Analysis of Heterosis and Combining Ability for Seed Yield and its Components in Bread Wheat (*Triticum aestivum L.*)

A B S T R A C T

The present study was carried out during the two successive seasons 2020-21 and 2021-22 at the Crop Research Farm, R.A.K. College of Agriculture, RVSKVV, Sehore (MP). General and specific combining ability estimates were obtained by employing Griffin's diallel cross analysis, model 1 (fixed model) method 2 (Griffing, 1956). Heterosis over mid parents and better parents (Fonseca and Patterson, 1968) were determined as per standard procedure. Significance of heterosis value was tested using 't' test. The analysis of variance revealed highly significant values among the treatments and parents for all the characters, indicating appreciable variability. The aim of this work was to study the general (GCA) and specific (SCA) combining ability and heterosis through half diallel mating among six different wheat varieties. Based on GCA effects, GS-2031, HI-1634 and HI-1633 considered as good general combiners Seed yield /plant (g), Based on per se performance and significant SCA effects, the following crosses *viz.*, GS-2031 x HI-8777, HI- 8777 x HI -1633, CWYT-614 x HI-1633, CWYT-644 x HI-1634, CWYT-614 x GS-2031, CWYT-644 x HI-8777, CWYT-644 x HI-1633, HI-1634 x HI-1633 and CWYT-644 x GS-2031 combination emerged as promising combiners for Seed yield/plant. A perusal of estimates of economic heterosis for yield and yield contributing characters revealed that hybrid CWYT-614 x GS -2031, CWYT-614 x HI -1633, CWYT- 644 x HI -1634, CWYT- 644 x GS -2031, CWYT- 644x HI -1633, HI -1634 x GS -2031, HI -1634 x HI -1633, GS -2031 x HI- 8777 and HI- 8777 x HI -1633 exhibited maximum estimates of significant positive economic heterosis for Seed yield/plant (g).

Key words- ANOVA, GCA, SCA, Heterosis, Wheat, half diallel

Itroduction

Wheat (*Triticum aestivum* L.) is one of the most important and strategic crops all over the world. 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 95.91 million tonnes during the last decade and it is a major contributor to the food security system in India, occupying nearly 31.00 million hectares and productivity 30.10 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, 2023). 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.

During breeding programs, it is necessary to select pure lines of high general combining ability (GCA) that indicates the additive gene effect. On the base of that predicting progenies and making choice of cross combination and genotypes can be carried out. Combining ability investigations carried out by breeders to select parents with efficient transferring desirable genes to the progenies (Madic *et al.*, 2005). For starting a breeding program to improve any crop, the breeder need to knew the type of gene action and genetic system controlling the inheritance of the interest characters and the best breeding strategy to be used to improve them.

Combining ability analysis of Griffing (1956) is most widely used as biometrical tool for identifying parental lines in terms of their ability to combine in hybrid combination. With this method, the resulting total genetic variation is partitioned into the variance effects of general combining ability, as a measure of additive gene action and specific combining ability, as measure of additive gene action.

Hybrid vigor is the phenomenon depending on the equilibrium of additive, dominance and their interrelating characters as well as delivery of genes in parental lines and distinct the advantage of the hybrid over the mid-parent (heterosis), better parent (heterobeltiosis) and Economic/Useful (heterosis) (Allard, 1960). Such information will lead to isolation of potential cross combinations and the selection of superior parental lines for the use in plant breeding programs by crossing good general combining lines for grain yield and selecting transgressive sergeants from resulting hybrids, Breeders could develop of productive wheat varieties (Nour et al., 2011).

The main objectives of this study were to detect the magnitude of both general and specific combining ability (GCA and SCA) as well as heterosis for grain yield and some agronomic characters in 15 wheat crosses made among six bread wheat genotypes using partial or one way diallel crosses.

Materials and Methods

The present study was carried out during the two successive seasons 2020-21 and 2021-22 at the Crop Research Farm, R.A.K. College of Agriculture, RVSKVV, Sehore (MP). The aim of this work was to study the general (GCA) and specific (SCA) combining ability and heterosis through half diallel mating among six different wheat varieties.

These genotypes represent a wide range of variability. List of parents and cross combinations used in morphological assessment are presented in table 1. The present experiment was carried out during the Rabi 2020-21 at the Crop Research Farm, R.A.K. College of Agriculture, RVSKVV, Sehore (MP). The experiment involved six genetically diverse parent plants that exhibited a wide range of variation. Total of 15 crosses derived from these parents were selected for further investigation. In the *Rabi* season of 2021-2022, the final experimental material, consisting of the selected crosses, was evaluated using a randomized block design with three replications. Each plot consisted of four rows for parents and F_1. One popular variety sown in separate plot used as check for estimation of standard heterosis. Each row was 3m long and 30 cm apart, and the seeds within row were spaced 3.5 cm apart. The sowing was made in two different experimental years by hand dibbling method of seeding each in rows. All recommended cultural practices were considered.

Data were recorded on five individual guarded plants chosen at random from each row. The studied characters were Days to heading, Days to maturity, Plant height (cm), Number of effective tillers/plant, Number of spikes/plant, Number of spikelets/spike, Spike length (cm), Spike weight (g), Number of grains/spike, Biological yield/plant (g), Harvest Index (%), 1000 Seed Weight (g) and Seed yield/plant (g). Data analysis was done according to Steel and Torrie (1980). General and specific combining ability estimates were obtained by employing Griffin's diallel cross analysis, model 1 (fixed model) method 2 (Griffing, 1956). Heterosis over mid parents and better parents (Fonseca and Patterson, 1968) were determined as per standard procedure. Significance of heterosis value was tested using 't' test.

Results and Discussion

Analysis of Variance

The present study primarily focused on understanding the nature of gene action within a carefully selected group of materials. Its implications were significant in formulating appropriate breeding programs and facilitating the development of desired genotypes. This investigation played a major role in utilizing the studied materials and achieving the goal of creating improved crop varieties.

The analysis of variance revealed highly significant values among the treatments and parents for all the characters, indicating appreciable variability. Parents and F1s indicated highly significant differences for all the characters in F1s. The parents vs F1s, exhibited highly significant differences for all the characters indicating variability present in parents as well as in crosses (Table 2). The selection of parents based on morphological differences was validated by analysis of variance. Similar findings were also reported by Ghaffar et al., (2018); Elahi et al., (2020), Singh et al., (2021).

