the estimates of additive (d) and dominance (h) components were significant for almost all the traits under study indicating the importance of both additive as well as non-additive gene effects. However, the magnitudes of dominant components were higher than additive components indicating the predominance of non-additive gene effects for the inheritance of these traits except days to ear emergence in both the environments.

Sonia *et al.* (2005) determined genetic architecture of six generations of four wheat crosses for seed yield and four quality traits. For PBW 154 x W 9159, seed yield was controlled by additive gene effects and grain hardness by additive and dominance gene effects, whereas interactions were involved for test weight, protein content and sedimentation value. For 9D x HD 2009, epistasis was observed for seed yield and quality traits. For PBW 154 x 9D, test weight was controlled by both additive and dominance components. For W 9159 x 9D, additive gene effect was significant for seed yield and grain hardness, both additive and dominance for sedimentation value, and additive, dominance and dominance x dominance interaction for test weight, and all interactions for protein content.

Prakash *et al.* (2006) revealed that dominance gene action contributed the most to the expression of heterosis for the yield and its component trait.

Shekhawat *et al.* (2006) studied twelve generations of two crosses involving four diverse cultivars of bread wheat to inheritance of grain yield and tillers per plant. In cross UP 301 x HD 2009, dominance and epistatic effects were found predominant for both the traits while in the cross RS 31-1 x Raj 1482 only epistatic effects were observed to be more important for these traits. The utilize non-fixable gene effects (non-additive) which were higher in magnitude than fixable (additive), breeding

methods involving reciprocal recurrent selection or biparental mating are suggested for further improvement in grain yield and tillers per plant in wheat.

Kavar *et al.* (2007) studied generation means analyses for yield and its component traits in six crosses of macaroni wheat. Individual scaling tests and joint scaling tests indicated that an additive-dominance model was adequate for plant height in crosses 2, 3 and 6; effective tillers per plant in crosses 5; grain yield per plant in crosses 1, 3, 5 and 6 as well as 100-grain weight in cross 2. On fitting simple model, both additive (d) and dominance (h) effects were significant for grains per spike in crosses 3 and 100-grain weight in crosses 2, while only additive (d) gene effect was significant for rest of the traits. All the characters recorded in six crosses except listed above in simple model showed evidence of digenic non-allelic interactions. On fitting epistatic model, both (d) and (h) effects were significant for plant height in crosses 5; length of spike in cross 1; days to maturity in crosses 1, 2 and 3; grain yield per spike and 100-grain weight in crosses 4 and 5. Duplicate type of gene action was noticed for almost all the traits. Population improvement approach in the form of biparental mating among potentially desirable plants in early segregating generations would be suggested.

Khan *et al.* (2007) observed significant additive gene effects for plant height, biomass per plant, number of grains per spike, and grain yield per plant. While the numbers of tillers per plant and 1000-grain weights were controlled by non-additive gene effects.

Khan *et al.* (2010) reported that both additive and dominance variances with predominance in the inheritance of plant height, stomata frequency, epidermal cell size, spike length, spike density, 1000-grain weight, grain yield per plant, protein content and harvest index.

2.3 HEAT TOLERANCE

Heat tolerance is a function of integrated plant system at the tissues, organs or whole plant level. It is largely associated with the cellular and sub cellular components. The plant ability to heat harden differ with the species and its inherent level at heat tolerance. Heat causes injury to the plasma membrane and can be estimated by the conductometric measurement of solute from the cell. Sullivan and

Ross (1979) used the method for selecting heat tolerant sorghum lines out of one population. They demonstrated a reasonable correlation between membrane thermo-stability (MT) and yield under hot dry conditions. Heat tolerance is associated with grain quality and grain yield, based on the MT (Saadalla *et al.*, 1990). The information on heat tolerance in wheat is reviewed here.

Radmehr *et al.* (1996) indicated that very late sowings (20th 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. There was a positive correlation between yield and time of spike emergence. Further decrease in mean yield was observed in the 21st December sowing and 20th January sowing to 21 per cent and 37 per cent respectively, compared to the 21st November sowing.

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°C to 30.6°C continued to decline in productive ears, biological yield, 1000-grain weight and grain yield under late sowing. Coefficient of correlation of grain yield showed significant positive relationship with effective ear number, biological yield and 1000-grain weight, indicating their improvement in heat tolerance of wheat under late sown condition.

Sharma and Tandon (1998) compared eight wheat cultivars for heat tolerance based on yield levels and on the cell membrane thermo-stability (CMS) by subjecting them to normal and high temperature during the grain filling period. Reduction in period from anthesis to maturity and yield ranged from 18 to 32 per cent and 19 to 37 per cent respectively, due to effect of high temperature.

Sarkar *et al.* (2001) evaluated 15 diverse genotypes of wheat for grain growth and heat susceptibility index (HSI) under high temperature stress conditions. The results revealed that early maturing genotypes like HD 2285, HD 2307, Sonalika, UP 2338, Lok 1 and C 306 showed better performance under high temperature stress conditions with less reduction in grain yield and have relatively higher grain growth rates with more tolerance to heat stress for most of the yield contributing characters (low HSI values).

Singh and Prasad (2001) reported to hyper-thermal stress of eight wheat cultivars. High temperature stress (+3.0°C seasonal mean and +5.6°C during ripening growth phase) reduced yield and yield contributing characters to varying of extent among the cultivars. This reduction in economic yield for 35-70 per cent was mainly attributed due to yield components such as grain per spike and 1000-grain weight. Biological yield, which reduced 22-52 per cent, showed greater stability than economic yield under high temperature condition.

Dhanda and Munjal (2006) evaluated 20 diverse wheat genotypes under normal and heat stress conditions for 2 years. The varieties Seri and Raj 3765 had a desirable combination of cellular thermo tolerance, heat tolerance (HRI) and high grain yield potential under heat stress, while WH 730 and WH 533 were better in cellular thermo tolerance and heat tolerance.

Kumar *et al.* (2007) evaluated 4 wheat genotypes for terminal drought and heat tolerance by imposing 3 irrigation levels under timely and late planting and reported that grain yield was higher under timely than late sown condition and in irrigated than unirrigated. Genotype PBW 343 showed higher RWC, CTD and grain yield than genotypes NIAW 34, Raj 3765 and WH711. RWC and CTD showed positive while RI showed negative association with grain yield.

Verma and Shah (2008) evaluated 10 parents and their 45 F₁s, for grain yield per plant and heat tolerance characters in very late sowing condition. None of the crosses showed uniformly high heterosis for all the characters under the study. The magnitude of heterosis and heterobeltiosis for grain yield per plant varied from -31.75 to 97.50 and -33.25 to 95.64 per cent. The most of the high heterobeltiotic crosses for grain yield per plant also depicted significant heterobeltiosis for one or more heat tolerance characters also, particularly for proline content, seedling vigour index and heat injury.

Chauhan *et al.* (2009) concluded that Hindi 62 exhibited a slower rate of senescence than PBW 343 during heat-stress environment, which may contribute towards heat stability.

3. MATERIALS AND METHODS

The present investigation entitled, “Inheritance in bread wheat (*Triticum aestivum* (L.) em. Thell)” was conducted at Instructional Farm of Rajasthan College of Agriculture, Udaipur, India. Udaipur is situated at an elevation of 579.50 meters above mean sea level on latitude of 24° – 35° N and longitude of 70° – 42° E. The experiment was conducted on clay loam soil under irrigated conditions. The meteorological data on maximum and minimum temperatures, relative humidity and rainfall for the crop period (November, 2009 to April 2010) are given in Appendix I.

