

Combining ability and path analysis for morpho-physiological characters in bread wheat (*Triticum aestivum* L.)

THESIS



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CERTIFICATE – I

This is to certify that the thesis entitled “**Combining ability and path analysis for morpho-physiological characters in bread wheat (*Triticum aestivum* L.)**” submitted in partial fulfilment of the requirement of the degree of **MASTER OF SCIENCE in Agriculture (Plant Breeding & Genetics)** of the Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior is a record of the bonafide research work carried out by **Mr. RAHUL SINGH RAJPUT** under my guidance and supervision. The subject of the thesis has been approved by Students Advisory Committee and the Director of Instruction.

No part of the thesis has been submitted for any degree or diploma or has been published. All the assistance and help received during the course of investigation have been duly acknowledged by the scholar.

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CERTIFICATE – II

This is to certify that the thesis entitled “**Combining ability and path analysis for morpho-physiological characters in bread wheat (*Triticum aestivum* L.)**” submitted by **Mr. RAHUL SINGH RAJPUT** to the Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior in partial fulfilment of the requirements for the degree of Master of Science in Agriculture in the Department of **Plant Breeding & Genetics**, has been accepted after evaluation by the external examiner and approved by the Students Advisory Committee after an oral examination of the same.

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Chapter- I

INTRODUCTION

Wheat is the principal food crop in most areas of the world and also occupies prominent position in Indian agriculture after rice. It is nutritionally important cereal essential for the food security, poverty alleviation and for livelihoods. It is widely cultivated as staple food crop among the cereals and is contributing about 30% to the food basket of the country. India is the second largest producer of wheat in the world with the production around 75 million tonnes during the last decade and it is a major contributor to the food security system in India, occupying nearly 30.37 million hectares, producing 90.78 million tonnes and productivity 29.89 q/ha and in Madhya Pradesh, grown in 5.56 million hectares with production of 13.37 million tonnes and productivity of 24.05 q/ha (Anonymous 2014-2015).

The substantial improvement in production is utmost necessary not only to meet ever increasing food requirement for domestic consumption, but also for export to earn foreign exchange. To feed the growing population, the country's wheat requirement by 2030 has been estimated at 100 million metric tonnes and to achieve this target, wheat production has to be increased at the rate of <1per annum (Sharma *et al.*, 2011) and this can be achieved through horizontal approach i.e. by increasing area under cultivation or through vertical approach i.e. varietal / hybrid improvement, which is one of the strongest tool to take a quantum jump in production and productivity under various agro- climatic conditions.

Triticum aestivum (bread wheat) ($2n=6x=42$) is an allo-hexaploid produced from two separate naturally occurring hybridization events. The initial hybridization, that occurred between the two grass species *Triticum urartu* ($2n=2x=14$) (the A genome donor), and *Triticum speltoides* ($2n=2x=14$) (B genome donor). This

new species would have been tetraploid wheat ($2n=4x=28$) viz., *Triticum turgidum* var. durum (Durum wheat). Hexaploid wheat arose as a result of a second hybridization between the new tetraploid and a third diploid species ($2n=2x=14$) viz., *Triticum tauschii* (D genome donor). Again, doubling chromosome must have occurred in order to produce a fertile individual. This new species would then have 42 chromosomes; i.e. six complete genomes each of 7 chromosomes.

One of the most important advances in plant improvement is the discovery of heterosis / hybrid vigour and its utilization in breeding programs. Superiority of hybrids over pure line, mid parents and better parents is related with heterotic effects of yield contributing traits. Improvement in wheat plant depends upon the amount of genetic variability present. General and specific combining ability effects are frequently used by plant breeders to evaluate newly developed cultivars for their parental usefulness and to assess the gene action involved in various characters, so as to design an efficient breeding plan for further genetic upgrading of the existing material. Line $\times$ tester analysis is a simple and efficient statistical approach that has been very commonly used for combining ability analysis in plant breeding.

Objectives:

1. To identify good combining parents to be use in future breeding programme.
2. To estimate genetic parameters i.e. heritability and genetic advances etc.
3. To determine general combining ability (GCA) as well as specific combining ability (SCA) for genotypes.
4. To estimate heterosis in the experimental hybrids for grain yield and contributing traits.
5. To find out causes of associations of components traits through path analysis affecting grain yield and their application in crop improvement.

Chapter-II

REVIEW OF LITERATURE

The literature pertaining to various aspects of the present investigation entitled “Combining ability and path analysis for morpho-physiological characters in bread wheat (*Triticum aestivum* L.)” has been reviewed under the following heads:

1. General Combining Ability and Specific Combining Ability
2. Heterosis analysis
3. Path analysis, Phenotypic and Genotypic coefficient of variance (PCV and GCV), Heritability and Genetic advance

General Combining Ability and Specific Combining Ability:

Combining Ability was reviewed in the light of work done by various researchers in India and abroad in recent past.

Kandil *et al.* (2016) reported that general and specific combining ability was significant for all studied characters. Wheat cultivars SIDES 12 was the best general combiner for all studied characters except number of spikes/plant; GEMMIZA 11 for all studied characters except 1000-grain weight; MISER1 for spike length and 1000- grain weight wheat. The three crosses were the best combinations, SIDES 12 × MISER 1 for spike length, SIDES 12 × MISER 2 for number of spikes/plant and 1000-Kernel weight and MISER 2 × SHANDAWHEEL 1 for number of spikes/spike, 1000-kernel weight and Kernel yield/plant. The mean squares of types of gene action indicated that additive and dominance genetic variance were significant for all the studied characters except b for 1000- grain weight.

Khiabani *et al.* (2015) reported that the genetic components of variation as well as ratio of GCA/SCA showed that all the characters were predominantly controlled by additive gene action. The results revealed insensitivity of both kinds of gene effects to the environmental variations. Best general combiners for the plant height and its

components were dwarf mutant (AS-48) which appeared to appreciate parent for reduce plant height and also increase spike length in wheat breeding program. Our results revealed that selection for plant height and its components would be effective in early generation. The dwarf mutant (AS-48) might be helpful for wheat breeders to develop new varieties with semi-dwarf and lodging resistance.

Samier and Ismail (2015) reported that GCA/SCA ratios were more than unity indicating the prevailing of additive gene effect. In general, the cultivar SIDS-4 was a good combiner for early heading and maturity, long spike and great number of kernels/spike. GIZA-168 was good combiner for high grain yield/plant and GEMMIZA-10 for heavy 1000-kernel weight. Besides SAKHA-94 was a good combiner for tall plant. These results seem to be useful for wheat breeding program in making the proper decision when initiating a crossing plan.

Kalhor *et al.* (2015) reported that the mean sum of squares corresponding to different traits of various hexaploid wheat genotypes indicated significant ($P < 0.01$) GCA (parents) and SCA (F_1 hybrids) effects for the characters (plant height, tillers plant⁻¹, spike length, spikelet spike⁻¹, seeds spike⁻¹, seed index, and grain yield plant⁻¹). The mean performance of F_1 hybrids differed significantly ($P < 0.01$) for all the traits studied. Among the parents, IMDAD and TD-1 proved to be better general combiners for almost all the studied traits. In regards to SCA effects, the F_1 hybrids IMDAD × TD-1 and IMDAD × SKD-1 expressed higher SCA.

Istipliler *et al.* (2015) reported that the specific combining ability (SCA) effects were generally found higher than general combining ability effects (GCA) in terms of the agronomic traits in Line X tester design in wheat. As a result, low ratios of, and low narrow sense heritability showed that non-additive effects controlled the traits. Hence, the selection process for superior individual plants should be postponed to further generations like F_4 or F_5 .

Jatav *et al.* (2014) reported that additive variances governed the days to heading and days to maturity. Whereas, only first inter-node length governed by non-additive inheritance. Lines 'WH-1062' was good

general combiner for days to heading, days to flowering, days to maturity, plant height, length of spike, grain per spike and test weight. 'HI-8696 (d)' was good general combiner for days to heading, grain filling period, plant height, second-inter-nodes length, flag leaf area, spike length, peduncle length and test weight. Tester viz., 43rd IBWSN-1043, 43rd IBWSN-1157 and 18en HRWYT-227 identified as good general combiners for grain yield and most of the attributes including harvest index. The cross, VL-920 X 18th HRWYT-227 and VL-920 X 18th SAWYT-303 was good specific combiner for grain yield and various yield components.

Aslam *et al.* (2014) reported that the parent line 9452 and tester SH-2002 were found good general combiner for yield and its components which are important in grain yield improvement. 9436 × SH-2002, 9444 × SH-2002, 9452 × SEHAR-2006 and 9452 × LASANI-2008 were more promising hybrids for grain yield components. The combining ability studies indicate the existence of both additive and non-additive gene effects in genetic material.

Pawar *et al.* (2014) reported that highly significant variances were observed for GCA and SCA which indicated the importance of both additive and non-additive gene effects for all the traits except panicle length (where only SCA variance was highly significant indicating non-additive gene action for this trait). Among the parents, HW-147, GW-273 and C-306 identified as the good general combiner and HI-1544/GW-273, GW-273/C-306, HD-2864/HW-147, HD-2864/GW-366, HI-1544/GW-366, JWS-17/LOK-1, HI-1544/LOK-1, HI-1544/HD-2864, GW-273/LOK-1, C-306/LOK-1 and C-306/JWS-17 identified as good specific combiners for grain yield, therefore, crosses involving high x low general combiners in respect of different characters in the present study may be utilized for obtaining transgressive segregants in further generations for yield and its components.

Desale *et al.* (2014) reported that the GCA and SCA ratio ($\sigma^2_{GCA}/\sigma^2_{SCA}$) was less than unity for all the traits indicated that non-additive component play relatively greater role in the inheritance of all the studied traits. The line, HW 5018 and HI 1544 were good general combiners for grain yield per plant and some of its component traits.

The cross KYZ 300 x RAJ 4136 was found most promising having high SCA effect together with *per se* performance for grain yield per plant, number of effective tillers per plant, grain weight per spike and 100-grain weight which could be further exploited in practical plant breeding programme.

Lohithaswa *et al.* (2013) reported that the general and specific combining ability variance ratio revealed the preponderance of additive gene action for all the traits except number of seeds/spike. Significant GCA effects for grain yield and its component traits were exhibited by the lines VIJAY and DK-1001 and testers DWR-1006 and Raj-1555. The cross NIDW-15 X RAJ-1555 exhibited significant SCA effects in the desired direction for leaf rust and protein content.

Zeeshan *et al.* (2013) reported that all the genotypes showed significant amount of diversity for all the traits. Genotype, BRAS-09 proved best general combiner for traits like grain yield per plant, plant height, number of tillers per plant, spikelet per spike, biological yield per plant and harvest index. The cross TUKURU / WL-01 exhibited highest specific combining ability values for grain yield per plant. Non additive gene effect was demonstrated by all the characters.

Padhar *et al.* (2013) reported that the mean squares due to GCA and SCA showed highly significant differences for all the characters in both the environments, suggesting the importance of both additive and non-additive gene action. The estimates of GCA effects of the parents revealed that GW 496 (in both the environments), GW 273, MACS 2496 and PBW 373 (in E1) while J 24 and HUW 234 (in E2) were observed to be good general combiners for grain yield and some contributing traits. The crosses GW 496 x PBW 373 in E1 and GW 496 x HD 2189 in E2 gave the highest SCA effects as well as *per se* performance in respective generation.

Raj and Kandalkar (2013) reported that the parents HD2964, DDW32, DDW11 and HS493 identified as good general combiners for grain yield and for most of the characters including harvest index. The crosses, DBW39 X HPW285, SONALIKA X RAJ4119, MP4010 X HS493

and MP4010 X HD2964 were good specific combiner for grain yield and either two or more components traits.

Singh *et al* (2013) reported that parents RAJ 4063, HD 2851 and WH 789 were the good general combiners, whereas crosses WH 789 x NW 3015, HUW 468 x UP 2614 and HS 448 x RAJ 4063 were found to be best specific combiners for grain yield per plant and some of the yield contributing traits. However on the basis of *per se* performance and significant SCA effects for grain yield per plant and some of its important components, hybrids WH 789 x NW 3015; HS 448 x RAJ 4063 and K 209 x HD 2851 were considered to be most promising for further exploitation in breeding programme.

Jain and Sastry (2012) reported that varieties viz., HD-2687 and WH- 542 among lines and K-65 and RAJ-3077 among testers were adjudged the best general combiner as it depicted high GCA effect in desirable direction for grain yield and yield contributing traits. Among the selected hybrids WH-542 x RAJ-3077 and WH 542 x K-65 were exhibited highest magnitude of positive significant SCA effects with highest magnitude of heterobeltiosis and *per se* performance for grain yield

Kumar *et al.* (2011) reported that that analysis of variance (ANOVA) revealed the presence of significant variance due to general combining ability (GCA) among the parents for all the traits, and due to specific combining ability (SCA) among the crosses for the all the traits except for number of tillers per plant, plant height and number of spikelet per spike. Combining ability analysis revealed the involvement of both additive and non additive gene action in the inheritance of most of the traits. On the basis of GCA, SCA effects and *per se* performance, parents K-9107 for 6 traits, K-9162 for 4 traits and GW 373 for 3 traits and crosses K-9107 × K-7903 for 2 traits, K-68 × K-7903 for 2 traits were found good general and specific combiners, respectively.

Akram *et al.* (2011) reported that the general combining ability effects were significant for all the characters except days to maturity, whereas specific combining ability effects were significant for most of the characters except grain yield, flag leaf area, number of spikelet

spike-1, protein contents and lysine contents. The part of variance due to SCA was greater than GCA for most of the characters indicating the importance of non-additive gene action. The parental varieties, CHAKWAL 97 and KOHISTAN 97, proved as the best general combiners for grain yield plant-1. The cross Pak 81 x KOHISTAN-97 showed maximum SCA values for grain yield plant-1

Kapoor *et al.* (2011) reported four winter wheat lines viz., DRINA NS 720, CHINA 84-40022, WW-7 and NORDRESPREZ were good general combiners for grain yield and three other yield contributing traits. Among the testers, PBW 343 and RAJ 3765 were the best general combiners for grain yield and other yield contributing traits. Cross combinations WW-7 x Raj 3765, DRINA NS 720 x PBW 343, NORDRESPREZ x PBW 343, CHINA 84-40022 x PBW 343 and Vir 453-47 PBW 343 were found to show significant positive SCA effect for grain yield and yield contributing traits.

Nour *et al.* (2011) reported that DOVIN-2, SIDS-1, GIZA-170 and IRINA proved to have better general combiners for grain yield per plant and most of its components in grain yield improvement. Tester number GEMMIZA-9 appeared to have better general combiner for grain yield per plant and some other traits. These parents presumed to have a relatively large number of favorable alleles for these traits. However, the hybrids (DOVIN-3 X GIZA-168), (SIDS-1 X GEMMIZA-9), (GIZA-170 X SAKHA-93) and (IRINA X SAKHA-93) were excellent harmonious combiners for specific combining ability effects for all characters including grain yield per plant.

Akbar *et al.* (2009) reported that among lines, FAISALABAD-83 and FAISALABAD -85 were good general combiners for most of the agronomic traits including grain yield per plant. The tester PBW65 / ROER /3/ PB6 // MIRLOW / BUC followed by PBW502 was found good general combiner for grain yield and some other traits studied. Faisalabad-85, PBW502 and Faisalabad-83 ▯PBW65 / ROER /3/ PB6 // MIRLOW / BUC performed better for grain yield and most of other traits studied

Khan *et al.* (2007) reported the additive gene effects were operating in plant height, biomass plant, number of grains per spike and grain yield per plant while number of tillers per plant and 1000 grain weight were controlled by non-additive gene effects. The genotypes of

"UQAB 2000" proved to be good general combiner for grain yield, 1000 grain weight, biomass plant, number of tillers per plant and plant height. While, V-00055 was found good general combiner for grain yield, biomass plant, plant height and number of grains per spike. The cross "SH-02 x UQAB 2000" and its reciprocal and "V-00125 x V-00055" were the best specific combiners for grain yield plant and yield components.

Awan *et al.* (2005) reported that genotypes showed significant differences for all the characters. General Combining ability (GCA) variance was highly significant for all the characters except number of spikelet per spike. The variance was more than the specific combining ability (SCA), indicating additive gene effects for all the characters. However, variances for SCA and reciprocals were non-significant. Considering all the characters together, INQLAB 91 was good general combiner for 1000-grain weight and grain yield per plant. While highest value of SCA effects for grain yield per plant were recorded in the cross CHAKWAL-86 x INQLAB-91.

Ajmal *et al.* (2004) reported that the proportion of variance-components, due to specific combining ability was greater than that of general combining ability for grain-yield, weight of 100 grains, spike length, spikelet per spike, and maturity period, which indicated the preponderance of non-additive type of gene-action for these characters. Parents SHALIMAR-88 was a better general combiner for grain-yield and weight of 100 grains. cross combinations BARANI-83 x PIRSABAK-91, BLUE-SILVER x PIRSABAK-91 and BLUE-SILVER x SUTLEJ-86 expressed their superiority as specific combiners for grain-yield and for at least one yield component.

Saeed *et al.* (2001) reported that highest positive GCA estimates for number of tillers per plant, numbers of grains per spike and grain yield per plant were obtained in Chakwal-86, while BARANI-83 showed highest positive GCA effects for flag leaf area. Cross combination KOHISTAN-97 x PASBAN-90 showed highest positive SCA effects for number of tillers per plant, number of grains per spike and grain yield per plant. About 55% of the hybrids showed positive SCA effects for

number of grains per spike, grain yield per plant and 67% for flag leaf area and number of tillers per plant.

Heterosis analysis:

Samier and Ismail (2015) reported that the mean square of genotypes, parents and crosses were significant for all studied characters. Positive and negative heterosis over the better parents was detected for all studied characters indicating that parental genotypes were genetically diversified.

Kalhor *et al.* (2015) reported that the parents (IMDAD, TD-1, SKD-1, and Moomal) were crossed in half partial mating fashion; thus, six possible cross combinations (F_1 s) were obtained (IMDAD $\times$ TD-1, IMDAD $\times$ SKD-1, IMDAD $\times$ MOOMAL, TD-1 $\times$ SKD-1, TD-1 $\times$ MOOMAL, and SKD-1 $\times$ MOOMAL). A three-replicated RCB Design was used. the F_1 hybrids IMDAD $\times$ TD-1 and IMDAD $\times$ SKD-1 expressed higher heterotic effects for most of the studied traits.

Hussain *et al.* (2014) reported that maximum heterosis and heterobeltiosis (39.84%) and (23.29%), were exhibited in the crosses, PAVON / 076397 and 076396 / AAS-11, respectively under E1. Highly significant heterosis (14.72%) was showed by the cross PAVON / 076396 while the cross PAVON / 076397 gave highly significant grain yield (8.74%) over better parent under E2.

Raj and Kandalkar (2013) reported that heterosis over mid parents and better parent were significant in favorable direction in crosses viz., DBW39 X HD2964, SONALIKA X RAJ4119, SONALIKA X DDW11, DBW17 X RAJ4119, for grain yield and its components.

Batool *et al.* (2013) reported that the significant differences and highest values in heterosis, heterobeltiosis for cross combinations (SEHR-06 $\times$ Blue Silver) for pollen viability, (SA-42 $\times$ FSD-08) for flag leaf area, (PAK-81 $\times$ LASANIL-08) for number of grains per spike and (CHENAB-70 $\times$ FSD-08) for grain yield plant-1.

Devi *et al.* (2013) reported that the cross UP 2596 X DBW 17 was recognized as the best heterotic cross for grain yield as it exhibited highly significant positive heterosis over both the standard checks UP

2554 and PBW 343. The cross HW 2019 × UP 2338 exhibited highest and significant positive heterosis over better parent, mid parent and over both the standard checks for number of grains per spike

Cifci (2012) reported that the hybrids of 11-27 × GEDIZ for plant height, 12-21 × GEDIZ for spike length, spikelet number per spike, 9-65 × 12-21 for grain number per spike, PINAR-2001 × GEDIZ and 12-21 × GEDIZ for grain yield per spike and PINAR-2001 × 9-65 for 1000 grains weight had the highest heterosis and heterobeltiosis values.

Kumar *et al.* (2011) reported that significant heterosis over economic parent and mid parent was observed for almost all the traits studied. The magnitude of heterosis was highest (21.74%) for number of spikelet per spike over economic parent and for number of tillers per plant (13.73%) over mid parent.

Tuhina-khatun *et al.* (2010) reported that relative heterosis revealed cross SONORA × ANZA exhibited superior performance for grain yield/plot in environment-1. Estimate of heterobeltiosis for different yield contributing characters showed that cross SONORA × ANZA exhibited highest heterosis for grain yield/plant in environment-1 and KANCHAN × BALAKA in environment-2.

Emreilker *et al.* (2010) reported that promising findings of the crosses 72 × GOLIA, 70 × GOLIA, 70 × BASRIBEY, 48 × BASRIBEY, 48 × ATILLA-12 and 72 × ATILLA12 were obtained to breed new varieties or pure lines having shorter plant height and taller spike length, more number of spikelet and kernel per spike, besides higher grain yield than their mid or better parents to improve powdery mildew resistant varieties.

Singh *et al.* (2004) reported that the maximum heterobeltiosis for grain yield per plant observed was 50.94% (RAJ 3765 × HD 2285), 121.08% (PBW 373 × HD 2329) and 93.96% (PBW 373/× HD 2329) under early, normal and late sowing conditions, respectively. Cross PBW 373 ×/HD 2329 in both early and normal plantings and cross RAJ 3765 × HD 2285 under late planting were observed most heterotic for grain yield.

Saeed *et al.* (2001) reported that Cross combination KOHISTAN-97 x Pasban-90 showed highest positive SCA effects for number of tillers per plant, number of grains per spike and grain yield per plant. About 55% of the hybrids showed positive SCA effects for number of grains per spike, grain yield per plant and 67% for flag leaf area and number of tillers per plant.

Path analysis, Heritability, Genetic Advance, PCV and GCV:

Bhutto *et al.* (2016) reported that the phenotypic correlations revealed that tillers/plant and grains/spike were highly positively associated. The results from correlation and regression of plant height indicated significantly positive association with spikelet's /spike, tillers/plant and grain/spike which revealed that increase in plant height will cause corresponding increase in associated traits.

Poor *et al.* (2015) reported that correlation analysis of grain yield and its components showed that grain yield had a positive correlation with traits including agronomy score, 1000-grain weight, grain weight per spike, total spike weight and number of grains per spike. Result of path coefficient analysis showed that 1000- grain weight had the most direct effect on grain yield.

Suleiman *et al.* (2014) reported that association between the grain yield with leaf area index and days to 95% maturity were positive in the 2008-2009 season. Meanwhile, simple correlation coefficients depicted positive but non-significant association of grain yield with number of grains per spike. Path coefficient analysis revealed that most of the evaluated traits exhibited positive direct effects on grain yield except plant height and days to 50% heading.

Nasri *et al.* (2014) reported that grain yield traits such as the number of fertile spikes, spike weight per unit area, harvest index, biomass, thousand-grain weight, number of grains per spike, and height plant showed significant positive correlations. Path analysis showed the most significant and positive direct effect ($P= 0.57$) by harvest index and grain yield. Harvest index also showed positive indirect effect ($P= 0.51$) on grain yield.

Ata *et al.* (2014) reported that spike length, spike density and 1000-grain weight were the main contributor in yield in concerned environments. In normal conditions maximum correlation was recorded for number of grains per spike followed by grain weight per spike whereas number of grains per spike was also have top most value of correlation in drought environment.

Zeeshan *et al.* (2014) reported that harvest index exhibited highest heritability value of 83.31% while 1000-grain weight showed minimum value of 42.32%. Grain yield correlated positively with flag leaf area, plant height, biomass, number of spikes, spike length, number of spikelet / spike, number of grains / spike, 1000-grain weight and harvest index. Path coefficient analysis indicated that grain yield had a positive direct effect with spike length and number of grains per spike.

Singh and Upadhyay (2013) reported that phenotypic variance value for most characters was closer than the corresponding genotypic variance value showing little environment effect on the expression of characters. The estimated value of broad sense heritability was found between 50.10% (Spike length) and 97.20% (grain yield/ha). High heritability coupled with high genetic advance as percent over mean was observed for grain yield /ha, plant height at maturity, number of grain per spike and days to maturity. Grain yield/ha showed significant positive genotypic and phenotypic correlation with grain yield per plant ($r_g=0.454$, $r_p=0.442$) and spike length ($r_g=0.536$). Grain yield per ha (0.938, 0.502) had highest positive direct effect on grain yield per plant followed by 1000 grain weight (0.490, 0.336).

Bhusan *et al.* (2013) reported that the higher magnitudes of GCV and PCV were recorded for grain yield, biological yield, productive tillers per plant and plant height. The high heritability in broad sense was estimated for all the characters except for grain filling period and test weight. High heritability coupled with high genetic advance as percent of means were recorded for plant height, harvest index, biological yield and grain yield that indicated predominance of additive gene action in the inheritance of these traits. The correlation coefficients estimate showed high direct genotypic and phenotypic correlations for

the test weight, biological yield, spikelet per spike and grain filling period. Path analysis showed that harvest index had highest direct positive effect on grain yield followed by biological yield, productive tillers per plant, spikelet per spike and test weight.

Nukasani *et al.* (2013) reported that high values of GCV and PCV were recorded for tillers meter-1 and grain yield meter-1. High heritability coupled with high genetic advance were recorded for traits plant height, tillers m-1, grain yield m-1, grain wt spike-1 and spike length indicating that these characters are governed by additive gene effects. Correlation and path analysis studies revealed that, three characters, tiller number m-1 > grain weight spike-1 > number of grains spike-1 in that order are the most important characters as these exhibited positive and strong association and maximum positive direct effects on grain yield.

Fellahi *et al.* (2013) reported that grain yield was positively correlated to biological yield, straw yield and number of spike per plant. In the path coefficient analysis, biological yield and harvest index should be considered as the main yield components because these traits showed a positive direct effects towards increasing grain yield with the values of + 1.051 and + 0.364, respectively.

Abderrahmane *et al.* (2013) reported that grain yield per plant was significantly and positively correlated with above ground biomass, straw yield, number of spikes per plant and number of grains per spike.

Solomon and Hanchinal (2013) reported that the genotypic as well as phenotypic correlation between grain yield and other yield components such as number of tillers per plant, number of spikes per square meter, number of grains per spike, total biomass per plant, harvest index and 1000 kernel weight were highly significant. Path analysis indicated that biomass, harvest index, days to flowering and plant height imparted significant direct influence on grain yield.

Khan *et al.* (2013) reported that positive and significant correlation was found for plant height, spikes/m², and 1000-grain weight with grain yield. Maturity days, spikes/m², and 1000-grain weight had significant positive direct effects on grain yield.

Cifci (2012) reported that the correlations between traits revealed that important characters, influencing grain yield per spike were spike length, spikelet number per spike and grain number per spike. The results of path analysis also indicated that spike length, spikelet number/ spike and grain number per spike had the maximum direct effects on grain yield per spike.

Mollasadeghi *et al.* (2011) reported that the grain yield has a direct and positive effect (0.527) over harvest index. Number of grain per spike (0.212), grain weight (0.408), 1000 grain weight (0.093) and biological yield (0.853) had the most direct and positive effect on grain yield.

Singh *et al.* (2011) reported that high phenotypic and genotypic coefficient of variation coupled with high heritability and genetic advance as percent of mean were reported for grain yield, biological yield, days to 50% flowering, spikelet per spike, effective tillers per plant and days to maturity. Seed yield had significant and positive correlation with days to maturity, plant height, effective tillers/plant, 1000-grain weight and biological yield. Path coefficient analysis revealed positive direct effect of days to 50 % flowering, plant height, spike length, number of seeds per spike, biological yield and harvest index on seed yield.

