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Evaluation of heterosis and inbreeding depression for grain yield and its contributing traits in bread wheat under late sown conditions

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Abstract
The objective of the present investigation was to examine heterosis, heterobeltiosis, and inbreeding depression in ten bread wheat genotypes grown at the Research Farm of the Rajasthan Agricultural Research Institute, Durgapura, Jaipur, in *Rabi* 2021–2022. Significant differences observed in the mean performance of all the characters studied. For grain yield per plant and other yield attributing traits, the crosses Raj 3765 x UP 2425, Raj 4079 x PBW 343, Raj 4079 x Raj 3765, PBW 343 X HD 2967, Raj 4079 x WH 1021, Raj 4079 x HD 2967, HD 2967 x UP 2425, Raj 3765 x WH 1021 and Raj 3765 x PBW 343 exhibited significant and desirable heterobeltiosis over better parent. These crosses were recognized as desirable which may throw better transgressive segregants in succeeding generations. No inbreeding depression was recorded in any cross for grain yield per plant which can be used to maintain specific gene pool for future breeding programs of yield improvement in wheat.

Keywords: Heterosis, transgressive segregants, grain yield, bread wheat etc.

Introduction

Wheat occupies a prominent position in Indian agriculture after rice and maize. It can be grown as an annual fodder crop even though it is often used as a grain crop. It is a nutritionally significant grain that is necessary for food security, eradicating poverty, and sustaining livelihoods. A several billions of people rely on wheat for a substantial part of their diet in the countries of primary production and in other countries where wheat cannot be grown. It is widely cultivated as a staple food crop among the cereals and is contributes about 30% to the food basket of the country. Wheat is a rich source of essential human diet ingredients like 14.70% protein, 78.10% carbohydrate (Kumar *et al.*, 2011) [3]. Thiamin, Riboflavin, Niacin and small amounts of vitamin A are present, but the milling processes remove most of those nutrients with the bran and germ. Worldwide wheat crop occupies an area of 222.17 million hectares producing nearly 779.90 million metric tonnes with an average productivity of 3510 kg/ ha (Anonymous, 2021-22) [4].

In order to enhance and sustain wheat production, as well as to satisfy the future food needs of a growing population, it is necessary to find solutions for rigid problems such as climate change, diminishing of natural resources, biotic and abiotic stress etc. The success of any breeding programme depends on existence of genetic diversity among the selected parents and breeding procedure involved. Estimation of Heterosis is a significant tool to evaluating genetic parameters in most of crops including wheat. The type and extent of heterosis and inbreeding depression helps in determining appropriate breeding strategy for a breeder (Kumar *et al.*, 2016) [1]. Hence, the aim of present study was to identify promising parents and their crosses that would be useful in future wheat development programmes.

Materials and Methods

Ten bread wheat genotypes were selected and crossed in a diallel fashion excluding reciprocals, during *Rabi* 2018-19 at RARI, Durgapura. In *kharif* 2019, half of F_1's seed was raised at IARI Regional Station Wellington (Tamil Nadu) to get F_2's seed for experimentation. During *Rabi* 2021-22 selected ten parents along with their 45 F_1's and 45 F_2's progenies were planted in a randomized block design with three replications under late sown conditions at Agricultural Research Farm of RARI, Durgapura. The 10 parents and 45 F_1's were grown by dibbling seeds in two rows each and the 45 F_2's in a plot of four rows each, in three replications.

Each row was 3 m long with row to row spacing of 30 cm and plant to plant spacing of 10 cm was maintained in all the plots. Non-experimental rows were planted all around the experimental plot to eliminate the border effects, if any. Recommended uniform agronomical package and practices were implemented to maintain a good crop population in the field. Data were observed on grain yield per plant and some other attributing traits such as days to 50% heading, days to maturity, plant height (cm), fertile tillers per plant, flag leaf area (cm^2), spike length (cm), number of grains per spike, 1000-grain weight (g), biomass per plant (g) and grain yield per spike (g) by 10 randomly selected plants for parents, F_1's and while 40 plants for F_2's.