3.1 EXPERIMENTAL MATERIALS

Four diverse wheat genotypes namely Raj 3765, PBW 373, Raj 4037 and Raj 4083 were selected as parents on the basis of their origin, adaptability, diversity, yield potential and heat tolerance characters. Pedigree of parents is given in Table 3.1. Crosses were attempted during *rabi*, 2008-09 to generate F₁, F₂ and backcross generation keeping one common parent viz., Raj 3765. All the material was received from Department of Plant Breeding and Genetics, Rajasthan College of Agriculture, Maharana Pratap Agriculture University, Udaipur.

Table 3.1: Name and pedigree of the parents and crosses in different generations

Material	Pedigree/ Generation
Parents	
Raj 3765	HD 2402 / VL 639
PBW 343	ND/BG1944//KAL//BB/3/BACO'S'/4/BAA//5'S
Raj 4037	DL788-2/Raj3717
Raj 4083	PBW343/UP2442//WR258/UP2425
Crosses	
Raj 3765 x PBW 343	F ₁ , F ₂ , BC ₁ and BC ₂
Raj 3765 x Raj 4037	F ₁ , F ₂ , BC ₁ and BC ₂
Raj 3765 x Raj 4083	F ₁ , F ₂ , BC ₁ and BC ₂

3.2 EXPERIMENTAL DESIGN AND CROP HUSBANDRY

Final experimental trial comprising 4 parents along with their 3 F₁s, 3 F₂s and 6 back cross generations were evaluated during *rabi*, 2009-10 in randomized block design with three replications. Parents, F₁s and back cross generations were grown in single row while F₂s in three rows. Sowing was done by dibbling the seeds at a

distance of 10 cm in the rows of 2 m length with row to row spacing of 25 cm. Non experimental rows were planted around the layout to eliminate border effects. 60 kg N: 40 kg P and 40 kg K/ha were applied at the time of sowing. 60 kg N/ha was top-dressed 21 days after sowing coinciding with crown root initiation. Five irrigations were given during the entire crop period. Appropriate and uniform cultural practices were adopted for the entire crop season.

Data were recorded on whole plot basis for days to heading and days to maturity, while rest of the characters were recorded on 10 randomly selected plants for parents, F₁s and backcrosses while 30 plants for F₂s.

A brief description of the procedure adopted for recording of the observations for various traits is as under:

Morphological Characters:

Days to heading: Numbers of the days were counted from the date of sowing to date of emergence of the first spike in 50 per cent plants.

Days to maturity: Numbers of days were counted from date of sowing to the date when all the plants in plot attained complete physiological maturity (ear turned dark golden yellow in colour).

Plant height: The plant height was measured in centimeters from ground level to the top of upper spikelets of the main spike (excluding awns) at the maturity.

Number of effective tillers per plant: Numbers of effective tillers were counted for each plant at the time of harvesting.

Number of grains per spike: Number of grains per spike was counted from randomly selected plants and average was worked out.

Flag leaf area: The length and maximum breadth of the flag leaf sheath of the main tiller of each sampled plant was measured in centimeter. The area was calculated in cm² by using (Simpson, 1968) formula:

$$\text{Flag leaf area (cm}^2\text{)} = \text{Length} \times \text{Breadth (maximum)} \times 0.79$$

Flag leaf sheath area: The length of the main spike of each sampled plant was measured in centimeter. The diameter at the middle of spike was measured with the help of Vernier's Caliper in centimeter and the area was calculated in cm² by using (Yap and Harvey, 1972) formula:

$$\text{Flag leaf sheath area (cm}^2\text{)} = \text{Length} \times \text{Spike Diameter} \times 3.1416$$

1000-grain weight: Thousand seeds were counted from the bulk of yield of randomly selected samples from each entry. The weight was recorded in grams on single pan electronic balance and average was worked out.

Biomass per plant: The weight of randomly selected plants from each entry in each replication was taken after sun drying for constant weight in gram and average as biomass yield per plant.

Grain yield per plant: The randomly selected plants per plot per treatment were threshed individually to obtained grain weight in gram and averaged as grain yield per plant.

Harvest index: Harvest index is the ratio of economic yield (grain) to biological yield expressed in percentage and was calculated using the formula of Donald (1962) as under:

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

Grain protein content: Two samples of seeds per treatment per replication were analyzed by standard Micro-Kjeldhal's method to obtain nitrogen content (per cent) and the values so obtained were multiplied by a factor of 5.70 to obtain seed protein content. The details of the method used are given in Appendix II.

Heat Tolerance Parameters:

Heat injury: Heat injury was estimated in percentage according to method suggested by Sullivan (1972) (Appendix III).

Chlorophyll stability index: Chlorophyll Stability Index was determined in percentage by the method as suggested by Murty and Majumdar (1962) (Appendix IV).

3.3 STATISTICAL METHODOLOGY

3.3.1 Analysis of Variance

The generation means for each characters were subjected to standard statistical analysis to test the difference among various generations studied (Panse and Sukhatme, 1985). Skeleton ANOVA is given as under (Table 3.2):

Table 3.2: Analysis of variance and expectations of mean squares for parents, hybrids, F₂'s and backcrosses

Source	d.f.	S.S.	MSS	Expected MSS
Replications	(r-1)	a	al	$\sigma_e^2 + \sigma_r^2$
Genotypes	(t-1)	b	bl	$\sigma_e^2 + \sigma_t^2$
Error	(r-1)(t-1)	c	cl	σ_e^2
Total	r.t-1			

Where,

r = Number of replication, and

t = Number of treatment

Standard error for differences between treatment means was calculated as:

$$SE(\text{diff.}) = \frac{\sqrt{2EMS}}{r}$$

Where,

EMS = Error mean sum of square for the experiment, and

r = number of replication.

Coefficient of variation was calculated as:

$$CV(\%) = \frac{\sqrt{2EMS}}{\bar{X}} \times 100$$

Where,

CV = Coefficient of variation, and

\bar{X} = Population mean.

3.3.2 Estimation of Heterosis and Inbreeding Depression

Per cent increase or decrease of F₁ over the mid parent and better parent referred as relative or average heterosis and heterobeltiosis, respectively. Inbreeding depression was estimated as per cent decrease in the F₂ over the mean performance of F₁. Following formulae have been used in estimation:

$$\text{Heterosis (\%)} = \frac{F_1 - MP}{MP} \times 100 \quad (\text{Matinzinger } et al., 1968)$$

$$S.E.(F_1 - MP) = \sqrt{3Me/2r}$$

$$t(F_1 - MP) = \frac{F_1 - MP}{S.E.(F_1 - MP)}$$

$$\text{Heterobeltiosis (\%)} = \frac{F_1 - BP}{BP} \times 100 \text{ (Fonseca and Patterson, 1968)}$$

$$S.E.(F_1 - BP) = \sqrt{2Me/r}$$

$$t(F_1 - BP) = \frac{F_1 - BP}{S.E.(F_1 - BP)}$$

$$\text{Inbreeding depression (\%)} = \frac{F_1 - F_2}{F_1} \times 100 \text{ (Matinzinger et al., 1968)}$$

$$S.E.(F_1 - F_2) = \sqrt{2Me/r}$$

$$t(F_1 - F_2) = \frac{F_1 - F_2}{S.E.(F_1 - F_2)}$$

Where,

- F_1 = Mean performance of F_1 hybrid
- MP = Mean performance of the parents (P_1 and P_2) of a hybrid
- BP = Mean performance of better parents
- F_2 = Mean performance of F_2
- Me = Error mean square
- r = Number of replications.

The test of significance of the heterosis, heterobeltiosis and inbreeding depression were carried out by comparing the calculate value of 't' with the tabulated value 't' at respective degrees of freedom.