Khokhar *et al.* (2010) reported that grain yield per plant was positively and highly significantly correlated with days to maturity but negatively and highly significantly associated with plant height. Days to maturity had highest positive direct effect on yield

Aydin *et al.* (2010) reported that grain yield was significantly correlated with plant height in high rainfall condition. It was significantly correlated with all components except Zeleny sedimentation and protein content in low rainfall condition. Results suggest that plant height and test weight are primary selection criteria for improving grain yield in bread wheat in high and low rainfall conditions

Mohsin *et al.*, (2009) reported that Harvest index exhibited highest heritability value of 83.31% while 1000-grain weight showed minimum value of 42.32%. Grain yield correlated positively with flag leaf

area, plant height, biomass, number of spikes, spike length, number of spikelet per spike, number of grains per spike, 1000-grain weight and harvest index. Path coefficient analysis indicated that grain yield had a positive direct effect with spike length and number of grains per spike.

Ahmed *et al.*, (2007) reported that significant and positive genetic correlations among yield related traits predominated the phenotypic association for the direct cross Fakhre Sarhad × Saleem-2000 and it's reciprocal under both planting conditions. The strong relationship of yield with yield component traits suggested that grain yield potential can be effectively improved by obtaining maximum expression of spike length, spikes plant-1, number of grains spike-1, biological yield and harvest index.

Kashif and khaliq (2004) reported that moderate to very high broad sense heritability was estimated for all the morphological characters except fertile tillers per plant. Plant height exhibited highest heritability value of 92.08% while fertile tillers per plant showed minimum value of 40.71%. Genotypically, plant height, spike length, spikelet per spike, grains per spike and 1000-grain weight was positively and significantly correlated with grain yield while highly significantly associated phenotypically. Plant height, flag leaf area, spike length and grains per spike had positive direct effects on grain yield.

Chapter-III

MATERIALS AND METHODS

The experimental materials and methods used during the present investigation entitled “Combining ability and path analysis for morpho-physiological characters in bread wheat (*Triticum aestivum* L.)” have been described as follows.

Location: Experiment was conducted at Research field of AICRP on wheat, College of Agriculture, Gwalior located in the Gird region (Agro climatic zone No 6, wheat-pearl millet crop zone). The Gwalior is situated at an altitude of 211.52 MSL, 26° 13' N Latitude and 78° 14' E Longitude. The soil is sandy loam, low in available nitrogen, medium in phosphorus and high in potash with pH of 8.5

Climate: the summer is hot and dry; May and June are the hottest months. Maximum and minimum temperature varies between 47°C to 28.5°C, respectively. December and January constitutes the cooler months of the year and minimum temperature ranges from 4°C to 10.8°C. The average rainfall ranges between 80 to 90 cm most of which is received in the months of July, August and September with few showers in winter months.

Weekly meteorological data for crop season is presented in Table 3.1. During wheat season, maximum temperature was ranging from 16.0°C to 40.2°C and minimum temperature from 4.0°C to 22.7°C. Total rainfall received was 740.4 mm (July 14 to April 15) mm during the year 2014-15. The total rainfall received was 196.8 mm from October 2014 to April 2015. Overall season was favorable for crop growth.

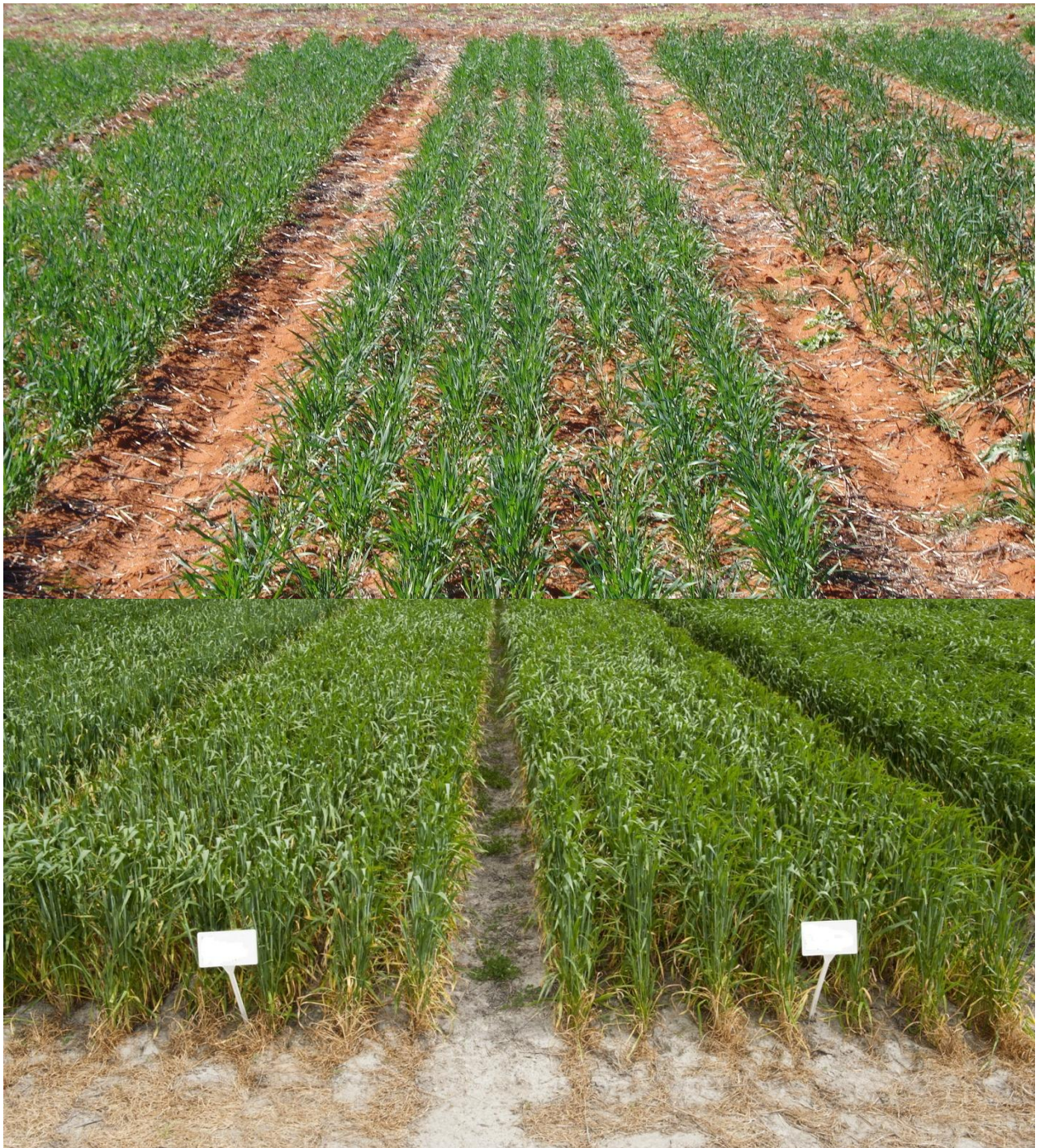


Fig: Experimental trail at research field of AICRP on wheat, College of Agriculture, Gwalior, M.P.

Table 3.1 Weekly meteorological data for wheat season (Oct. 2014 to March 2015)

STD Week	Period	Temperature(⁰ C)		Relative Humidity (%)		Rain-fall	Pan-Evaporation
No	2014-2015	Max.	Min.	Morning	Evening	(mm)	(mm)
40	Oct 1-7	36.8	21.9	82.0	48.2	0.00	5.7
41	Oct. 8-14	34.7	19.4	83.8	53.7	0.00	3.8
42	Oct. 15-21	31.9	16.7	89.5	47.2	0.00	3.8
43	Oct. 22-28	33.7	16.5	86.5	43.4	0.00	3.6
44	Oct.-Nov. 29-4	33.1	15.8	82.8	42.8	0.00	3.8
45	Nov. 5-11	32.6	15.4	86.0	46.2	0.00	4.0
46	Nov. 12-18	29.1	10.4	91.8	44.5	0.00	2.2
47	Nov. 19-25	29.8	8.6	93.5	51.4	0.00	2.8
48	Nov 26-Dec 2	30.1	10.2	89.8	46.5	0.00	3.0
49	Dec. 3-9	28.1	8.2	88.8	49.1	0.00	3.6
50	Dec. 10-16	22.3	9.1	96.1	69.5	35.0	1.5
51	Dec. 17-23	19.2	5.1	97.5	73.7	0.00	1.2
52	Dec. 24-31	18.8	4.0	99.2	74.1	0.00	1.0
	2015						
1	Jan1-7	18.7	10.8	94.8	78.1	03.0	1.1
2	Jan 8-14	18.8	5.6	97.5	74.7	0.00	1.3
3	Jan15-21	17.0	7.5	97.0	84.0	01.4	0.8
4	Jan22-28	16.0	8.7	97.0	92.2	24.0	0.8
5	Jan 29-Feb 4	21.5	6.6	95.5	70.8	0.00	2.2
6	Feb5-11	22.5	8.7	96.0	74.8	04.2	1.8
7	Feb12-18	26.9	10.5	94.7	64.7	0.00	3.0
8	Feb19-25	30.1	13.9	93.4	67.8	02.4	2.6
9	Feb 26-march 4	26.0	12.3	91.0	73.0	18.4	2.1
10	March 5-11	26.8	10.5	92.7	65.4	02.8	3.2
11	March 12-18	28.2	14.7	93.2	67.2	70.4	3.0
12	March 19-25	31.3	15.0	92.4	55.0	0.00	4.1
13	Mar 26- April 1	34.8	18.9	90.1	60.1	26.8	4.6
14	April 2-8	33.5	17.9	85.7	57.4	01.0	4.9
15	April 9-15	33.5	17.7	86.0	61.8	07.4	4.4
16	April 16-22	38.4	21.8	77.0	47.4	0.00	7.4
17	April 23-29	40.2	22.7	76.4	40.5	0.00	8.4
					Total	196.8	

Experimental Material: The experimental material consisted of 14 wheat varieties involving 10 lines and 4 testers and their 40 crosses. The parents were crossed in line x tester mating design during Rabi season of 2014-15.

S. No.	Parent	Pedigree/Source
Lines		
1.	33 rd ESWYT150	KFA/2*KACHU
2.	20 th HRWYT213	E.I.G.N.1 2014-2015
3.	20 th HRWYT235	E.I.G.N.1 2014-2015
4.	45 th IBWSN1021	E.I.G.N.1 2014-2015
5.	14 th FHBSN6418	E.I.G.N.1 2014-2015
6.	36 th SAWSN3065	E.I.G.N.1 2014-2015
7.	PBW658	N.G.S.N. 2014-2015
8.	KB 2013-03	N.G.S.N. 2014-2015
9.	KB2013	N.G.S.N. 2014-2015
10.	VW921	N.G.S.N. 2014-2015
Tester		
1.	GW273	CPAN 2084/VW 205
2.	GW366	DL802-3/GW232
3.	RVW4106	CHIBIA//PRL11/CM65531
4.	SUJATA	1154- 388/AN/3/YT54/NIOB/LR64

Experimental Details:

Experiment was conducted in randomized complete block design with 2 replications at research farms, college of agriculture, Gwalior, MP. The sowing was done by dibbling seeds in rows with spacing of 20 cm apart and 4-6 cm within row on November 15th (Timely sown environment 2014-15). The recommended packages of practices were adopted for optimum crop growth. The observations were recorded on the following characters.

1. **Days to Heading:** Numbers of days were recorded from the date of sowing to date of 50 per cent plant showing full ear-head emergence.

2. **Days to maturity:** Numbers of days were counted from the date of sowing to physiological maturity of the plant.
3. **Plant height (cm):** Plant height was measured from the base of the plant to top of ear head of main tiller at maturity stage.
4. **Tillers per plant:** The numbers of productive tillers per plant was recorded at the time of maturity.
5. **Spike length (cm):** Spike length was measured from the base of spike to the top at the time of maturity.
6. **1st Inter-node length (cm):** 1st inter-node length was measured from the ground level to the 1st node of main tiller at the time maturity.
7. **Grains per spike:** The spike of the mother shoot was threshed manually and numbers of grains per spike were counted for each genotype.
8. **Spike weight per plant (g):** The spike of the mother shoot of each selected plant was weighted on electronic balance
9. **Grain weight per spike (g):** The grain of the individual spike was weighed (g) and average was taken for each genotype
10. **1000 grain weight or Test weight (g):** 1000 grains were counted and weight was recorded in gram
11. **Grain yield per plant (g):** The grain yield of the individual plant was weighed (g) and average was taken for each genotype.
12. **Canopy temperature index:** The canopy temperature index was measured in each genotype at reproductive stage using a non-contact infrared thermometer.

$$CTI = \frac{\text{environment temperature} - \text{canopy temperature}}{\text{environment temperature}}$$

13. **Biological yield (g):** The Biological yield was recorded by weight of the selected plants at harvest.
14. **Harvest index (%):** Harvest index was calculated by the following formula

$$HI = \frac{\text{Grain yield per plant}}{\text{Biological yield per plant}} \times 100$$

Statistical Methods:

1. **Analysis of variance:** The mean of each character were analyzed following the procedure given by Panse and Sukhatme (1967) for randomized block design.

(a) Model of RBD is expressed as follow

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

Where, μ = General mean; g_i = Effect of the i^{th} genotype; b_j = Effect of j^{th} replication over the genotype and e_{ij} = Error associated with each observation

The analysis of variance for parents and crosses explained in table 3.2

Table 3.2 : Analysis of variance for crosses and parents in randomized block design

Source of variance	Degree of freedom	Mean sum of square
Replications	$(r - 1)$	MSS_r
Genotypes	$(g - 1)$	MSS_g
Parents	$(p - 1)$	MSS_p
Crosses	$(c - 1)$	MSS_c
C v/s P	1	$MSS_{c \text{ v/s } p}$
Error	$(r - 1)(t - 1)$	MSS_e
Total	$(rt - 1)$	

Where, r = number of replications, g = number of genotypes, t = number of tester, l = number of lines, p = number of parents, c = number of crosses.

(b) **Standard error, critical difference and coefficient of variation:**

(i) **Standard error of mean:** Standard error of mean was calculated using the following formula

$$SE(m) \pm = \frac{\sqrt{MSS_e}}{r}$$

Where, $SE(m) \pm$ = Standard error of mean, MSS_e = Error mean sum of square,

r = Number of replications

(ii) **Standard error of difference:** Standard error of difference was calculated using the formula, $SE(d) \pm = \frac{\sqrt{2MSS_e}}{r}$

Where, $SE(d) \pm$ = Standard error of difference, MS_{Se} = Error mean sum of squares r = Number of replications

(iii) **Critical difference:** It was calculated as formula given below

$$C D (5\%) = S E (d) \times 't' \text{ value}$$

Where, $C D$ = critical difference, $SE(d) \pm$ = standard error difference

't' = table value at error degree of freedom at 5% level of significance

(IV) **Coefficient of variation:** The coefficient of variation as percentage of mean was estimated as mentioned below.

$$cv (\%) = \frac{\sqrt{M_e}}{\bar{X}}$$

Where, $C V (\%)$ = Coefficient of variation in percent, M_e = Error mean sum of square, $\bar{X}$ = Sample mean of observations

2. Combining ability analysis: When the data were found significant for a given character in randomized block design, it was subjected to combining ability analysis according to the procedure given by Kempthorne (1957). The format for the analysis of variance along with the expectation of mean squares is given in table 3.3.

Table 3.3: Format for line $\times$ tester analysis

Source	Degree of freedom	M.S.	Expected mean square
Lines	$f-1$	M_1	$\sigma_e^2 + r(\text{Cov F.S.} - 2\text{Cov H.S.}) + rm(\text{CovH.S.})$
Testers	$m-1$	M_2	$\sigma_e^2 + r(\text{Cov F.S.} - 2\text{Cov H.S.}) + rf(\text{CovH.S.})$
Line $\times$ Tester	$(f-1)(m-1)$	M_3	$\sigma_e^2 + r(\text{Cov F.S.} - 2\text{Cov H.S.})$
Error	$(r-1)(fm+f+m-1)$	M_4	σ_e^2

Where, r = number of replications, f = lines, m = testers, Cov H.S. = Covariance of half-sibs, Cov F.S. = Covariance of full-sibs

Significance of various sources was tested by F test. Line $\times$ tester source was first tested against error mean square. Thus,

$$F = \frac{M3}{M4}$$

3. Estimation of covariance and variance components: When the mean squares of the lines and testers were found significant, estimates of covariance of half-sibs were calculated as:

$$\text{Cov. (H.S.) lines} = \frac{M1 - M3}{rm}$$

$$\text{Cov. (H.S.) testers} = \frac{M2 - M3}{rf}$$

However, when the mean squares for both lines and testers were significant, averages estimate of Cov. (H.S.) calculated following King *et al.* (1961)

$$\text{Cov. (H.S.) average} = \frac{M1 + M2 - 2M3}{r(f + m)}$$

Covariance of full-sibs was calculated as:

$$\text{Cov. (F.S.)} = \frac{M1 + M2 - 3M4 + ry(6 - m - f)}{3r}$$

The σ_{gca}^2 , σ_{sca}^2 , σ_A^2 and σ_D^2 were calculated as under

$$\sigma_{gca}^2 = \text{Cov. H.S.}$$

$$\sigma_{sca}^2 = \text{Cov. F.S.} - 2 \text{ Cov.H.S.}$$

$$\sigma_A^2 = 4 (\sigma_{gca}^2)$$

$$\sigma_D^2 = 4 (\sigma_{sca}^2)$$

4. Estimation of general (g_i and g_j) and specific (S_{ij}) combining ability effects: The general combining ability for i^{th} line or j^{th} tester and specific combining ability effects (for ij^{th} cross) were computed as shown below:

GCA effects:

$$g_i \text{ (lines)} = \frac{y_{i..}}{rm} - \frac{y_{...}}{rfm}, \quad i = 1, 2, 3, 4, \dots, 10$$

$$g_j \text{ (testers)} = \frac{y_{.j.}}{rf} - \frac{y_{...}}{rfm}, \quad j = 1, 2, 3, 4$$

SCA effects:

$$S_{ij} = \frac{y_{ij.}}{r} - \frac{y_{i..}}{rf} - \frac{y_{.j.}}{rm} + \frac{y_{...}}{rfm}$$

Where,

$y_{ij.}$ = (ij)th combination total over all replications

$y_{i..}$ = total of ith female parent over all males and replications

$y_{.j.}$ = total of jth male parent over all females and replications

$y_{...}$ = total of all hybrids

5. Standard errors for general and specific combining ability effects:

(i) Standard errors for general combining ability calculated as below:

$$S.E. (g_i) = \sqrt{\frac{M4}{rm}} \quad \text{and} \quad S.E. (g_j) = \sqrt{\frac{M4}{rf}}$$

The significance of g_i and g_j was tested by means of 't' test using the following formula.

$$t \text{ (for } g_i) = \frac{g_i - 0}{S.E.(g_i)} \quad \text{and} \quad t \text{ (for } g_j) = \frac{g_j - 0}{S.E.(g_j)}$$

The values of the ratio so obtained were referred to 't' table at error degrees of freedom.

(ii) The standard error for specific combining ability calculated as below:

$$S.E. (s_{ij}) = \sqrt{\frac{M4}{r}}$$

The significance of g_i and g_j was tested by means of 't' test using the following formula:

$$t \text{ (for } g_i) = \frac{g_{ij} - 0}{S.E.(S_{ij})}$$

The values of the ratio so obtained were referred to 't' table at error degrees of freedom.

6. Computation of heterosis:

(i) **Heterosis over mid-parents:** It was estimated as formula mentioned below:

$$h = \frac{\bar{F}_1 - \overline{MP}}{\overline{MP}} \times 100$$

Where, $\bar{F}_1$ = Mean value of the F_1 hybrid, $\overline{MP}$ = Mean value of parents involved in a particular cross.

(ii) **Heterosis over better parents:** It was estimated as formula mentioned below:

$$h = \frac{\bar{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

Where, $\bar{F}_1$ = Mean of $\bar{F}_1$ hybrid

$\overline{BP}$ = Mean of the superior parents of the particular cross under Study.

Test of significance for heterosis:

Test of significance of heterosis over mid parents was calculated by applying t- test

$$t = \frac{\bar{F}_1 - \overline{MP}}{SE(H)}$$

Where, $SE(H) = \sqrt{(3s^2/r)}$

S^2 = Error mean sum of square and r = number of replication

Test of significance of heterosis over better parents and standard parent was done by applying t-test

$$t = \frac{\bar{F}_1 - \overline{BP}}{SE(H)}$$

Where, $SE(H) = \sqrt{\left(\frac{2s^2}{r}\right)}$

S^2 = Error mean sum of square and r = number of replication

- 7. Estimation of phenotypic and genotypic coefficients of variation:** The phenotypic and genotypic coefficients of variation were computed by the following formulae given by Burton (1952).

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

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

Where, "

PCV = Phenotypic coefficient of variation

GCV = Genotypic coefficient of variation

- 8. Heritability:** Heritability in per cent in broad sense was estimated by the following formula given by Singh and Chowdhary (1977).

$$\text{Heritability}(h^2) = \frac{\text{Genotypic variance}}{\text{Phenotypic variance}} \times 100$$

$$\text{Genotypic variance} = \frac{M_t - M_e}{r} "$$

$$\text{Phenotypic variance} = \text{Genotypic variance} + M_e$$

Where,

M_t = Treatment mean sum of square ,

M_e = Error mean sum of square and

r = Number of replications

- 9. Genetic advance G(s):** The estimates of expected genetic advance from selection. $G(s)$, was obtained by the formula suggested by Robinson, Comstock, and Harvey (1949).

$$G(s) = k \times h^2 \times \sigma_p$$

Where, k = Selection differential

h^2 = Heritability in broad sense,

σ_p = Phenotypic standard deviation

10. Estimation of correlations: Phenotypic and genotypic correlation coefficient between characters were computed utilizing respective components of variance and co-variance, by following formula suggested by Miller *et al.* (1958).

$$r_{XY} = \frac{Cov_{X,Y}}{\sqrt{V_X + V_Y}}$$

Where,

r_{XY} = Correlation coefficient between character X and Y,

Cov_{XY} = Covariance of character X and Y,

V_X = Variance of character X,

V_Y = Variance of character Y

The significance of phenotypic and genotypes correlation coefficients were tested with estimated values compared with the tabulated values of Fisher and Yates (1938) at n-2 d.f. at two levels of probability, viz., 5% and 1%.

11. Path coefficient analysis: Path coefficient is a standardized partial regression coefficient, which measures the direct influence of one variable upon another and allows partition of correlation coefficient into components of direct and indirect effects. The proportion of direct and indirect contributions of various characteristics to the total correlation coefficients with grain yield per plant, was estimated through path coefficient analysis as suggested by Wright (1921, 1934) and elaborated by Dewey and Lu (1959). To estimate various direct and indirect effect, the following set of simultaneous equations were formed and solved.

$$r_{1y} = P_{1y} + r_{12}P_{2y} + r_{13}P_{3y} + \dots + r_{1i}P_{iy}$$

$$r_{2y} = r_{2y}P_{1y} + P_{2y} + r_{23}P_{3y} + \dots + r_{2i}P_{iy}$$

$$r_{iy} = r_{i1}P_{1y} + r_{i2}P_{2y} + r_{i3}P_{3y} + \dots + P_{iy}$$

Where,

r_{1y} to r_{iy} = Correlation between causal factor 1 to i and dependent character y

r_{12} to $r_{i-1,i}$ = Correlation among causal factors themselves, and

P_{1y} to P_{iy} = Direct effect of characters 1 to i on character y

Residual effect, which measures the contribution of the characters not considered in the causal scheme, was obtained as:

$$\text{Residual effect}(P_{RY}) = \sqrt{1 + R^2}$$

Where,

$$R^2 = \sum_{iy} P^2_{iy} + 2 \sum_{\substack{i \neq j \\ i > j}} P_{iy} P_{jy} r_{ij}$$

Chapter-IV

RESULTS

The experimental data of investigation entitled “Combining ability and path analysis for morpho-physiological characters in bread wheat (*Triticum aestivum* L)” have been statistically analyzed and results described under following headings:

4.1 Analysis of variance

4.2 Mean performance

4.3 Genetic parameters:

- Phenotypic coefficient of variation
- Genotypic coefficient of variation,
- Heritability
- Genetic advance

4.4 Correlation coefficient and Path analysis

4.5 Line × tester analysis and genetic component

4.6 Combining ability analysis

4.7 Heterosis analysis

4.1 Analysis of variance:

Analysis of variance for grain yield and its contributing traits is presented in table 4.1 Genotypes consisting parents and crosses in line X tester design showed significant variation for all the 14 characters viz., days to heading, days to maturity, plant height, tillers per plant, spike length, 1st inter-nodes length, weight of spikes per plant, weight of grains per spike, grains per spike, test weight, grain yield per plant, canopy temperature index, biological yield and harvest index. It indicated that there was considerable variability for these characters in the present material thus combining ability analysis may yield significance of genetic components for these traits. Parents had significant variation for days to heading, days to maturity, plant height, tillers per plant, spike length, 1st inter-nodes length, weight of spikes per plant, weight of grains per spike, grains per spike, test weight, grain

yield per plant, biological yield and harvest index, whereas, crosses were significant for days to heading, days to maturity, plant height, tillers per plant, spike length, 1st inter-nodes length, weight of grains per spike, grains per spike, test weight, grain yield per plant, canopy temperature index, biological yield and harvest index. The mean sums of squares due to crosses vs. parents were significant for days to heading, days to maturity, plant height, tillers per plant, spike length, 1st inter-nodes length, weight of spikes per plant, weight of grains per spike, grains per spike, test weight, grain yield per plant, canopy temperature index, biological yield and harvest index.

Table 4.1 Analysis of Variance for 14 characters in wheat crosses in Line X Tester mating design

Sources	D F	Days to headin g	Days to maturit y	Plant height	Tillers /Plant	1 st inter - node length	Spike length	Wt. of Spike/Pl ant
Replicati on	1	1.81*	0.45	2.71*	0.12	0.00 3	0.08* *	0.39
Treatmen t	53	3.73**	5.14**	55.91* *	0.57**	0.08 **	1.81* *	3.84**
Parents	13	5.98**	6.34**	38.97* *	0.77**	0.07 **	1.61* *	3.68**
C v/s P	1	28.12* *	0.002* *	33.42* *	1.24**	0.10 **	0.59* *	2.84**
Crosses	39	2.35**	4.87**	62.13* *	0.49**	0.08 **	1.91* *	3.92**
Error	53	0.40	0.49	0.66	0.08	0.01	0.01* *	0.17**

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Sources	D F	Grain s weig ht/ Spike	Grai ns/ Spi ke	Test weight	Grains yield/ Plant	Canopy tempera ture index	Biologi cal yield	Harve st index
Replicati on	1	0.000 8	35. 94**	0.08	0.01	0.0032**	0.01	2.24
Treatmen t	53	0.04* *	57. 55**	18.67* *	2.93**	0.0026**	9.50**	40.42* *
Parents	13	0.02* *	52. 13**	7.78**	1.54**	0.0008	8.67**	34.87* *
C vs P	1	0.11* *	7.8 0**	51.60* *	5.61**	0.0924**	212.81 **	664.7 4**
Crosses	39	0.04* *	60. 63**	21.45* *	3.32**	0.0010**	4.56**	26.26* *
Error	53	0.01	1.0 6	0.18	0.02	0.0001	0.32	1.57

*, ** significant at 5 and 1 per cent level, respectively

4.2 Mean performance: The mean performance of parents and their 40 F₁'s made in Line × Tester mating design have been described for different characters and presented in table 4.2

- Days to heading:** Genotypes were significantly varied for days to heading; it ranged from 85.50 days (GW273) to 91.00 days (45thIBWSN1021) among the parents. Whereas, among the crosses, it ranged from 83.50 days (PBW658 × GW366) to 89.50 days (45thIBWSN1021 × GW273) Genotype viz., 20thHRWYT 213, 36thSAWSN3065 and GW273 showed significantly early for days to heading among the parents and among the crosses, '36thSAWSN3065 × RVW4106' and 'PBW658 × GW366' showed significantly early for days to heading.
- Days to maturity:** Genotypes were significantly varied for days to maturity; it ranged from 134.50 days (14thFHBSN6418) to 141.00 days (36thSAWSN3065) among the parents. Crosses were ranging from 135days (33rdESWYT150 × GW366) to 141days (36thSAWSN3065 × GW273). Genotype 14thFHBSN6418, VW 921, GW273 showed significantly early in maturity among the parents and among crosses, '33rdESWYT150 × GW 366', 'PBW658 × RVW4106', '33rdESWYT150 × RVW4106' showed significantly early in maturity.
- Plant height:** Parents were significantly varied for plant height; it ranged from 93.50 cm (36thSAWSN3065) to 109.80 cm (20thHRWYT235). Among crosses, it ranged from 88.40 cm (PBW658 × GW366) to 110.10 cm (36thSAWSN3065 × RVW4106).