Combining ability

Combining ability analysis was a valuable tool in screening desirable strains and their cross combinations for effective utilization. It provides essential information necessary to develop a systematic breeding program aimed at achieving rapid and sustained improvement. The present study revealed significant contribution of both the additive and non-additive components of genetic variance for all the characters.

The ANOVA indicate that the mean sum of squares due to general combining ability (GCA) were observed highly significant for all the attributes studied. Similarly, the mean sum of squares due to specific combining ability were also observed highly significant for all the characters in F1 generation indicating that additive as well as non-additive genetic effects in determining the attributes. Genetic components analysis also indicated predominance of non-additive genetic estimate for all the characters (Table 2). Similar result also was reported by Singh et al. (2012), Samier (2015), Kumar and Kumar (2017), Patel et al. (2020), Kamara et al. (2021) also reported most of traits significant.

The aforesaid analysis involves per se performance (Table 3), GCA and SCA effects (Table 5 and 6) to determine the potentiality of parents or crosses for mobilizing them in an efficient hybridization programme. The different standard methods for combining ability estimates (Griffing, 1956b; Kempthorne, 1957; Kempthorne and Curnow, 1961; Fyfe and

Gilbert, 1963; Gardner and Eberhart, 1966) may or may not be compatible with one another with equal weightage and in the same order of ranking. On the other hand, a plant breeder is mainly concerned with relative ranking coupled with desirable and significant combining abilities rather than absolute values.

A. General combining ability (GCA) effects

The GCA effects include both additive and additive x additive interaction components of genetic variability (Griffing, 1956b; Sprague, 1966) which represents predictable (fixable) genetic variance as also reported by Gilbert (1967). The additive parental effects as measured by GCA effects are of practical use, whereas non-allelic interactions are unpredictable and cannot be easily manipulated.

In the present investigation considering GCA effects, good general combiners were; HI-1633 and HI-8777 for days to heading; HI-1633 and HI-8777 for days to maturity; HI-8777 and CWYT-614 for plant height; HI-1633 and HI-8777 for the number of effective tillers per plant; HI-8777 and CWYT-614 for the Number of spikes/ plant; CWYT-614 and HI-1634 for the Number of spikelets/spike; HI-1633, CWYT-614 and GS-203 for Spike length (cm); CWYT-644 and CWYT-614 for Spike weight (g); CWYT-614, GS-2031 and CWYT-644 for the Number of grains per spike; GS-2031, HI-1634 and HI-1633 for Biological yield/plant; GS-2031, HI-1634, HI-1633 and HI-8777 1000 grain seed weight; HI-1633 and GS-2031 Harvest Index (%); GS-2031, HI-1634 and HI-1633 Seed yield /plant (g) (Table 4). The result also supported by Murphy et al. (2008), Akinci (2009), Kapoor et al. (2011), Singh et al. (2012), Jaiswal et al. (2013), Jatav et al. (2014), Mandal and Madhuri (2016), Rajput and Kandalkar (2018), Bajaniya et al. (2019), Khaled et al. (2020), Singh et al. (2021), Kajla et.al (2022) and Kumari et al. (2022).

B. Specific combining ability (SCA) effect

Grafius (1959) proposed that the existence of a specific gene system solely responsible for yield might be a misconception. Some researchers found that the genetic basis for high Specific Combining Ability (SCA) in complex traits could be explained by the interaction of different components of directly and indirectly related traits on the phenotypic level. Generally, SCA effects do not significantly contribute to improving self-fertilizing crops unless there is potential for exploiting heterosis commercially. Breeders are usually interested in obtaining transgressive offspring through crosses to produce homozygous lines in self-pollinated crops such as barley. Jinks and Jones (1958) highlighted that the superiority of hybrids might be attributed to their ability to generate transgressive offspring through the interaction of heterosis and non-additive gene effects. Based on the analysis of specific combining ability (SCA) effects and the individual performance of the crosses, the following findings were observed:

Based on per se performance and significant SCA effects, the following cross combination emerged as promising combiners:

In the present investigation the hybrid GS-2031 x HI-1633, HI- 8777 x HI -1633, CWYT-614 x GS-2031 and CWYT-614 x CWYT-644 for Days to heading; GS-2031 x HI-1633, HI- 8777 x HI -1633, CWYT-614 x CWYT-644, CWYT-614 x HI-1634 and CWYT-

614 x GS-2031 for days to maturity; GS-2031 x HI-8777 and GS-2031 x HI-1633 for plant height; CWYT-614 x HI-8777, CWYT-644 x GS-2031, CWYT-644 x HI-1634, CWYT-614 x GS-2031, CWYT-644 x HI-1633, HI- 8777 x HI -1633, HI-1634 x HI-8777, HI-1634 x HI-1633 and HI-1634 x GS-2031 for number of effective tillers/plant; CWYT-614 x HI-8777, CWYT-644 x GS-2031, CWYT-644 x HI-1634, HI-1634 x HI-1633, HI- 8777 x HI -1633, HI-1634 x HI-8777, CWYT-614 x GS-2031, GS-2031 x HI-1633 for number of spikes/plant; CWYT-614 x HI-1633, CWYT-614 x GS-2031, CWYT-644 x HI-1633, CWYT-644 x HI-1634, GS-2031 x HI-1633 and CWYT-644 x HI-8777 for number of spikelets/spike; CWYT-614 x HI-1633, CWYT-614 x CWYT-644, CWYT-614 x HI-8777, CWYT-644 x HI-8777, HI-1634 x HI-8777, HI-1634 x GS-2031 and CWYT-644 x HI-1633 for Spike length; CWYT-614 x HI-1633, CWYT-644 x HI-8777, CWYT-614 x CWYT-644 and CWYT-644 x GS-2031 for Spike weight; GS-2031 x HI-8777, CWYT-644 x HI-1633, CWYT-614 x HI-8777, HI-1634 x HI-1633, CWYT-614 x HI-1633 and CWYT-644 x HI-8777 for number of grains per spike; GS-2031 x HI-8777, CWYT-614 x HI-1633, HI- 8777 x HI -1633, CWYT-644 x HI-1634, CWYT-644 x HI-1633, CWYT-614 x GS-2031, CWYT-644 x GS-2031, CWYT-644 x HI-8777 and HI-1634 x GS-2031 biological yield/plant; HI- 8777 x HI -1633, CWYT-644 x HI-1634, CWYT-614 x GS-2031, CWYT-614 x HI-1633, CWYT-644 x GS-2031, CWYT-614 x HI-1634 and HI-1634 x HI-8777 for 1000 grain seed weight; HI- 8777 x HI -1633, CWYT-614 x HI-8777, HI-1634 x HI-1633, CWYT-614 x GS-2031, GS-2031 x HI-8777, CWYT-644 x HI-8777, HI-1634 x HI-8777, CWYT-614 x HI-1634 and CWYT-644 x HI-1634 for Harvest Index; GS-2031 x HI-8777, HI- 8777 x HI -1633, CWYT-614 x HI-1633, CWYT-644 x HI-1634, CWYT-614 x GS-2031, CWYT-644 x HI-8777, CWYT-644 x HI-1633, HI-1634 x HI-1633 and CWYT-644 x GS-2031 for Seed yield/plant (Table 4). This conclusion was supported by Zalewski (2001), Arshad and Chowdhry (2002), Siddique et al. (2004), Joshi et al. (2004), Awan et al. (2005), Vanpariya et al. (2006) Murphy et al. (2008), Mandal and Madhuri (2016), Khaled et al. (2020) and Kajla et.al (2022).