3.3.3 Scaling tests:

Scaling test as described by Hayman and Mather (1955) was used to check the adequacy of the additive – dominance model for different characters in each cross. The adequacy to scale must satisfy 2 conditions viz additivity of gene effects and independence of heritable components from non-heritable ones. The test of first condition provides information regarding the absence or presence of gene interactions. A, B, C and D test were made using the following equations for calculating their values and variances.

$$A = 2\overline{B_1} - \overline{P_1} - \overline{F_1}$$

$$B = 2\overline{B_2} - \overline{P_2} - \overline{F_1}$$

$$C = 4\overline{F_2} - 2\overline{F_1} - \overline{P_1} - \overline{P_2}$$

$$D = 2\overline{F_2} - \overline{B_1} - \overline{B_2}$$

$$V(A) = 4V(\overline{B_1}) - V(\overline{P_1}) - V(\overline{F_1})$$

$$V(B) = 4V(\overline{B_2}) - V(\overline{P_2}) - V(\overline{F_1})$$

$$V(C) = 16V(\overline{F_2}) - 4V(\overline{F_1}) - V(\overline{P_1}) + V(\overline{P_2})$$

$$V(D) = 4V(\overline{F_2}) - V(\overline{B_1}) - V(\overline{B_2})$$

Where,

P_1, P_2, F_1, F_2, B_1 and B_2 generation, respectively

$$V(\overline{P_1}) = \frac{VP_1}{n}$$

Where,

$V(P_1)$ = Variance of mean of P_1 parent

VP_1 = Total variances of P_1 parent

n = Total number of plants in P_1 generations.

Similarly, variances of mean of P_2, F_1, F_2, B_1 and B_2 generations were calculated.

The standard error of each test was calculated by taking the square root of corresponding variances.

$$S.E.(A) = \sqrt{VA}$$

$$S.E.(B) = \sqrt{VB}$$

$$S.E.(C) = \sqrt{VC}$$

$$S.E.(D) = \sqrt{VD}$$

Significance of each scale was tested by calculating the 't' value

$$tA_{[3(r-1)]} = A/S.E.(A)$$

$$tB_{[3(r-1)]} = B/S.E.(B)$$

$$tC_{[4(r-1)]} = C/S.E.(C)$$

$$tD_{[3(r-1)]} = D/S.E.(D)$$

The calculated value of 't' were compared with tabulated values of 't' at respective degrees of freedom. In each test, the degree of freedom is sum of the degree of freedom of various generation involved. Generally degree of freedom for each generation was calculated as total observations taken minus number of

replications. The significance of any one of these scales was taken to indicate the presence of epistasis i.e. non-allelic interaction. The type of epistasis was revealed by the significance of specific scale as given below:

- (a) The significance of A and B scales indicates the presence of all the 3 types of non-allelic gene interactions, viz additive x additive **i**, additive x dominance **j** and dominance x dominance **l**.
- (b) The significance of C scale suggests dominance x dominance **l** type of non-allelic gene interaction.
- (c) The significance of D scale reveals additive x additive **i** type of gene interaction and significance of both C and D scales indicates additive x additive **i** and dominance x dominance **l** type of gene interactions.

3.3.4 Estimation of gene effects:

In the presence of non-allelic interaction, various gene effects were estimated using 6 parameter model suggested by Hayman (1958a) as under:

Gene effect	Symbol	Method of estimation
Mean	M	\bar{F}_2
Additive	D	$\bar{B}_1 - \bar{B}_2$
Dominance	H	$\bar{F}_1 - 4\bar{F}_2 - 1/2\bar{P}_1 - 1/2\bar{P}_2 + 2\bar{B}_1 + 2\bar{B}_2$
Additive x Additive	I	$2\bar{B}_1 + 2\bar{B}_2 - 4\bar{F}_2$
Additive x Dominance	J	$2\bar{B}_1 - \bar{P}_1 - 2\bar{B}_2 + \bar{P}_2$
Dominance x Dominance	L	$\bar{P}_1 + \bar{P}_2 + 2\bar{F}_1 + 4\bar{F}_2 - 4\bar{B}_1 - 4\bar{B}_2$

Where, \bar{P}_1 , \bar{P}_2 , \bar{F}_1 , \bar{F}_2 , \bar{B}_1 and \bar{B}_2 were the mean values of P_1 , P_2 , F_1 , F_2 , B_1 and B_2 generations, respectively.

The variances of these estimates were obtained using the following formulae:

$$V_m = V(\bar{F}_2)$$

$$V_d = V(\bar{B}_1) + V(\bar{B}_2)$$

$$V_h = V(\bar{F}_1) + 16V(\bar{F}_2) + 1/4V(\bar{P}_1) + 4V(\bar{B}_1) + 4V(\bar{B}_2)$$

$$V_i = 4V(\overline{B_1}) + 4V(\overline{B_2}) + 16V(\overline{F_2})$$

$$V_j = 4V(\overline{B_1}) + V(\overline{P_1}) + 4V(\overline{B_2}) + V(\overline{P_2})$$

$$V_l = V(\overline{P_1}) + V(\overline{P_2}) + 4V(\overline{F_1}) + 16V(\overline{F_2}) + 16V(\overline{B_1}) + 16V(\overline{B_2})$$

The standard error of gene effects was calculated as follows:

$$\text{S.E.}(m) = (V_m)^{1/2}$$

$$\text{S.E.}(d) = (V_d)^{1/2}$$

$$\text{S.E.}(h) = (V_h)^{1/2}$$

$$\text{S.E.}(i) = (V_i)^{1/2}$$

$$\text{S.E.}(j) = (V_j)^{1/2}$$

$$\text{S.E.}(l) = (V_l)^{1/2}$$

The 't' values were worked out using following formulae:

$$t(m) = m/\text{S.E.}(m)$$

$$t(d) = m/\text{S.E.}(d)$$

$$t(h) = m/\text{S.E.}(h)$$

$$t(i) = m/\text{S.E.}(i)$$

$$t(j) = m/\text{S.E.}(j)$$

$$t(l) = m/\text{S.E.}(l)$$

The test of significance of gene effects was carried out by comparing the calculated values of 't' with the tabulated values of 't' at respective degree of freedom.

4. EXPERIMENTAL RESULTS AND DISCUSSION

Before developing the wheat varieties, there is a need to search out the genetic material having potential to grow in prevailing suitable environment under stress conditions like high temperature. Climate change especially increasing temperature will be the major challenge in the coming years as far as increasing crop yield is concerned. Recent UN Report (Anonymous, 2011) predicts that earth will be warmer by 2.4°C by 2020 and crop yield in India would fall by up to 30 per cent by the end of the year 2020.

The present day rice-wheat system has compelled wheat crop to be subjected to rapidly ascending temperature coupled with hot dry winds during the post anthesis stage, especially during grain development. These unfavourable environments terminate grain growth prematurely and reduce yield considerably (Sarkar *et al.*, 2001). Therefore, breeding for heat stress is an important objective of wheat improvement programme. Reynolds *et al.* (1994) used a number of physiological traits to identify varieties that showed heat tolerance with respect to grain yield at a range of hot locations throughout the world. It was seen that membrane stability of flag leaf at milk stage of the plant was significantly correlated with grain yield (Yildirim *et al.*, 2009).

Hence in this era of climate change now breeding for heat tolerance has become an integral component of wheat breeding programmes at both national and international level.

In an autogamous crop like wheat, the mating system does not provide built in mechanism for self-improvement. Therefore, breeding programme in autogamous crops requires mainly exploitation of fixable gene effects that may be accumulated in a homozygous line or it is necessary to hybridize different genotypes for getting desirable recombinants. For selection of efficient parental lines, the knowledge about their genetic makeup is essential. Thus, in order to initiate breeding programme with well defined objectives it is pre-requisite to obtain information on the inheritance pattern of the desired characters.