Parent 36thSAWSN3065 showed significantly lower plant height. Crosses, 'PBW658×GW366' and '33rdESWYT150 × GW273' showed significantly lower plant height.

4. **Tillers per plant:** Parents were significantly varied for tillers per plant, it ranged from 6.50 (14thFHBSN 6418) to 8.40 (GW366). Among the crosses, it ranged from 6.00 (KB2013 × GW273) to 8.30 (33rdESWYT150 × GW366). Parents GW366 followed by SUJATA and GW273 showed significantly higher tillers per plant. Whereas, '33rdESWYT150 × GW366', '33rdESWYT150 × RVW4106' and 'KB2013-03 × GW273' crosses showed significantly higher tillers per plant
5. **1st inter-node length:** Parents varied significantly for 1st inter-node length; it ranged from 2.58 cm (36thSAWSN3065) to 3.13 cm (GW366). Crosses ranged from 2.54 cm (33rdESWYT150 × GW273) to 3.37 cm (36thSAWSN3065 × GW273). Parents, 36thSAWSN3065, 14thFHBSN6418 and SUJATA showed significantly lower 1st inter-node length and genotype GW366, GW273 and 20thHRWYT 213 significantly higher 1st inter-node length. Among crosses, '33rdESWYT150 × GW273', '45thIBWSN1021 × RVW4106' and 'KB2013-03 × GW273' showed significantly lower 1st inter-node length and crosses '36thSAWSN3065 × GW273' and '36thSAWSN3065 × GW366' significantly higher 1st inter-node length.
6. **Spike length:** Parent varied significantly for spike length, it ranged from 8.91 cm (20thHRWYT 235) to 11.32 cm (SUJATA). Among crosses, it ranged from 8.35 cm (KB2013-03 × RVW4106) to 12.07 cm (45thIBWSN1021 × SUJATA). Parents, SUJATA, RVW4104 and 45thIBWSN1021 showed significantly higher spike length. Among crosses '45thIBWSN1021 × SUJATA' showed significantly higher spike length.
7. **Weight of spikes per plant:** Parents were significantly varied for weight of spikes per plant it ranged from 20.09 g (KB2013) to 24.46 g (GW273). Crosses ranged from 20.47 g (KB2013-03 × GW273) to 24.58 g (KB2013-03 × SUJATA). Parents, GW273, GW366 and SUJATA showed significantly higher weight of spikes per plant and crosses 'KB2013-03 × SUJATA', '33rdESWYT150 × RVW4106' and '33rdESWYT150 × GW366' showed significantly higher weight of spikes per plant.
8. **Weight of grains per spike:** Parents varied significantly for weight of grains per spikes; it ranged from 1.94 g (20thHRWYT235) to 2.28 g (GW366). Crosses ranged from 1.74 g (20thHRWYT213 × GW366) to 2.22 g (KB2013-03 × SUJATA). Parents, GW366 and GW273 showed significantly higher weight of grains per spike. 'KB2013-03 × SUJATA', '33rdESWYT150×GW366' and 'VW921×SUJATA' showed significantly higher weight of grains per spike.

9. **Grains per spikes:** Parents varied significantly for grains per spikes, it ranged from 53.80 (20thHRWYT235) to 70.80 (SUJATA) among parents. Crosses ranged from 53.60 (VW921 × GW366) to 72.70 (45thIBWSN1021 × SUJATA). SUJATA showed significantly higher grains per spikes. Cross '45thIBWSN1021 × SUJATA', 'PBW658 × GW366' and '20thHRWYT 213 × GW366' showed significantly higher grains per spikes.
10. **Test weight:** Parents varied significantly for test weight it ranged from 38.02 g (RVW4104) to 44.78 g (GW273). Crosses ranged from 32.37 g (20thHRWYT213 × GW366) to 45.05 g (33rdESWYT150 × RVW4106). GW273 and GW366 showed significantly higher test weight and crosses, '33rdESWYT150 × RVW4106', '33rdESWYT150 × GW366' and 'KB2013-03 × SUJATA' recorded higher significant test weight.
11. **Grain yield per plant:** Parents varied significantly for grain yield per plant; it ranged from 14.89 g (RVW4104) to 17.91 g (GW273). Crosses ranged from 12.97 g (20thHRWYT213 × GW366) to 18.06 g (33rdESWYT150 × RVW4106). Parents, GW273 and GW366 showed significantly higher grain yield per plant and '33rdESWYT150 × RVW4106', 'KB2013-03 × SUJATA' and '33rdESWYT150 × GW366' showed significantly higher grain yield per plant.
12. **Canopy temperature index:** Parents varied significantly for canopy temperature index, it ranged from 0.33 (20thHRWYT213) to 0.41 (GW273). Crosses ranged from 0.25 (20thHRWYT213 × GW366) to 0.35 (VW921 × RVW4106). Parents, GW273 and GW366 showed significantly higher canopy temperature index and 20thHRWYT213 and 36thSAWSN 3065 showed significantly lower canopy temperature index. Among crosses 'VW921 × RVW4106' showed significantly higher canopy temperature index and '20thHRWYT213 × GW366', '33rdESWYT150 × GW273' and '14thFHBSN6418 × SUJATA' showed significantly lower canopy temperature index.
13. **Biological yield:** Parents varied significantly for biological yield, it ranged from 32.70 g (GW273) to 39.40 g (33rdESWYT150). Among crosses, it ranged from 35.30 g (KB2013-03 × SUJATA) to 42.66 g (33rdESWYT150 × GW273). Parents, 33rdESWYT150 recorded significantly higher biological yield. '33rdESWYT150 × GW273' recorded significantly higher biological yield.
14. **Harvest index:** Parent varied significantly for harvest index, it ranged from 41.22 (33rdESWYT150 × GW273) to 54.75 (GW273). Crosses ranged from 34.13 (20thHRWYT213 × GW366) to 50.96 (KB2013-03 × SUJATA). Parents, GW273 and GW366 showed significantly higher harvest index. Cross 'KB2013-03 × SUJATA' showed significantly lower harvest index.

Table 4.2 Mean observations on Grains yield and its components of 40 crosses and parents in wheat

S.N o.	Genotypes	Days to head ing	Days to matur ity	Plan t heig ht (cm)	Tille rs / Plan t	1 st inter - nod e leng th (cm)	Spik e leng th (cm)	Wt. of Spike/Pl ant (g)
1	33rd ESWYT 150xGW 273	86.50	139.0 0	89.7 5	7.80	2.54	8.54	22.80
2	33rd ESWYT 150xGW 366	85.00	135.0 0	104. 30	8.30	3.06	9.87	23.98
3	33rd ESWYT 150xRVW4106	86.00	135.5 0	109. 10	8.30	3.02	8.73	24.49
4	36th ESWYT 150xSUJATA	86.50	137.0 0	105. 95	6.90	2.93	11.2 3	22.05
5	20thHRWYT 213xGW273	86.00	136.5 0	105. 80	7.70	2.68	10.2 7	23.38
6	20thHRWYT 213xGW366	86.50	138.0 0	96.9 0	6.40	3.05	11.2 5	19.21
7	20thHRWYT 213xRVW4106	85.00	135.5 0	103. 80	6.90	3.03	10.2 4	21.72
8	20thHRWYT 213xSUJATA	86.50	135.5 0	109. 50	7.10	3.07	8.92	20.71
9	20thHRWYT 235xGW273	85.00	136.0 0	104. 60	7.30	2.83	11.3 4	19.13
10	20thHRWYT 235xGW366	85.00	135.5 0	105. 10	7.10	2.75	10.1 1	21.06
11	20thHRWYT 235xRVW4106	87.50	140.5 0	103. 70	7.00	3.08	10.9 9	19.82
12	20thHRWYT 235xSUJATA	86.50	137.5 0	106. 50	7.20	3.09	10.1 4	22.09
13	45thIBWSN1021xGW 273	89.50	138.0 0	109. 20	7.00	3.09	8.90	23.06
14	45thIBWSN1021xGW 366	85.50	137.0 0	105. 60	7.70	3.06	11.2 7	18.99
15	45thIBWSN1021xRV W4106	85.50	136.5 0	105. 20	6.90	2.55	10.1 4	21.67
16	45thIBWSN1021xSU JATA	87.00	140.0 0	90.0 0	7.30	2.79	12.0 7	20.71
17	14thFHBSN6418xG W273	86.50	138.5 0	104. 00	7.00	3.03	9.99	22.27
18	14thFHBSN6418xG W366	85.50	138.0 0	108. 80	7.10	3.13	8.93	22.50
19	14thFHBSN6418xRV W4106	86.50	137.0 0	106. 90	6.50	2.89	11.3 5	20.98
20	14thFHBSN6418xSU JATA	88.00	135.5 0	106. 40	6.40	2.72	10.2 1	22.04
21	36thSAWSN3065xG W273	86.00	141.0 0	99.4 0	7.10	3.37	10.8 6	20.95
22	36thSAWSN3065xG W366	85.50	137.0 0	104. 30	7.00	3.27	10.0 0	21.95
23	36thSAWSN3065xR VW4106	84.50	138.0 0	110. 10	7.10	3.20	8.91	22.09
24	36thSAWSN3065xS UJATA	85.50	138.0 0	105. 60	6.90	3.01	11.2 0	20.56
25	PBW658xGW273	86.00	136.0	106.	6.70	2.92	10.3	23.05

S.N o.	Genotypes	Days to head ing	Days to matur ity	Plan t heig ht (cm)	Tille rs / Plan t	1 st inter - nod e leng th (cm)	Spik e leng th (cm)	Wt. of Spike/Pl ant (g)
			0	30			2	
26	PBW658xGW366	83.50	138.5 0	88.4 0	7.10	2.62	11.1 7	21.71
27	PBW658xRVW4106	85.50	135.0 0	104. 30	6.50	2.86	9.97	22.47
28	PBW658xSUJATA	85.00	136.5 0	109. 70	7.10	2.98	8.75	21.92
29	KB2013-03xGW273	85.00	136.0 0	106. 20	8.00	2.62	11.0 9	20.47
30	KB2013-03xGW366	85.50	135.5 0	106. 30	6.90	2.67	10.2 7	23.37
31	KB2013- 03xRVW4106	86.00	139.0 0	92.4 0	7.00	2.99	8.35	22.19
32	KB2013-03xSUJATA	87.50	135.5 0	104. 60	6.50	3.06	10.1 9	24.58
33	KB2013xGW273	85.50	135.5 0	110. 00	6.00	3.05	8.85	23.06
34	KB2013xGW366	87.50	136.0 0	104. 50	6.90	2.73	10.9 1	21.11
35	KB2013xRVW4106	85.50	135.5 0	106. 20	6.20	2.71	10.6 9	22.85
36	KB2013xSUJATA	86.00	138.5 0	97.6 0	7.10	3.11	11.2 4	23.14
37	VW921xGW273	85.50	135.5 0	105. 50	6.80	3.07	10.1 6	23.07
38	VW921xGW366	86.00	137.5 0	110. 00	7.20	3.12	8.87	23.87
39	VW921xRVW4106	87.00	137.0 0	107. 90	7.30	2.93	11.1 1	20.56
40	VW921xSUJATA	87.50	135.5 0	104. 40	6.90	2.80	10.8 7	23.02
41	33rd ESWYT 150	87.00	139.0 0	100. 20	7.20	3.02	10.4 3	21.22
42	20th HRWYT 213	86.50	138.0 0	104. 70	7.20	3.06	10.3 0	21.21
43	20thHRWYT 235	87.00	135.5 0	109. 80	6.90	2.83	8.91	21.52
44	45th IBWSN 1021	91.00	137.5 0	108. 60	7.70	2.68	11.1 4	21.22
45	14th FHBSN 6418	89.50	134.5 0	105. 00	6.50	2.64	11.0 7	22.51
46	36thSAWSN 3065	86.50	141.0 0	93.5 0	7.00	2.58	9.84	23.05
47	PBW 658	86.50	138.5 0	104. 70	7.00	2.90	10.2 9	23.41
48	KB 2013-03	89.50	136.5 0	109. 60	6.90	3.02	8.94	21.01
49	KB 2013	88.00	137.0 0	109. 00	6.90	2.91	11.0 3	20.09
50	VW 921	87.50	135.0 0	103. 90	7.10	2.77	11.1 1	23.08

S.N o.	Genotypes	Days to heading	Days to maturity	Plant height (cm)	Tillers / Plant	1 st internode length (cm)	Spike length (cm)	Wt. of Spike/Plant (g)
51	GW 273	85.50	135.00	104.80	8.30	3.11	10.75	24.46
52	GW 366	85.50	136.00	108.00	8.40	3.13	8.91	24.25
53	RVW 4104	85.50	137.00	109.05	6.80	2.83	11.22	21.91
54	SUJATA	85.50	137.00	104.60	8.30	2.68	11.32	23.78
	Mean	86.35	136.97	104.45	7.12	2.92	10.25	22.06
	SE (m)	0.45	0.50	0.57	0.21	0.06	0.06	0.29
	CD at 5%	1.24	1.37	1.59	0.57	0.16	0.18	0.80
	CV %	0.73	0.51	0.77	4.08	2.75	0.88	1.86

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S.N o.	Genotypes	Grains weight/ Spike (g)	Grains per Spike	Test weight (g)	Grains yield per Plant (g)	Canopy temperature index (%)	Biological yield (g)	Harvest index (%)
1	33rd ESWYT 150xGW 273	2.04	57.30	43.30	17.31	0.27	42.66	40.57
2	33rd ESWYT 150xGW 366	2.19	59.90	44.78	17.87	0.31	41.48	43.08
3	33rd ESWYT 150xRVW4106	2.12	56.90	45.05	18.06	0.28	40.97	44.07
4	33rd ESWYT 150xSUJATA	2.12	70.50	41.22	16.49	0.29	39.90	41.31
5	20thHRWYT 213xGW273	2.10	62.60	42.62	16.98	0.32	38.74	43.83
6	20thHRWYT 213xGW366	1.74	70.70	32.37	12.97	0.25	37.99	34.13
7	20thHRWYT 213xRVW4106	2.14	62.50	37.93	15.18	0.31	38.79	39.13
8	20thHRWYT 213xSUJATA	2.09	56.10	38.89	15.44	0.32	39.34	39.49
9	20thHRWYT 235xGW273	1.69	71.20	35.30	14.42	0.28	39.40	36.61
10	20thHRWYT 235xGW366	1.92	62.00	39.08	15.57	0.31	40.50	38.24
11	20thHRWYT 235xRVW4106	1.74	63.90	32.40	12.99	0.30	36.87	35.23
12	20thHRWYT 235xSUJATA	1.77	63.60	37.00	14.80	0.29	40.47	36.56
13	45thIBWSN1021xGW273	1.91	55.10	39.25	15.70	0.28	41.25	38.07
14	45thIBWSN1021xGW366	1.76	70.20	33.33	13.31	0.32	37.65	35.36
15	45thIBWSN1021xR	1.98	61.6	39.6	15.8	0.30	40.42	39.23

S.N o.	Genotypes	Grai ns weig ht/ Spik e (g)	Grai ns per Spik e	Test weig ht (g)	Grai ns yield per Plan t (g)	Canopy tempera ture index (%)	Biologi cal yield (g)	Harv est index (%)
	VW4106		5	4	7			
16	45thIBWSN1021xS UJATA	1.91	72.7 0	36.4 4	14.5 7	0.30	37.84	38.51
17	14thFHBSN6418xG W273	2.00	56.8 0	39.0 4	15.6 2	0.31	38.98	40.06
18	14thFHBSN6418xG W366	1.86	54.4 0	39.4 7	15.7 9	0.32	40.90	38.59
19	14thFHBSN6418xR VW4106	1.82	70.6 0	35.7 9	14.3 2	0.29	38.96	36.74
20	14thFHBSN6418xS UJATA	2.00	62.2 0	39.7 2	15.8 7	0.25	42.04	37.80
21	36thSAWSN3065xG W273	2.03	63.9 0	39.6 1	15.7 6	0.26	40.00	39.39
22	36thSAWSN3065xG W366	2.03	64.9 0	40.9 9	16.3 1	0.25	39.40	41.40
23	36thSAWSN3065xR VW4106	2.01	57.5 0	40.1 6	16.0 6	0.28	39.49	35.67
24	36thSAWSN3065xS UJATA	1.74	69.5 0	36.1 0	14.4 4	0.30	38.38	37.62
25	PBW658xGW273	2.04	63.2 0	41.5 4	16.6 0	0.28	38.91	42.66
26	PBW658xGW366	1.99	70.9 0	40.0 7	16.0 4	0.29	39.19	40.95
27	PBW658xRVW4106	2.09	66.4 0	40.0 1	16.0 6	0.26	36.48	44.03
28	PBW658xSUJATA	1.99	54.7 0	42.2 3	16.8 9	0.29	37.90	44.55
29	KB2013-03xGW273	1.82	68.1 0	36.9 8	14.7 9	0.29	39.62	37.33
30	KB2013-03xGW366	2.12	65.7 0	42.9 0	17.1 6	0.30	38.91	44.10
31	KB2013- 03xRVW4106	2.05	56.1 0	42.7 0	16.6 3	0.30	38.25	43.46
32	KB2013- 03xSUJATA	2.22	66.9 0	44.9 2	18.0 0	0.30	35.30	50.96
33	KB2013xGW273	2.20	57.2 0	43.0 7	17.2 7	0.30	37.76	45.72
34	KB2013xGW366	1.80	62.8 0	38.3 2	15.3 2	0.31	37.92	41.07
35	KB2013xRVW4106	2.11	63.3 0	43.5 4	17.4 2	0.29	38.55	45.16
36	KB2013xSUJATA	2.11	68.3 0	41.0 6	16.4 2	0.32	38.39	42.79
37	VW921xGW273	2.02	66.3 0	42.0 4	16.4 9	0.30	37.72	43.67
38	VW921xGW366	2.11	53.6 0	43.5 8	17.4 3	0.28	37.69	46.25
39	VW921xRVW4106	1.91	66.8 0	39.4 6	15.7 5	0.35	38.31	41.10
40	VW921xSUJATA	2.15	63.3 0	42.3 0	17.0 1	0.32	39.67	42.86
41	33rd ESWYT 150	2.00	61.9 0	40.7 9	16.2 3	0.36	39.40	41.22

S.No.	Genotypes	Grains weight/ Spike (g)	Grains per Spike	Test weight (g)	Grains yield per Plant (g)	Canopy temperature index (%)	Biological yield (g)	Harvest index (%)
42	20th HRWYT 213	1.99	62.30	40.92	16.37	0.33	37.64	43.49
43	20thHRWYT 235	1.94	53.80	40.67	16.27	0.36	36.51	44.55
44	45th IBWSN 1021	1.97	59.80	39.86	15.95	0.35	37.17	42.90
45	14th FHBSN 6418	2.05	61.50	41.74	16.48	0.36	36.21	45.50
46	36thSAWSN 3065	2.01	60.80	42.86	16.87	0.34	38.18	44.19
47	PBW 658	2.12	60.80	41.82	16.46	0.35	35.76	46.59
48	KB 2013-03	2.07	54.20	40.49	16.11	0.36	35.29	45.65
49	KB 2013	2.02	67.30	38.69	14.98	0.37	37.96	43.09
50	VW 921	2.04	66.50	41.54	16.56	0.36	35.04	47.27
51	GW 273	2.26	68.10	44.78	17.91	0.41	32.70	54.75
52	GW 366	2.28	60.60	44.54	17.81	0.39	33.10	53.75
53	RVW 4104	1.97	68.60	38.02	14.89	0.35	33.77	44.10
54	SUJATA	2.11	70.80	43.33	17.33	0.36	33.48	51.75
	Mean	2.00	63.10	40.26	16.06	0.31	38.24	42.14
	SE (m)	0.05	0.73	0.30	0.10	0.01	0.40	0.89
	CD at 5%	0.15	2.02	0.84	0.28	0.02	1.11	2.46
	CV %	3.81	1.63	1.06	0.90	3.84	1.48	2.97

4.3 Phenotypic and genotypic coefficient of variation (PCV and GCV). PCV and GCV have been presented in table 4.3. Phenotypic coefficient of variation (PCV) were recorded highest for canopy temperature index (13.93%) followed by harvest index (10.78%), spike length (9.30%), grain/spike (8.58%), tillers/plant (8.06%), test weight (7.62%), grain yield/plant (7.56%), weight of grains/spike (7.45%), 1st inter-node length (7.00%), weight of spike/plant (6.42%), biological yield (5.71%) and plant height (5.09%) whereas, comparatively lower in days to maturity (1.23%) and days to heading (1.66%). The highest genotypic coefficient of variation (GCV) were observed for the canopy temperature

index (13.21%) followed by harvest index (10.37%), spike length (9.26%), grain/spike (8.42%), test weight (7.55%), grain yield/plant (7.51%), tillers/plant (6.95%), 1st inter-node length (6.44), weight of grain/spike (6.40%), weight of spike/plant (6.15%), biological yield (5.52%) and plant height (5.03%) whereas, comparatively lower in days to maturity (1.11%) and days to heading (1.49%).

Heritability: (broad- sense heritability)

The estimates of broad-sense heritability % have been presented in Table 4.3 the Higher heritability were observed for spike length (99.11%), grain yield per plant (98.58%), test weight (98.07%), plant height (97.68%), grains per spike (96.39%), biological yield (93.45%), harvest index (92.52%), weight of spikes per plant (91.61%), canopy temperature index (89.91%), 1st inter-node length (84.56%), days to maturity (82.55), days to heading (80.64%), tillers per plant (74.34%), weight of grains per spike (73.88%).

Genetic advance:

The estimates of genetic advance in Table 4.3 revealed that the higher genetic advance as per cent were observed for canopy temperature index (25.80%), harvest index (20.54%). the moderate genetic advance were observed for spike length (18.99%), grains per spike (17.03%), test weight (15.40%), grain yield per plant (15.36%), tillers per plant (12.35%), 1st inter-node length (12.19%), weight of spike per plant (12.12%), weight of grains per spike (11.33%), biological yield (11.00%), plant height (10.25%).

Table 4.3 Range, mean, phenotypic coefficients of variation (PCV) and genotypic coefficient of variation (GCV), heritability (broad sense) and genetic advance for different characters in wheat

S · N o	Characters	Range	Me an	G V	PV	G CV	PC V	Broa d sens e herita bility (%)	Gen etic adv anc e	Gen etic adv anc e as % of mea n
1	Days to heading	83.50 - 90	86. 35	1. 66	2. 06	1. 49	1. 66	80.64	2.39	2.76
2	Days to maturity	134.50 - 141	136. .97	2. 32	2. 82	1. 11	1. 23	82.55	2.85	2.08
3	Plant height (cm)	88.70 - 110.10	104. .45	27. .6 2	28. .2 8	5. 03	5. 09	97.68	10.7 0	10.2 5
4	Tillers / Plant	6 - 8.40	7.1 2	0. 24	0. 33	6. 95	8. 06	74.34	0.88	12.3 5
5	1 st inter-node length (cm)	2.54 - 3.37	2.9 2	0. 04	0. 04	6. 44	7. 00	84.56	0.36	12.1 9
6	Spike length (cm)	8.35 - 12.07	10. 25	0. 90	0. 91	9. 26	9. 30	99.11	1.95	18.9 9
7	Wt. of Spike/Plant (g)	20.09 - 24.58	22. 06	1. 84	2. 01	6. 15	6. 42	91.61	2.67	12.1 2
8	Grains weight/Spike (g)	1.74 - 2.28	2.0 0	0. 02	0. 02	6. 40	7. 45	73.88	0.23	11.3 3
9	Grains/Spike	53.60 - 72.70	63. 10	28. .2 4	29. .3 0	8. 42	8. 58	96.39	10.7 5	17.0 3
10	Test weight (g)	32.37 - 45.05	40. 26	9. 24	9. 42	7. 55	7. 62	98.07	6.20	15.4 0
11	Grains yield/Plant (g)	12.97 - 18.06	16. 06	1. 45	1. 47	7. 51	7. 56	98.58	2.47	15.3 6
12	Canopy temperature index	0.25 - 0.41	0.2 7	0. 00	0. 00	13. .2 1	13. .9 3	89.91	0.07	25.8 0
13	Biological yield (g)	32.70 - 42.66	38. 80	4. 59	4. 91	5. 52	5. 71	93.45	4.27	11.0 0
14	Harvest index (%)	34.13 - 54.75	42. 52	19. .4 2	21. .0 0	10. .3 7	10. .7 8	92.52	8.73	20.5 4

4.4 Correlation analysis: Phenotypic and genotypic correlation coefficient among grain yield per plant and its contributing characters are presented below:-

Phenotypic correlation coefficient:

1. **Grain yield:** Correlation analysis presented in Table 4.4.1 revealed that grain yield exhibited significant positive association with test weight (0.9895), weight of spike/plant (0.8565), weight of grains/spike (0.7921) and harvest index (0.7667), whereas, spike length (-0.4579), grains/spike (-0.3757) and days to maturity (-0.3077) exhibited negative but significant association with grain yield.
2. **Days to maturity:** It exhibited significant negative correlation with plant height (-0.5237), weight of grain/spike (-0.3009), harvest index (-0.3355), test weight (-0.2849).
3. **Spike length:** It showed significant positive correlation with grains/spike and significant negative correlation with test weight (-0.4618), weight of spike/plant (-0.3865), weight of grains/spike (-0.3163) and 1st inter-node length (-0.2499).
4. **Grain/spike:** It showed significant negative correlation with test weight (-0.3849), plant height (-0.3010), weight of spike/plant (-0.2857) and significant positively correlated with spike length (0.8640).
5. **Weight of grain/spike:** It exhibited significant positive correlation with test weight (0.8094), weight of spike/plant (0.7115), harvest index (0.7232) and canopy temperature index (0.2768), significantly negatively correlated with spike length (-0.3163) and days to maturity (-0.3009).
6. **Test weight:** It exhibited significant positive correlation with weight of grains/spike (0.8094), weight of spike/plant (0.7115) and harvest index (0.7323) significantly negatively correlated with spike length (-0.4618), grains/spike (-0.3849) and days to maturity (-0.2849).
7. **Harvest index:** It exhibited the significant positive correlation with weight of grains/spike (0.7232), test weight (0.7795), weight of spike/plant (0.6948) and canopy temperature index (0.5617) significantly negatively correlated with biological yield (-0.6739), days to maturity (-0.3355).
8. **Weight of spike/plant:** It exhibited the significant positive correlation with test weight (0.8531), weight of grain/spike (0.7115) and harvest index (0.6948) significantly negatively correlated with spike length (-0.3868) and grains/spike (-0.2857).