Based on their individual performance, the top two crosses were CWYT-614 x GS-2031 and CWYT-644 x HI-1633. Both of the crosses CWYT-614 x GS-2031 and CWYT-644 x HI-1633 observed superior performance in all traits except Harvest Index. These top-performing crosses show great potential and can be considered for further breeding and selection in order to enhance the desired traits.

Estimation of Heterosis

Heterosis breeding play an important role in crop improvement for obtaining high degree of productivity. The primary step in the exploitation of heterosis is to know its magnitude and direction in both directly and indirectly components related to productivity in particular crop of economic value. The hybrid vigour has not widely been exploited in self-pollinated crops except paddy in China and Japan. In barley, it is due to non- availability of stable male sterile lines on commercial scale.

The concept of heterosis was given by Shull (1914) refers to the superiority of the hybrid over better parent. The estimates of heterosis over F1 hybrids in real sense decide whether the hybrid is worth exploiting or not, though, the production of hybrid seed is technically feasible (Briggle, 1963), yet the practical approach of this concept needs further exploration and perfection.

The mean performance of F1 hybrids for different traits studied were compared with the corresponding mid parent (MP), better parent (BP) and standard check GW366 and the differences are being expressed as per cent heterosis for yield and yield components (Table 6). In wheat, positive heterosis was desirable for all the characters studied except days to heading, days to maturity and plant height where negative heterosis is desirable, on the other hand positive and significant values were considered desirable for remaining characters.

A perusal of estimates of economic heterosis for yield and yield contributing characters revealed that hybrid CWYT-614 x GS -2031, CWYT-614 x HI -1633, CWYT-644 x HI -1634, CWYT- 644 x GS -2031, CWYT- 644x HI -1633, HI -1634 x GS -2031, HI -1634 x HI -1633, GS -2031 x HI- 8777 and HI- 8777 x HI -1633 exhibited maximum estimates of significant positive economic heterosis for Seed yield/plant (g). The cross combinations, viz., CWYT-614 x GS -2031, CWYT-614 x HI- 8777, CWYT-614 x HI -1633, CWYT- 644 x HI -1634, CWYT- 644 x GS -2031, CWYT- 644x HI -1633, HI -1634 x GS -2031, HI -1634 x HI- 8777, HI -1634 x HI -1633, GS -2031 x HI- 8777, GS -2031 x HI -1633 and HI- 8777 x HI -1633 with positive and significant values were in the order of merit for Number of effective tillers/ plant. Cross combination CWYT-614 x GS -2031, CWYT-614 x HI- 8777, CWYT- 644 x GS -2031, HI -1634 x HI- 8777 and HI- 8777 x HI -1633 were also exhibited desirable heterosis for Number of spikes/ plant and Number of spikelets/spike. CWYT-614 x CWYT-644, CWYT-614 x HI- 8777, CWYT-614 x HI -1633, CWYT- 644x HI -1633, HI -1634 x GS -2031, HI -1634 x HI -1633 and GS -2031 x HI -1633 were exhibited desirable heterosis for Spike length (cm). Cross combination CWYT-614 x CWYT-644, CWYT-614 x HI -1633, CWYT- 644 x GS -2031 and CWYT- 644 x HI-8777 were exhibited desirable heterosis for Spike weight (g). Cross combination CWYT-614 x HI -1633, CWYT- 644 x HI -1634, CWYT- 644 x GS -2031, HI -1634 x GS -2031 and GS -2031 x HI- 8777 were exhibited desirable heterosis for Biological yield/plant (g). The cross combination CWYT-614 x GS -2031, CWYT- 644 x HI -1634, HI -1634 x GS -2031, HI -1634 x HI- 8777 and HI- 8777 x HI -1633 exhibited desirable heterosis for 1000 grain weight (g). The cross combination CWYT-614 x GS -2031, HI -1634 x HI -1633 and HI-8777 x HI -1633 were also exhibited desirable heterosis for Harvest index (Table 6). Similar trends of results for yield and yield contributing traits in wheat were also reported by Habouh (2019), Panwar et al. (2022) and Akashdeep et al. (2021), Sharma and Sain (2005), Singh et al. (2009), Jaiswal et al. (2010), Raiyani et al. (2016), Kumar et al. (2017), Jaiswal et al. (2018), Kumar et al. (2021) and Choudhary et al. (2022).

On the other hand, the traits viz., days to heading, days to maturity and plant height related traits, negative direction of heterosis is desirable. The hybrid HI -1634 x HI -1633, GS -2031 x HI -1633 and HI- 8777 x HI -1633 showed high negative significant economic heterosis for days to heading. The hybrids GS -2031 x HI -1633 and HI- 8777 x HI -1633 showed high negative significant for days to maturity. Similar results of economic heterosis for maturity related traits were also reported by Chowdhary et al. (2001), Abdullah et al. (2002), Wan Chang et al. (2003), Singh et al. (2007), Kumar and Maloo (2011), Samier and Ismail (2015), Kumar et al. (2017), Kaur et al. (2020), Kumar et al. (2021) and Choudhary et al. (2022) also observed negative significant economic heterosis for plant height in wheat.