This knowledge not only helps in selection of suitable lines but is also useful in developing effective breeding strategies. With this in view, effort have been made

to gather information on heterosis, inbreeding depression and gene effects with overall objective to identify superior heterotic crosses for higher yield concomitant with heat tolerance from segregating generations in bread wheat. The results have been discussed under following heads:

4.1 Analysis of variance and mean performance

4.2 Heterosis and inbreeding depression, and

4.3 Gene effects

4.1 ANALYSIS OF VARIANCE AND MEAN PERFORMANCE

Observations were recorded on total 14 traits namely, days to heading, days to maturity, plant height, effective tillers, grains per spike, flag leaf area, flag leaf sheath area, 1000-grain weight, biomass per plant, grain yield per plant, harvest index, grain protein content and heat tolerance traits viz., heat injury and chlorophyll stability index.

ANOVA revealed highly significant differences among all the genotypes indicating sufficient amount of variation present in the material for aforesaid characters except flag leaf area and harvest index (Table 4.1.1)

A perusal of mean values (Table 4.1.2 and Appendix-V) showed that among the parents PBW 343 and Raj 4083 exhibited early heading while, Raj 3765 and Raj 4037 depicted early maturity. Among the F_1 hybrids, the earliest heading was observed in Raj 3765 \times Raj 4083 followed by Raj 3765 \times Raj 4037, while early maturity was recorded for Raj 3765 \times PBW 343 followed by Raj 3765 \times Raj 4037. All the F_1 hybrids flowered and matured earlier than the F_2 generation.

Lower mean value for plant height was observed in Raj 4083 and Raj 4037 whereas higher mean value for effective tiller and grains per spike was recorded in Raj 3765. Cross Raj 3765 \times Raj 4037 was short statured and had maximum grains per spike, whereas Raj 3765 \times PBW 343 had higher effective tillers per plant. It is obvious that parent Raj 3765 contributed for higher grains per spike and number of effective tillers in aforesaid F_1 s. F_2 population were short stature with less number of effective tillers and number of grains per spike than F_1 and backcross generations.

Parents Raj 3765 and Raj 4083 exhibited higher mean for flag leaf area and flag leaf sheath area. In F₁ generations Raj 3765 × PBW 343 had higher flag leaf area while higher flag leaf sheath area observed in Raj 3765 × Raj 4037.

Among the parents, a high 1000-grain weight and grain yield was reported in Raj 3765, high biomass per plant in Raj 4037 with high harvest index while high grain protein content was reported in Raj 4083. Among F₁ hybrids, Raj 3765 × Raj 4037 emerged superior in terms of grain yield per plant and harvest index. While cross Raj 3765 × PBW 343 showed higher mean values for 1000-grain weight and protein content. Cross Raj 3765 × Raj 4083 showed higher mean values for biomass per plant. However, F₂ generations were at par with parents for the characters like grain protein content and yield per plant. However, F₂ showed superior performance in case of harvest index than F₁ and backcross generations. Backcross generations exhibited inferior performance than F₁ hybrids for 1000-grain weight, biomass per plant and grain yield per plant.

Raj 3765 displayed minimum heat injury while maximum chlorophyll stability index was reported in PBW 343. Among crosses F₁ of cross Raj 3765 × PBW 343 had minimum heat injury and the highest chlorophyll stability index. However, F₂ generations showed less heat injury but poor chlorophyll stability index than backcross generations.

The parent Raj 3765 performed better than other parents. For high grain yield as well as possessed high biomass per plant, number of grains per spike and flag leaf area (Appendix v).

To sum up, results revealed that Raj 3765 and Raj 4083 appeared to be the most productive parents for grain yield and its important component traits. Among hybrids, Raj 3765 × PBW 343 and Raj 3765 × Raj 4083 were superior involving at least one of the parents with high mean values. For heat tolerance character, parents Raj 3765 and PBW 343 turned out to be superior parents for heat injury and chlorophyll stability index respectively whereas Raj 3765 × PBW 343 turned out to be superior over other hybrids.

4.2 HETEROSIS AND INBREEDING DEPRESSION:

Wheat productivity in recent past has stagnated and at the same time area under wheat in the country has stabilized leaving a little scope for its expansion. Thus, the only available option of increasing wheat production is enhancing the productivity. Hybrid wheat production has been discouraged due to very limited heterotic advantage (10%) but application of biotechnological methods allows the capture of increased heterosis by direct selection of favourable alleles and development of new genetically based systems to control male sterility.

In the present investigation expression of heterosis, heterobeltiosis as well as inbreeding depression in general were variable for different traits. The high value of heterotic effects indicated that the parents used for the study were genetically diverse. Considerable high heterosis in certain hybrids and low in other revealed that nature of gene action varied with the genetic architecture of the parents.

The extent of heterosis, heterobeltiosis and inbreeding depression were estimated for all the characters in given environment. The magnitude of relative heterosis (MP) and heterobeltiosis (BP) have been expressed as percentage increase or decrease in F_1 performance in comparison to mid-parent (relative heterosis) and better parent (heterobeltiosis), respectively. Inbreeding depression was calculated as per cent reduction in the mean values of F_2 over F_1 . Character wise results of relative heterosis, heterobeltiosis and inbreeding depression are presented below:

The earliness in days to heading and days to maturity has been considered as desirable trait in wheat crop. As evident from Table 4.2.1 significant negative heterosis as well as heterobeltiosis with also significant negative inbreeding depression was recorded for days to heading in cross Raj 3765 \times Raj 4037 and Raj 3765 \times Raj 4083. Raj 3765 \times PBW 343 heterotic for mid-parent with negative significant inbreeding depression for days to heading. For days to maturity Raj 3765 \times PBW 343 and Raj 3765 \times Raj 4037 were heterotic for mid as well as better parent with negative significant inbreeding depression for days to maturity. Whereas, hybrids Raj 3765 \times Raj 4083 heterotic for mid-parent with negative significant inbreeding depression thereby it indicates involvement of non-additive gene action for aforesaid trait. Yadav and Narshinghai (2000) observed significant negative heterosis followed by negative inbreeding depression while Prakash and Joshi (2003) reported inbreeding depression for days to heading and days to maturity but contrary to this Singh (2003)

highlighted inbreeding depression for most of character except days to heading in some crosses.

Among the agronomic yield components mean heterosis for plant height was 3.86 per cent as evident from Table 4.2.2, for plant height none of crosses displayed significant heterosis. Similar results were reported by Singh (2003), Sharma and Tandon (1998), Jahanzeb and Khaliq (2004), Deshpande and Nayeem (1999).

Effective tillers and grains per spike are among the important yield contributing traits in wheat. Mean heterosis and heterobeltiosis for effective tillers and grains per spike were 12.25 per cent, 10.48 per cent and 10.72 per cent, 1.01 per cent respectively. Average heterosis over mid-parent for 1000-grain weight was 2.69 per cent and ranged between 1.29 to 3.90 per cent. Maximum heterosis was recorded in hybrid Raj 3765 x PBW 343 for 1000-grain weight. Prasad *et al.* (1998) suggested that 1000-grain weight was generally independently associated with heterosis for grain yield per plant. However none of cross expressed significant heterosis and heterobeltiosis for aforesaid trait as evident from Table 4.2.1.

For harvest index mean heterosis and heterobeltiosis were 6.65 per cent and 2.74 per cent and ranged between -14.21 to 3.87 per cent. None of hybrids exhibited significant heterosis and inbreeding depression.