Genotypic correlation coefficient:

1. **Grain yield :** Correlation analysis presented in Table 4.4.2 revealed that grain yield exhibited significant positive association with test weight (0.9992); weight of

grains/spike (0.9217); weight of spike/plant (0.8985); and harvest index (0.7966), whereas, spike length (-0.4632), days to maturity (-0.3385) and grains/spike (-0.3855) and exhibited negative but significant association between yield.

2. **Test weight:** It showed significant positive correlation with weight of grains/spike (0.9198), weight of spike/plant (0.8941) and harvest index (0.8076). Significantly negatively correlated with spike length (-0.4684), grains/spike (-0.3894) and days to maturity (-0.3174).
3. **Weight of grain/spike:** It showed significant positive correlation with test weight (0.9198), weight of spike/plant (0.8730), harvest index (0.8367) and canopy temperature index (0.3177), significantly negatively correlated with spike length (-0.3696), days to maturity (-0.3690) and biological yield (-0.2872).
4. **Weight of spike/plant:** It exhibited the significant positive correlation with test weight (0.8941), weight of grain/spike (0.8730) and harvest index (0.7513) significantly negatively correlated with spike length (-0.4056), grains/spike (-0.3098) and days to maturity (-0.2911).
5. **Harvest index:** It showed significant positive correlation with weight of grains/spike (0.8367), test weight (0.8076), weight of spike/plant (0.7513) and canopy temperature index (0.6279) significantly negatively correlated with biological yield (-0.6876), days to maturity (-0.3511).
6. **Spike length:** It exhibited significant positive correlation with grains/spike and significant negative correlation with test weight (-0.4684), weight of spike/plant (-0.4056), weight of grains/spike (-0.3696) and 1st inter-node length (-0.2735).
7. **Days to maturity:** It recorded significant negative correlation with plant height (-0.5804), weight of grain/spike (-0.3639), harvest index (-0.3511), test weight (-0.3174) and weight of spike/plant (-0.2911).
8. **Grain/spike:** It recorded significant negative correlation with test weight (-0.3894), plant height (-0.3120), weight of spike/plant (-0.3098) and significant positively correlated with spike length (0.8840).

Table 4.4.1: Phenotypic correlation coefficient among 14 traits of wheat

	DH	DM	PH	TP	FIN	SL	GS	WGS	TW	BY	HI	CTI	WSP	GYP
DH	1.0000	0.0312	0.1456	-0.1438	-0.0872	0.0699	-0.1980	-0.0629	-0.0531	-0.1089	0.0472	0.2467	-0.0841	-0.0730
DM		1.0000	-0.5237*	0.0195	0.1435	0.0736	0.0018	-0.3009*	-0.2849*	0.1485	-0.3355*	-0.1228	-0.2619	-0.3077*
PH			1.0000	-0.0313	0.2442	-0.2208	-0.3010*	0.0627	0.0561	-0.1444	0.1241	0.1912	0.0778	0.0688
TP				1.0000	0.0143	-0.0464	-0.0049	0.1409	0.2142	-0.0808	0.2395	0.3027*	0.2127	0.2294
FIN					1.0000	-0.2499	-0.1686	0.0601	-0.0602	-0.0525	-0.0378	-0.1150	0.0072	-0.0596
SL						1.0000	0.8640**	-0.3163*	-0.4618**	-0.1928	-0.1766	0.0973	-0.3865**	-0.4579**
GS							1.0000	-0.2379	-0.3849**	-0.2051	-0.1135	-0.0316	-0.2857*	-0.3757**
WGS								1.0000	0.8094**	-0.2539	0.7232**	0.2768*	0.7115**	0.7921**
TW									1.0000	-0.1329	0.7795**	0.2394	0.8531**	0.9895**
BY										1.0000	-0.6739**	-0.6393**	-0.1613	-0.1087
HI											1.0000	0.5617**	0.6948**	0.7667**
CTI												1.0000	0.0013	0.2075
WSP													1.0000	0.8565**

*, ** significant at 5 and 1 per cent level, respectively

DH: Days to heading, DM: Days to maturity, PH: Plant height, TP: Tillers/plant, FIN: 1st inter-node length, SL: Spike length, GS: Grains/spike, WGS: Weight of grains/spike, TW: Test weight, BY: biological yield, HI: harvest index, CTI: canopy temperature index, WSP: weight of spike/plant, GYP: grain yield/plant

Table: 4.4.2 Genotypic correlation coefficient among 14 traits of wheat

	DH	DM	PH	TP	FIN	SL	GS	WGS	TW	BY	HI	CTI	WSP	GYP
DH	1.00 0	0.053 5	0.1661	0.1926	0.1375	0.0643	-0.2361	-0.0580	-0.0665	-0.0997	0.0535	0.3077*	-0.0884	-0.0785
DM		1.000 0	0.5804* *	0.0390	0.1828	0.0796	0.0291	0.3690* *	-0.3174*	0.1654	-0.3511*	-0.1659	-0.2911	-0.3385*
PH			1.0000	0.0490	0.2719	-0.2222	0.3120*	0.0673	0.0590	-0.1529	0.1346	0.1968	0.0848	0.0708
TP				1.0000	0.0188	-0.0641	0.0024	0.1613	0.2512	-0.1028	0.2598	0.3954* *	0.2104	0.2663
FIN					1.0000	0.2735* *	-0.1826	0.0791	-0.0664	-0.0354	-0.0584	-0.1132	0.0046	-0.0661
SL						1.0000	0.8840* *	0.3696* *	0.4684* *	-0.2003	-0.1844	0.1030	0.4056* *	0.4632* *
GS							1.0000	-0.2704	0.3894* *	-0.2213	-0.1149	-0.0443	-0.3098*	0.3855* *
WGS								1.0000	0.9198* *	-0.2872* *	0.8367* *	0.3177*	0.8730* *	0.9217* *
TW									1.0000	-0.1411	0.8076* *	0.2622	0.8941* *	0.9992* *
BY										1.0000	0.6876* *	0.6844* *	-0.1846	-0.1281
HI											1.0000	0.6279* *	0.7513* *	0.7966* *
CTI												1.0000	0.1685	0.2320
WSP													1.0000	0.8985* *

*, ** significant at 5 and 1 per cent level, respectively

DH: Days to heading, DM: Days to maturity, PH: Plant height, TP: Tillers/plant, FIN: 1st inter-node length, SL: Spike length, GS: Grains/spike, WGS: Weight of grains/spike, TW: Test weight, BY: biological yield, HI: harvest index, CTI: canopy temperature index, WSP: weight of spike/plant, GYP: grain yield/plant

Phenotypic path analysis: Direct and indirect effect of various traits on grain yield presented in table: 4.4.3.

1. **Days to heading:** Days to heading exhibited negative direct effect on grain yield (-0.0527) and its positive indirect effect on grain yield via canopy temperature index (0.1217) and tillers/plant (0.0196)
2. **Days to maturity:** Days to maturity recorded negative direct effect on grain yield (-0.0715) and its positive indirect effect on grain yield via biological yield (0.0532), plant height (0.0521) and weight of grain/spike (0.0299).
3. **Plant height:** Plant height exhibited negative direct effect on grain yield (-0.0995) and its positive indirect effect on grain yield via canopy temperature index (0.0943), weight of spike/plant (0.0766) and spike length (0.0191)
4. **Tiller / plant:** Tillers / plant exhibited negative direct effect on grain yield (-0.1365) but positive indirect effect via spike weight /plant (0.2093), canopy temperature index (0.1493) and test weight (0.0291).
5. **1st inter-node length:** It recorded positive direct effect on grain yield (0.0460) and showed positive indirect effect via spike length (0.0216) and weight of spike/plant (0.0070)
6. **Spike length:** Spike length showed negative direct effect on grain yield (-0.0863) and positive indirect effect on grain yield via grains/spike (0.0589), canopy temperature index (0.0480) and weight of grain/spike (0.0314)
7. **Grains / spikes:** Grain/spike exhibited positive direct effect on grain yield (0.0682) and positive indirect effect on grain yield via plant height (0.0299), weight of grains/spike (0.0236) and days to heading (0.0104)
8. **Weight of grain/spike:** Weight of grain/spike recorded negative direct effect on grain yield (-0.0994) and its positive indirect effect on grain yield via weight of spike/plant (0.7002), canopy temperature index (0.1366) and test weight (0.1101).
9. **Test weight:** Test weight had exhibited positive direct effect on grain yield (0.1360) and also showed positive indirect effect on grain yield via weight of spike/plant (0.08397), canopy temperature index (0.1181), spike length (0.0399) and harvest index (0.0240)
10. **Biological yield:** Grain/spike exhibited positive direct effect on grain yield (0.3583) and positive indirect effect on grain yield via weight of grains/spike (0.0252), spike length (0.0166) and tillers/plant (0.0110)
11. **Harvest index:** Harvest index exhibited positive direct effect on grain yield (0.0308) and also showed positive indirect effect on grain yield via weight of spike/plant

(0.6836), canopy temperature index (0.2771), test weight (0.1060) and days to maturity (0.0240)

12. Canopy temperature index: It exhibited positive direct effect on grain yield (0.4933) and showed positive indirect effect via test weight (0.0326) and harvest index (0.0173)

13. Weight of spike/plant: Weight of spike/plant exhibited positive direct effect on grain yield (0.9842) and showed positive indirect effect via spike length (0.0334) and harvest index (0.0214)

The residual path effect value found to be 0.1233

Genotypic path analysis: Direct and indirect effect of various traits on grain yield is presented in Table: 4.4.4.

- 1. Days to heading:** Days to heading showed positive direct effect on grain yield (0.0065) and its indirect effect on grain yield via grains/spike (0.0245) and biological yield (0.0121)
- 2. Days to maturity:** Days to maturity recorded meagre negative direct effect on grain yield (-0.0065) and high positive indirect effect on grain yield via harvest index (0.0448), canopy temperature index (0.0213) and weight of spike/plant (0.0109)
- 3. Plant height:** Plant height exhibited positive direct effect on grain yield (0.0171) and its indirect effect on grain yield via test weight (0.0609), grains/spike (0.0323) and biological yield (0.0185)
- 4. Tillers / plant:** it recorded positive direct effect on grain yield (0.0791) and its positive indirect effect on grain yield via test weight (0.2596)
- 5. 1st inter-node length:** It exhibited negative direct effect on grain yield (-0.0230) and it has indirect positive effect on grain yield via grain/spike (0.0189) and canopy temperature index (0.0145)
- 6. Spike length:** Spike length exhibited positive direct effect on grain yield (0.1065) and showed positive indirect effect via biological yield (0.0242), harvest index (0.0235), weight of spike/plant (0.0152), 1st inter-node length (0.0051) and days to heading (0.0004)
- 7. Grains/spikes:** Grain/spike exhibited negative direct effect on grain yield (-0.1037) but it indirectly contributed via spike length (0.0942), biological yield (0.0268), harvest index (0.0147), weight of spike/plant (0.0116)
- 8. Weight of grain/spike:** Weight of grain/spike exhibited positive direct effect on grain yield (0.1081) and showed positive indirect effect via test weight (0.9506), biological yield (0.0347), grains/spike (0.0280), tillers/plant (0.0128), plant height (0.0011) and days to maturity (0.0083)

- 9. Test weight:** Test weight had exhibited highest positive direct effect on grain yield (1.0335) and showed positive indirect effect via weight of grain/spike (0.0994), grains/spike (0.0404), tillers/plant (0.0199), biological yield (0.0171), days to maturity (0.0071), 1st inter-node length (0.0015) and plant height (0.0010)
- 10. Biological yield:** Grain/spike exhibited negative direct effect on grain yield (-0.1209) but it indirectly positive effect via harvest index (0.0878), canopy temperature index (0.0877) and grain/spike (0.0229)
- 11. Harvest index:** Harvest index exhibited negative direct effect on grain yield (-0.1277) but it indirectly contributed via test weight (0.8346), biological yield (0.0832), weight of grain/spike (0.0905), tillers/plant (0.0205) and grains/spike (0.0119)
- 12. Canopy temperature index:** It exhibited negative direct effect on grain yield (-0.1281) but it has indirect positive effect on grain yield via test weight (0.2710), biological yield (0.0828) and weight of grain/spike (0.0344)
- 13. Weight of spike/plant:** Weight of spike/plant exhibited negative direct effect on grain yield (-0.0376). It had positive indirect effect through test weight (0.9240), weight of grains/spike (0.0944), grains/spike (0.0321), biological yield (0.0223) and tillers/plant (0.0166)

The residual path effect value found to be 0.0352

Table 4.4.3: Phenotypic path analysis: Direct (diagonal) and indirect effect of 14 traits on Grains yield

	DH	DM	PH	TP	FIN	SL	GS	WGS	TW	BY	HI	CTI	WSP	GYP
DH	-0.0527	-0.0022	-0.0145	0.0196	-0.0040	-0.0060	-0.0135	0.0063	-0.0072	-0.0390	0.0015	0.1217	-0.0828	-0.0730
DM	-0.0016	-0.0715	0.0521	-0.0027	0.0066	-0.0063	0.0001	0.0299	-0.0388	0.0532	-0.0103	-0.0606	-0.2578	-0.3077
PH	-0.0077	0.0375	-0.0995	0.0043	0.0112	0.0191	-0.0205	-0.0062	0.0076	-0.0517	0.0038	0.0943	0.0766	0.0688
TP	0.0076	-0.0014	0.0031	-0.1365	0.0007	0.0040	-0.0003	-0.0140	0.0291	-0.0290	0.0074	0.1493	0.2093	0.2294
FIN	0.0046	-0.0103	-0.0243	-0.0020	0.0460	0.0216	-0.0115	-0.0060	-0.0082	-0.0188	-0.0012	-0.0567	0.0070	-0.0596
SL	-0.0037	-0.0053	0.0220	0.0063	-0.0115	-0.0863	0.0589	0.0314	-0.0628	-0.0691	-0.0054	0.0480	-0.3804	-0.4579
GS	0.0104	-0.0001	0.0299	0.0007	-0.0078	-0.0746	0.0682	0.0236	-0.0524	-0.0735	-0.0035	-0.0156	-0.2812	-0.3757
WGS	0.0033	0.0215	-0.0062	-0.0192	0.0028	0.0273	-0.0162	-0.0994	0.1101	-0.0910	0.0223	0.1366	0.7002	0.7921
TW	0.0033	0.0204	-0.0056	-0.0292	-0.0028	0.0399	-0.0262	-0.0804	0.1360	-0.0476	0.0240	0.1181	0.8397	0.9895
BY	0.0057	-0.0106	0.0144	0.0110	-0.0024	0.0166	-0.0140	0.0252	-0.0181	0.3583	-0.0208	-0.3154	-0.1587	-0.1087
HI	-0.0025	0.0240	-0.0123	-0.0327	-0.0017	0.0152	-0.0077	-0.0719	0.1060	-0.2414	0.0308	0.2771	0.6838	0.7667
CTI	-0.0130	0.0088	-0.0190	-0.0413	-0.0053	-0.0084	-0.0022	-0.0275	0.0326	-0.2290	0.0173	0.4933	0.0013	0.2075
WSP	0.0044	0.0187	-0.0077	-0.0290	0.0003	0.0334	-0.0195	-0.0707	-0.0219	-0.0578	0.0214	0.0006	0.9842	0.8565

DH: Days to heading, DM: Days to maturity, PH: Plant height, TP: Tillers/plant, FIN: 1st inter-node length, SL: Spike length, GS: Grains/spike, WGS: Weight of grains/spike, TW: Test weight, BY: biological yield, HI: harvest index, CTI: canopy temperature index, WSP: weight of spike/plant, GYP: grain yield/plant

Table 4.4.4 Genotypic path analysis: Direct (diagonal) and indirect effect of 14 traits on Grains yield

	DH	DM	PH	TP	FIN	SL	GS	WGS	TW	BY	HI	CTI	WSP	GYP
DH	0.0065	-0.0012	0.0028	-0.0152	0.0032	0.0069	0.0245	-0.0063	-0.0688	0.0121	-0.0068	-0.0394	0.0033	-0.0785
DM	0.0003	-0.0224	-0.0099	0.0031	-0.0042	0.0085	-0.0030	-0.0399	-0.3280	-0.0200	0.0448	0.0213	0.0109	-0.3385
PH	0.0011	0.0130	0.0171	-0.0039	-0.0063	-0.0237	0.0323	0.0073	0.0609	0.0185	-0.0172	-0.0252	-0.0032	0.0708
TP	-0.0013	-0.0009	-0.0008	0.0791	-0.0004	-0.0068	-0.0002	0.0174	0.2596	0.0124	-0.0332	-0.0507	-0.0079	0.2663
FIN	-0.0009	-0.0041	0.0046	0.0015	-0.0230	-0.0291	0.0189	0.0086	-0.0686	0.0043	0.0075	0.0145	-0.0002	-0.0661
SL	0.0004	-0.0018	-0.0038	-0.0051	0.0063	0.1065	-0.0916	-0.0400	-0.4841	0.0242	0.0235	-0.0132	0.0152	-0.4632
GS	-0.0015	-0.0007	-0.0053	0.0002	0.0042	0.0942	-0.1037	-0.0292	-0.4024	0.0268	0.0147	0.0057	0.0116	-0.3855
WGS	-0.0004	0.0083	0.0011	0.0128	-0.0018	-0.0394	0.0280	0.1081	0.9506	0.0347	-0.1069	-0.0407	-0.0328	0.9217
TW	-0.0004	0.0071	0.0010	0.0199	0.0015	-0.0499	0.0404	0.0994	1.0335	0.0171	-0.1031	-0.0336	-0.0336	0.9992
BY	-0.0006	-0.0037	-0.0026	-0.0081	0.0008	-0.0213	0.0229	-0.0311	-0.1458	-0.1209	0.0878	0.0877	0.0069	-0.1281
HI	0.0003	0.0079	0.0023	0.0205	0.0013	-0.0196	0.0119	0.0905	0.8346	0.0832	-0.1277	-0.0804	-0.0063	0.8185
CTI	0.0020	0.0037	0.0034	0.0313	0.0026	0.0110	0.0046	0.0344	0.2710	0.0828	-0.0802	-0.1281	-0.0063	0.2320
WSP	-0.0006	0.0065	0.0014	0.0166	-0.0001	-0.0432	0.0321	0.0944	0.9240	0.0223	-0.0959	-0.0216	-0.0376	0.8985

DH: Days to heading, DM: Days to maturity, PH: Plant height, TP: Tillers/plant, FIN: 1st inter-node length, SL: Spike length, GS: Grains/spike, WGS: Weight of grains/spike, TW: Test weight, BY: biological yield, HI: harvest index, CTI: canopy temperature index, WSP: weight of spike/plant, GYP: grain yield/plant

4.5 Line × tester and combining ability analysis:

Analysis of variances for combining ability showed that variances due to testers were significant for days to heading, plant height, tillers per plant, spike length, weight of spikes per plant, grains per spike, test weight, grain yield per plant, canopy temperature index, biological yield and harvest index (Table 4.5.1). Whereas, lines were significant for days to heading, days to maturity, plant height, tillers per plant, spike length, 1st inter-nodes length, weight of spikes per plant, weight of grains per spike, grains per spike, test weight, grain yield per plant, canopy temperature index, biological yield and harvest index. Variance due to Line × tester were significant for days to heading, days to maturity, plant height, tillers per plant, spike length, 1st inter-nodes length, weight of spikes per plant, weight of grains per spike, grains per spike, test weight, grain yield per plant, canopy temperature index, biological yield and harvest index. Thus it is indicated significance of both GCA and SCA variances in the present material.

Genetic components: The genetic component's magnitudes are presented in table 4.5.2 showed that additive components of variances were higher than dominance components of variances for all characters. The ratio of genetic components " $\sigma^2_{gca} / \sigma^2_{sca}$ " also showed more than one, indicating predominance of additive variances for all characters.

Table 4.5.1 Analysis of variance for combining ability for Grains yield and yield contributing characters in wheat

Sources	DF	Days to heading	Days to maturity	Plant height	Tillers/Plant	1 st inter-node length	Spike length	Wt. of Spike/Plant
Lines	9	2.48**	4.47**	25.01**	0.91**	0.09**	0.76**	6.10**
Tester	3	3.90**	0.55	8.04**	0.27	0.01	0.90**	0.54*
L X T	27	2.14**	5.49**	80.51**	0.38**	0.08**	2.41**	3.58**
Error	53	0.40	0.49	0.66	0.08	0.01	0.01	0.17

Continued.

Sources	DF	Grains weight/ Spike	Grains/Sp ike	Test weight	Grains yield/Plant	Canopy temperature index	Biological yield	Harvest index
Lines	9	0.08**	16.35**	48.25**	7.40**	0.0011**	8.66**	64.79**
Tester	3	0.01	26.96**	2.42**	0.42**	0.0004*	2.32**	3.69**
L X T	27	0.03**	79.12**	14.63**	2.29**	0.0010**	3.45**	15.93**
Error	53	0.01	1.06	0.18	0.02	0.0001	0.32	1.57

*, ** significant at 5 and 1 percent levels, respectively

Table 4.5.2 Genetic components for Grains yield and its attributes in wheat

Parameters	Days to heading	Days to maturity	Plant height	Tillers/Plant	1st inter-node length	Spike length	Wt. of Spike/Plant
Covariances							
Cov HS (Line)	0.04	-0.05	-2.77	0.03	0.00	-0.08	0.13
Cov HS (Tester)	0.09	-0.62	-9.06	-0.01	-0.01	-0.19	-0.38
Cov HS (Average)	0.01	-0.02	-0.45	0.00	0.00	-0.01	0.01
Cov FS	5.85	4.90	45.96	1.06	0.10	2.07	6.85
Genetic components							
σ^2 GCA (Lines)	0.01	-0.02	-0.45	0.00	0.00	-0.01	0.01
σ^2 GCA(Testers)	0.02	-0.06	-1.81	0.01	0.00	-0.05	0.03
σ^2 GCA (Parents)	11.77	-33.10	-526.51	-0.16	-0.50	-11.43	-17.24
σ^2 SCA	0.87	2.50	39.93	0.15	0.04	1.20	1.70
σ^2 GCA / σ^2 SCA	13.52	-13.26	-13.19	-1.06	-12.87	-9.54	-10.11
σ^2 A	23.54	-66.19	-1053.02	-0.31	-1.00	-22.87	-34.48
σ^2 D	0.87	2.50	39.93	0.15	0.04	1.20	1.70

Continued...

	Grains weight/Spike	Grains/Spike	Test weight	Grains yield/Plant	Canopy temperature index	Biological yield	Harvest index
Covariances							
Cov HS (Line)	0.00	-3.14	1.68	0.26	0.0000	0.65	6.11
Cov HS (Tester)	0.00	-6.52	-1.53	-0.23	-0.0001	-0.06	-0.61
Cov HS (Average)	0.00	-0.46	0.17	0.03	0.0000	0.03	0.25
Cov FS	0.08	55.12	52.38	8.10	0.0014	10.79	67.04
Genetic components							
σ^2 GCA (Lines)	0.00	-0.46	0.17	0.03	0.00	0.03	0.25
σ^2 GCA(Testers)	0.00	-1.82	0.67	0.10	0.00	0.11	1.02
σ^2 GCA (Parents)	-0.09	-401.83	-45.77	-7.03	0.00	-2.09	-30.72
σ^2 SCA	0.01	39.03	7.23	1.13	0.00	1.56	7.18
σ^2 GCA / σ^2 SCA	-6.58	-10.29	-6.33	-6.20	-7.80	-1.34	-4.28
σ^2 A	-0.18	-803.67	-91.54	-14.05	-0.01	-4.19	-61.45
σ^2 D	0.01	39.03	7.23	1.13	0.00	1.56	7.18

4.6 Combining ability analysis:

General combining ability effects: GCA effects presented in table 4.6.1.

1. **Days to heading:** Three lines viz., 45thIBWSN1021 (0.83), 14thFHBSN6418 (0.58) and VW921 (0.45) and tester SUJATA (0.55) recorded significant positive value of GCA effect. Whereas, lines 36thSAWSN3065 (-0.67) and PBW658 (-1.05) and tester GW366 (-0.50) recorded significant negative value of GCA effect.
2. **Days to maturity:** Lines 45thIBWSN1021 (0.90) and 36thSAWSN3065 (1.53) recorded significant positive and lines 20thHRWYT213 (-0.60), KB2013 (-0.60) and VW921 (-0.60) recorded significant negative value of GCA effect.
3. **Plant height:** Lines 20thHRWYT213 (0.85), 14thFHBSN6418 (2.41), 36thSAWSN3065 (0.73) and VW921 (2.83) and tester RVW 4106 (0.84) recorded significant positive value of GCA effect. Whereas, lines 33rdESWYT150 (-1.85), 45thIBWSN1021 (-1.62), PBW658 (-1.95), and KB2013-03 (-1.75 and tester GW 366(-0.70) recorded significant negative value of GCA effect.
4. **Tillers per plant:** Line 33rdESWYT150 recorded significant positive GCA effect (0.77) whereas, lines 14thFHBSN6418 (-0.31), PBW658 (-0.21) and KB2013-03 (-0.51) recorded significant negative GCA effect.
5. **1st inter-node length:** Lines 36thSAWSN3065 (0.28) recorded significant positive GCA effect and lines 45thIBWSN1021 (-0.07), PBW658 (-0.09) and KB2013-03 (-0.10) recorded significant negative value of GCA effect.
6. **Spike length:** Lines 20thHRWYT235 (0.44), 45thIBWSN1021 (0.39) and KB2013 (0.22) and tester GW366 (0.06) and SUJATA (0.28) significant positive GCA effect. Whereas, lines 33rdESWYT150 (-0.61), 14thFHBSN6418 (-0.09) and KB2013-03 (-0.23) and tester GW273 (-0.17) and RVW4106 (-0.16) recorded significant negative effect.
7. **Weight of spikes per plant:** Lines 33rdESWYT150 (1.36), PBW658 (0.32), KB2013-03 (0.68), KB2013 (0.58) and VW921 (0.66) recorded significant positive GCA effect. Whereas, lines 20thHRWYT213 (-0.71), 20thHRWYT235 (-1.44), 45thIBWSN1021 (-0.86), 36thSAWSN 3065 (-0.58) and tester GW366 (-0.19) recorded significant negative value of GCA effect.
8. **Weight of grains per spike:** Lines 33rdESWYT150 (0.13), KB2013-03 (0.07), KB2013 (0.07) and VW921 (0.06) recorded significant positive value of GCA effect and lines 20thHRWYT235 (-0.20), 45thIBWSN1021 (-0.10), 36thSAWSN3065 (-0.07) and tester GW366 (-0.03) recorded significant negative value of GCA effect.