The majority of the hybrids of yield and yield related traits exhibited positive significant relative heterosis, thereby indicating that for these traits the genes with positive effect were dominant. While for maturity related traits, majority of the hybrids exhibited negative significant relative heterosis, thereby indicating that for these traits the genes with negative effect were dominant. The existence of wide spectrum of heterosis in either direction with expression of high degree of desirable heterosis by some crosses for all the characters observed in present study is in conformity with the earlier reports reporting presence of high heterosis for such characters in wheat (Abdullah et al., 2002; Singh et al., 2004a,b; Kumar et al., 2005; Jogendra and Raje, 2007; Kumar et al., 2008; Jaiswal et al., 2010; Ali and Falahy, 2011; Titan and Meglic,2011 and Devi et al., 2013). It was also noted that higher heterosis over better-parent was found in some lower yielding crosses when compared to other crosses which have displayed high yield. This suggested that while selecting the best hybrid, besides the heterotic response over better-parent, the mean performance of the crosses should also be given due consideration. Since, heterosis estimate results from F1-BP and depends more or less on the mean of the parents in question, there is every possibility of getting a cross with lower mean performance but high heterotic response, in case the parental performance is very poor. On the contrary, there can be a cross with high mean performance but low heterosis in case parental performance is also high. The mean performance being the realized value and the heterotic response being an estimate, the former should be given due to consideration while making selection of cross combinations especially when objective is to identify a hybrid for commercial cultivation as in present case.

Conclusion-

Considering GCA effects, good general combiners were; HI-1633 and HI-8777 for days to heading; HI-1633 and HI-8777 for days to maturity; HI-8777 and CWYT-614 for plant height; HI-1633 and HI-8777 for the number of effective tillers per plant; HI-8777 and CWYT-614 for the Number of spikes/ plant; CWYT-614 and HI-1634 for the Number of spikelets/spike; HI-1633, CWYT-614 and GS-203 for Spike length (cm); CWYT-644 and CWYT-614 for Spike weight (g); CWYT-614, GS-2031 and CWYT-644 for the Number of grains per spike; GS-2031, HI-1634 and HI-1633 for Biological yield/plant; GS-2031, HI-1634, HI-1633 and HI-8777 1000 grain seed weight; HI-1633 and GS-2031 Harvest Index (%); GS-2031, HI-1634 and HI-1633 Seed yield /plant. Based on per se performance and significant SCA effects for Seed yield/plant, the cross combination emerged as promising combiners viz., GS-2031 x HI-8777, HI- 8777 x HI -1633, CWYT-614 x HI-1633, CWYT-644 x HI-1634, CWYT-614 x GS-2031, CWYT-644 x HI 8777, CWYT-644 x HI-1633, HI-1634 x HI-1633 and CWYT-644 x GS-2031, was identified as good combiner.

A perusal of estimates of economic heterosis for yield revealed that hybrid CWYT-614 x GS -2031, CWYT-614 x HI -1633, CWYT- 644 x HI -1634, CWYT- 644 x GS -2031, CWYT- 644x HI -1633, HI -1634 x GS -2031, HI -1634 x HI -1633, GS -2031 x HI- 8777 and HI- 8777 x HI -1633 exhibited maximum estimates of significant positive economic heterosis for Seed yield/plant (g). The magnitude of Average heterosis and Heterobeltiosis for Seed yield/plant revealed that Out of fifteen crosses, only two (GS-2031 x HI-8777 and HI- 8777 x HI -1633) crosses showed significant positive Average heterosis and heterobeltiosis. These crosses merit further testing and evaluation in on-station trials to find out their feasibility for their utilization in breeding programmes aimed to develop wheat varieties for different environmental conditions.

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Table.1 List of genotypes used in morphological assessment

S. No.	Parents	S. No.	Crosses

1	CWYT-614	1	CWYT-614 x CWYT-644
2	CWYT- 644	2	CWYT-614 x HI -1634
3	HI -1634	3	CWYT-614 x GS -2031
4	GS -2031	4	CWYT-614 x HI- 8777
5	HI- 8777	5	CWYT-614 x HI -1633
6	HI -1633	6	CWYT- 644 x HI -1634
	Check	7	CWYT- 644 x GS -2031
1	GW366	8	CWYT- 644 x HI- 8777
		9	CWYT- 644x HI -1633
		10	HI -1634 x GS -2031
		11	HI -1634 x HI- 8777
		12	HI -1634 x HI -1633
		13	GS -2031 x HI- 8777
		14	GS -2031 x HI -1633
		15	HI- 8777 x HI -1633

Table.2 Mean squares from analysis of variance and general and specific combining ability analysis for all studied characters in bread wheat crosses

Characters	**GCA**	**SCA**	**Error**
df	**5**	**15**	**40**
Days to heading	106.391**	36.112**	1.840
Days to maturity	104.206**	39.975**	6.574
Plant height	81.509**	57.272**	2.087
Number of effective tillers/ plant	15.312**	12.508**	0.061
Number of spikes/ plant	3.795**	6.666**	0.059
Number of spikelets/spike	9.233**	17.078**	1.843
Spike length	9.289**	2.878**	0.047
Spike weight	2.505**	2.624**	0.010
Number of grains per spike	320.782**	208.677**	1.386
Biological yield/plant	231.524**	310.123**	4.074
1000 grain seed weight	113.679**	116.475**	0.639
Harvest Index	2.718**	1.453**	0.674
Seed yield / plant	72.808**	72.904**	0.714

Table.3 Mean performance of the six parents and their F1s for the studied characters