The mean heterosis for grain yield and biological yield was 5.87 per cent and 12.32 per cent, while heterobeltiosis reported 11.42 per cent and 10.84 per cent, respectively. Heterosis for grain yield ranged from -7.62 to 16.84 per cent (2 crosses positive), while heterobeltiosis ranged from 8.15 to 14.69 per cent. Similarly for biological yield per plant, heterosis ranged from 9.08 to 17.31 per cent (3 crosses positive) over mid-parent and 8.07 to 14.07 per cent (3 crosses positive) over better parent. Considering inbreeding depression for grain yield and biological yield mean values were 3.48 per cent and 14.35 per cent respectively. None of cross showed significant value for heterosis, heterobeltiosis as well as inbreeding depression for aforesaid traits. Similar work done by Khan and Khan (1996), Larik *et al.* (1999), Singh and Prasad (2001), Ijaz *et al.* (2002), Singh (2003), Prakash and Joshi (2003), Hussain *et al.* (2004), Jahanzeb and Khaliq (2004), Sharma *et al.* (2004).

For grain protein content out of three crosses, Raj 3765 x PBW 343 showed positive significant heterosis as well as heterobeltiosis with positive significant

inbreeding depression. Mean value for heterosis and heterobeltiosis were 20.13 per cent and 14.49 per cent respectively, whereas heterosis ranged for this trait from 10.94 to 36.69 per cent.

None of hybrids showed significant heterosis for heat tolerance traits viz., heat injury and chlorophyll stability index. Mean heterosis values were 6.05 per cent and 7.41 per cent for heat injury and chlorophyll stability index, and it ranged 5.16 to 6.68 per cent and -14.14 to 28.36 per cent respectively.

Based on estimates of mean performance and heterosis for grain yield and its component traits Raj 3765 was identified as superior parent. Raj 3765 \times PBW 343 could be gainfully utilized.

4.3 GENE EFFECTS:

Scaling test is an important method in working out the estimates of gene effects. The test for adequacy of scale is important because in most of the cases the estimation of additive and dominance components of variances are made assuming the absence of gene interactions. When the scale is adequate the value of A, B, C and D should be zero within the limits of their respective standards errors. The significance of any of these scales indicates inadequacy of additive-dominance model. Adequacy of scale can be further tested upon digenic interactions suggested by Hayman (1958) for the estimation of various genetic components from the generation means when non-allelic interactions are present. The analysis is based on six generations viz., P₁, P₂, F₁, F₂, BC₁ and BC₂ and six parameters are obtained. These parameters include mean (**m**), additive gene effect (**d**), dominance gene effect (**h**), and three types of non-allelic gene interactions, viz., additive \times additive (**i**), additive \times dominance (**j**), dominance \times dominance (**l**) types of gene interactions.

In the present study, all the four scales and six parameters were computed for three crosses for various characters. All the four scales were not significant for any cross, however, at least one or more than one scale was found significant in some crosses for characters like days to heading, days to maturity and grain protein content which indicated inadequacy of simple additive-dominance model and presence of epistasis.

The estimates of mean (**m**) were highly significant for both earliness in days to heading and days to maturity in all the crosses. While none of crosses showed significant component for days to heading other than mean **m** as evident from Table 4.3.2.

The presence of dominance component (**h**) with additive x additive (**i**) gene effects were significant in the crosses Raj 3765 x PBW 343 and Raj 3765 x Raj 4037 for days to maturity. Estimates of digenic interactions revealed that additive x additive (**i**) and dominance x dominance (**l**) type of gene interactions were found significant in the crosses Raj 3765 x PBW 343 and Raj 3765 x Raj 4037 for aforesaid character. Similar finding reported by Dhayal *et al.* (2003), Sonia *et al.* (2005) and Kavar *et al.* (2007).

The presence of dominance component (**h**) with additive x additive (**i**) and dominance x dominance (**l**) gene effects were significant in cross Raj 3765 x Raj 4037 for grain protein content. Similar results were reported by Sonia *et al.* (2005), Khan *et al.* (2010). Whereas only dominance component (**h**) was reported significant in cross Raj 3765 x PBW 343 for character days to maturity and grain protein content. These findings also supported by Dhayal *et al.* (2003), Sonia *et al.* (2005), Prakash *et al.* (2006), Kavar *et al.* (2007), Khan *et al.* (2010).

Opposite sign of dominance component (**h**) and dominance x dominance (**l**) type of gene effect were recorded for days to maturity in two crosses Raj 3765 x PBW 343 and Raj 3765 x Raj 4037, while for grain protein content in one cross Raj 3765 x Raj 4037, which revealed that duplicate type of epistatic gene action were important in the inheritance of both the traits.

Grain yield per plant predominantly controlled by dominance gene effect (**h**) and it is higher than additive gene effect (**d**). Similar finding reported by Shekhawat *et al.* (2006) and also suggest recurrent reciprocal selection or biparental mating for improvement various generations.

Hence, on the basis of estimates of gene effect above results suggested that days to maturity and grain protein content were predominantly under the control of dominance gene effects (**h**). Gene interactions additive x additive (**i**) and dominance x dominance (**l**) were also found for character days to maturity and grain protein content.

Suggestion regarding breeding methodology:

The present investigation has provided some interesting information regarding heterosis, heterobeltiosis, inbreeding depression and gene effect for various characters in bread wheat. From the foregoing discussion of results obtained in the present study, certain suggestions can be made in respect of future wheat improvement programme based on the material used.

Grain yield is a complex character, depended upon the contribution of a large number of components affecting directly or indirectly. The existence of total genetic variability and nature of gene effect in the population under improvement to a large extent would dictate the choice of the breeding approach. Population with preponderance of additive genetic variance would support the improvement through selection, the presence of non-additive genetic variance are important where hybridization would be more effective. Whereas, in case of equal importance of both additive and non-additive gene effects, the population improvement scheme such as recurrent selection or reciprocal recurrent selection would be most useful.

Grain yield and its most of the important components did not show significant gene effects. However, some characters like days to maturity, grain protein content showed dominance gene effect mostly so improvement for these traits can be made with appropriate hybridization program.

The utilization of non-fixable gene effects (non-additive) which were higher in magnitude than fixable (additive), breeding methods involving reciprocal recurrent selection or biparental mating are suggested for further improvement in grain yield and tillers per plant in wheat (Shekhawat *et al.*, 2006).

On the basis of present study the cross Raj 3765 x PBW 343 exhibited high heterosis, high heterobeltiosis and significant gene effects for days to maturity, whereas, for protein content cross Raj 3765 x Raj 4037 depicted high heterosis, high heterobeltiosis and significant gene effects. Under such situations, the improvement in these crosses under study may be expected through standard selection procedures, which may first exploit the additive gene effects. Simultaneously, care should be taken that non-additive effects were not dissipated, rather concentrated. It is therefore, suggested to develop pure lines by progeny selection for early improvement.

5. SUMMARY

The present investigation entitled “Inheritance in Bread Wheat [*Triticum aestivum* (L.) em. Thell]” was undertaken to elicit the heterosis, heterobeltiosis, inbreeding depression and gene effect for different morphological and heat tolerance characters in six generations of three crosses involving four diverse parents viz. Raj 3765, PBW 343, Raj 4037 and Raj 4083 of wheat [*Triticum aestivum* (L.) em. Thell].

Crosses were attempted during *rabi*, 2008-09 to generate F₁, F₂ and backcross generations keeping one common parent viz., Raj 3765. All the material was received from Department of Plant Breeding and Genetics, Rajasthan College of Agriculture, Maharana Pratap Agriculture University, Udaipur. Parents, F₁'s and backcrosses in single row plot (2 m) and three rows plot (2 m) of F₂'s will be grown in each replication. Spacing, row to row and plant to plant distance will be of 25 cm and 10 cm, respectively. Non-experimental rows were planted all around the experimental plot to eliminate border effects. All the recommended cultural practices were adopted to raise good crop.