9. **Grains per spikes:** Lines 20thHRWYT235 (1.92), 45thIBWSN1021 (1.66), KB2013-03 (0.94) and tester SUJATA recorded significant positive value of GCA effect. Whereas, lines 33rdESWYT150 (-2.11), 14thFHBSN6418 (-2.26) and VW921 (-0.76), and tester GW273 (-1.09) and RVW4104 (-0.69) recorded significant negative value of GCA effect and
10. **Test weight:** Lines 33rdESWYT150 (3.73), PBW658 (1.11), KB2013-03 (2.02), KB2013 (1.64), VW921 (1.99) and tester GW273 (0.42) recorded significant positive value of GCA effect. Whereas, lines 20thHRWYT213 (-1.90), 20thHRWYT235 (-3.91), 45thIBWSN1021 (-2.69), 14thFHBSN6418 (-1.35), 36thSAWSN3065 and tester GW366 (-0.37) and RVW4106 (-0.19) recorded significant negative value of GCA effect.
11. **Grain yield per plant:** Lines 33rdESWYT150 (1.51), PBW658 (0.47), KB2013-03 (0.72), KB2013 (0.68) and VW921 (0.75) and tester GW273 (0.17) and SUJATA (0.07) recorded significant positive value of GCA effect. Whereas, lines 20thHRWYT213 (-0.78), 20thHRWYT235 (-1.48), 45thIBWSN1021 (-1.06), 14thFHBSN6418 (-0.53), 36thSAWSN3065 (-0.20) and tester GW366 (-0.15) and RVW4106 (-0.09) recorded significant negative value of GCA effect.
12. **Canopy temperature index:** Lines KB2013 (0.01) and VW921 (0.02) recorded significant positive value of GCA effect. Whereas, lines 36thSAWSN3065 (-0.02) and PBW 658 (-0.01) and tester GW273 (-0.01) recorded significant negative value of GCA effect
13. **Biological yield:** Lines 36thSAWSN3065 (2.18), 36thSAWSN3065 (0.24), PBW658 (0.96) and KB2013-03 (1.05) recorded significant positive value and lines KB2013 (-0.92) and VW921 (-0.73) recorded significant negative value of GCA effect. Whereas, tester GW273 (0.43) recorded positive significant and tester RVW4104 (-0.37) recorded significant negative value of GCA effect.
14. **Harvest index:** Lines 33rdESWYT150 (1.57), PBW658 (2.36), KB2013-03 (3.28), KB2013 (3.00) and VW921 (2.79) recorded positive significant value and tester SUJATA recorded positive significant GCA effect.

Table 4.6.1 General combining effect (GCA) effect for Lines and Tester parents in wheat
Continued...

Lines	Days to heading	Days to maturity	Plant height	Tillers/Plant	1st inter-node length	Spike length	Wt. of Spike/Plant
33rd ESWYT 150	-0.05	-0.35	-1.85**	0.77**	-0.05	-0.61**	1.36**
20th HRWYT 213	-0.05	-0.60**	-0.12	-0.03	0.02	-0.04	-0.71**
20thHRWYT 235	-0.05	0.40	0.85**	0.09	0.00	0.44**	-1.44**
45th IBWSN 1021	0.83**	0.90**	-1.62**	0.17	-0.07**	0.39**	-0.86**
14th FHBSN 6418	0.58**	0.28	2.41**	-0.31**	0.01	-0.09**	-0.02
36thSAWSN 3065	-0.67**	1.53**	0.73**	-0.03	0.28**	0.04	-0.58**
PBW 658	-1.05**	-0.47	-1.95**	-0.21**	-0.09**	-0.15**	0.32**
KB 2013-03	-0.05	-0.47	-1.75**	0.04	-0.10**	-0.23**	0.68**
KB 2013	0.075	-0.60**	0.45	-0.51**	-0.04	0.22**	0.58**
VW 921	0.45*	-0.60**	2.83**	-0.01	0.04	0.05	0.66**
SE (GCA for line)	0.22	0.25	0.31	0.11	0.03	0.04	0.15
Tester							
GW 273	0.1	0.22	-0.05	0.08	-0.02	-0.17**	0.16
GW 366	-0.5**	-0.17	-0.70**	0.11	0.01	0.06**	-0.19**
RVW 4104	-0.15	-0.03	0.84**	-0.09	-0.01	-0.16**	-0.08
SUJATA	0.55**	-0.03	-0.09	-0.12	0.02	0.28**	0.12
SE (GCA for Tester)	0.14	0.16	0.18	0.07	0.02	0.02	0.09

Lines	Grains weight/Spik e	Grains/Spik e	Test weight	Grains yield/Plant	Canopy temperature index	Biological yield	Harvest index
33rd ESWYT 150	0.13**	-2.11**	3.73**	1.51**	-0.01	2.18**	1.57**
20th HRWYT 213	0.03	-0.28	-1.90**	-0.78**	0.01	-0.36	-1.54**
20thHRWYT 235	-0.20**	1.92**	-3.91**	-1.48**	0.00	0.24	-4.02**
45th IBWSN 1021	-0.10**	1.66**	-2.69**	-1.06**	0.01	0.21	-2.89**
14th FHBSN 6418	-0.07**	-2.26**	-1.35**	-0.53**	0.00	1.15**	-2.39**
36thSAWSN 3065	-0.03	0.69	-0.64**	-0.28**	-0.02**	0.24**	-2.16**
PBW 658	0.04	0.54	1.11**	0.47**	-0.01	-0.96**	2.36**
KB 2013-03	0.07**	0.94**	2.02**	0.72**	0.01	-1.05**	3.28**
KB 2013	0.07**	-0.36	1.64**	0.68**	0.01**	-0.92**	3.00**
VW 921	0.06**	-0.76**	1.99**	0.75**	0.02**	-0.73**	2.79**
SE (GCA for line)	0.03	0.55	0.15	0.05	0.01	0.20	0.44
Tester							
GW 273	0.00	-1.09**	0.42**	0.17*	-0.01**	0.43**	0.11
GW 366	-0.03**	0.25	-0.37**	-0.15*	0.00	0.09	-0.37
RVW 4104	0.01	-0.69**	-0.19*	-0.09*	0.00	-0.37**	-0.30
SUJATA	0.02	1.52**	0.13	0.07*	0.00	-0.15	0.56*
SE (GCA for Tester)	0.02	0.23	0.10	0.03	0.003	0.13	0.28

*, ** significant at 5 and 1 percent levels, respectively

Specific combining ability effects: The SCA effects for grain yield and its contributing traits are given in Table 4.6.2

Days to heading: Cross combination '20thHRWYT213 × GW366' (1.00), '20thHRWYT235 × RVW4106' (1.65), '45thIBWSN1021 × GW273' (2.52), 'PBW658 × GW273' (0.90) and 'KB2013-03 × SUJATA' (0.95) recorded significant positive value of SCA effect. Whereas crosses '45thIBWSN1021 × GW366' (-0.88), '45thIBWSN1021 × RVW4106' (-1.23), 'PBW658 × GW366' (-1.00), 'KB2013-03 × GW273' (-1.10) and 'VW921 × GW273' (-1.10) recorded significant negative value of SCA effect.

Days to maturity: Cross combination '33rdESWYT150 × GW273' (2.15), '20thHRWYT213 × GW366' (1.80), '20thHRWYT235 × RVW4106' (3.15), '45thIBWSN1021 × SUJATA' (2.15), '14thFHBSN6418 × GW273' (1.03), '36thSAWSN3065 × GW273' (2.28), 'PBW658 × GW366' (2.17), 'KB2013-03 × RVW4106' (2.53), 'KB2013 × SUJATA' (2.15) and 'VW921 × GW366' (1.30) recorded significant positive value of SCA effect and '33rdESWYT150 × GW366' (-1.45), '33rdESWYT150 × RVW4106' (-1.10), '20thHRWYT235 × GW366' (-1.70), '45thIBWSN1021 × RVW4106' (-1.35), '14thFHBSN6418 × SUJATA' (-1.72), '36thSAWSN3065 × GW366' (-1.33), 'PBW658 × RVW4106' (-1.47), 'KB2013 × SUJATA' (-0.97), 'KB2013 × GW366' (-1.10) and 'VW921 × GW273' (-1.10) recorded significant negative value of SCA effect.

Plant height : Crosses '33rdESWYT150 × GW366' (2.73), '33rdESWYT150 × RVW4106' (5.99), '36thESWYT150 × SUJATA' (3.77), '20thHRWYT213 × GW273' (1.85), '20thHRWYT213 × SUJATA' (5.59), '20thHRWYT235 × SUJATA' (1.62), '45thIBWSN1021 × GW273' (6.75), '45thIBWSN1021 × GW366' (3.80), '45thIBWSN1021 × RVW4106' (1.86), '14thFHBSN6418 × GW366' (2.98), '36thSAWSN3065 × RVW4106' (4.41), 'PBW658 × GW273' (4.17), 'PBW658 × SUJATA' (7.62), 'KB2013-03 × GW273' (3.87), 'KB2013-03 × GW366' (4.63), 'KB2013-03 × SUJATA' (2.32), 'KB2013 × GW273' (5.47) and 'VW921 × GW366'

(3.75) recorded significant positive value of SCA effect. Whereas, cross combination '33rdESWYT150 × GW273' (-12.48), '20thHRWYT213 × GW366' (-6.40), '20thHRWYT235 × RVW4106' (-2.11), '45thIBWSN1021 × SUJATA' (-12.41), '14thFHBSN6418 × GW273' (-2.48), '36thSAWSN3065 × GW273' (-5.40), 'PBW658 × GW366' (-13.08), 'KB2013-03 × RVW4106' (-10.82), 'KB2013 × SUJATA' (-6.88), 'VW921 × GW273' (-6.88) and 'VW921 × SUJATA' (-2.46) recorded significant negative value of SCA effect.

Tillers per plant: Cross combination '33rdESWYT15 × RVW4106' (0.56), '20thHRWYT213 × GW273' (0.59), 'KB2013-03 × GW273' (0.82) and 'KB2013 × SUJATA' (0.67) recorded significant positive value of SCA effect. Whereas, crosses '33rdESWYT150 × SUJATA' (-0.81), '20thHRWYT213 × GW366' (-0.74), 'KB2013-03 × SUJATA' (-0.48) and 'KB2013 × GW273' (-0.63) recorded significant negative value of SCA effect.

1st inter-node length: Crosses '33rdESWYT150 × GW366' (0.16), '33rdESWYT150 × RVW4106' (0.14), '20thHRWYT235 × RVW4106' (0.15), '20thHRWYT235 × SUJATA' (0.13), '45thIBWSN1021 × GW273' (0.24), '45thIBWSN1021 × GW366' (0.18), '45thIBWSN1021 × RVW4106' (0.10), '14thFHBSN6418 × GW273' (0.18), '14thFHBSN6418 × GW366' (0.18), '36thSAWSN3065 × GW273' (0.17), 'PBW658 × SUJATA' (0.12), 'KB2013-03 × RVW4106' (0.17), 'KB2013-03 × SUJATA' (0.21), 'KB2013 × GW273' (0.17), 'KB2013 × SUJATA' (0.19) and 'VW921 × GW366' (0.13) recorded significant positive value of SCA effect. Whereas, crosses '33rdESWYT150 × GW273' (-0.33), '20thHRWYT213 × GW273' (-0.26), '20thHRWYT235 × GW366' (-0.20), '45thIBWSN1021 × RVW4106' (-0.31), '14thFHBSN6418 × SUJATA' (-0.24), '36thSAWSN3065 × SUJATA' (-0.22), 'PBW658 × GW366' (-0.23), 'KB2013-03 × GW273' (-0.20), 'KB2013-03 × GW366' (-0.17), 'KB2013 × GW366' (-0.18), 'KB2013 × RVW4106' (-0.18) and 'VW921 × SUJATA' (-0.20) recorded significant negative value of SCA effect.

Spike length: Crosses '33rdESWYT150 × GW366' (0.22), '33rdESWYT150 × SUJATA' (1.36), '20thHRWYT213 × GW273' (0.27),

'20thHRWYT213 × GW366' (1.02), '20thHRWYT213 × RVW4106' (0.23), '20thHRWYT235 × RVW4106' (0.50), '45thIBWSN1021 × GW366' (0.62), '45thIBWSN1021 × SUJATA' (1.20), '14thFHBSN6418 × RVW4106' (1.39), '36thSAWSN3065 × GW273' (0.79), '36thSAWSN3065 × SUJATA' (0.68), 'PBW658 × GW273' (0.44), 'PBW658 × GW366' (0.79), 'PBW658 × RVW4106' (1.06), 'KB2013-03 × GW273' (1.29), 'KB2013-03 × GW366' (0.24), 'KB2013 × GW366' (0.43), 'KB2013 × RVW4106' (0.43), 'KB2013 × SUJATA' (0.54), 'VW921 × RVW4106' (1.02) and 'VW921 × SUJATA' (0.34) recorded significant positive value of SCA effect. Whereas, crosses '33rdESWYT150 × GW273' (-0.88), '33rdESWYT150 × RVW4106' (-0.70), '20thHRWYT213 × SUJATA' (-1.53), '20thHRWYT235 × GW366' (-0.59), '20thHRWYT235 × SUJATA' (-0.78), '45thIBWSN1021 × RVW4106' (-0.30), '14thFHBSN6418 × GW366' (-1.25), '14thFHBSN6418 × SUJATA' (-0.19), '36thSAWSN3065 × GW366' (-0.30), '36thSAWSN3065 × RVW4106' (-1.17), 'PBW658 × SUJATA' (-1.58), 'KB2013-03 × RVW4106' (-1.47), 'KB2013 × GW273' (-1.40), 'VW921 × GW366' (-1.44) recorded significant negative value of SCA effect.

Weight of spikes per plant: Crosses '33rdESWYT150 × GW366' (0.84), '33rdESWYT150 × RVW4106' (1.24), '20thHRWYT213 × GW273' (1.96), '20thHRWYT235 × GW366' (0.73), '20thHRWYT235 × SUJATA' (1.45), '45thIBWSN1021 × GW273' (1.79), '14thFHBSN6418 × GW366' (0.74), '36thSAWSN3065 × GW366' (0.75), '36thSAWSN3065 × RVW4106' (0.79), 'PBW658 × GW273' (0.60), 'KB2013-03 × GW366' (0.91), 'KB2013-03 × SUJATA' (1.81) and 'VW921 × GW366' (1.43) recorded significant positive value of SCA effect whereas, crosses '33rdESWYT150 × GW273' (-0.69), '33rdESWYT150 × SUJATA' (-1.39), '20thHRWYT213 × GW366' (-1.85), '20thHRWYT213 × SUJATA' (-0.66), '20thHRWYT235 × RVW4106' (-0.62), '45thIBWSN1021 × GW366' (-1.93), '14thFHBSN6418 × RVW4106' (-0.88), '36thSAWSN3065 × GW273' (-0.60), '36thSAWSN3065 × SUJATA' (-0.94), 'KB2013-03 × GW273' (-2.34), 'KB2013 × GW366' (-1.24) and 'VW921 × RVW4106' (-1.99) recorded significant negative value of SCA effect.

Weight of grains per spike: Crosses '33rdESWYT150 × GW366' (0.11), '20thHRWYT213 × RVW4106' (0.11), '20thHRWYT235 × GW366' (0.17), '36thSAWSN3065 × GW366' (0.11), 'KB2013-03 × SUJATA' (0.14), 'KB2013 × GW273' (0.14) recorded significant positive value of SCA effect. Whereas, crosses '20thHRWYT213 × GW366' (-0.24), '14thFHBSN6418 × RVW4106' (-0.11), '36thSAWSN3065 × SUJATA' (-0.23), 'KB2013 × GW366' (-0.22) and 'VW921 × RVW4106' (-0.15) recorded significant negative value of SCA effect.

Grains per spike: Crosses '33rdESWYT150 × SUJATA' (7.83), '20thHRWYT213 × GW366' (7.47), '45thIBWSN1021 × GW366' (5.03), '45thIBWSN1021 × SUJATA' (6.26), '14thFHBSN6418 × RVW4106' (10.29), '36thSAWSN3065 × SUJATA' (4.03), 'PBW658 × GW366' (6.85), 'PBW658 × RVW4106' (3.29), 'KB2013-03×GW273' (4.99), 'KB2013 × SUJATA' (3.88), 'VW921 × GW273' (4.89), 'VW921 × RVW4106' (4.99) recorded significant positive value of SCA effect. Whereas, crosses '33rdESWYT150 × GW273' (-2.76), '33rdESWYT150 × GW366' (-1.50), '33rdESWYT150 × RVW4106' (-3.56), '20thHRWYT213 × SUJATA' (-8.40), '20thHRWYT235 × GW366' (-3.43), '20thHRWYT235 × SUJATA' (-3.10), '45thIBWSN1021 × GW273' (-8.73), '45thIBWSN1021 × RVW4106' (-2.57), '14thFHBSN6418 × GW366' (-6.85), '36thSAWSN3065 × RVW4106' (-5.76), 'PBW658×SUJATA' (-10.62), 'KB2013-03 × RVW4106' (-7.41), 'KB2013 × GW273' (-4.61) and 'VW921 × GW366' (-9.15) recorded significant negative value of SCA effect.

Test weight: Cross combination '33rdESWYT150 × GW366' (1.56), '33rdESWYT150 × RVW4106' (1.65), '20thHRWYT213 × GW273' (4.25), '20thHRWYT213 × SUJATA' (0.80), '20thHRWYT235 × GW366' (3.50), '20thHRWYT235 × SUJATA' (0.92), '45thIBWSN1021 × GW273' (1.67), '45thIBWSN1021 × RVW4106' (2.66), '14thFHBSN6418 × GW366' (1.33), '14thFHBSN6418 × SUJATA' (1.08), '36thSAWSN3065 × GW366' (2.14), '36thSAWSN3065×RVW4106' (1.13), 'PBW658 × SUJATA' (1.13), 'KB2013-03 × GW366' (1.39), 'KB2013-03 × RVW4106' (1.01), 'KB2013-03 × SUJATA' (2.91), 'KB2013 × GW273' (1.15), 'KB2013 × RVW4106'

(2.23) and 'VW921 × GW366' (2.10) recorded significant positive value of SCA effect. Whereas, cross combination '33rdESWYT150 × GW273' (-0.71), '363rdESWYT150' × SUJATA' (-2.50), '20thHRWYT213 × GW366' (-5.22), '20thHRWYT 235 × RVW4106' (-3.36), '45thIBWSN1021 × GW366' (-3.47), '45thIBWSN1021 × SUJATA' (-0.86), '14thFHBSN6418 × RVW4106' (-2.53), '36thSAWSN3065 × SUJATA' (-3.25), 'PBW658 × RVW4106' (-0.77), 'KB2013-03 × GW273' (-5.32), 'KB2013 × GW366' (-2.81) and 'VW921 × RVW4106' (-2.20) recorded significant negative value of SCA effect

Grain yield per plant: Crosses '33rdESWYT150 × GW366' (0.59), '33rdESWYT150 × RVW4106' (0.72), '20thHRWYT213 × GW273' (1.67), '20thHRWYT213 × SUJATA' (0.23), '20thHRWYT235 × GW366' (1.27), '20thHRWYT235 × SUJATA' (0.29), '45thIBWSN1021 × GW273' (0.67), '45thIBWSN1021 × RVW4106' (1.09), '14thFHBSN6418 × GW366' (0.54), '14thFHBSN6418 × SUJATA' (0.41), '36thSAWSN3065 × GW366' (0.82), '36thSAWSN3065 × RVW4106' (0.51), 'PBW658 × SUJATA' (0.42), 'KB2013-03 × GW366' (0.66), 'KB2013-03 × SUJATA' (1.29), 'KB2013 × GW273' (0.49), 'KB2013 × RVW4106' (0.90) and 'VW921 × GW366' (0.27) recorded significant positive value of SCA effect. Whereas, crosses '33rdESWYT150 × GW273' (-0.29), '33rdESWYT150 × SUJATA' (-1.01), '20thHRWYT213 × GW366' (-2.03), '20thHRWYT235 × RVW4106' (-1.36), '45thIBWSN1021 × GW366' (-1.40), '45thIBWSN1021 × SUJATA' (-0.36), '14thFHBSN6418 × RVW4106' (-0.99), '36thSAWSN3065 × SUJATA' (-1.27), 'PBW658 × GW366' (-1.21), 'PBW658 × RVW4106' (-0.24), 'KB2013-03 × GW273' (-2.02), 'KB2013 × GW366' (-1.14), 'KB2013 × SUJATA' (-0.25), 'VW921 × GW273' (-0.35) and 'VW921 × RVW4106' (-0.83) recorded significant negative value of SCA effect.

Canopy temperature index: Cross combination '33rdESWYT150 × GW366' (0.02), '20thHRWYT213 × GW273' (0.03), '45thIBWSN1021 × GW366' (0.02), '14thFHBSN6418 × GW273' (0.02), '14thFHBSN6418 × GW366' (0.03), '36thSAWSN3065 × SUJATA' (0.03) and 'VW921 ×

RVW4106' (0.03) recorded significant positive value of SCA effect. Whereas, '20thHRWYT213 × GW366' (-0.05), '14thFHBSN6418 × SUJATA' (-0.04), '36thSAWSN3065 × GW366' (-0.02), 'PBW658 × RVW4106' (-0.02), 'KB2013 × RVW4106' (-0.020) and 'VW921 × GW366' (-0.03) recorded significant negative value of SCA effect.

Biological yield: Cross combination '33rdESWYT150 × GW273' (0.97), '20thHRWYT235 × GW366' (1.10), '20thHRWYT235 × SUJATA' (1.31), '45thIBWSN1021 × GW273' (1.53), '45thIBWSN1021 × RVW4106' (1.49), '14thFHBSN6418 × SUJATA' (1.97), 'PBW658 × GW366' (0.98), 'KB2013-03 × GW273' (1.17), 'KB2013-03 × GW366' (0.80) and VW921 × SUJATA (1.48) recorded significant positive value of SCA effect and '36thESWYT150 × SUJATA' (-1.20), '20thHRWYT213 × GW366' (-0.81), '20thHRWYT235 × RVW4106' (-2.07), '45thIBWSN1021 × GW366' (-1.73), '45thIBWSN1021 × SUJATA' (-1.30), '14thFHBSN6418 × GW273' (-1.67), '14thFHBSN6418 × RVW4106' (-0.90), '36thSAWSN3065 × SUJATA' (-0.79), 'PBW658 × RVW4106' (-1.27), 'KB2013-03 × SUJATA' (-2.57), 'KB2013 × GW273' (-0.82) and 'VW921 × GW273' (-1.05) recorded significant negative value of SCA effect.

Harvest index: Crosses '33rdESWYT150 × RVW4106' (2.11), '20thHRWYT213 × GW273' (4.58), '36thSAWSN3065 × GW366' (3.25), 'KB2013-03 × SUJATA' (6.44) and 'VW921 × GW366' (3.14) recorded significant positive value of SCA effect. Whereas, cross combination '20thHRWYT213 × GW366' (-4.65), '45thIBWSN1021 × GW366' (-2.07), '36thSAWSN3065 × RVW4106' (-2.55), 'KB2013-03 × GW273' (-6.74), 'KB2013 × GW366' (-2.25) and 'VW921 × RVW4106' (-2.07) recorded significant negative value of SCA effect.

Table 4.6.2 Specific combining ability (SCA) effect for Line x Tester parents in wheat

	CROSSES	Days to heading	Days to maturity	Plant height	Tillers/Plant	1st inter-node length	Spike length	Wt. of Spike/Plant
1	33rd ESWYT 150xGW 273	0.40	2.15**	12.48**	-0.11	0.33**	0.88**	-0.69**
2	33rd ESWYT 150xGW 366	-0.50	1.45**	2.73**	0.36	0.16**	0.22**	0.84**
3	33rd ESWYT 150xRVW4106	0.15	1.10**	5.99**	0.56**	0.14**	0.70**	1.24**
4	36th ESWYT 150xSUJATA	-0.05	0.40	3.77**	-0.81**	0.02	1.36**	-1.39**
5	20thHRWYT 213xGW273	-0.10	-0.10	1.85**	0.59**	0.26**	0.27**	1.96**
6	20thHRWYT 213xGW366	1.00**	1.80**	-6.40**	-0.74**	0.08	1.02**	-1.85**
7	20thHRWYT 213xRVW4106	-0.85	-0.85	-1.04	-0.04	0.08	0.23**	0.55
8	20thHRWYT 213xSUJATA	-0.05	-0.85	5.59**	0.19	0.09	1.53**	-0.66**
9	20thHRWYT 235xGW273	-1.10	-1.60	-0.33	0.07	-0.09	0.87	-1.56
10	20thHRWYT 235xGW366	-0.50	1.70**	0.83	-0.16	0.20**	0.59**	0.73**
11	20thHRWYT 235xRVW4106	1.65**	3.15**	-2.11**	-0.06	0.15**	0.50**	-0.62**
12	20thHRWYT 235xSUJATA	-0.05	0.15	1.62**	0.17	0.13**	0.78**	1.45**
1	45thIBWSN1021xGW273	2.52**	-0.10	6.75**	-0.31	0.24**	-	1.79**

	CROSSES	Days to headin g	Days to maturit y	Plant height	Tillers/Plan t	1st inter- node length	Spike length	Wt. of Spike/Plan t
3							1.52**	
1 4	45thIBWSN1021xGW366	- 0.88**	-0.70	3.80**	0.36	0.18**	0.62**	-1.93**
1 5	45thIBWSN1021xRVW4106	- 1.23**	- 1.35**	1.86**	-0.24	- 0.31**	- 0.30**	0.65
1 6	45thIBWSN1021xSUJATA	-0.42	2.15**	- 12.41**	0.19	-0.10	1.20**	-0.51
1 7	14thFHBSN6418xGW273	-0.23	1.03**	-2.48**	0.17	0.10**	0.04	0.17
1 8	14thFHBSN6418xGW366	-0.63	0.92	2.98**	0.24	0.18**	- 1.25**	0.74**
1 9	14thFHBSN6418xRVW4106	0.02	-0.22	-0.46	-0.16	-0.04	1.39**	-0.88**
2 0	14thFHBSN6418xSUJATA	0.83	- 1.72**	-0.03	-0.23	- 0.24**	- 0.19**	-0.03
2 1	36thSAWSN3065xGW273	0.52	- 2.28**	-5.40**	-0.01	0.17**	0.79**	-0.60**
2 2	36thSAWSN3065xGW366	0.63	- 1.33**	0.15	-0.14	0.05	- 0.30**	0.75**
2 3	36thSAWSN3065xRVW4106	-0.73	-0.47	4.41**	0.16	0.00	- 1.17**	0.79**
2 4	36thSAWSN3065xSUJATA	-0.42	-0.47	0.84	-0.01	- 0.22**	0.68**	-0.94**
2	PBW658xGW273	0.90*	-0.72	4.17**	-0.23	0.09	0.44**	0.60**

	CROSSES	Days to headin g	Days to maturit y	Plant height	Tillers/Plan t	1st inter- node length	Spike length	Wt. of Spike/Plan t
5								
2 6	PBW658xGW366	- 1.00**	- 2.17**	- 13.08**	0.14	- 0.23**	1.06**	-0.38
2 7	PBW658xRVW4106	0.65	- 1.47**	1.29	-0.26	0.03	0.08	0.26
2 8	PBW658xSUJATA	-0.55	0.03	7.62**	0.37	0.12*	- 1.58**	-0.48
2 9	KB2013-03xGW273	- 1.10**	-0.72	3.87**	0.82**	- 0.20**	1.29**	-2.34**
3 0	KB2013-03xGW366	0.00	-0.83	4.63**	-0.31	- 0.17**	0.24**	0.91**
3 1	KB2013-03xRVW4106	0.15	2.53**	- 10.82**	-0.01	- 0.17**	- 1.47**	-0.38
3 2	KB2013-03xSUJATA	0.95**	-0.97*	2.32**	-0.48**	0.21**	-0.06	1.81**
3 3	KB2013xGW273	-0.73	- 1.10**	5.47**	-0.63**	- 0.17**	- 1.40**	0.36
3 4	KB2013xGW366	1.88**	-0.20	0.63	0.24	- 0.18**	0.43**	-1.24**
3 5	KB2013xRVW4106	-0.48	-0.85	0.79	-0.27	- 0.18**	0.43**	0.39
3 6	KB2013xSUJATA	-0.67	2.15**	-6.88**	0.67**	0.19**	0.54**	0.48
3	VW921xGW273	-	-	-1.40**	-0.33	0.11	0.08	0.29

	CROSSES	Days to heading	Days to maturity	Plant height	Tillers/Plant	1st inter-node length	Spike length	Wt. of Spike/Plant
7		1.10**	1.10**					
38	VW921xGW366	0.00	1.30**	3.75**	0.04	0.13**	1.44**	1.43**
39	VW921xRVW4106	0.65	0.65	0.11	0.34	-0.04	1.02**	-1.99**
40	VW921xSUJATA	0.45	-0.85	-2.46**	-0.03	0.20**	0.34**	0.27
	SE (SCA)	0.48	0.50	0.61	0.21	0.05	0.07	0.30

	CROSSES	Grains weight/Spike	Grains/Spike	Test weight	Grains yield/Plant	Canopy temperature index	Biological yield	Harvest index
1	33rd ESWYT 150xGW 273	-0.07	-2.76**	0.71**	-0.29**	-0.01	0.97**	-1.80
2	33rd ESWYT 150xGW 366	0.11*	-1.50**	1.56**	0.59**	0.02**	0.14	1.19
3	33rd ESWYT 150xRVW4106	-0.01	-3.56**	1.65**	0.72**	-0.01	0.08	2.11**
4	36th ESWYT 150xSUJATA	-0.03	7.83**	2.50**	-1.01**	0.00	-1.20**	-1.51
5	20thHRWYT 213xGW273	0.08	0.71	4.25**	1.67**	0.03**	-0.40	4.58**
6	20thHRWYT 213xGW366	-0.24**	7.47**	5.22**	-2.03**	-0.05**	-0.81**	4.65**

Continued...