Treatments	Days to heading	Days to maturity	Plant height (cm)	Number of effective tillers/plant	Number of spikes/ plant	Number of spikelets/ spike	Spike length (cm)	Spike weight (g)	Number of grains per spike	Biological yield/plant (g)	Seed yield / plant (g)	1000 grain seed weight (g)	Harvest Index (%)
Parents													
CWYT-614	80.85	122.55	63.65	9.03	13.50	20.90	12.15	4.78	85.05	127.03	59.52	46.48	46.96
CWYT- 644	79.00	121.50	83.75	5.00	10.50	21.07	10.40	4.50	72.80	114.81	56.22	49.75	48.97
HI -1634	74.10	114.85	75.10	6.00	12.00	21.33	12.55	5.25	90.00	121.83	58.50	45.52	48.02
GS -2031	83.80	122.50	86.40	8.00	13.50	18.00	14.50	5.47	71.50	110.34	54.30	47.98	49.22
HI- 8777	66.95	106.00	70.65	10.00	12.00	18.50	7.55	4.42	34.00	88.19	39.50	53.42	44.79
HI -1633	66.70	106.00	82.70	12.50	10.50	19.43	15.50	4.64	39.50	100.67	50.50	45.62	50.17
Mean	**75.23**	**115.57**	**77.04**	**8.42**	**12.00**	**19.87**	**12.11**	**4.84**	**65.48**	**110.48**	**53.09**	**48.13**	**48.02**
Min	**66.70**	**106.00**	**63.65**	**5.00**	**10.50**	**18.00**	**7.55**	**4.42**	**34.00**	**88.19**	**39.50**	**45.52**	**44.79**
Max	**83.80**	**122.55**	**86.40**	**12.50**	**13.50**	**21.33**	**15.50**	**5.47**	**90.00**	**127.03**	**59.52**	**53.42**	**50.17**
Crosses													
CWYT-614 x CWYT-644	80.90	120.55	87.50	6.50	13.00	20.80	15.30	5.40	57.10	54.71	26.31	11.05	48.10
CWYT-614 x HI -1634	81.85	120.50	90.00	7.00	10.00	21.30	10.25	3.64	51.75	88.37	43.09	44.61	48.75
CWYT-614 x GS -2031	80.85	121.75	94.55	14.00	14.50	17.83	12.50	4.51	67.50	108.82	53.58	49.76	49.24
CWYT-614 x HI- 8777	89.88	131.00	84.00	17.30	12.00	18.67	13.60	4.30	75.20	70.43	34.17	18.83	48.51
CWYT-614 x HI -1633	82.65	124.00	89.10	13.03	13.00	19.63	17.55	5.61	72.85	109.04	53.14	45.50	48.74
CWYT- 644 x HI -1634	81.98	122.50	93.50	12.55	14.00	18.60	12.40	4.76	66.80	113.42	55.76	53.53	49.16
CWYT- 644 x GS -2031	80.95	121.50	96.60	13.55	16.00	20.83	12.60	5.10	68.20	110.43	54.04	49.91	48.93
CWYT- 644 x HI- 8777	80.18	120.50	84.75	9.00	13.00	20.60	12.35	5.54	66.45	96.66	47.16	40.87	48.79
CWYT- 644x HI -1633	79.78	123.00	94.80	15.35	11.50	21.47	14.55	4.14	81.85	107.17	52.46	39.66	48.95
HI -1634 x GS -2031	83.73	125.50	88.60	11.23	10.50	19.20	13.45	4.34	74.15	115.90	56.90	49.77	49.09
HI -1634 x HI- 8777	79.63	121.00	88.72	14.32	14.50	21.30	11.60	3.21	50.50	94.22	46.04	51.56	48.87
HI -1634 x HI -1633	75.06	116.09	88.50	14.60	13.50	19.70	13.65	3.54	76.00	109.33	55.50	46.65	50.77
GS -2031 x HI- 8777	84.06	125.01	82.29	10.01	11.00	20.73	11.55	3.43	80.85	117.41	57.66	46.58	49.11
GS -2031 x HI -1633	64.90	105.90	88.00	11.05	13.00	19.90	13.30	3.33	53.10	94.73	46.26	49.46	48.83
HI- 8777 x HI -1633	61.05	103.05	82.73	17.57	15.00	17.87	11.45	3.63	43.00	104.49	54.00	55.81	51.68
Mean	**79.16**	**120.12**	**88.91**	**12.47**	**13.57**	**19.90**	**13.07**	**4.30**	**65.69**	**99.67**	**49.07**	**43.57**	**49.17**
Min	**61.05**	**103.05**	**82.29**	**6.50**	**10.50**	**17.83**	**10.25**	**3.21**	**43.00**	**54.71**	**26.31**	**11.05**	**48.10**
Max	**89.88**	**131.00**	**96.60**	**17.57**	**15.00**	**21.47**	**17.55**	**5.61**	**81.85**	**117.41**	**57.66**	**55.81**	**51.68**
Check													
GW366 (Check)	77.69	118.31	84.29	10.98	12.98	20.99	12.66	4.51	65.32	103.49	50.28	45.39	48.69

Table 4. Estimation of general combining ability (GCA) effects for different characters studied in Wheat (*Triticum aestivum* L.)

Characters/Parents	CWYT-614	CWYT-644	HI-1634	GS-2031	HI-8777	HI-1633
Days to heading	3.94 **	1.94 **	0.52	1.98 **	-2.20 **	-6.18 **
Days to maturity	3.90 **	2.41 **	0.44	1.61	-2.40 **	-5.96 **
Plant height (cm)	-3.27 **	3.25 **	0.11	3.03 **	-4.35 **	1.24 *
Number of effective tillers/ plant	-0.42 **	-1.53 **	-0.94 **	-0.42 **	1.13 **	2.18 **
Number of spikes/ plant	0.83 **	-0.42 **	-0.67 **	0.02	0.83 **	-0.60 **
Number of spikelets/spike	1.25 **	-0.81*	1.44 **	-0.94 *	-0.75*	-0.19
Spike length (cm)	0.49 **	-0.20 **	-0.39 **	0.35 **	-1.74 **	1.49 **
Spike weight (g)	0.23 **	0.34 **	-0.15 **	0.06	-0.28 **	-0.21 **
Number of grains per spike	4.39 **	3.33 **	4.98 **	3.43 **	-9.42 **	-6.70 **
Biological yield/plant (g)	-4.24 **	-0.91	5.70 **	6.08 **	-7.47 **	0.85
1000 grain seed weight (g)	-6.43 **	-2.45 **	2.88 **	3.42 **	0.80 **	1.78 **
Harvest Index (%)	-0.58 *	0.01	0.10	0.22*	-0.67 *	0.93 **
Seed yield /plant (g)	-2.77 **	-0.42	2.84 **	3.19 **	-4.19 **	1.35 **

** and ** significant at 5% and 1% level of significance, respectively*

Table 5 Estimation of specific combining ability (SCA) effects for different characters studied in Wheat (*Triticum aestivum* L.)