The Analysis of variance was estimated from the method suggested by Panse and Sukhatme (1985) [6]. The heterosis (over mid parent), heterobeltiosis (over better parent) and inbreeding depression were calculated as per standard methods given by Fonseca and Patterson (1968) [5].

Results and Discussion

The analysis of variance (Table 1) exhibited significant differences among the genotypes, parents and generations for all studied characters, indicating considerable genetic diversity exist among the selected parents. Similarly, the mean squares due to F_1, F_2 generations and F_1 *vs* F_2 were also found significant for grain yield and all other studied characters. Correspondingly, the differences among the parents *vs* generations were significant for all studied characters, suggesting presence of hybrid vigour. Similar results were also observed by some researchers such as Akbar *et al*. (2010) [8], Pancholi *et al*. (2012) [7], Singh *et al*. (2012) [9] and Nageshwar *et al*. (2021) [10] for various characters.

The exploitation of heterosis at commercial level is considered as a magnificent achievement of genetics in the plant breeding. The extent of heterosis in a crop depends on how well it is exploited, used, and capable of producing hybrid seeds. Heterosis is an imperative genetic tool for determining the direction of the imminent breeding programmes and the selection of promising crosses to achieve superior sergeants in advanced generations for further improvement of grain yield in bread wheat. The extent of heterosis and number of heterotic crosses for grain yield and other associated traits are in Table 2.

The negative and significant heterosis (over mid-parent) and heterobeltiosis (better parent) are desirable for days to 50% heading, days to maturity and plant height in wheat. A total of 29 and 17 crosses for days to 50% flowering; 25 and 15 for days to maturity and 20 and 15 crosses for plant height respectively, exhibited negative significant heterosis over mid parent and a better parent. Whereas, it is preferable to have positive significant heterosis and heterobeltiosis for grain yield and the most of other contributing traits. A total of 29 and 16 crosses for fertile tillers per plant; 25 and 15 for flag leaf area; 23 and 13 for spike length; 24 and 17 for number of grains per spike; 27 and 15 for 1000-grain weight; 35 and 19 for biomass per plant; 25 and 15 for grain yield per spike and 21 and 14 crosses for grain yield per plant respectively, exhibited negative significant heterosis over mid parent and a better parent.

In the present study, heterosis ranged from -16.44 to 10.64 for days to 50% heading; -10.55 to 7.51 for days to maturity; -15.40 to 14.46 for plant height; -6.05 to 36.00 for fertile tillers per plant; -32.96 to 43.10 for flag leaf area; -17.98 to 19.78 for spike length; -20.49 to 30.81 for number of grains per spike; -20.49 to 12.48 for 1000-grain weight; 1.27 to 30.49 for biomass per plant; -13.04 to 35.94 for grain yield per spike and -18.46 to 34.65 for grain yield per plant whereas, heterobeltiosis ranged from -8.41 to 13.61 for days to 50% heading; -9.69 to 9.61 for days to maturity; -13.54 to 19.83 for plant height; -9.14 to 24.38 for fertile tillers per plant; -45.09 to 34.33 for flag leaf area; -23.27 to 15.88 for spike length; -27.48 to 23.97 for number of grains per spike; -9.19 to 9.80 for 1000-grain weight; -0.16 to 25.05 for biomass per plant; -18.41 to 22.87 for grain yield per spike and -22.84 to 22.32 for grain yield per plant. The results were in conformity with the findings of earlier researchers such as Subhani *et al.* (2000) [11], Kumar and Kerkhi (2014) [12], Thomas *et al.* (2017) [14] and Choudhary *et al.* (2022) [13].

Heterobeltiosis (over better parent) is more important and valuable in order to determine the practicability of commercial exploitation of heterosis and also identifies the parental combinations that can produce the transgressive segregantsntss. The cross HD 2967 x UP 2425 for days to 50% heading, days to maturity, spike length and1000-grain weight; Raj 3765 x HD 2967 for plant height and fertile tillers per plant; WH 1021 x UP 2425 for flag leaf area; Raj 4079 x PBW 343 for number of grains per spike; Raj 4079 x WH 1021 for biomass per plant; PBW 343 X UP 2425 for grain yield per spike and Raj 3765 x UP 2425 for grain yield per plant were desirable as they revealed maximum significant heterosis over the better parent. Similar findings were reported by Gaur *et al*. (2014) [15] and Garg *et al.* (2015) [16].