7	20thHRWYT 213xRVW4106	0.11**	0.22	0.16	0.13	0.01	0.44	0.29
8	20thHRWYT 213xSUJATA	0.05	-8.40**	0.80**	0.23**	0.01	0.77	-0.22
9	20thHRWYT 235xGW273	-0.09	7.11	-1.07	-0.20	-0.01	-0.34	-0.15
10	20thHRWYT 235xGW366	0.17**	-3.43**	3.50**	1.27**	0.01	1.10**	1.95
11	20thHRWYT 235xRVW4106	-0.05	-0.58	3.36**	-1.36**	0.01	-2.07**	-1.13
12	20thHRWYT 235xSUJATA	-0.03	-3.10**	0.92**	0.29**	-0.01	1.31**	-0.66
13	45thIBWSN1021xGW273	0.02	-8.73**	1.67**	0.67**	-0.02	1.53**	0.17
14	45thIBWSN1021xGW366	-0.10	5.03**	3.47**	-1.40**	0.02**	-1.73**	2.07**
15	45thIBWSN1021xRVW4106	0.08	-2.57**	2.66**	1.09**	0.00	1.49**	1.74
16	45thIBWSN1021xSUJATA	0.00	6.26**	0.86**	-0.36**	-0.01	-1.30**	0.15
17	14thFHBSN6418xGW273	0.08	-3.11	0.11	0.05	0.02**	-1.67**	1.65
18	14thFHBSN6418xGW366	-0.03	-6.85**	1.33**	0.54**	0.03**	0.60	0.66
19	14thFHBSN6418xRVW4106	-0.11**	10.29**	2.53**	-0.99**	-0.01	-0.90**	-1.25
20	14thFHBSN6418xSUJATA	0.06	-0.32	1.08**	0.41**	-0.04**	1.97**	-1.06

2 1	36thSAWSN3065xGW27 3	0.08	1.04	-0.03	-0.05	-0.01	0.26	0.76**
2 2	36thSAWSN3065xGW36 6	0.11**	0.70	2.14**	0.82**	-0.02**	-0.01	3.25**
2 3	36thSAWSN3065xRVW4 106	0.05	-5.76**	1.13**	0.51**	0.00	0.54	- 2.55**
2 4	36thSAWSN3065xSUJAT A	-0.23**	4.03**	- 3.25**	-1.27**	0.03**	-0.79**	-1.46
2 5	PBW658xGW273	0.01	0.49	0.16	0.03	0.01	0.36	-0.49
2 6	PBW658xGW366	0.00	6.85**	-0.53	-0.21**	0.01	0.98**	-1.73
2 7	PBW658xRVW4106	0.05	3.29**	- 0.77**	-0.24**	-0.02**	-1.27**	1.28
2 8	PBW658xSUJATA	-0.06	-10.62**	1.13**	0.42**	0.01	-0.07	0.94
2 9	KB2013-03xGW273	-0.23**	4.99**	- 5.32**	-2.02**	0.00	1.17**	- 6.74**
3 0	KB2013-03xGW366	0.10	1.25	1.39**	0.66**	0.00	0.80*	0.50
3 1	KB2013-03xRVW4106	-0.02	-7.41**	1.01**	0.07	0.00	0.60	-0.20
3 2	KB2013-03xSUJATA	0.14**	1.18	2.91**	1.29**	0.00	-2.57**	6.44**
3 3	KB2013xGW273	0.14**	-4.61**	1.15**	0.49**	0.00	-0.82**	1.93
3	KB2013xGW366	-0.22**	-0.35	-	-1.14**	0.01	-0.32	-

4				2.81**				2.25**
3								
5	KB2013xRVW4106	0.04	1.09	2.23**	0.90**	-0.02**	0.76	1.78
3								
6	KB2013xSUJATA	0.03	3.88**	-0.57	-0.25**	0.01	0.39	-1.45
3								
7	VW921xGW273	-0.02	4.89**	-0.23	-0.35**	-0.01	-1.05**	0.09
3								
8	VW921xGW366	0.09	-9.15**	2.10**	0.91**	-0.03**	-0.75	3.14**
3				-				-
9	VW921xRVW4106	-0.15**	4.99**	2.20**	-0.83**	0.03**	0.33	2.07**
4								
0	VW921xSUJATA	0.08	-0.72	0.32	0.27**	0.00	1.48**	-1.17
	SE (SCA)	0.05	1.09	0.30	0.10	0.01	0.40	0.88

*, ** significant at 5 and 1 percent levels, respectively

4.7 Heterosis: The estimates of heterosis over mid-parents (relative heterosis) and heterosis over better parents (heterobeltiosis) for grain yield and its contributing traits are presented in Table: 4.8. Heterosis over mid-parents and over better parents show significant for all the 14 character are as follow:

Days to heading: Heterosis over the better parent ranged from -1.65% (45thIBWSN1021 × G273) to -6.04% (45thIBWSN1021 × GW366) for days to heading. Higher significant negative heterosis were noticed in cross '45thIBWSN1021 × GW366' (-6.04%), '45thIBWSN1021 × RVW4106' (-6.04%) followed by 'KB2013-03 × GW273' (-5.03%), '14thFHBSN6418 × GW366' (-4.47%), 'KB2013-03 × GW366' (-4.47%), '45thIBWSN1021 × SUJATA' (-4.40%), 'KB2013-03 × RVW4106' (-3.91%), 'PBW658×GW366' (-3.47%), '14thFHBSN6418 × GW273' (-3.35%), '14thFHBSN6418 × RVW4106' (-3.35%), '36thSAWSN3065 × RVW4106' (-2.31%), 'KB2013-03 × SUJATA' (-2.31%), '33rdESWYT150 × GW366' (-2.30%), '20thHRWYT235 × GW273' (-2.30%), '20thHRWYT235 × GW366' (-2.30%), 'KB2013 × GW273' (-2.84%), 'KB2013 × RVW4106' (-2.84%), 'VW921 × GW273' (-2.29%), 'KB2013 × SUJATA' (-2.27%), '20thHRWYT213 × RVW4106' (-1.73%), 'PBW658 × SUJATA' (-1.73%), 'VW921 × GW366' (-1.71%), '14th FHBSN6418 × SUJATA' (-1.68) and '45thIBWSN1021 × GW273' (-1.65%).

Heterosis over the mid parent ranged from -2.29% (KB2013-03 × GW366) to -3.12% (45thIBWSN1021 × RVW4106) for days to heading. Higher significant negative heterosis were noticed in crosses '45thIBWSN1021 × GW366' (-3.12%), '45thIBWSN1021 × RVW4106' (-3.12%) followed by 'PBW658 × GW366' (-2.91%), 'KB2013-03 × GW273' (-2.86%), '14thFHBSN6418 × GW366' (-2.29%) and 'KB2013-03 × GW366' (-2.29%).

Days to maturity: Heterosis over the better parent ranged from -1.08% (KB2013-03 × SUJATA) to -2.88% (33rdESWYT150 × GW366) for days to maturity. Higher significant negative heterosis were noticed in crosses viz., '33rdESWYT150 × GW366' (-2.88), '36thSAWSN3065 × GW366' (-2.84%), 'PBW658 × RVW4106' (-2.53%), '36thSAWSN3065 × RVW4106' (-2.13%), '36thSAWSN3065 × SUJATA' (-2.13%),

'20thHRWYT213 × RVW4106' (-1.81%), '20thHRWYT213 × SUJATA' (-1.81%), 'PBW658 × GW273' (-1.81%), '33rdESWYT150 × SUJATA' (-1.44%), 'PBW658 × SUJATA' (-1.44%), '20thHRWYT213 × GW273' (-1.09%), '14thFHBSN6418 × SUJATA' (-1.09%), 'KB2013 × GW273' (-1.09%), 'VW921 × SUJATA' (-1.09%) and 'KB2013-03 × SUJATA' (-1.08%).

Heterosis over the mid parent ranged from -1.45% (20thHRWYT 213 × SUJATA) to 3.12% (20thHRWYT235 × RVW4106) for days to maturity. Higher significant negative heterosis were noticed in crosses viz., 'PBW658 × RVW4106' (-2.00%), '33rdESWYT150 × GW366' (-1.82%), '33rdESWYT150 × RVW4106' (-1.81%), '20thHRWYT213 × RVW4106' (-1.45%) and '20thHRWYT 213 × SUJATA' (-1.45%).

Plant height: Heterosis over better parent ranged from 1.85% (VW921 × GW366) to 18.15% (PBW658 × GW366) for plant height. Higher significant negative heterosis were noticed in '20thHRWYT235 × RVW4106' (-5.56%), '36thSAWSN3065 × GW273' (-5.15%), '20thHRWYT213 × RVW4106' (-4.81%), 'PBW658 × SUJATA' (-4.78%), 'KB2013-03×SUJATA' (-4.78%), '20thHRWYT235 × GW273' (-4.74%), 'PBW658 × RVW4106' (-4.36%), '20thHRWYT235 × GW366' (-4.28%), 'KB2013 × GW366' (-4.13%), '45thIBWSN1021 × RVW4106' (-3.53%), '33rdESWYT150 × GW 366' (-3.43%), '36thSAWSN3065 × GW366' (-3.43%), 'KB2013-03 × GW273' (-3.10%), 'KB2013-03 × GW366' (-3.01%), '45thIBWSN1021 × GW366' (-2.76%), 'KB2013 × RVW4106' (-2.61%), 'KB2013 × RVW4106' (-2.59%) and '14thFHBSN6418 × RVW4106' (-1.97%).

Heterosis over the mid parent ranged from 2.16% (14thFHBSN6418 × GW366) to -16.88% (PBW658 × GW366) for plant height. Higher significant negative heterosis were noticed in 'PBW658 × GW366' (-16.88%) followed by '45thIBWSN1021 × SUJATA' (-15.57%), 'KB2013-03 × RVW4106' (-15.48%), '33rdESWYT150 × GW 273' (-12.44%), '20thHRWYT213 × GW366' (8.89%), 'KB2013 × SUJATA' (-8.61%), '20thHRWYT235 × RVW4106' (-5.23%), 'KB2013 × GW366' (-3.69%), '20thHRWYT235 × GW366' (-3.49%), '45thIBWSN1021 × RVW4106' (-3.33%), '20thHRWYT213 × RVW4106' (-2.88%), 'KB2013 × RVW4106'

(-2.59%), '20thHRWYT235 × GW273' (-2.52%), '45thIBWSN1021 × GW366' (-2.49%), 'PBW658 × RVW4106' (-2.41%), 'KB2013-03 × SUJATA' (-2.33%) and 'KB2013-03 × GW366' (-2.30%).

Tillers per plant: Heterosis over the better parent ranged from -8.33% (45thIBWSN1021 × GW366) to -27.71% (KB2013 × GW273) for tillers per plant. Higher significant positive heterosis was noticed in only in one cross '33rdESWYT150 × RVW4106' (15.28%).

Heterosis over the mid parent ranged from -9.80% (KB2013 × GW366) to -21.05% (KB2013 × GW273) for tillers per plant. Higher significant positive heterosis was noticed only in one cross combination '33rdESWYT150 × RVW4106' (18.57%).

1st inter-node length: Heterosis over better parent ranged from -6.11% (PBW658 × GW273) to -18.33% (33rdESWYT150 × GW273) for 1st inter-node length. Higher significant negative heterosis were noticed in '33rdESWYT150 × GW273' (-18.33%), 'PBW658 × GW366' (-16.29%), 'KB2013-03 × GW273' (-15.76%), 'KB2013-03 × GW366' (-14.70%), '20thHRWYT213 × GW273' (-13.83%), 'KB2013 × GW366' (-12.78%), '20thHRWYT235 × GW366' (-12.14%), '45thIBWSN1021 × RVW4106' (-10.07%), '20thHRWYT235 × GW273' (-9.00%), 'KB2013 × RVW4106' (-6.87%), 'PBW658 × GW273' (-6.11%).

Heterosis over the mid parent ranged from 6.97% (20thHRWYT213 × SUJATA) to 18.45% (36thSAWSN3065 × GW273) for tillers per plant. Higher significant negative heterosis were noticed in '33rdESWYT150 × GW273' (-17.13%), 'KB2013-03 × GW273' (-14.52%), 'KB2013-03 × GW366' (-13.17%), 'PBW658 × GW366' (-13.10%), 'KB2013 × GW366' (-9.60%), '20thHRWYT235 × GW366' (-7.72%), '45thIBWSN1021 × RVW4106' (-7.62%).

Spike length: Heterosis over the better parent ranged from 3.16% (KB2013-03 × GW273) to -25.58% (KB2013-03 × RVW4106) for spike length. Higher significant positive heterosis were noticed in 'KB2013-03 × GW366' (14.88%) followed by '20thHRWYT235 × GW366' (13.47%), '20thHRWYT213 × GW366' (9.22%), '45thIBWSN1021 × SUJATA' (6.63%), '20thHRWYT 235 × GW273' (5.49%), 'KB2013-03 × GW273' (3.16%). Heterosis over the mid parent ranged from -2.42%

(20thHRWYT213 × GW273) to -19.36% (33rdESWYT150 × GW273) for the spike length. Higher significant positive heterosis were noticed in crosses '20thHRWYT213 × GW366' (17.13%) followed by 'PBW658 × GW366' (16.35%), '20thHRWYT235 × GW273' (15.36%), '20thHRWYT235 × GW366' (13.47%), 'KB2013-03 × GW273' (12.65%), '45thIBWSN1021 × GW366' (12.42%), 'KB2013 × GW366' (9.43%), '20thHRWYT235 × RVW4106' (9.19%), '45thIBWSN1021 × SUJATA' (7.48%), '36thSAWSN3065 × GW366' (6.67%), '36thSAWSN3065 × SUJATA' (5.86%), '36thSAWSN3065 × GW273' (5.49%), '36thESWYT150 × SUJATA' (3.26)

Weight of spikes per plant: Heterosis over the better parent is ranged from -3.63% (KB2013-03 × GW366) to -21.80% (20thHRWYT235 × GW273) for weight of spikes per plant. Higher significant positive heterosis were noticed only in two cross combination '33rdESWYT150 × RVW4106' (11.80%) and 'KB2013 × RVW4106' (4.35%). Heterosis over the mid parent ranged from -4.78% (KB2013 × GW366) to -16.79% (20thHRWYT235 × GW273) for weight of spikes per plant. Higher significant positive heterosis were noticed in crosses '33rdESWYT150 × RVW4106' (13.59%) followed by 'KB2013-03 × SUJATA' (9.76%), 'KB2013 × RVW4106' (8.82%), '33rdESWYT150 × GW366' (5.47%) and 'KB2013 × SUJATA' (5.51%).

Weight of grains per spike: Heterosis over the better parent ranged from 7.56% (20thHRWYT213 × RVW4106) to -25.22% (20thHRWYT235 × GW273) for weight of grains per spike. Higher significant positive heterosis was noticed only in one cross combination '20thHRWYT213 × RVW4106' (7.56%). Heterosis over the mid parent ranged from -9.00% (20thHRWYT235 × GW366) to -19.52% (20thHRWYT235 × GW273) for weight of grains per spike. All the significant crosses were noticed in negative heterosis.

Grains per spike: Heterosis over the better parent ranged from 4.55% (20thHRWYT235 × GW273) to -20.76% (20thHRWYT213 × SUJATA) for grains per spike. Higher significant positive heterosis were noticed in crosses '45thIBWSN1021 × GW366' (15.84%) followed by '20thHRWYT213 × GW366' (13.48%) and '20thHRWYT235 × GW273'

(4.55%). Heterosis over the mid parent ranged from 5.62% (36thSAWSN3065 × SUJATA) to -16.87% (PBW658 × SUJATA) for grains per spike. Higher significant positive heterosis were noticed in 'PBW658 × GW366' (16.80%) followed by 'KB2013-03 × GW366' (14.46%), 'KB2013-03 × GW273' (11.37%), '14thFHBSN6418 × RVW4106' (8.53%), 'KB2013-03 × SUJATA' (7.04%), '36thSAWSN3065 × GW366' (6.92%) and '36thSAWSN3065 × SUJATA' (5.62%).

Test weight: heterosis over the better parent ranged from -2.38% (VW921 × SUJATA) to -27.32% (20thHRWYT213 × GW366) for test weight. Higher significant positive heterosis were noticed in 'KB2013 × RVW4106' (12.54%) followed by '33rdESWYT150 × RVW4106' (10.44%), 'KB2013-03 × RVW4106' (5.46%), 'KB2013-03 × SUJATA' (3.67%). Heterosis over the mid parent ranged from -2.59% (VW921 × GW273) to -24.25% (20thHRWYT213 × GW366) for test weight. Higher significant positive heterosis were noticed in '33rdESWYT150 × RVW4106' (14.33%) followed by 'KB2013 × RVW4106' (13.52%), 'KB2013-03 × RVW4106' (8.78%), 'KB2013-03 × SUJATA' (7.18%), '33rdESWYT150 × GW 366' (4.96%) and 'KB2013 × GW273' (3.20%).

Grain yield per plant: heterosis over the better parent ranged from -1.85% (VW92 × SUJATA) to -27.20% (20thHRWYT213 × GW366) for grain yield per plant. Only 4 crosses viz., 'KB2013 × RVW4106' (16.33%), '33rdESWYT150 × RVW4106' (11.24%), 'KB2013-03 × SUJATA' (3.90%) and 'KB2013-03 × RVW4106' (3.20%) were noticed in positive direction. Heterosis over the mid parent is ranged from 2.47% (PBW658 × RVW4106) to -24.14% (20thHRWYT213 × GW366) for grain yield per plant. Higher significant positive heterosis were noticed in crosses 'KB2013 × RVW4106' (16.68%), '33rdESWYT150 × RVW4106' (16.05%), 'KB2013-03 × SUJATA' (7.67%), 'KB2013-03 × RVW4106' (7.28%), '33rdESWYT150 × GW366' (4.99%), '45thIBWSN1021 × RVW4106' (2.90%) and 'PBW658 × RVW4106' (2.47%).

Canopy temperature index: Heterosis over the better parent is ranged from -10.14% (20thHRWYT213 × RVW4106) to -37.18% (20thHRWYT213 × GW366) for canopy temperature index. All the crosses showed significant negative heterosis except one. Heterosis over the mid parent

is ranged from -11.27% (20thHRWYT213 × SUJATA) to -32.88% (36thSAWSN3065 × GW366) for canopy temperature index. All crosses were noticed significant heterosis in negative direction.

Biological yield: Heterosis over the batter parent is ranged from 2.67% (KB2013-03 × SUJATA) to 20.65% for biological yield. crosses viz., '14thFHBSN6418 × SUJATA' (20.65%), '33rdESWYT150 × GW273' (18.33%), '45thIBWSN1021 × GW273' (18.06%), '14thFHBSN6418 × GW366' (18.03%), 'KB2013-03 × GW273' (16.53%), 'VW921 × SUJATA' (15.81%), '20thHRWYT235 × SUJATA' (15.66%), '33rdESWYT150 × GW366' (14.44%), '45thIBWSN1021 × RVW4106' (13.95%), 'PBW658 × GW273' (13.67%), '14thFHBSN6418 × GW273' (13.14%), 'VW921×GW273' (11.38%), 'VW921 × RVW4106' (11.35%), '14thFHBSN6418 × RVW4106' (11.35%), 'KB2013-03 × RVW4106' (10.78%), 'VW921 × GW366' (10.62%), '20thHRWYT213 × SUJATA' (10.62%), '20thHRWYT213 × GW273' (10.15%), '33rdESWYT150 × SUJATA' (9.51%), 'PBW658 × SUJATA' (9.49%), 'KB2013 × GW273' (6.89%), 'KB2013 × GW366' (6.72%), '20thHRWYT213 × RVW4106' (8.65%), 'PBW658 × RVW4106' (4.95%) and 'KB2013-03 × SUJATA' (2.67%) were noticed significant heterosis in positive direction

Heterosis over the better parent is ranged from 3.06% (20thHRWYT213 × RVW4106) to 16.10% (14thFHBSN6418 × SUJATA) for biological yield. All the 40 crosses were noticed significant heterosis in positive direction.

Harvest index: Heterosis over the better parent is ranged from -11.04% (45thIBWSN1021 × RVW4106) to -36.50% (20thHRWYT213 × GW366) for harvest index. All the significant crosses were noticed in negative direction. Heterosis over the mid parent is ranged from -8.44% (VW921 × GW366) to -29.80% (20thHRWYT213 × GW366) for harvest index. All the significant crosses were noticed in negative direction.

Table 4.7 Heterosis percent over mid parent and better parent in 40 crosses of wheat

	CROSSES	Days to heading		Days to maturity		Plant height		Tillers/Plant		1st inter-node length	
		BP	MP	BP	MP	BP	MP	BP	MP	BP	MP
1	33rd ESWYT 150xGW 273	-0.57	0.29	0.00	1.46**	-14.36**	-12.44**	-6.02	0.65	-18.33**	-17.13**
2	33rd ESWYT 150xGW 366	-2.30**	-1.45	-2.88**	-1.82**	-3.43**	0.19	-1.19	6.41	-2.24	-0.49
3	33rd ESWYT 150xRVW4106	-1.15	-0.29	-2.52**	-1.81**	0.05	4.28**	15.28**	18.57**	0.00	3.25
4	36th ESWYT 150xSUJATA	-0.57	0.29	-1.44**	-0.72	1.29	3.47**	-16.87**	-10.97**	-2.98	2.81
5	20thHRWYT 213xGW273	-0.58	0.00	-1.09**	0.00	0.95	1.00	-7.23	-0.65	-13.83**	-13.13**
6	20thHRWYT 213xGW366	0.00	0.58	0.00	0.73	-10.28**	-8.89**	-23.81**	-17.95**	-2.56	-1.45
7	20thHRWYT 213xRVW4106	-1.73**	-1.16	-1.81**	-1.45**	-4.81**	-2.88**	-4.17	-1.43	-0.98	2.89
8	20thHRWYT 213xSUJATA	0.00	0.58	-1.81**	-1.45**	4.58**	4.63**	-14.46**	-8.39**	0.33	6.97**
9	20thHRWYT 235xGW273	-2.30**	-1.45	0.37	0.55	-4.74**	-2.52**	-12.05**	-3.95	-9.00**	-4.71
10	20thHRWYT 235xGW366	-2.30**	-1.45	-0.37	-0.18	-4.28**	-3.49**	-15.48**	-7.19	-12.14**	-7.72**
11	20thHRWYT 235xRVW4106	0.57	1.45	2.55**	3.12**	-5.56**	-5.23**	1.45	2.19	8.83**	8.83
12	20thHRWYT 235xSUJATA	-0.57	0.29	0.36	0.92	-3.01**	-0.65	-13.25**	-5.26	9.19**	12.16**
13	45thIBWSN1021xGW273	-1.65**	1.42	0.36	1.28*	0.55	2.34**	-15.66**	-12.50**	-0.64	6.74*
14	45thIBWSN1021xGW366	-6.04**	-3.12**	-0.36	0.18	-2.76**	-2.49**	-8.33**	-4.35	-2.24	5.34
15	45thIBWSN1021xRVW4106	-6.04**	-3.12**	-0.73	-0.55	-3.53	-3.33**	-10.39**	-4.83	-10.07**	-7.62**
16	45thIBWSN1021xSUJATA	-4.40**	-1.42	1.82**	2.00**	-17.13**	-15.57**	-12.05**	-8.75**	4.10	4.10
17	14thFHBSN6418xGW273	-3.35**	-1.14	2.59**	2.78**	-0.95	-0.86	-15.66**	-5.41	-2.57	5.39
18	14thFHBSN6418xGW366	-4.47**	-2.29**	1.47**	2.03**	0.74	2.16**	-15.48**	-4.70	0.00	8.49**
19	14thFHBSN6418xRVW4106	-3.35**	-1.14	0.00	0.92	-1.97**	-0.12	-4.41	-2.26	2.12	5.67
20	14thFHBSN6418xSUJATA	-1.68**	0.57	-1.09**	-0.18	1.33	1.53	-22.89**	-13.51**	1.49	2.26
21	36thSAWSN3065xGW273	-0.58	0.00	0.00	2.17**	-5.15**	0.25	-14.46**	-7.19	8.36**	18.45**
22	36thSAWSN3065xGW366	-1.16	-0.58	-2.84**	-1.08	-3.43**	3.52**	-16.67**	-9.09*	4.47	14.54**

	CROSSES	Days to heading		Days to maturity		Plant height		Tillers/Plant		1st inter-node length	
		BP	MP	BP	MP	BP	MP	BP	MP	BP	MP
23	36thSAWSN3065xRVW4106	-2.31**	-1.74	-2.13**	-0.72	0.96	8.71**	1.43	2.90	13.07**	18.30**
24	36thSAWSN3065xSUJATA	-1.16	-0.58	-2.13**	-0.72	0.96	6.61**	-16.87**	-9.80**	12.31**	14.45**
25	PBW658xGW273	-0.58	0.00	-1.81**	-0.55	1.43	1.48	-19.28**	-12.42**	-6.11**	-2.83
26	PBW658xGW366	-3.47**	-2.91**	0.00	0.91	-18.15**	-16.88**	-15.48**	-7.79	-16.29**	-13.10**
27	PBW658xRVW4106	-1.16	-0.58	-2.53**	-2.00**	-4.36**	-2.41**	-7.14	-5.80	-1.38	-0.17
28	PBW658xSUJATA	-1.73**	-1.16	-1.44**	-0.91	4.78**	4.83**	-14.46**	-7.19**	2.76	6.81
29	KB2013-03xGW273	-5.03**	-2.86**	-0.37	0.18	-3.10**	-0.93	-3.61	5.26	-15.76**	-14.52**
30	KB2013-03xGW366	-4.47**	-2.29**	-0.73	-0.55	-3.01**	-2.30**	-17.86**	-9.80**	-14.70**	-13.17**
31	KB2013-03xRVW4106	-3.91**	-1.71	1.46**	1.65**	-15.69**	-15.48**	1.45	2.19	-0.99	2.22
32	KB2013-03xSUJATA	-2.31**	0.00	-1.08**	-0.91	-4.78**	-2.33**	-21.69**	-14.47**	1.38	7.37**
33	KB2013xGW273	-2.84**	-1.44	-1.09**	-0.37	0.92	2.90**	-27.71**	-21.05**	-1.93	1.33
34	KB2013xGW366	-0.57	0.86	-0.73	-0.37	-4.13**	-3.69**	-17.86**	-9.80**	-12.78**	-9.60**
35	KB2013xRVW4106	-2.84**	-1.44	-1.09**	-1.09	-2.61**	-2.59**	-10.14**	-9.49	-6.87**	-5.57
36	KB2013xSUJATA	-2.27**	-0.86	1.09**	1.09	-10.46**	-8.61**	-14.46**	-6.58	6.87**	11.27**
37	VW921xGW273	-2.29**	-1.16	0.37	0.37	0.67	1.10	-18.07**	-11.69**	-1.29	4.42
38	VW921xGW366	-1.71**	-0.58	1.10**	1.48**	1.85**	3.82**	-14.29**	-7.10	-0.32	5.76
39	VW921xRVW4106	-0.57	0.58	0.00	0.74	-1.05	1.34	2.82	5.04	3.53	4.64
40	VW921xSUJATA	0.00	1.16	-1.09**	-0.37	-0.19	0.14	-16.87**	-10.39**	1.08	2.75

BP: better parent, MP: mid parent

Continued...