SCA EFFECTS	Days to heading	Days to maturity	Plant height (cm)	Number of effective tillers/ plant	Number of spikes/ plant	Number of spikelets/s pike	Spike length (cm)	Spike weight (g)	Number of grains per spike	Biological yield/plan t (g)	1000 grain seed weight (g)	Harves t Index (%)	Seed yield /plant (g)
CWYT-614 x CWYT-644	-3.02 **	-4.58 *	2.00*	-2.87 **	-0.54 **	-1.72	2.21 **	0.37 **	-16.24 **	-42.90 **	-24.95 **	-0.16	-20.71 **
CWYT-614 x HI-1634	-0.65	-2.66*	7.65 **	-2.96 **	-3.29 **	0.53	-2.64 **	-0.90 **	-23.24 **	-15.85 **	3.28 **	0.39	-7.20 **
CWYT-614 x GS-2031	-3.11 **	-2.58*	9.28 **	3.52 **	0.53 **	4.40 **	-1.14 **	-0.23 **	-5.94 **	4.22 **	7.90 **	0.76	2.95 **
CWYT-614 x HI-8777	10.09 **	10.68 **	6.11 **	5.27 **	6.22 **	-2.79 **	2.05 **	-0.10	14.61 **	-20.63 **	-20.41 **	0.92	-9.09 **
CWYT-614 x HI-1633	6.85 **	7.25 **	5.62 **	-0.05	-0.35*	5.15 **	2.77 **	1.13 **	9.53 **	9.67 **	5.27 **	-0.45	4.34 **
CWYT-644 x HI-1634	1.48	0.82	4.62 **	3.70 **	1.96 **	3.09 **	0.19	0.11	-7.13 **	5.87 **	8.23 **	0.22	3.12 **
CWYT-644 x GS-2031	-1.01	-1.35	4.80 **	4.19 **	3.28 **	-3.53 **	-0.35 *	0.25 **	-4.18 **	2.51 **	4.07 **	-0.13	1.05*
CWYT-644 x HI-8777	2.39 *	1.67	0.33	-1.91 **	-0.54 **	1.28*	1.49 **	1.02 **	6.92 **	2.28 **	-2.36 **	0.62	1.55 *
CWYT-644 x HI-1633	5.98 **	7.73 **	4.79 **	3.39 **	-0.60 **	3.21 **	0.46 **	-0.46 **	19.60 **	4.48 **	-4.54 **	-0.82	1.31 *
HI-1634 x GS-2031	3.19 **	4.62 *	-0.06	1.27 **	-1.97 **	-9.29 **	0.69 **	-0.02	0.12	1.36 **	-1.40 *	-0.07	0.65
HI-1634 x HI-8777	3.26 **	4.14 *	7.45 **	2.82 **	1.22 **	0.53	0.93 **	-0.81 **	-10.68 **	-6.77 **	3.01 **	0.6	-2.83 **
HI-1634 x HI-1633	2.68 **	2.79*	1.63	2.05 **	1.66 **	-4.54 **	-0.24	-0.56 **	12.10 **	0.02	-2.88 **	0.9	1.08*
GS-2031 x HI-8777	6.25 **	6.97 **	-2.90*	-2.01 **	-2.97 **	-0.60	0.14	-0.80 **	21.22 **	16.04 **	-2.51 **	0.71	8.44 **
GS-2031 x HI-1633	-8.94 **	-8.57 **	-2.78*	-2.02 **	0.46 *	1.84*	-1.34 **	-0.97 **	-9.26 **	-14.96 **	-0.61	-1.15	-8.50 **
HI- 8777 x HI -1633	-8.61 **	-7.41 **	0.32	2.95 **	1.65 **	0.15	-1.10 **	-0.34 **	-6.51 **	8.35 **	8.36 **	2.58 **	6.61 **

** and ** significant at 5% and 1% level of significance, respectively*

Table 6 Estimation of heterosis (%) over mid-parent (H1), better parent (H2) and standard check (H3) for yield and other yield contributing traits

S. No	Crosses	Days to heading			Days to maturity			Plant height (cm)		
		(H1)	**(H2)**	**(H3)**	**(H1)**	**(H2)**	**(H3)**	**(H1)**	**(H2)**	**(H3)**
1	CWYT-614 x CWYT-644	1.23	0.07	0.07	-1.21	-1.63	-1.63	18.73 **	4.48	3.81
2	CWYT-614 x HI -1634	5.65 *	1.24	1.24	1.52	-1.67	-1.67	29.74 **	19.84 **	6.77*
3	CWYT-614 x GS -2031	-1.79	-3.52	0	-0.63	-0.65	-0.65	26.02 **	9.43 **	12.17**
4	CWYT-614 x HI- 8777	21.61 **	11.17 **	11.17 **	14.64 **	6.89 *	6.89 *	25.09 **	18.89 **	-0.34
5	CWYT-614 x HI -1633	12.03 **	2.23	2.23	8.51 **	1.18	1.18	21.76 **	7.73 **	5.71*
6	CWYT- 644 x HI -1634	7.08 **	3.76	1.39	3.66	0.82	-0.05	17.72 **	11.64 **	10.93**
7	CWYT- 644 x GS -2031	-0.56	-3.4	0.12	-0.41	-0.82	-0.86	13.55 **	11.81 **	14.60**
8	CWYT- 644 x HI- 8777	9.86 **	1.49	-0.83	5.93 *	-0.82	-1.68	9.77 **	1.19	0.55
9	CWYT- 644x HI -1633	9.51 **	0.98	-1.32	8.13 **	1.23	0.36	13.91 **	13.19 **	12.47**
10	HI -1634 x GS -2031	6.05 **	-0.08	3.57	5.75 *	2.45	2.4	9.72 **	2.54	5.11*
11	HI -1634 x HI- 8777	12.90 **	7.45 **	-1.51	9.58 **	5.36	-1.27	21.74 **	18.14 **	5.26*
12	HI -1634 x HI -1633	6.61 **	1.29	-7.16 **	5.13	1.08	-5.27	12.16 **	7.01 **	4.99
13	GS -2031 x HI- 8777	11.52 **	0.31	3.98	9.42 **	2.05	2.00	4.79 *	-4.76 *	-2.37
14	GS -2031 x HI -1633	-13.75 **	-22.55 **	-19.72 **	-7.31 *	-13.55 **	-13.59 **	4.07 *	1.85	4.4
15	HI- 8777 x HI -1633	-8.64 **	-8.81 **	-24.48 **	-2.78	-2.78	-15.91 **	7.88 **	0.02	-1.86
	SE(D)±	**3.59**	**4.15**	**4.15**	**6.78**	**7.83**	**7.83**	**6.16**	**7.12**	**7.12**
	CD 5%	**7.18**	**8.29**	**8.29**	**13.56**	**15.66**	**15.66**	**12.32**	**14.23**	**14.23**
	CD 1%	**9.55**	**11.03**	**11.03**	**18.03**	**20.82**	**20.82**	**16.39**	**18.92**	**18.92**