Data were recorded on whole plot basis for days to heading and days to maturity, While rest of the characters were recorded on ten randomly selected plants for non-segregating generations like parents, F₁'s and backcrosses while 30 plants for segregating F₂ generation for rest of characters, namely days to heading, days to maturity, plant height, number of effective tillers, number of grains per spike, flag leaf area, flag leaf sheath area, 1000-grain weight, biomass per plant, grain yield per plant and harvest index. Following standard biochemical analysis grain protein content and two heat tolerance traits viz., chlorophyll content and heat tolerance were determined.

Data were statistically computed for estimation of heterosis over mid parent and better parent, inbreeding depression. The scaling tests A, B, C and D as given by Hayman and Mather (1955) were calculated for all the characters in all the 3 crosses. The estimates of gene effects and interactions were determined using the digenic epistatic model (Hayman, 1958). Important results of study are summarized as follows:

1. The analysis of variance for experimental design done for all the characters which revealed significant differences for 12 characters out of 14 characters

studied which indicated presence of adequate genetic variability among the genotypes except flag leaf area and harvest index.

2. (a) Parents Raj 3765 were identified as the most productive on the basis of their higher mean values for grain yield and its component traits. Raj 3765 and PBW 343 turned-out to be superior parent for heat injury and chlorophyll stability index respectively. Whereas, Raj 4083 showed higher mean values for grain protein content.

(b) Among crosses Raj 3765 × PBW 343 and Raj 3765 × Raj 4083 were found superior for grain yield and its components as they involved at least one of the parents with high *per se* performance. Hybrid Raj 3765 x Raj 4037 showed high grain protein content, while Raj 3765 × PBW 343 was superior over other hybrids for heat tolerant traits.
 3. Heterosis over mid parent ranged -7.62 (Raj 3765 x PBW 343) to 16.84 (Raj 3765 x Raj 4037) and inbreeding depression ranged -17.31 (Raj 3765 x PBW 343) to 16.37 (Raj 3765 x Raj 4037) for grain yield per plant but none of cross was significant for grain yield.
 4. Studies based on scaling tests revealed that additive-dominance model was inadequate for all the two crosses for days to maturity and one cross for grain protein content, which indicated presence of non-allelic interactions. However all the three crosses showed adequacy of additive-dominance model for grain yield and its components.
 5. Duplicate type of epistasis noticed for days to maturity in two crosses and grain protein content in one cross. However, none of the character showed complementary epistasis for any cross.
 6. On the basis of above findings, suggestion regarding breeding methodology for improving grain yield with heat tolerance parameters in bread wheat have been given.
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6. LITERATURE CITED

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Inheritance in Bread Wheat [*Triticum aestivum* (L.) em. Thell]

Chhagan Lal*

Prof. S. R. Maloo**

ABSTRACT

The present investigation entitled “Inheritance in Bread Wheat [*Triticum aestivum* (L.) em. Thell]” was undertaken to elicit information on heterosis, nature and magnitude of gene action 14 characters in six generations of three crosses involving four parents viz., Raj 3765, PBW 343, Raj 4037, and Raj 4083.

In present study experimental material comprising six generations (P₁, P₂, F₁, F₂, BC₁, BC₂) of three wheat crosses was planted during *rabi*, 2009-2010 in randomized block design with three replications under irrigated condition at Instructional Farm of Rajasthan College of Agriculture, Udaipur, Rajasthan. Parents, F₁'s and backcrosses in single row plot (2 m), and three rows plot (2 m) of F₂'s were grown in each replication at row to row and plant to plant distance of 25 cm and 10 cm respectively. Non-experimental rows were planted all around the experimental plot to eliminate border effects. All the recommended cultural practices were adopted to raise the experiment.

Significant variability among genotypes was found for almost all the characters except flag leaf area and harvest index. Raj 3765 and Raj 4083 were identified as the most productive on the basis of their higher mean values for grain yield and its important component traits. Raj 3765 and PBW 343 turned-out to be superior parent for heat injury and chlorophyll stability index respectively. Among hybrids Raj 3765 × PBW 343 and Raj 3765 × Raj 4083 were spotted as superior for grain yield and its components.

Heterosis over mid parent ranged -7.62 (Raj 3765 x PBW 343) to 16.84 (Raj 3765 x Raj 4037) and inbreeding depression ranged -17.31 (Raj 3765 x PBW 343) to 16.37 (Raj 3765 x Raj 4037) for grain yield per plant but none of the cross was significant for grain yield.

Studies based on scaling tests revealed that additive-dominance model was inadequate for all the three crosses for days to maturity, two crosses for days to heading, and one cross for grain protein content, which indicated presence of non-allelic interactions. However all the three crosses showed adequacy of additive-dominance model for grain yield and its components.

Additive gene effect played a major role than dominance deviation for grain yield and its components traits. Among digenic interaction dominance x dominance l and additive x additive i were more important as compared to additive x dominance j for most of characters. Duplicate type of epistasis noticed for days to maturity in two crosses and grain protein content in one cross. However, none of the character showed complementary epistasis for any cross.

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xsgw [fVVde ,LVbe ¼ y-½ b, e- Fky] eaoákkuxfr

Nxu yky*

MKW, I -vkj- ekyii

vuqki .k

orþku 'kksk ^xsgw [fVVde ,LVbe ¼ y-½ b, e- Fky] eaoákkuxfr** 'kh'kZl ds vllrxr l fefyr pkj i s-dkajkt 3765] ih ch MCY; w343] jkt 4037 , oajkt 4083 earhu l adjka dh N% ihf<+ ka ds pkng y{k.kka dks ydj l adj vkst] iÑfr vks] thu fØ; k dk ifjek.k tkuusgrqfd; k x; kA

orþku v/; ; u ea ijh{k.k.kkRed l kexh ds rks] ij rhu xsgw l adjka dh N% ihf<+ ka P₁, P₂, F₁, F₂, BC₁, BC₂ dksjch 2009&10 ds nkjku ; knfPNd [kM d vfHkdYi uk earhu i qjkofr; ka ea ds l kfk fl apr voLFkkvka ea jktLFkku Ñf" k egkfo |ky;] mn; ij ds funðkkRed i {ks= ij mxk; k x; kA i s-dkaj F₁ vks] izhi l adjka dh , dy i adr HkufkM ½ ehVj½ rFkk F₂ dh rhu i adr HkufkM ½ ehVj½ dks i R; sd i qjkofr; ka ea i adr l s i adr vks] i ksk l s i ksk dh njh Øe'k% 24 l eh vks] 10 l eh ij mxk; k x; kA vijh{k.k.kkRed i adr; k; ijh{k.k.kkRed HkufkM ds pkjka vks] l hek j s k i Hkko dks gVkus ds fy, mxkbz xbA vPNh Ql y ds fy, l Hkh idkj dh vko' ; d d" k k fØ; k, a vi ukbz xbA

l ei s-dka ea 'kh'kZ i Ykh {ks= Qy o dVkbz l pdkad dks NkM edj yxHkx l Hkh y{k.kka ds fy, l kfkZl fofo/krk i kbz xbA jkt 3765 vks] jkt 4083 dks nkuka dh yC/kh o bl ds egroi w k z y{k.kka ds mPp ek/; eku ds vk/kkj ij i adk mRi kend igpkuk x; kA jkt 3765 vks] ih ch MCY; w343 Øe'k% rki vk?kkr vks] gfjr yod LFkrf; Ro l pdkad ds fy, JSB i s-d l kfc r gqA l adjka ea jkt 3765 x ih ch MCY; w343 vks] jkt 3765 x jkt 4083 dks nkuka dh yC/kh o ml ds ?kVdka ds fy, JSB fpflgr fd; k x; kA

l adj vkst dh l hek nkuka dh yC/kh ifr ikni ds fy, &7-62 ¼ jkt 3765 x ih ch MCY; w343½ l s 16-84 ¼ jkt 3765 x jkt 4037½ rd rFkk vllr% iztuu voueu dh l hek &17-31 ¼ jkt 3765 x ih ch MCY; w343½ l s 16-37 ¼ jkt 3765 x jkt 4037½ rd jghA y s du dkbz Hkh l adj nkuka dh vPNh yC/kh ds fy, l kfkZl ugha FkA

eku ijh{k.k ds v/; ; u ds vk/kkj ij ; kskRed i Hkfork ifreku l Hkh rhu l adjka ds fy, i fji Dou ds fnuka ds fy,] nks l adjka ds fy,] i qi u ds fnuka ds fy, vks] , d l adj nkuka ea i k s hu dh ek=k ds fy, vi; klr t kfgj gqk t k s fd izyrk dh mi LFkfr dks