For grain yield per plant some promising crosses identified (Table 3), which exhibited heterobeltiosis along with their high *per se* performance such as Raj 3765 x UP 2425 (22.32%), Raj 4079 x PBW 343 (20.48%), Raj 4079 x Raj 3765 (20.12%), PBW 343 X HD 2967 (19.79%), Raj 4079 x WH 1021 (19.41%), Raj 4079 x HD 2967 (19.03%), HD 2967 x UP 2425 (17.81%), Raj 3765 x WH 1021 (17.58%) and Raj 3765 x PBW 343 (15.56%). These crosses also exhibited significant heterobeltiosis in the desirable direction for the majority of other yield-contributing traits therefore may be considered as superior crosses for grain yield. These results were in agreement with earlier researchers of Singh *et al.* (2004) [18], Kumar and Maloo (2011) [19], Gite *et al.* (2014) [17] and Nagar *et al.* (2019) [20].

Generally, inbreeding depression occurs in the F_2 generation as the effects of dominance or dominant interaction decrease in this generation due to reduced heterozygosis. The magnitude of inbreeding depression in F_2 generation may be a reliable indicator to predict heterotic performance in F_1 hybrids of wheat (Bailey *et al*., 1980) [2]. Negative magnitude of inbreeding depression is desirable for grain yield and other contributing characters except days to 50% heading, days to maturity and plant height. Several F_2 crosses exhibited inbreeding depression in desirable direction for various characters under this study such as for days to 50% heading, flag leaf area and 1000-grain weight (one cross for each); for days to maturity (four crosses) and for fertile tillers/plant (three crosses). No inbreeding depression was recorded in any cross for grain yield per plant, plant height, spike length, number of grains/spike, biomass/plant and grain yield per spike that can be utilized to maintain the specific gene pool for further breeding programs of yield improvement in wheat.

Table 1: Analysis of variance (mean squares) for parents, F₁'s and F₂'s for grain yield and its contributing characters

Characters	Source of variation								
	Replication	Genotypes	Parents	Generation	F_1's	F_2's	F_1 *vs* F_2	Parents vs generation	Error
DF	(2)	(99)	(9)	(89)	(44)	(44)	(1)	(1)	(198)
Days to 50% heading	0.12	78.83**	65.05**	78.87**	66.11**	92.92**	22.53**	198.45**	2.4
Days to maturity	1.44	144.72**	42.83**	153.95**	129.45**	181.22**	32.03*	240.01**	7.11
Plant height	4.32	194.59**	74.56**	205.86**	158.33**	254.99**	134.92*	272.47**	22.78
Fertile tillers/plant	0.41	3.82**	1.77**	3.67**	2.69**	4.68**	2.76**	35.57**	0.36
Flag leaf area	11.39	179.21**	58.49**	191.18**	186.44**	199.77**	21.61*	200.24**	4.53
Spike length	0.05	3.3**	0.93**	3.48**	2.6**	4.4**	1.99*	8.97**	0.36
Number of grains/spike	2.41	121.69**	33.56**	128.18**	110.21**	148.24**	35.91**	338.05**	5.28
1000-grain weight	2.43	22.92**	10.4**	23.36**	19.79**	27.28**	7.97*	96.89**	1.26
Biomass/plant	12.17	67.13**	16.49*	64.16**	50.79**	73.32**	248.77**	787.72**	7.19
Grain yield/plant	0.42	29.72**	10.18**	31.04**	26.55**	35.98**	11.24*	87.75**	2.15
Grain yield/spike	0.008	0.15**	0.09**	0.15**	0.13**	0.17**	0.1**	0.79**	0.01

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

Table 2: Extent of heterosis (H), heterobeltiosis (HB) and inbreeding depression (ID) for different characters in bread wheat