** and ** significant at 5% and 1% level of significance, respectively,*

H1 = Average heterosis, H2 = Heterobeltiosis, H3 = Standard heterosis

Table 6 Continue…

No	Crosses	Number of effective tillers/ plant			Number of spikes/ plant			Number of spikelets/spike		
		(H1)	(H2)	(H3)	(H1)	(H2)	(H3)	(H1)	(H2)	(H3)
1	CWYT-614 x CWYT-644	-7.32	-28.00 **	-28.00 **	8.32 **	-3.7	-3.7	8.32 **	-3.7	-3.7
2	CWYT-614 x HI -1634	-6.81	-22.42 **	-22.42 **	-21.56 **	-25.93 **	-25.93 **	-21.56 **	-25.93 **	-25.93 **
3	CWYT-614 x GS -2031	64.47 **	55.12 **	55.12 **	7.41 **	7.41 **	7.41 **	7.41 **	7.41 **	7.41 **
4	CWYT-614 x HI- 8777	81.88 **	73.02 **	91.69 **	64.73 **	55.56 **	55.56 **	64.73 **	55.56 **	55.56 **
5	CWYT-614 x HI -1633	21.05 **	4.21	44.37 **	8.32 **	-3.73	-3.73	8.32 **	-3.73	-3.73
6	CWYT- 644 x HI -1634	128.19 **	109.11 **	39.05 **	24.41 **	16.67 **	3.68	24.41 **	16.67 **	3.68
7	CWYT- 644 x GS -2031	108.62 **	69.49 **	50.20 **	33.31 **	18.52 **	18.52 **	33.31 **	18.52 **	18.52 **
8	CWYT- 644 x HI- 8777	20.05 **	-9.97 **	-0.26	15.53 **	8.34 **	-3.73	15.53 **	8.34 **	-3.73
9	CWYT- 644x HI -1633	75.46 **	22.80 **	70.11 **	9.52 **	9.49 **	-14.81 **	9.52 **	9.49 **	-14.81 **
10	HI -1634 x GS -2031	60.42 **	40.39 **	24.42 **	-17.64 **	-22.22 **	-22.22 **	-17.64 **	-22.22 **	-22.22 **
11	HI -1634 x HI- 8777	79.04 **	43.25 **	58.70 **	20.89 **	20.89 **	7.43 **	20.89 **	20.89 **	7.43 **
12	HI -1634 x HI -1633	57.87 **	16.83 **	61.84 **	20.07 **	12.56 **	0.02	20.07 **	12.56 **	0.02
13	GS -2031 x HI- 8777	11.26 **	0.13	10.93 **	-13.71 **	-18.52 **	-18.52 **	-13.71 **	-18.52 **	-18.52 **
14	GS -2031 x HI -1633	7.82 *	-11.60 **	22.46 **	8.35 **	-3.7	-3.7	8.35 **	-3.7	-3.7
15	HI- 8777 x HI -1633	56.17 **	40.53 **	94.68 **	33.37 **	25.03 **	11.11 **	33.37 **	25.03 **	11.11 **
	SE(D)±	**3.64**	**4.04**	**4.66**	**0.48**	**0.26**	**0.26**	**0.54**	**0.63**	**0.63**
	CD 5%	**6.632**	**8.07**	**9.32**	**0.5**	**0.59**	**0.59**	**1.09**	**1.26**	**1.26**
	CD 1%	**10.43**	**10.73**	**12.39**	**0.7**	**0.8**	**0.8**	**1.45**	**1.68**	**1.68**