* 'kks'kd r k z ikni iztuu , oavkupki' kch foHkx] jktLFkku d f" k egkfo |ky;] mn; ij ¼ jkt-½
** v k p k ; i k n i i z t u u , o a v k u p k i ' k c h f o H k x] j k t L F k u d f " k e g k f o | k y ;] m n ; i j ¼ j k t - ½

n'kkzrk gA tcf d l Hkh rhuka l d j ; kskRed i Hkkfork ifreku nkuka dh yC/kh o ml ds
?kVdka dsfy, i ; klr n'kkzrk gA

; kskRed thu i Hkko i Hkkoh fopyu dh rgyuk ea nkuka dh yC/kh vkSj ml ds ?kVd
y{k.kka dsfy, eq[; Hkredk fuHkkrk gA Mk; t\$ud vl; ksu fØ; k ea i Hkkoh x i Hkkoh (l) vkSj
; kskRed x ; kskRed (i) ; kskRed x ; kskRed (j) dh rgyuk ea vf/kdrj y{k.kka dsfy,
T; knk egRoiwkZ FkA f}d izlkj dh izyrk ifjiDou ds fnuka dsfy, nks l d jka ea rFkk
nkuka ea i kS/hu dh ek=k dsfy, , d l d j ea n\$kh xbA tcf d dkbZ Hkh y{k.k fdl h Hkh
l d j dsfy, i j d izyrk ugha n'kkzrkA

**Appendix-I: Meteorological observations (weekly average) at Instructional farm
of Rajasthan College of Agriculture, Udaipur during *rabi* 2009-10**
Latitude: 24⁰35' Longitude: 73⁰41'

Week	Temperature (°C)		R.H. (%)		Wind velocity (km/h)	Sunshine (Hrs)	Rain (mm)	Evaporation (mm)
	Max.	Min.	I	II				
19 Nov-25 Nov	27.8	8.7	77.3	23.3	1.0	8.4	0.0	2.9
26 Nov-2 Dec	29.2	9.7	76.9	24.0	0.7	8.5	0.0	3.0
3 Dec-9 Dec	28.4	10.6	81.4	29.8	0.8	8.4	0.0	2.6
10 Dec-16 Dec	29.3	11.7	83.3	33.0	1.1	7.2	0.0	2.5
17 Dec-23 Dec	25.7	11.0	88.6	42.6	1.1	5.4	0.0	2.0
24 Dec-31 Dec	25.8	8.4	74.5	32.0	1.2	7.3	0.0	2.3
1 Jan- 7 Jan	24.6	7.8	83	30	1.4	7.7	1.6	2.5
8 Jan-14 Jan	24.3	6.5	86	35	1.9	8.0	0.0	2.5
15 Jan-21 Jan	25.1	5.9	82	24	1.0	8.8	0.0	2.7
22 Jan-28 Jan	28.5	8.6	78	20	0.8	8.9	0.0	3.4
29 Jan-4 Feb	28.0	9.8	73	24	1.2	8.2	0.0	3.3
5 Feb-11 Feb	28.2	11.4	68	24	3.0	7.2	0.6	3.9
12Feb-18 Feb	27.0	9.9	73	26	1.1	8.1	0.0	3.6
19 Feb-25 Feb	30.7	10.4	67	20	1.6	9.1	0.0	4.7
26 Feb-4 Mar	33.1	14.1	60	21	2.3	9.1	0.0	5.7
5 Mar-11 Mar	31.9	14.5	65	22	2.7	8.2	0.0	5.8
12Mar-18 Mar	36.5	16.5	56	12	1.6	9.1	0.0	6.4
19 Mar-25 Mar	38.2	17.5	54	13	2.9	9.2	0.0	8.2
26 Mar-1 Apr	37.6	19.3	56	14	4.8	9.2	0.0	9.3
2 Apr-8 Apr	37.9	20.6	43	17	3.7	8.4	0.0	9.1
9 Apr-15 Apr	39.6	22.0	37	14	4.3	7.7	0.0	10.1
16 Apr-22 Apr	40.2	25.7	40	16	9.1	9.6	0.0	13.0
23 Apr -29 Apr	39.8	23.4	40	12	5.6	10.0	0.0	11.5

Source: Agromet. Observatory, Deptt. of Agronomy, RCA, Udaipur

Appendix-II

Estimation of grain protein content by Micro-Kjeldhal method

PRINCIPLES:

For determination of total nitrogen in plant by Kjeldahl method, organic nitrogen in the sample under analysis is converted to $\text{NH}_4\text{-N}$ by digestion with concentrated H_2SO_4 containing substances (K_2SO_4 or Na_2SO_4) that promote this conversion. The $\text{NH}_4\text{-N}$ in the digest is determined from the amount of NH_3 liberated by distillation of the digest with an alkali (NaOH). Ammonia absorbed in the boric acid containing mixed indicator is determined with a standard acid.

PROCEDURE:

Digestion:

1. Grind the seed material and weight 0.1g of sample and put in a dried Kjeldhal's Flask.
2. Add 2 ml of concentrated H_2SO_4 (Analar) and digest on heater for 1.30 h (a short funnel may be used as a reflux).
3. To this add 0.5 ml of H_2O_2 (30 per cent) with alternate heating and cooling till the colour disappears. Heat further until H_2O_2 fumes escape.
4. Transfer the contents of Kjeldhal's flask to 100 ml volumetric flask and make volume.

Colour development:

1. Take 5 ml volumetric flask; add 2 ml and 1 ml of 10 per cent solution of NaOH and Sodium Silicate, respectively. Add 1.6 ml Nessler's reagent and finally make volume with distilled water. Allow 10 min for colour to develop.
2. Run a control with distilled water by the same procedure.
3. Adjust colorimeter using control and take absorbance (O.D.) readings at 540 nm. In this study, calorimetric readings were taken at 630 nm.

(A) Standard curve:

Dissolve 0.1179 g of ammonium sulphate in distilled and make the volume to 11 (25 ppm $\text{NH}_3\text{-N}$ solution), pipette out 1, 2, 3, 4, 5, 6, 7 and 8 ml (or 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 ppm) of this solution in 50 ml volumetric flask. Develop colour by procedure given above and read absorbance at same wave length draw a standard graph between ppm $\text{NH}_3\text{-N}$ and absorbance value.

(B) Estimation of grain protein content:

Determine the N- content of sample using the standard curve. The crude protein content is calculated by multiplying the N-content with 5.70 for wheat grain.