	CROSSES	Spike length		Wt. of Spike/Plant		Grains weight per Spike	
		BP	MP	BP	MP	BP	MP

	CROSSES	Spike length		Wt. of Spike/Plant		Grains weight per Spike	
		BP	MP	BP	MP	BP	MP
1	33rd ESWYT 150xGW 273	-20.56**	-19.36**	-6.77**	-0.15	-9.73**	-4.11
2	33rd ESWYT 150xGW 366	-5.37**	2.07	-1.13	5.47**	-3.95	2.46
3	33rd ESWYT 150xRVW4106	-22.19**	-19.35**	11.80**	13.59**	6.27	7.07
4	36th ESWYT 150xSUJATA	-0.80	3.26**	-7.26**	-1.98	0.24	3.05
5	20thHRWYT 213xGW273	-4.47**	-2.42**	-4.42**	2.38	-7.30**	-1.30
6	20thHRWYT 213xGW366	9.22**	17.13**	-20.78**	-15.49**	-23.90**	-18.64**
7	20thHRWYT 213xRVW4106	-8.73**	-4.83**	-0.84	0.75	7.56**	8.10
8	20thHRWYT 213xSUJATA	-21.20**	-17.48**	-12.89**	-7.92**	-1.18	1.83
9	20thHRWYT 235xGW273	5.49**	15.36**	-21.80**	-16.79**	-25.22**	-19.52**
10	20thHRWYT 235xGW366	13.47**	13.47**	-13.15**	-7.96**	-15.79**	-9.00*
11	20thHRWYT 235xRVW4106	-2.05**	9.19**	-9.52**	-8.71**	-11.45**	-10.88**
12	20thHRWYT 235xSUJATA	-10.42**	0.25	-7.09**	-2.45	-16.11**	-12.59**
13	45thIBWSN1021xGW273	-20.11**	-18.68**	-5.72**	0.95	-15.71**	-9.82**
14	45thIBWSN1021xGW366	1.17	12.42**	-21.69**	-16.47**	-22.81**	-17.08**
15	45thIBWSN1021xRVW4106	-9.63**	-9.30**	-1.07	0.50	0.76	0.76
16	45thIBWSN1021xSUJATA	6.63**	7.48**	-12.89**	-7.95**	-9.48**	-6.26
17	14thFHBSN6418xGW273	-9.76**	-8.43**	-8.93**	-5.15**	-11.73**	-7.32
18	14thFHBSN6418xGW366	-19.33**	-10.61**	-7.22**	-3.75	-18.64**	-14.22**
19	14thFHBSN6418xRVW4106	1.16	1.84	-6.78**	-5.52**	-11.00**	-9.23**
20	14thFHBSN6418xSUJATA	-9.81**	-8.80**	-7.32**	-4.78**	-5.21	-3.73
21	36thSAWSN3065xGW273	1.02	5.49**	-14.35**	-11.81**	-10.40**	-5.04
22	36thSAWSN3065xGW366	1.63	6.67**	-9.51**	-7.20**	-11.18**	-5.48
23	36thSAWSN3065xRVW4106	-20.59**	-15.38**	-4.14**	-1.71	0.00	1.01

	CROSSES	Spike length		Wt. of Spike/Plant		Grains weight per Spike	
		BP	MP	BP	MP	BP	MP
24	36thSAWSN3065xSUJATA	-1.06	5.86**	-13.54**	-12.20**	-17.54**	-15.43**
25	PBW658xGW273	-4.00**	-1.90	-5.77**	-3.71	-9.96**	-6.97
26	PBW658xGW366	8.55**	16.35**	-10.47**	-8.90**	-12.72**	-9.44**
27	PBW658xRVW4106	-11.14**	-7.30**	-4.04**	-0.85	-1.18	2.45
28	PBW658xSUJATA	-22.70**	-19.02**	-7.82**	-7.11**	-5.91	-5.80
29	KB2013-03xGW273	3.16**	12.65**	-16.32**	-9.96**	-19.47**	-15.84**
30	KB2013-03xGW366	14.88**	15.07**	-3.63**	3.28	-7.02**	-2.42
31	KB2013-03xRVW4106	-25.58**	-17.16**	1.28	3.40	-0.97	1.49
32	KB2013-03xSUJATA	-9.98**	0.59	3.36	9.76**	4.96	6.11
33	KB2013xGW273	-19.76**	-18.73**	-5.70**	3.54	-2.88	2.57
34	KB2013xGW366	-1.09	9.43**	-12.95**	-4.78**	-21.05**	-16.28**
35	KB2013xRVW4106	-4.72**	-3.91**	4.31**	8.82**	4.21	5.65
36	KB2013xSUJATA	-0.71	0.58	-2.67	5.51**	0.00	2.18
37	VW921xGW273	-8.55**	-7.04**	-5.66**	-2.93	-10.62**	-6.05
38	VW921xGW366	-20.16**	-11.39**	-1.57	0.87	-7.68**	-2.55
39	VW921xRVW4106	-0.98	-0.49	-10.94**	-8.61**	-6.62	-4.87
40	VW921xSUJATA	-3.98**	-3.08**	-3.20	-1.76	1.90	3.61

BP: better parent, MP: mid parent

Continued...

	CROSSES	Grains/Spike		Test weight		Grains yield/Plant	
		BP	MP	BP	MP	BP	MP

	CROSSES	Grains/Spike		Test weight		Grains yield/Plant	
		BP	MP	BP	MP	BP	MP
1	33rd ESWYT 150xGW 273	-15.86**	-11.85	-3.31**	1.20	-3.35**	1.39
2	33rd ESWYT 150xGW 366	-3.23	-2.20	0.54	4.96**	0.34	4.99**
3	33rd ESWYT 150xRVW4106	-17.06**	-12.80	10.44**	14.33*	11.24**	16.05**
4	36th ESWYT 150xSUJATA	-0.42	6.25	-4.87**	-2.00	-4.85**	-1.74
5	20thHRWYT 213xGW273	-8.08**	-3.99	-4.82**	-0.54	-5.17**	-0.92
6	20thHRWYT 213xGW366	13.48**	15.05	-27.32**	-24.25**	-27.20**	-24.14**
7	20thHRWYT 213xRVW4106	-8.89**	-4.51	-7.31**	-3.90**	-7.27**	-2.86**
8	20thHRWYT 213xSUJATA	-20.76**	-15.70	-10.25**	-7.68**	-10.91**	-8.38**
9	20thHRWYT 235xGW273	4.55**	16.82	-21.17**	-17.38**	-19.49**	-15.63**
10	20thHRWYT 235xGW366	2.31	8.39	-12.26**	-8.27**	-12.61**	-8.64**
11	20thHRWYT 235xRVW4106	-6.85**	4.41	-20.33**	-17.65**	-20.14**	-16.60**
12	20thHRWYT 235xSUJATA	-10.17**	2.09	-14.61**	-11.90**	-14.60**	-11.91**
13	45thIBWSN1021xGW273	-19.09**	-13.84	-12.35**	-7.25**	-12.31**	-7.25**
14	45thIBWSN1021xGW366	15.84**	16.61	-25.17**	-21.02**	-25.27**	-21.15**
15	45thIBWSN1021xRVW4106	-10.13**	-3.97	-0.55	1.80	-0.53	2.90**
16	45thIBWSN1021xSUJATA	2.68	11.33	-15.91**	-12.41**	-15.90**	-12.43**
17	14thFHBSN6418xGW273	-16.59	-12.35**	-12.82**	-9.75**	-12.79**	-9.16**
18	14thFHBSN6418xGW366	-11.54	-10.89**	-11.38**	-8.51**	-11.37**	-7.92**
19	14thFHBSN6418xRVW4106	2.92	8.53**	-14.25**	-10.26**	-13.11**	-8.71**
20	14thFHBSN6418xSUJATA	-12.15	-5.97**	-8.33**	-6.62**	-8.40**	-6.09**
21	36thSAWSN3065xGW273	-6.17	-0.85	-11.55**	-9.61**	-12.01**	-9.39**
22	36thSAWSN3065xGW366	6.74	6.92**	-7.97**	-6.20**	-8.42**	-5.94**
23	36thSAWSN3065xRVW4106	-16.18	-11.13**	-6.30**	-0.69	-4.80**	1.15

	CROSSES	Grains/Spike		Test weight		Grains yield/Plant	
		BP	MP	BP	MP	BP	MP
24	36thSAWSN3065xSUJATA	-1.84	5.62**	-16.69**	-16.23**	-16.68**	-15.57**
25	PBW658xGW273	-7.20	-1.94	-7.24**	-4.06**	-7.32**	-3.42**
26	PBW658xGW366	16.61*	16.80**	-10.04**	-7.20**	-9.97**	-6.42**
27	PBW658xRVW4106	-3.21	2.63	-4.33**	0.23	-2.43**	2.47**
28	PBW658xSUJATA	-22.74	-16.87**	-2.54**	-0.81	-2.54**	-0.04
29	KB2013-03xGW273	0.00	11.37**	-17.42**	-13.26**	-17.40**	-13.04**
30	KB2013-03xGW366	8.42	14.46**	-3.68**	0.91	-3.65**	1.18
31	KB2013-03xRVW4106	-18.22	-8.63**	5.46**	8.78**	3.20**	7.28**
32	KB2013-03xSUJATA	-5.51	7.04**	3.67**	7.18**	3.90**	7.67**
33	KB2013xGW273	-16.01	-15.51**	-3.82**	3.20**	-3.57**	5.02**
34	KB2013xGW366	-6.69	-1.80	-13.96**	-7.92**	-13.98**	-6.54**
35	KB2013xRVW4106	-7.73	-6.84**	12.54**	13.52**	16.33**	16.68**
36	KB2013xSUJATA	-3.53	-1.09	-5.24**	0.12	-5.22**	1.67
37	VW921xGW273	-2.64	-1.49	-6.12**	-2.59**	-7.90**	-4.29**
38	VW921xGW366	-19.40**	-15.66**	-2.16**	1.25	-2.13**	1.44
39	VW921xRVW4106	-2.62	-1.11	-5.01**	-0.80	-4.89**	0.16
40	VW921xSUJATA	-10.59**	-7.79**	-2.38**	-0.32	-1.85**	0.38

BP: better parent, MD: mid parent

Continued...

	CROSSES	Canopy temperature index		Biological yield		Harvest index	
		BP	MP	BP	MP	BP	MP
1	33rd ESWYT 150xGW 273	-34.57**	-30.26**	8.28**	18.33**	-25.91**	-15.46**

		Canopy temperature index		Biological yield		Harvest index	
	CROSSES	BP	MP	BP	MP	BP	MP
2	33rd ESWYT 150xGW 366	-21.79**	-18.12**	5.29**	14.44**	-19.86**	-9.28**
3	33rd ESWYT 150xRVW4106	-21.13**	-20.00**	4.00**	12.00**	-0.08	3.30
4	36th ESWYT 150xSUJATA	-18.31**	-18.31**	1.28	9.51**	-20.17**	-11.13**
5	20thHRWYT 213xGW273	-22.22**	-13.70**	2.92	10.15**	-19.95**	-10.77**
6	20thHRWYT 213xGW366	-37.18**	-31.47**	0.92	7.39**	-36.50**	-29.80**
7	20thHRWYT 213xRVW4106	-10.14**	-7.46*	3.06*	8.65**	-11.27**	-10.65**
8	20thHRWYT 213xSUJATA	-11.27**	-7.35**	4.50**	10.62**	-23.69**	-17.07**
9	20thHRWYT 235xGW273	-32.10**	-27.63**	7.93**	13.86**	-33.13**	-26.26**
10	20thHRWYT 235xGW366	-21.79**	-18.12**	10.93**	16.36**	-28.87**	-22.21**
11	20thHRWYT 235xRVW4106	-15.49**	-14.29**	1.00	4.94**	-20.93**	-20.53**
12	20thHRWYT 235xSUJATA	-19.72**	-19.72**	10.86**	15.66**	-29.36**	-24.08**
13	45thIBWSN1021xGW273	-32.10**	-27.15**	10.96**	18.06**	-30.47**	-22.04**
14	45thIBWSN1021xGW366	-19.23**	-14.86**	1.28	7.14**	-34.22**	-26.84**
15	45thIBWSN1021xRVW4106	-14.29**	-13.67**	8.73**	13.95**	-11.04**	-9.82**
16	45thIBWSN1021xSUJATA	-16.90**	-16.31**	1.80	7.13**	-25.59**	-18.64**
17	14thFHBSN6418xGW273	-24.69**	-20.26**	7.66**	13.14**	-26.84**	-20.09**
18	14thFHBSN6418xGW366	-19.23**	-16.00**	12.97**	18.03**	-28.20**	-22.24**
19	14thFHBSN6418xRVW4106	-20.83**	-19.15**	7.60**	11.35**	-19.25**	-17.99**
20	14thFHBSN6418xSUJATA	-30.56**	-30.07**	16.10**	20.65**	-26.97**	-22.27**
21	36thSAWSN3065xGW273	-37.04**	-31.54**	4.77**	12.87**	-28.06**	-20.38**
22	36thSAWSN3065xGW366	-37.18**	-32.88**	3.18**	10.54**	-22.99**	-15.46**
23	36thSAWSN3065xRVW4106	-20.29**	-19.71**	3.43**	9.78**	-19.27**	-19.19**
24	36thSAWSN3065xSUJATA	-15.49**	-13.67**	0.51	7.11**	-27.31**	-21.58**

		Canopy temperature index		Biological yield		Harvest index	
	CROSSES	BP	MP	BP	MP	BP	MP
25	PBW658xGW273	-32.10**	-26.67**	8.81**	13.67**	-22.09**	-15.82**
26	PBW658xGW366	-26.92**	-22.45**	9.59**	13.82**	-23.82**	-18.39**
27	PBW658xRVW4106	-26.09**	-26.09**	2.03	4.95**	-5.51*	-2.91
28	PBW658xSUJATA	-18.31**	-17.14**	6.00**	9.49**	-13.92**	-9.41**
29	KB2013-03xGW273	-28.40**	-24.18**	12.26**	16.53**	-31.82**	-25.64**
30	KB2013-03xGW366	-23.08**	-20.00**	10.26**	13.79**	-17.96**	-11.28**
31	KB2013-03xRVW4106	-18.06**	-16.31**	8.39**	10.78	-4.81	-3.16
32	KB2013-03xSUJATA	-16.90**	-16.08**	0.03	2.67**	-1.53	4.64**
33	KB2013xGW273	-27.16**	-23.38**	-0.51	6.89**	-16.50**	-6.55**
34	KB2013xGW366	-21.79**	-19.21**	-0.11	6.72**	-23.60**	-15.19**
35	KB2013xRVW4106	-21.92**	-19.72**	1.55	7.49**	2.40	3.59
36	KB2013xSUJATA	-13.70**	-12.50**	1.15	7.49**	-17.31**	-9.76**
37	VW921xGW273	-27.16**	-22.37**	7.66**	11.38**	-20.24**	-14.39**
38	VW921xGW366	-28.21**	-24.83**	7.56**	10.62**	-13.96**	-8.44**
39	VW921xRVW4106	-2.82	-1.43	9.33**	11.35**	-13.05**	-10.04**
40	VW921xSUJATA	-11.27**	-11.27**	13.23**	15.81**	-17.18**	-13.43**

BP: better parent, MD: mid parent

Chapter-V

DISCUSSION

The present investigation entitled “Combining ability and path analysis for morpho-physiological characters in bread wheat (*Triticum aestivum* L.)” was undertaken to study combining ability, heterosis for grain yield and its components through Line $\times$ Tester analysis. Data of F₁ generation and their parents was used to estimate phenotypic and genotypic coefficient of variation, heritability, genetic advance and path analysis.

Mean performance: It is essential to select most promising parents for implementing a successful breeding program. The selection for the important and economically significant characters will be helpful to achieve the target in crop improvement. Analysis of variance revealed that variances due to parents and crosses were significant for all 14 characters studied. Aslam *et al.* (2014) and Devi *et al.* (2013) reported similar result in their experiment. Parent ‘GW273’ showed significantly higher grain yield per plant along with early heading and maturity. ‘GW273’ also recorded higher tillers per plant, weight of spikes per plant, weight of grains per spike, test weight and harvest index. Whereas, GW366 also showed significantly higher grain yield per plant, tillers per plant, weight of spikes per plant, weight of grains per spike, test weight and harvest index. Among 3 significant higher yielding crosses, cross ‘33rdESWYT150 $\times$ RVW4106’ showed significantly higher grain yield per plant and early maturity. It also recorded higher tillers per plants, weight of spikes per plant and test weight. ‘KB2013-03 $\times$ SUJATA’ also showed significant higher grain yield per plant, weight of spikes per plant, weight of grains per spike, test weight and harvest index. ‘33rdESWYT150 $\times$ GW366’ also showed significant higher grain yield per plant and early maturity. It also showed higher tillers per

plants, weight of spikes per plant, weight of grains per spike and test weight.

Phenotypic and genotypic coefficient of variation: Genetic variability is a prerequisite for any breeding program. It provides not only a sound basis for selection but also provides some valuable information regarding selection of diverse parent to be used in hybridization program. Wide range of variability for yield and yield component is also necessary to isolate significantly superior genotype for commercial cultivation to be used as a parent in hybridization for combination breeding to develop high yielding varieties / hybrids and to create useful genetic diversity for further selection. Phenotypic and genotypic coefficient of variation is used for the assessment of variability. In the present investigation, almost equal magnitude of GCV and PCV showed for days to heading, days to maturity, plant height, spike length, weight of spike/plant, grains/spike, test weight, grain yield/plant, canopy temperature index, biological yield and harvest index, indicating, that these characters were less influenced by the environment, whereas, tillers/plant and weight of grain/spike exhibited high value of PCV over its GCV value, indicating large amount of variation for this characters was due to environment only. Present finding are in confirmation with Nukasani *et al.*, (2013).

Heritability (broad sense) and genetic advance: Heritability provides information about the degree of inheritance of particular traits. Broad sense heritability is an important parameter for selection of parent. Selection based phenotypic values of the characters depend upon heritability and genetic advance, which are the result of breeding value and their inter-play with environment. Traits with high heritability and intense desirable correlation would give correlated response as a result of which selection process to be hastened.

Heritability are useful in predicting the transmission of characters from the parent to their offspring, while, genetic advance help in understanding the type of gene action involved in the expression of characters. When the high heritability accompanied with high genetic

advance indicated that most likely heritability is due to additive gene action and selection may be effective. In the present research work, high heritability was accompanied with high genetic advance for characters *viz.*, canopy temperature index, harvest index, spike length, grains per spike, test weight, grain yield per plant, tillers per plant, 1st inter-node length, weight of spike per plant, weight of grains per spike, biological yield and plant height. High heritability with low genetic advance for days to heading and days to maturity, indicating presence of non additive gene action, high heritability was exploited due to favourable influence of environment rather than genotype and selection for such traits may not be rewarding. Present finding are in confirmation with Nukasani *et al.*, (2013) and Singh *et al.*, (2011)

Correlation analysis: Correlation studies provide information about degree and direction of association of yield contributing characters. This information is useful to plant breeder in selection of elite genotype from divers genetic population. Phenotypic and genotypic correlation coefficient among grain yield per plant and its contributing characters are presented below:-

Phenotypic correlation coefficient: It is the observable correlation between two variables. It includes both genotypes and environmental effect and therefore, differs under different environmental condition so it is less stable than genotypic correlation. In present research, phenotypic correlation analysis revealed that grain yield showed significant and positive association with four yield contributing characters *viz.*, test weight (0.9895); weight of spike/plant (0.8565); weight of grains/spike (0.7921) and harvest index (0.7667). Selection for these characters may lead instant yield improvement of wheat crop. Character *viz.*, spike length (-0.4579), grain/spike (-0.3757) and days to maturity (-0.3077) exhibited negative and significant association with grain yield, indicating that the direct selection for these characters may not be helpful for improving the yield.

Genotypic correlation coefficient: It is inherent association between two variables. It is more stable and is of paramount importance to the

plant breeder to bring about genetic improvement in one character by selecting other character of pair that is genetically correlated. In present study, genotypic correlation analysis revealed that grain yield was establish positive and significant association with 4 yield contributing characters viz., test weight (0.9992), weight of grains/spike (0.9217), weight of spike/plant (0.8985) and harvest index (0.7966). Selection for these characters can directly be followed for inherent yield improvement in wheat. Characters viz., spike length (-0.4632), grain/spike (-0.3855) and days to maturity (-0.3385) exhibited significant negative association with grain yield, thereby, indicating that direct selection for these characters may not be helpful for improving the yield. Among the association of yield contributing characters themselves, weight of grain/spike has negatively significant association with biological yield (-0.2872) indicating that the improvement in weight of grain/spike, if selection imparted may hamper the *per se* performance of that character. Present finding are in confirmation with Poor *et al.*, (2015), Singh *et al.*, (2011) and Khan *et al.*, (2013).

Path coefficient analysis: It provides the information about the cause and effect situation in understanding the cause of association between two variables; it permitted the examination of direct effect of various characters on yield as well as their indirect effects via other component traits. Thus though the estimates of direct and indirect effect, it determines the yield component. Estimates of residual effects measure the role of other possible independent variables which are not included in the study.

Phenotypic path analysis: Direct and indirect effects for various traits on grain yield revealed that weight of spike/plant exhibited highest positive direct effect on grain yield (0.9842) followed by canopy temperature index (0.4933), biological yield (0.3583), test weight (0.1360), grains/spike (0.0682), 1st inter node length (0.0460) and harvest index (0.0308). Direct effect of days to heading on grain yield was negative (-0.0527) but recorded positive indirect effect on grain yield via canopy temperature index (0.1217) and tillers/plant (0.0196).

Similarly days to maturity (-0.0715), plant height (-0.0995), tillers/plant (-0.1365), spike length (-0.0863) and weight of grain/plant (-0.0994) had negative direct effect on grain yield and positive indirect effect via several characters. The residual effect was recorded lower value (0.1233), thus, indicated majority factors influencing the grain yield was considered in the present study. Present finding are in confirmation with Poor et al., (2015), Singh et al., (2011) and Khan et al. (2013), Sharma et al., (2006).

Genotypic path analysis: Direct and indirect effect for various traits on grain yield revealed that test weight registered highest positive direct effect on grain yield (1.0335) followed by weight of grains/spike (0.1081) and spike length (0.1065). Direct effect of harvest index on grain yield was negative (-0.1277) but it had positive indirect effect via test weight (0.8346) on grain yield. Similarly, weight of spike/plant (-0.0376) also exhibited negative direct effect on grain yield and had positive indirect effect via test weight (0.9240), weight of grain/spike (0.0944). Days to maturity exhibited negative direct effect (-0.0224) on grain yield and positive indirect effect via harvest index (0.0448). Grains/spike also showed negative direct effect (-0.1037) on grain yield. The residual effect value was showed very low (0.0352), thus, indicated majority factors influencing the grain yield was considered in the present study. Present finding are in confirmation with Poor et al., (2015), Singh et al., (2011) and Khan et al. (2013), Sharma et al., (2006).

Combining ability variances: Line $\times$ tester analysis techniques has been extensively used in almost all the major field crops to estimates GCA and SCA variances and effect and to understand In the present research work, variances due to both lines and testers were significant for days to heading, plant height, tillers per plant, spike length, weight of spikes per plant, grains per spike, test weight, grain yield per plant, canopy temperature index, biological yield and harvest index. However, lines were significant for days to maturity, 1st inter-node length, weight of grains per spike. Variances due to Line $\times$ tester were significant for

all the 14 characters (Singh *et al.*, 2013 and Kapoor *et al.*, 2011 also reported similar results). In the present study both GCA and SCA variances were significant for most of the characters, thereby, indicating importance of both additive as well as non additive components of genetic variance in the control of these traits. Singh *et al.*, (2013) and Kumar *et al.*, (2011) also reported similar results.

Genetic component of variances is assessed through the estimates of GCA and SCA variances. The additive genetic variance is equal to GCA variance and dominance variance is equal to SCA variance. In the present research, the genetic component's magnitudes showed that the additive components of variances were higher compared to dominance components of variances for all characters. The ratio of genetic components " $\sigma^2_{gca} / \sigma^2_{sca}$ " also showed more than one, indicating predominance of additive variances for almost all characters. Present findings are in confirmation with Kandil *et al.*, 2016, Khiabani *et al.*, (2015) and Samier & Ismail (2015) who recorded predominance of additive variances for all the traits.

Combining ability:

Combining ability plays major role in the evaluation of inbred in terms of their breeding values; and this will help to decide efficient breeding method to be applied in segregating generation.

General combining ability effects: It is primarily a function of additive genetic variance; it helps in the selection of suitable good general combining parents for hybridization. Data presented in table 5.1 revealed that 5 lines viz., 33rdESWYT150, PBW 658, KB 2013-03, KB 2013 and VW921 reported significant and positive GCA effect for grain yield, test weight, weight of spike/plant, biological yield and harvest index, thereby, suggesting good general combiner for these traits. Tester 'GW273' was good general combiner for grain yield, test weight and biological yield, whereas, tester SUJATA registered significant and positive GCA effect for grain yield, days to heading, spike length and harvest index, thereby, suggested good general combiner for these traits. Lines 33rdESWYT150 was also reported significant and positive

GCA effect for tillers/plant and weight of grains/plant. Line KB2013-03 also exhibited significant positive GCA effect for plant height, weight of grain/spike and grains/spike. Significant positive GCA effect was reported in KB2013 and VW921 for canopy temperature index. These genotypes can be used in the development of high yielding varieties through the pedigree selection and progeny selection or mass selection in later generations in promising segregating generations in wheat. Present finding are in confirmation with Kandil *et al.*, (2016), Samier and Ismail (2015), Kalhoro *et al.* (2015), Aslam *et al.* (2014), Singh *et al.* (2013), Raj and Kandalkar (2013), Kumar *et al.* (2011) and Kapoor *et al.* (2011).