** and ** significant at 5% and 1% level of significance, respectively,*

H1 = Average heterosis, H2 = Heterobeltiosis, H3 = Standard heterosis

Table 6 Continue…

No	Crosses	Spike length (cm)			Spike weight (g)			Number of grains per spike		
		(H1)	**(H2)**	**(H3)**	**(H1)**	**(H2)**	**(H3)**	**(H1)**	**(H2)**	**(H3)**
1	CWYT-614 x CWYT-644	35.73 **	25.99 **	25.99 **	16.43 **	13.06 **	13.06 **	-27.65 **	-32.86 **	-32.86 **
2	CWYT-614 x HI -1634	-16.97 **	-18.30 **	-15.59 **	-27.44 **	-30.73 **	-23.81 **	-40.87 **	-42.50 **	-39.15 **
3	CWYT-614 x GS -2031	-6.15 **	-13.77 **	2.94	-11.95 **	-17.51 **	-5.59	-13.76 **	-20.63 **	-20.63 **
4	CWYT-614 x HI- 8777	38.04 **	11.94 **	11.94 **	-6.45 *	-9.92 **	-9.92 **	26.34 **	-11.58 **	-11.58 **
5	CWYT-614 x HI -1633	26.94 **	13.20 **	44.46 **	19.16 **	17.46 **	17.46 **	16.99 **	-14.34 **	-14.34 **
6	CWYT- 644 x HI -1634	8.05 **	-1.2	2.09	-2.46	-9.46 **	-0.42	-17.94 **	-25.78 **	-21.46 **
7	CWYT- 644 x GS -2031	1.19	-13.10 **	3.73	2.41	-6.65 *	6.84 *	-5.47 **	-6.31 **	-19.81 **
8	CWYT- 644 x HI- 8777	37.52 **	18.68 **	1.65	24.26 **	23.20 **	16.06 **	24.44 **	-8.72 **	-21.87 **
9	CWYT- 644x HI -1633	12.34 **	-6.13 **	19.79 **	-9.49 **	-10.86 **	-13.41 **	45.77 **	12.44 **	-3.76
10	HI -1634 x GS -2031	-0.55	-7.24 **	10.73 **	-18.98 **	-20.56 **	-9.08 **	-8.18 **	-17.61 **	-12.82 **
11	HI -1634 x HI- 8777	15.40 **	-7.57 **	-4.5	-33.54 **	-38.79 **	-32.68 **	-18.55 **	-43.89 **	-40.62 **
12	HI -1634 x HI -1633	-2.65	-11.91 **	12.40 **	-28.52 **	-32.70 **	-25.98 **	17.38 **	-15.55 **	-10.64 **
13	GS -2031 x HI- 8777	4.78	-20.32 **	-4.88	-30.59 **	-37.22 **	-28.14 **	53.27 **	13.08 **	-4.93 *
14	GS -2031 x HI -1633	-11.33 **	-14.19 **	9.50 **	-34.06 **	-39.05 **	-30.24 **	-4.32	-25.73 **	-37.56 **
15	HI- 8777 x HI -1633	-0.67	-26.13 **	-5.74 *	-19.91 **	-21.78 **	-24.02 **	17.01 **	8.86 *	-49.44 **
	SE(D)±	**4.04**	**4.66**	**4.66**	**4.66**	**3.97**	**5.43**	**3.97**	**4.58**	**4.58**
	CD 5%	**8.07**	**9.32**	**9.32**	**9.32**	**7.94**	**10.52**	**7.94**	**9.16**	**9.16**
	CD 1%	**10.73**	**12.39**	**12.39**	**12.39**	**10.55**	**11.54**	**-4.29**	**-8.79**	**-16.28**

** and ** significant at 5% and 1% level of significance, respectively,*

H1 = Average heterosis, H2 = Heterobeltiosis, H3 = Standard heterosis

Table 6 Continue…

S. No	Crosses	Biological yield/plant (g)			Seed yield / plant (g)			1000 grain weight (g)			Harvest Index (%)		
		(H1)	(H2)	(H3)	(H1)	(H2)	(H3)	(H1)	(H2)	(H3)	(H1)	(H2)	(H3)
1	CWYT-614 x CWYT-644	26.87 **	-9.37 **	-47.13**	-54.54 **	-55.80 **	-47.68**	-77.04 **	-77.80 **	-76.23 **	0.29	-1.76	-1.21*
2	CWYT-614 x HI -1634	1.45	-3.84	-14.61*	-26.99 **	-27.62 **	-14.31*	-3.02	-4.02	-4.02	2.66	1.53	0.13
3	CWYT-614 x GS -2031	-9.03 **	-12.91 **	5.15	-5.85 **	-9.98 **	6.57*	5.36 *	3.71	7.06 **	2.4	0.05	1.14*
4	CWYT-614 x HI- 8777	-28.19 **	-30.45 **	-31.95*	-30.99 **	-42.60 **	-32.04**	-62.29 **	-64.74 **	-59.47 **	5.75 *	3.31*	-0.36
5	CWYT-614 x HI -1633	-11.30 **	-20.59 **	5.37*	-3.41	-10.73 **	5.70*	-1.2	-2.11	-2.11	0.36	-2.85	0.1
6	CWYT- 644 x HI -1634	5.18	-22.25 **	9.59*	-2.79	-4.68 *	10.89*	12.39 **	7.60 **	15.19 **	1.38	0.4	0.97
7	CWYT- 644 x GS -2031	27.85 **	-6.12 **	6.71*	-2.22	-3.88	7.47*	2.15	0.33	7.40 **	-0.32	-0.58	0.5
8	CWYT- 644 x HI- 8777	-18.96 **	-40.95 **	-6.60*	-1.47	-16.12 **	-6.21*	-20.78 **	-23.50 **	-12.07 **	4.07	-0.37	0.2
9	CWYT- 644x HI -1633	34.81 **	3.95	3.56	-1.7	-6.69 **	4.33	-16.84 **	-20.29 **	-14.68 **	-1.25	-2.43	0.53
10	HI -1634 x GS -2031	-3.76	-4.69 *	11.99*	0.88	-2.74	13.17*	6.46 **	3.73	7.09 **	0.98	-0.25	0.83
11	HI -1634 x HI- 8777	-16.91 **	-18.69 **	-8.96*	-6.03 **	-21.29 **	-8.42*	4.23 *	-3.48	10.95 **	5.31 *	1.77	0.37
12	HI -1634 x HI -1633	0.24	-5.70 *	5.64	1.83	-5.13 *	10.38*	2.37	2.26	0.37	3.42	1.2	4.27**
13	GS -2031 x HI- 8777	-19.63 **	-20.67 **	13.45*	22.92 **	6.17 **	14.67*	-8.13 **	-12.80 **	0.22	4.47 *	-0.22	0.85
14	GS -2031 x HI -1633	2.4	-4.45 *	-8.47*	-11.72 **	-14.81 **	-8.00*	5.68 **	3.08	6.42 *	-1.72	-2.65	0.3
15	HI- 8777 x HI -1633	-12.43 **	-19.25 **	0.96	19.99 **	6.92 **	7.40*	12.70 **	4.47 *	20.08 **	8.84 **	3.01*	6.13**
	SE(D)±	**0.24**	**0.28**	**0.28**	**3.97**	**4.587**	**4.58**	**2.43**	**4.54**	**0.54**	0.28	0.3	0.57
	CD 5%	**0.49**	**0.57**	**0.57**	**7.94**	**9.16**	**9.16**	**4.75**	**6.23**	**1.09**	0.61	0.63	1.12
	CD 1%	**0.65**	**0.75**	**0.75**	**10.55**	**12.18**	**12.18**	**6.42**	**8.53**	**1.45**	0.84	0.87	1.78