Appendix-III

Estimation of Heat injury (%), (Sullivan, 1972)

1. Sample of flag-leaves were collected randomly from field grown wheat plants at anthesis.
2. Two sets of 10 leaf discs (10 mm diameter) cut from the flag-leaf by leaf cutter.
3. Each set of leaf disc was collected in separate vials, which are containing 2 ml of deionized water to prevent desiccation of leaf tissues.
4. These leaf discs were washed thoroughly with three changes of deionized water to remove electrolytes.
5. After rinsing, tubes were drained, retaining 2 ml of water to prevent desiccation of tissues during heat treatment.
6. For heat treatment, vials were covered with aluminum foil and incubated in a controlled temperature water bath at 44⁰C for one hour, while controlled vials were maintained at 25⁰C during the same period.
7. After the treatment period, 10 ml of deionized water was added to both control and treated vials and were held at 10⁰C for 18 to 24 hours to allow diffusion of electrolytes from the leaf discs.
8. Then vials were brought to 25⁰C and shaken to mix the contents. An initial conductance of the vial contents was determined with an electrical conductivity meter.
9. After initial readings, vials were placed in either on autoclave at 0.10 Mpa pressure for 10 minutes or a container of boiling water for 30 minutes to release all of the electrolytes.
10. Subsequently, vials were cooled to 25⁰C, the contents were mixed and a final conductance measurement was made.
11. The level of injury was determined as relative injury (RI) from the following formula:

$$RI = \frac{\left[1 - \left(\frac{T_1}{T_2}\right)\right]}{\left[1 - \left(\frac{C_1}{C_2}\right)\right]} \times 100$$

Where,

T = Conductance values for treatment

C = Conductance values for control

T₁ = Initial conductance value

T₂ = Final conductance value

Appendix-IV

Estimation of Chlorophyll Stability Index (Murty and Majumdar, 1962)

1. In the morning hours the flag-leaf samples was brought from field to experiment laboratory in icebox.
2. One sample of 0.03 g flag-leaf was taken on electronic balance and put in the oven for drying. After 72 hours of dry weight of leaf sample was recorded.
3. Another sample of 0.03 g of above leaf was weighed and immersed in 10 ml N, N-dimethyl formamide (DMF) and stored in dark for 24 hours.
4. Optical density (OD) reading of extract was recorded at 663 A⁰ nm and 645 A⁰ nm by spectrophotometer.
5. The chlorophyll content mg/g of dry tissue was calculated as follows.

$$\text{Chlorophyll content (mg / g)} = \frac{10 \times 8.02 \times (663 \text{ nm}) + 20.20 \times (645 \text{ nm})}{1000 \times 0.03}$$

6. For chlorophyll stability index, one more sample of 0.03 g of fresh leaf was run under heat bath for one hour and chlorophyll was estimated as procedure given above.

Appendix-V: Generation mean values of different characters in bread wheat

Generations	Days to heading	Days to maturity	Plant height(cm)	Effective tillers/plant	Grains/spike
Parents					
Raj 3765	79.38	125.44	87.95	10.13	46.35
PBW 343	76.6	128.6	91.00	10.27	36.00
RAJ 4037	79.8	124.67	84.93	9.33	38.13
RAJ 4083	77.13	128	84.07	9.80	36.47
F₁s					
Raj 3765 × PBW 343	73.87	118.8	88.27	12.20	46.00
Raj 3765 × RAJ 4037	72.2	118.87	78.33	10.33	46.73
Raj 3765 × RAJ4083	71.33	120.27	85.27	11.07	45.47
F₂s					
Raj 3765 × PBW343	78.04	126.96	84.6	8.98	41.91
Raj 3765 × RAJ 4037	78.44	127.8	78.76	7.84	39.60
Raj 3765 × RAJ4083	77.38	126.6	82.36	9.49	38.87
BC₁s					
Raj 3765 × PBW343	76.6	120.87	87.07	8.73	43.20
Raj 3765 × RAJ 4037	78.73	120.8	79.13	9.60	43.20
Raj 3765 × RAJ4083	76.67	123.8	86.2	8.13	40.13
BC₂s					
Raj 3765 × PBW343	77.2	122.67	88.33	8.87	41.60
Raj 3765 × RAJ 4037	78.87	118.07	79.6	9.53	41.80
Raj 3765 × RAJ4083	76.73	123.93	86.67	8.67	40.80
GM	78.22	112.59	85.01	9.23	42.32
SEm	0.51	0.73	0.88	0.59	1.56
CD 5%	1.46	2.11	2.53	1.71	4.49
CD 1%	1.97	2.83	3.40	2.29	6.04
CV %	1.13	1.13	1.79	11.15	6.40

Generations	Flag leaf area(cm²)	Flag leaf sheath area(cm²)	1000-grain weight(g)	Biomass/plant(g)	Grain yield/plant(g)
Parents					
Raj 3765	39.29	39.50	40.51	40.13	15.89
PBW 343	31.37	31.16	37.6	38.93	13.87
RAJ 4037	28.85	35.95	37.53	41.07	15.73
RAJ 4083	35.42	33.31	37.8	37.6	15.53
F₁s					
Raj 3765 × PBW343	37.45	38.57	40.8	42.87	13.73
Raj 3765 × RAJ 4037	28.96	38.85	40.4	45.33	18.73
Raj 3765 × RAJ4083	36.41	31.77	39.2	45.4	16.80
F₂s					
Raj 3765 × PBW343	34.77	37.42	38.53	38.96	16.11
Raj 3765 × RAJ 4037	35.48	33.93	37.87	38.33	15.67
Raj 3765 × RAJ4083	34.98	32.41	37.71	37.00	14.89
BC₁s					
Raj 3765 × PBW343	36.89	34.57	38.27	39.6	16.00
Raj 3765 × RAJ 4037	37.96	33.58	37.4	41.2	15.73
Raj 3765 × RAJ4083	32.55	32.96	36.6	38.53	15.93
BC₂s					
Raj 3765 × PBW343	37.30	36.85	37.13	39.07	14.13
Raj 3765 × RAJ 4037	36.81	36.13	36.87	40.00	15.87
Raj 3765 × RAJ4083	37.23	33.83	36.6	39.8	15.67
GM	35.79	37.01	38.39	40.44	16.14
SEm	2.54	1.02	0.60	1.01	0.48
CD 5%	7.29	2.94	1.71	2.91	1.39
CD 1%	9.79	3.95	2.30	3.91	1.86
CV %	12.27	4.79	2.69	4.33	5.18

Generations	Harvest index(%)	Grain protein content(%)	Heat injury(%)	Chlorophyll stability index(%)
Parents				
Raj 3765	39.95	11.25	43.05	12.45
PBW 343	35.87	10.95	50.61	14.20
RAJ 4037	39.30	12.13	46.59	10.19
RAJ 4083	42.03	13.43	45.41	11.31
F₁s				
Raj 3765 × PBW343	32.33	14.39	47.35	14.67
Raj 3765 × RAJ 4037	41.27	13.69	49.18	13.25
Raj 3765 × RAJ4083	37.15	13.83	47.57	10.85
F₂s				
Raj 3765 × PBW343	41.80	11.46	46.50	11.20
Raj 3765 × RAJ 4037	41.24	11.77	41.72	12.19
Raj 3765 × RAJ4083	41.09	12.71	43.31	12.62
BC₁s				
Raj 3765 × PBW343	40.07	12.07	42.81	16.19
Raj 3765 × RAJ 4037	39.25	14.03	50.13	13.11
Raj 3765 × RAJ4083	41.64	14.17	47.30	12.81
BC₂s				
Raj 3765 × PBW343	36.29	13.43	49.44	13.83
Raj 3765 × RAJ 4037	40.19	14.60	42.09	13.79
Raj 3765 × RAJ4083	40.86	12.23	47.32	10.25
GM				
	0.40	12.58	44.02	14.32
SEm				
	0.02	0.51	2.66	1.34
CD 5%				
	0.05	1.48	7.63	3.85
CD 1%				
	0.07	1.99	10.25	5.17
CV %				
	7.38	7.08	10.45	16.21