Specific combining ability Effects: It is mainly a function of dominance variances; it helps in the identification of superior cross combination for commercial exploitation of heterosis. In self –pollinated crops like wheat, SCA effects are not much important as they are mostly related to non-additive gene effects excluding those of arising from complementary gene action or linkage effects they cannot be fixed in pure lines. Further superiority of the hybrids might not indicate their ability to yield transgressive segregates; rather SCA would provide satisfactory criteria. However, if a cross combination exhibiting high SCA as well as high *per se* performance having at least one parent as good general combiner for a specific trait, it is expected to throw desirable transgressive segregants in later generations. Data presented in table 5.2 revealed that 19 crosses showed significant and positive SCA effect, thereby, indicating good specific combinations for grain yield and other attributing traits. Crosses viz., KB2013-03 × SUJATA', KB2013 × GW273', PBW658 × SUJATA' and 'VW921 × SUJATA' registered best good specific combiner for grain/yield because these crosses were the results of good x good general combiners and reported significant positive SCA effect. Crosses '33rdESWYT150×GW366', '33rdESWYT150 × RVW4106', '20thHRWYT213 × GW273', '20thHRWYT213 × SUJATA', '20thHRWYT235×SUJATA', '45thIBWSN1021×GW273', '14thFHBSN6418 × SUJATA', 'KB2013-03 × GW366', 'KB2013 × RVW4106' and 'VW921 × GW366' were the result of

good x poor general combiner and also reported significant positive SCA effect for grain yield. Rest of the crosses viz., '45thIBWSN1021×RVW4106', '36thSAWSN3065 × RVW4106', '36thSAWSN3065 ×GW366', '14thFHBSN6418×GW366', '45thIBWSN1021×RVW4106', '20thHRWYT235×GW366' were result of poor x poor general combiner but exhibited significant positive SCA effect for grain/yield, thereby, suggesting good specific combiner for these traits. Present finding are in confirmation with Kandil *et al.*, (2016), Kalhoro *et al.* (2015), Aslam *et al.* (2014), Singh *et al.* (2013), Raj and Kandalkar (2013), Kumar *et al.* (2011), Kapoor *et al.* (2011).

Table 5.1 Parents showing significant GCA effects for grain yield along with GCA effects for other attributes

Parents	Lines(L) / Tester(T))	Grain yield/plant(g)		Days to heading		Days to maturity		Plant height(cm)		Tillers/plant (cm)	
		Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA
1. GW 273	T	17.91	0.17 *	85.50	0.10	135.0 0	0.22	104.8 0	-0.05	8.30	0.08
2. SUJATA	T	17.33	0.07 *	85.50	0.55* *	137.0 0	-0.09	104.6 0	-0.09	8.30	-0.12
3. VW 921	L	16.56	0.75 **	87.50	0.45* *	135.0 0	- 0.60**	103.9 0	2.83* *	7.10	-0.01
4. PBW 658	L	16.46	0.47 **	86.50	- 1.05* *	138.5 0	-0.47	104.7 0	- 1.95* *	7.00	- 0.21**
5. 33 rd ESWYT 150	L	16.23	1.51 **	87.00	-0.05	139.0 0	-0.35	100.2 0	- 1.85* *	7.20	0.77**
6. KB 2013-03	L	16.11	0.72 **	89.50	-0.05	136.5 0	-0.47	109.6 0	1.75* *	6.90	0.04
7. KB 2013	L	14.98	0.68 **	88.00	0.08	137.0 0	- 0.60**	109.6 0	0.45	6.90	- 0.51**

*, ** significant at 5 and 1 per cent level, respectively

Parents	Lines(L) / Tester(T))	1 st inter-node length(cm)		Spike length(cm)		Spike weight/plant (g)		Grain weight/spik e(g)		Grains /spike	
		Mean	GCA	Me	GCA	Mean	GCA	Mea	GC	mea	GCA

				an				n	A	n	
1. GW 273	T	3.11	-0.02	10.75	-0.17*	24.46	0.16	2.26	0.00	68.10	-1.09
2. SUJATA	T	2.68	0.02	11.32	0.28*	23.78	0.12	2.11	0.02	70.80	1.52
3. VW 921	L	2.77	0.04	11.11	0.05	23.08	0.66*	2.04	0.06	66.50	-0.76
4. PBW 658	L	2.90	-0.09**	10.29	-0.15*	23.41	0.32*	2.12	0.04	60.80	0.54
5. 33 rd ESWYT 150	L	3.02	-0.05	10.43	-0.61*	21.22	1.36*	2.00	0.13**	61.90	-2.11*
6. KB 2013-03	L	3.02	-0.10**	8.94	-0.23*	21.01	0.68*	2.07	0.07**	54.20	0.94*
7. KB 2013	L	2.91	-0.04	11.03	0.22*	20.09	0.58*	2.02	0.07**	67.30	-0.36

*, ** significant at 5 and 1 per cent level, respectively

Parents	Lines(L)/ Tester(T)	Test weight(g)		Canopy temperature index		Biological yield(g)		Harvest index (%)	
		Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA
1. GW 273	T	44.78	0.42*	0.41	-0.01**	32.70	0.43*	54.75	0.11
2. SUJATA	T	43.33	0.13	0.36	0.00	33.48	-0.15	51.75	0.56*
3. VW 921	L	41.54	1.99*	0.36	0.02**	35.04	-	47.27	2.79**

			*				0.73*		
4. PBW 658	L	41.82	1.11*	0.35	-0.01**	35.76	0.96*	46.59	2.36**
5. 33 rd ESWYT 150	L	40.79	3.73*	0.36	-0.01	39.40	2.18*	41.22	1.57**
6. KB 2013-03	L	40.49	2.02*	0.36	0.01	35.29	1.05*	45.65	3.28**
7. KB 2013	L	38.69	1.64*	0.37	0.01**	37.96	-0.92*	43.09	3.00**

Table 5.2 Crosses showing significant SCA effects for grain yield and its attributes

SN	Crosses	Grain yield/plant(g)		Days to heading	Days to maturity	Plant height	Tillers/plant	1 st inter-node length
		mean	SCA	SCA	SCA	SCA	SCA	SCA
1	33 rd ESWYT 150 ×GW 366	17.87	0.59*	-0.50	-1.45**	2.73**	0.36	0.16**
2	33 rd ESWYT 150 ×RVW 4106	18.06	0.72*	0.15	-1.10**	5.99**	0.56**	0.14**
3	20 th HRWYT 213 ×GW 273	16.89	1.67*	-0.10	-0.10	1.85**	0.59**	-0.26**
4	20 th HRWYT 213 ×SUJATA	15.44	0.23*	-0.05	-0.85	5.59**	0.19	0.09
5	20 th HRWYT 235 ×GW 366	15.57	1.27*	-0.50	-1.70**	0.83	-0.16	-0.20**

6	20 th HRWYT 235 ×SUJATA	14.80	0.29* *	-0.05	0.15	1.62**	0.17	0.13
7	45 th IBWSN 1021 ×GW 273	15.70	0.67* *	2.52**	-0.10	6.75**	-0.31	0.24
8	45 th IBWSN 1021 ×RVW 4106	15.87	1.09* *	-1.23**	1.35**	1.86**	-0.24	-0.31**
9	14 th FHBSN6 4188 ×GW ×366	15.79	0.54* *	-0.63	0.92	2.98**	0.24	0.18**
10	14 th FHBSN6 4188 ×SUJATA	15.87	0.41* *	0.80	- 1.72**	-0.03	-0.23	-0.24**
11	36 th SAWSN 3065 ×GW 366	16.31	0.82* *	0.63	- 1.33**	0.15	0.14	0.05
12	36 th SAWSN 3065 ×RVW 4106	16.06	0.51* *	-0.73	-0.47	4.41**	0.16	0.00
13	PBW 658 ×SUJATA	16.89	0.42* *	-0.55	0.03	7.62**	0.37	0.12*
14	KB 2013-03 ×GW366	17.16	0.66* *	0.00	-0.83	4.63**	-0.81	-0.17**
15	KB 2013-03 × SUJATA	18.00	1.29* *	0.95	0.97*	2.32**	-0.48**	0.21**
16	KB 2013 × GW 273	17.27	0.49* *	-0.73	-1.10**	5.47**	-0.63**	0.17**
17	KB 2013 × RVW 4106	17.42	0.90* *	-0.48	-0.85	0.79	-0.27	-0.18**
18	VW 921 × RVW 4106	17.43	0.91* *	0.00	1.30**	3.75**	0.04	0.13

19	VW 921 × SUJATA	17.01	0.27* *	0.45	-0.85	-2.46**	-0.03	-0.20**
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*, ** significant at 5 and 1 per cent level, respectively

SN	Crosses	Spike length	Spikes weight/plant	Grain weight/spike	Grains/sp ike	Test weight
		SCA	SCA	SCA	SCA	SCA
1	33 rd ESWYT 150 ×GW 366	0.22**	0.84**	0.11*	-1.50**	1.56**
2	33 rd ESWYT 150 ×RVW 4106	-0.70**	1.24**	-0.01	-3.56**	1.65**
3	20 th HRWYT 213 ×GW 273	0.27**	1.96**	0.08	0.71	4.25**
4	20 th HRWYT 213 ×SUJATA	-1.53**	-0.66**	0.05	-8.40**	0.80**
5	20 th HRWYT 235 ×GW 366	0.59**	0.73**	0.17	-3.43**	3.50**
6	20 th HRWYT 235 ×SUJATA	-0.78**	1.45**	-0.03	-3.10**	0.92**
7	45 th IBWSN 1021 ×GW 273	-1.52**	1.79**	0.02	-8.78**	1.67**
8	45 th IBWSN 1021 ×RVW 4106	-0.30**	0.65**	0.08	-2.57**	2.66**
9	14 th FHBSN6 4188 ×GW ×366	-1.25**	0.74**	-0.03	-8.85**	1.33**
10	14 th FHBSN6 4188 ×SUJATA	-0.19**	-0.03	0.06	-0.32	1.08**
11	36 th SAWSN 3065 ×GW 366	-0.30**	0.75**	0.11*	0.70	2.14**
12	36 th SAWSN 3065 ×RVW	-1.17**	0.79**	0.05	-5.76**	1.13**

SN	Crosses	Spike length	Spikes weight/plant	Grain weight/spike	Grains/spike	Test weight
		SCA	SCA	SCA	SCA	SCA
	4106					
13	PBW 658 ×SUJATA	-1.58**	-0.48	-0.06	-10.62**	1.13**
14	KB 2013-03 ×GW366	0.24**	0.91**	0.10	1.25	1.39**
15	KB 2013-03 × SUJATA	-0.06	1.81**	0.14**	1.18	2.91**
16	KB 2013 × GW 273	-1.40**	0.36	0.14**	-4.61**	1.15**
17	KB 2013 × RVW 4106	0.43	0.39	0.04	1.09	2.23**
18	VW 921 × RVW 4106	-1.44**	1.43**	0.09	-9.15**	2.10**
19	VW 921 × SUJATA	0.34**	0.27	0.08	-0.72	0.32

*, ** significant at 5 and 1 per cent level, respectively

SN	Crosses	Canopy temperature index	Biological yield	Harvest index
		SCA	SCA	SCA
1	33 rd ESWYT 150 ×GW 366	0.02**	0.14	1.19
2	33 rd ESWYT 150 ×RVW 4106	-0.01	0.08	2.11**
3	20 th HRWYT 213 ×GW 273	0.03**	-0.40	4.58**
4	20 th HRWYT 213 ×SUJATA	0.01	0.77	-0.22
5	20 th HRWYT 235 ×GW 366	0.01	1.10**	1.95
6	20 th HRWYT 235 ×SUJATA	-0.01	1.31**	-0.66
7	45 th IBWSN 1021 ×GW 273	-0.02	1.53**	0.17

8	45 th IBWSN 1021 ×RVW 4106	0.00	1.49**	1.74
9	14 th FHBSN6 4188 ×GW ×366	0.03**	0.60	0.66
10	14 th FHBSN6 4188 ×SUJATA	-0.04**	1.97**	-1.06
11	36 th SAWSN 3065 ×GW 366	-0.02**	-0.01	3.25**
12	36 th SAWSN 3065 ×RVW 4106	0.00	0.54	-2.55**
13	PBW 658 ×SUJATA	-0.01	-0.07	0.94
14	KB 2013-03 ×GW366	0.00	0.80*	0.50
15	KB 2013-03 × SUJATA	0.00	-2.57**	6.44**
.16	KB 2013 × GW 273	0.00	-0.82**	1.93
17	KB 2013 × RVW 4106	0.02**	0.76	1.78
18	VW 921 × RVW 4106	-0.03**	-0.75	3.14**
19	VW 921 × SUJATA	0.00	1.48**	-1.17

Heterosis:

The aim of estimation of heterosis in the present study has to spot out the best combination of parents giving high degree of useful heterosis and characterization of parents for their genotypic worth for future use in breeding programme. All characters had shown considerable amount of heterosis over better parent (Heterobeltiosis) and mid parent (relative heterosis). Present finding are in confirmation with Devi *et al.* (2013). The degree of heterosis however differed for different characters. Data presented in table 5.3 revealed that 4 cross *viz.*, 'KB2013 × RVW4106', '33rdESWYT150 × RVW4106', 'KB2013-03 × SUJATA' and 'KB2013-03 × RVW4106' recorded significant heterobeltiosis and relative heterosis in positive direction for grain yield, while another 3 cross '33rdESWYT150 × GW366', '45thIBWSN1021 × RVW4106' and 'PBW658 × RVW4106' recorded significant positive relative heterosis for grain yield. Devi *et al.* 2013 also reported similar result. Cross 'KB2013 × RVW4106' was also reported significant positive heterobeltiosis and relative heterosis for weight of spike/plant and test weight. Cross '33rdESWYT150 × RVW4106' also showed significant heterobeltiosis and relative heterosis in positive direction for tillers/plant, weight of spike/plant, test weight and biological yield. Cross 'KB2013-03 × RVW4106' was also reported significant positive heterobeltiosis and relative heterosis for days to maturity, test weight and biological yield. Cross 'KB2013-03 × SUJATA' showed significant positive relative heterosis for 1st inter-node length, weight of spike/plant, test weight, biological yield and harvest index, while significant positive heterobeltiosis was reported for test weight and canopy temperature index. Cross '33rdESWYT150 × GW366' was also reported significant positive relative heterosis for weight of spike/plant, test weight, and biological yield. Cross '45thIBWSN1021 × RVW4106' was also reported significant positive heterobeltiosis and relative heterosis for biological yield. Cross 'PBW658 × RVW4106' also showed significant positive relative heterosis for biological yield. Further it was noticed that both significant heterobeltiosis or / and relative heterosis

were recorded for attributing traits without showing heterosis for grain yield.

Table: 5.3 Heterosis over better parent and mid parent for grain yield and its attributes

Crosses	Grain yield/plant		Days to heading		Days to maturity		Plant height		Tillers/plant		1 st inter-node length		Spike length	
	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP
‘KB2013 × RVW4106’	16.33* *	16.88* *	- 2.84* *	-1.44	- 1.09* *	- 2.61* *	- 2.59**	- 10.14* *	-9.49	-6.87**	- 12.78* *	- 9.60* *	-1.09	9.43**
‘33 rd ESWYT150 × RVW4106’	11.24* *	16.05* *	-1.15	-0.29	- 2.52* *	- 1.81* *	0.05	4.28**	15.28* *	18.57* *	0.00	3.25* *	- 22.19* *	- 19.35* *
‘KB2013-03 × SUJATA’	3.90**	7.67**	- 2.31* *	0.00	- 1.08* *	-0.91	- 4.78**	- 2.33**	- 21.69* *	- 14.47* *	1.38	7.37* *	- 9.98**	0.59
‘KB2013-03 × RVW4106’	3.20**	7.28**	- 3.91* *	-1.71	1.46* *	1.65* *	- 15.69* *	- 15.48* *	1.45	2.19	-0.99	2.22	- 25.53* *	- 17.16* *
33 rd ESWYT150 × GW366’	0.34	4.99**	- 2.30* *	-1.45	- 2.88* *	- 1.82* *	- 3.43**	0.19	-1.19	6.41	-2.24	-0.49	- 5.37**	2.07
‘45 th IBWSN1021 × RVW4106’	-0.53	2.90**	- 6.04* *	- 3.12* *	-0.73	-0.55	- 3.53**	- 3.33**	- 10.39* *	-4.83	- 10.07* *	- 7.62* *	- 9.63**	- 9.30**
‘PBW658 ×	- 2.43**	2.47**	-1.16	-0.58	- 2.53* *	- 2.00* *	- 4.36**	- 2.41**	-7.14	-5.80	-1.38	-0.17	11.14* *	- 7.30**

RVW4106'					*	*								
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*, ** significant at 5 and 1 per cent level, respectively

MP: mid parent, BP: better parent

	Weight of spike/plant		Weight of grain/spike		Grain/spike		Test weight		Canopy temperature index		Biological yield		Harvest index	
Crosses	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP
'KB2013 × RVW4106'	4.31**	8.82**	4.21	5.65	-7.73	- 6.84* *	12.54* *	13.52* *	- 21.92* *	- 19.72* *	1.55	7.49	2.40	3.59
'33 rd ESWYT150 × RVW4106'	11.80* *	13.55* *	6.27	7.07	- 17.06**	- 12.08	10.44* *	14.33* *	- 21.13* *	-20.00	4.00* *	12.00* *	-0.08	3.30
'KB2013-03 × SUJATA'	3.36	9.76**	4.96	6.1	-5.51	7.04* *	3.67**	7.18**	- 16.90* *	- 16.08* *	0.03	2.67	-1.53	4.64* *
'KB2013-03 × RVW4106'	1.28	3.40	-0.97	1.49	-18.22	- 8.63* *	5.46**	8.78**	- 18.06* *	- 16.31* *	8.39* *	10.78* *	-4.81	-3.16
33 rd ESWYT15	-1.13	5.47**	-3.95	2.46	-3.23	-2.20	0.54	4.96**	-	-	5.29*	14.44*	-	-

0 × GW366'									21.79*	18.12*	*	*	19.86*	9.28*
									*	*			*	*
'45 th IBWSN10 21 × RVW4106'	-1.07	0.50	0.76	0.76	- 10.13**	-3.97	-0.55	1.80	- 14.29*	- 13.67*	8.73*	13.95*	- 11.04*	- 9.82*
									*	*	*	*	*	*
'PBW658 × RVW4106'	- 4.04**	-0.85	-1.18	2.45	-3.21	2.63	-4.33	0.23	- 26.09*	- 26.09*	2.03	4.95**	-5.51*	-2.91
									*	*				

*, ** significant at 5 and 1 per cent level, respectively

MP: mid parent, BP: better parent

Chapter-VI

SUMMARY, CONCLUSION AND SUGGETIONS FOR FURTHER WORK

SUMMARY:

The present investigation entitled “Combining ability and path analysis for morpho-physiological characters in bread wheat (*Triticum aestivum* L.)” was undertaken to study the combining ability for grain yield and its components in F₁ generation of wheat through Line X Tester analysis. Phenotypic and genotypic coefficient of variation, heritability, genetic advance and path analysis were carried out in present material. Experiment was conducted with 2 replications and 54 genotypes consisting 10 lines viz., 33rdESWYT150, 20thHRWYT213, 20thHRWYT235, 45thIBWSN1021, 14thFHBSN6418, 36thSAWSN3065, PBW658, KB2013-03, KB2013, VW921 and 4 testers viz., GW273, GW366, RVW 4106, SUJATA and their 40 crosses made in L X T mating fashion in randomized block design at experimental Research Farm, College of Agriculture, Gwalior, (M.P.) during 2014-2015. Observations were recorded on randomly selected 5 tagged plants for grain yield per plant and different yield contributing traits viz., days to heading, days to maturity, plant height, tillers per plant, spike length, 1st internodes length, weight of spikes per plant, weight of grains per spike, grains per spike, test weight, canopy temperature index, biological yield and harvest index. The analysis was carried out by adopting Kempthorne (1957) for estimation of variances components and combining ability effects. Heterosis over mid parents and better parents were determined as per standard procedure. Phenotypic and genotypic coefficient of variation, heritability, genetic advance and path analysis were also determined in above material.

Phenotypic coefficient of variation (PCV) were recorded highest for canopy temperature index (13.93%) followed by harvest index

(10.78%), spike length (9.30%), grain/spike (8.58%), tillers/plant (8.06%), test weight (7.62%), grain yield/plant (7.56%), weight of grains/spike (7.45%), 1st inter-node length (7.00%), weight of spike/plant (6.42%), biological yield (5.71%) and plant height (5.09%), whereas, comparatively lower in days to maturity (1.23%) and days to heading (1.66%). Highest genotypic coefficient of variation (GCV) were observed for the canopy temperature index (13.21%) followed by harvest index (10.37%), spike length (9.26%), grain/spike (8.42%), test weight (7.55%), grain yield/plant (7.51%), tillers/plant (6.95%), 1st inter-node length (6.44), weight of grain/spike (6.40%), weight of spike/plant (6.15%), biological yield (5.52%) and plant height (5.03%) whereas, comparatively lower in days to maturity (1.11%) and days to heading (1.49%)

High heritability (broad sense) was observed for spike length (99.11%), grain yield per plant (98.58%), test weight (98.07%), plant height (97.68%), grains per spike (96.39%), biological yield (93.45%), harvest index (92.52%), weight of spikes per plant (91.61%), canopy temperature index (89.91%), 1st inter-node length (84.56%), days to maturity (82.55), days to heading (80.64%), tillers per plant (74.34%), weight of grains per spike (73.88%).

Higher genetic advance as per cent of mean was expected for canopy temperature (25.80%), harvest index (20.54%). The moderate genetic advance as per cent of mean was observed for spike length (18.99%), grains per spike (17.03%), test weight (15.40%), grain yield per plant (15.36%), tillers per plant (12.35%), 1st inter-node length (12.19%), weight of spike per plant (12.12%), weight of grains per spike (11.33%), biological yield (11.00%), plant height (10.25%).

Phenotypic and genotypic correlation analysis revealed that the association between yield and yield contributing characters was found positive and significant only for four characters viz., test weight (0.9895); weight of spike/plant (0.8565); weight of grains/spike (0.7921) and harvest index (0.7667) selection for these characters can directly be followed for immediate yield improvement of wheat crop. Path coefficient

analysis revealed that some traits viz., test weight exhibited highest positive direct effect on grain yield (1.0335) followed by weight of grains/spike (0.1081), spike length (0.1065), tillers/plant (0.0791) and plant height (0.0171) on grain yield. Some traits viz., grain/spike, biological yield, harvest index, weight of spike/plant, 1st inter-node length, days to maturity and canopy temperature index exhibited direct negative effect on grain yield but these traits had positive indirect effect via another traits on grain yield. Each trait must be given preference in selection along with optimum days to heading and plant height while selecting the superior type.

Parents and crosses were highly significant for all the characters except canopy temperature index for parent. Variances due to Lines and variances due to Line X Tester were significant for all characters and variances due to tester were significant for all characters except days to maturity, 1st inter-node length and weight of grains per spike.

Genetic components revealed that additive components of variances were higher compared to dominance components of variances for all characters. The ratio of genetic components " $\sigma^2_{gca} / \sigma^2_{sca}$ " also showed more than one, indicating predominance of additive variances for almost all characters.

Analysis of GCA and SCA effects revealed that five lines viz., 33rdESWYT150, PBW658, KB2013-03, KB2013 and VW921 and two tester viz., GW273, SUJATA showed significant positive GCA effect for grain yield and its contributing traits, thereby, suggesting good general combiner for these traits. Nineteen crosses viz., '33rdESWYT150 × GW366', '33rdESWYT150 × RVW4106', '20thHRWYT213 × GW273', '20thHRWYT213 × SUJATA', '20thHRWYT235 × GW366', '20thHRWYT235 × SUJATA', '45thIBWSN1021 × GW273', '45thIBWSN1021 × RVW4106', '14thFHBSN6418 × GW366', '14thFHBSN6418 × SUJATA', '36thSAWSN3065 × GW366', '36thSAWSN3065 × RVW4106', 'PBW658 × SUJATA', 'KB2013-03 × GW366', 'KB2013-03 × SUJATA', 'KB2013 × GW273', 'KB2013 ×

RVW4106', 'VW921 × GW366' and 'VW921 × SUJATA' showed significant positive SCA effect for grain yield and its contributing traits, thereby, suggesting good specific combiner for these traits.

Four cross viz., 'KB2013 × RVW4106', '33rdESWYT150 × RVW4106', 'KB2013-03 × SUJATA' and 'KB2013-03 × RVW4106' recorded significant heterobeltiosis and relative heterosis in positive direction for grain yield while, another three cross '33rdESWYT150 × GW366', '45thIBWSN1021 × RVW4106' and 'PBW658 × RVW4106' were recorded significant positive only for relative heterosis in grain yield.

CONCLUSION:

The following relevant conclusions could be drawn from the present study:

The high heritability values coupled with high genetic advance were recorded for traits canopy temperature index, harvest index, spike length, grains per spike, test weight, grain yield per plant, tillers per plant, 1st inter-node length, weight of spike per plant, weight of grains per spike, biological yield and plant height, indicating that these characters are governed by additive gene effects and direct selection for these traits would be more effective for desired genetic improvement.

Correlation between grain yield/plant and four characters namely test weight (0.9895); weight of spike/plant (0.8565); weight of grains/spike (0.7921) and harvest index (0.7667) was found positive and significant and therefore selection for these characters can directly be followed for yield improvement in wheat. Path coefficient analysis revealed that some traits viz., test weight, weight of grain/spike and spike length exhibited highest positive direct effect and some traits have indirect positive effect on grain yield and each trait must be given preference in selecting the superior types.

Analysis of combining ability suggested an idea about breeding methodology to be applied and use of promising crosses for further improvement in wheat. In self –pollinated crops like wheat, SCA effects are not much important as they are mostly related to non-additive gene effects excluding those of arising from complementary gene action or

linkage effects they cannot be fixed in pure lines. Further superiority of the hybrids might not indicate their ability to yield transgressive segregates; rather SCA would provide satisfactory criteria. However, if a cross combination exhibiting high SCA as well as high *per se* performance having at least one parent as good general combiner for a specific trait, it is expected to throw desirable transgressive segregants in later generations. Crosses viz., 'KB2013-03 × SUJATA', 'KB2013 × GW273', 'PBW658 × SUJATA' and 'VW921 × SUJATA'. These crosses were the results of good × good general combiner. '33rdESWYT150 × GW366', '33rdESWYT150 × RVW4106', '20thHRWYT213 × GW273', '20thHRWYT213 × SUJATA', '20thHRWYT235 × SUJATA', '45thIBWSN1021 × GW273', '14thFHBSN6418 × SUJATA', 'KB2013-03 × GW366', 'KB2013 × RVW4106' and 'VW921 × GW366' these crosses were the result of good × poor general combiner so these crosses hold great promise in improving the grain yield in future breeding programme of bread wheat.

The present study reveals ample variability among the parents and high scope for the exploitation of heterosis for advancement of grain yield in wheat. The cross 33rdESWYT150 × RVW4106 followed by KB2013-03 × SUJATA and KB2013-03 × RVW4106 was recognized as the best heterotic cross as well as high *per se* performance for grain yield and it exhibited highly significant positive heterosis over both the better and mid parent. Therefore, these crosses can be further evaluated and used in hybrid breeding programme to boost up the grain yield.

SUGGETIONS FOR FURTHER WORK:

The following relevant suggestions could be drawn for further scope of improvement from the present study:

1. Good general combiners like 33rdESWYT150, PBW658, KB2013-03, KB2013 and VW921, GW273 and SUJATA can be used in the development of high yielding varieties through the pedigree selection and progeny selection or mass selection in later generations in promising segregating generations in wheat.

2. New recombinant promising single plants may be selected in F_2 generations of good cross viz., 'KB2013-03 × SUJATA', 'PBW658 × SUJATA', 'KB2013 × GW273' and 'VW921 × SUJATA' both parents involved in these crosses having good general combining ability effects so these crosses are highly desirable for effective selection.

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