Characters	Number of heterotic crosses		Number of crosses showing Inbreeding depression	Range of heterosis						
	Heterosis (%)	Heterobeltiosis (%)		Heterosis (%)		Heterobeltiosis (%)		Crosses with maximum heterobeltiosis	Inbreeding depression (%)	
				Min.	Max.	Min.	Max.		Min.	Max.
Days to 50% heading	29	17	1	-16.44	10.64	-8.41	13.59	HD 2967 x UP 2425	-9.21	4.74
Days to maturity	25	15	4	-10.55	7.51	-9.69	9.61	HD 2967 x UP 2425	-11.24	9.22
Plant height	20	15	-	-15.40	14.46	-13.54	19.83	Raj 3765 x HD 2967	-26.81	9.85
Fertile tillers/plant	29	16	3	-6.05	36.00	-9.14	24.38	Raj 3765 x HD 2967	-21.18	25.49
Flag leaf area	25	15	1	-32.96	43.10	-45.09	34.33	WH 1021 x UP 2425	-13.58	20.12
Spike length	23	13	-	-17.98	19.78	-23.27	15.88	HD 2967 x UP 2425	-8.79	16.46
Number of grains/spike	24	17	-	-20.49	30.81	-27.48	23.97	Raj 4079 x PBW 343	-3.42	18.05
1000-grain weight	27	15	1	-8.69	12.48	-9.19	9.80	HD 2967 x UP 2425	-4.87	3.49
Biomass/plant	35	19	-	1.27	30.49	-0.16	25.05	Raj 4079 x WH 1021	-2.36	10.85
Grain yield/spike	25	15	-	-13.04	35.94	-18.41	22.87	PBW 343 X UP 2425	-6.51	18.91
Grain yield/plant	21	14	-	-18.46	34.65	-22.84	22.32	Raj 3765 x UP 2425	-7.70	10.79

Table 3: Promising hybrids identified on the basis of *per se* performance and heterobeltiosis for grain yield per plant exhibiting desirable heterotic expression for other contributing characters

S. No.	Hybrids	*Per se performance* of grain yield per plant (g)	Heterobeltiosis (%)	Days to 50% heading	Days to maturity	Plant height	Fertile tillers per plant	Flag leaf area	Spike length	Number of grains per spike	1000-grain weight	Biomass per plant	Grain yield per spike
1.	Raj 3765 x UP 2425	25.81	22.32	+	+	+	+	+	+	+	+	+	+
2.	Raj 4079 x PBW 343	21.90	20.48	+	+	+	+	+	+	+	+	+	+
3.	Raj 4079 x Raj 3765	25.35	20.12	+	+	+	+	+	-	+	+	+	+
4.	PBW 343 X HD 2967	19.29	19.69	+	+	+	+	+	+	+	+	+	+
5.	Raj 4079 x WH 1021	24.24	19.41	+	+	+	+	+	-	+	+	+	+
6.	Raj 4079 x HD 2967	21.64	19.03	+	+	+	+	+	+	+	+	+	+
7.	HD 2967 x UP 2425	21.50	17.81	+	+	+	+	+	+	+	+	+	+
8.	Raj 3765 x WH 1021	24.81	17.58	+	+	+	+	+	-	+	+	+	+
9.	Raj 3765 x PBW 343	24.39	15.56	+	+	+	+	+	+	+	+	+	+

Conclusion

The significant differences among the genotypes, parents and generations for all studied characters, indicate considerable genetic diversity exist among the selected parents. For grain yield per plant nine promising crosses were identified on the basis of their *per se* performance and heterobeltiosis such as Raj 3765 x UP 2425, Raj 4079 x PBW 343, Raj 4079 x Raj 3765, PBW 343 X HD 2967, Raj 4079 x WH 1021, Raj 4079 x HD 2967, HD 2967 x UP 2425, Raj 3765 x WH 1021 and Raj 3765 x PBW 343 which may be utilized as better transgressed sergeants in further crossing programs. No inbreeding depression was recorded in any cross for grain yield per plant which can be used to maintain a specific gene pool for future breeding programs of yield improvement in wheat.

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