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Research Note

Heterosis and inbreeding depression for grain yield and yield contributing characters in wheat (*Triticum aestivum* L.)

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Abstract
The present investigation on heterosis and inbreeding depression in wheat was carried out at the Crop Research Farm of CSAUA&T, Nawabganj, Kanpur, U.P., India, during the *Rabi* crop season 2019-20. A ten parental half-diallel cross comprising of 45 F_1s and 45 F_2s together with parents was grown in three replications. The outcome of better parent heterosis revealed that the cross combinations, namely, HD3086 x HD-2733, HD3086 x K0307, HD3086 x HD2967, HD3086 x K1601, and HD2967 x K0402 exhibited positive and high heterosis for grain yield. In the case of economic heterosis over the check (HD2967), the cross combination *viz*. HD3086 x K0307, HD3086 x HD2967, HD-967 x K0402, HD2967 x K1601, and HD2967 x K1314 exhibited significant and positive heterosis for grain yield. Inbreeding depression for grain yield ranged from 1.51 (DH 29767 x K 8962) to 8.95 (DBW 88 x K 8962) percent. For grain yield, out of the 45 crosses, all combinations exhibited significant and positive inbreeding depression in F_2. The cross combinations may be used to increase grain yield and to produce better transgressive segregants for future breeding programs to maintain the specific gene pool of bread wheat.

Keywords- Wheat, Inbreeding depression, Heterosis

Wheat belongs to the family of Gramineae (Poaceae) and, is one of the leading food for about 36.2% of the world's population (Arya *et al.,* 2018). It has 1.8% minerals, 2% fat, 12% water, 12% protein, 22% crude fibers and 70% carbohydrates (Kumar *et al.,* 2017). Wheat is cultivated under various agro-climatic environments allying the geographical latitudes of 30°-60°North and 27°-40°South including India (Nuttonson 1955). In the last few decades, the human population is increasing, and wheat production has decreased. Hence, there is a need to develop high-yielding wheat genotypes to feed the increasing population of the world. In any breeding approach, the successful result depends primarily on the genetic variability present in the base population, the proper parent selection, the mating procedure and on the breeder's acute verdict in the selection among segregating populations. The simultaneous studies of inbreeding depression and heterosis are helpful for breeders to select the superior hybrid combinations that will provide the base for selection of superior genotypes. In cereals like wheat, heterosis is expressed to the tune of 10-25 % (Hoisington *et al.,* 1999). The estimates of economic heterosis for grain yield vary from as low as 6 % (Borghi *et al.,* 1986) to as high as 41 % (Yadav and Murty, 1976). Inbreeding depression is a consequence of self-pollination over several generations which may lead to a gradual loss or reduction in vigor and fertility. However, it is essential to have inbreeding for selection because it provides excellent segregants for the base population in wheat crops. (Gaur, 2014). The superiority of F_1 mostly over a better parent is further effective for the merchant use of heterosis and, also capable of producing better transgressive segregants (Singh *et al.,* 2004). Thus, crop improvement involves both inbreeding depression and heterosis (Zirkle, 1952). Hence, the present investigation was conducted to estimate the extent of heterosis in F_1 over both better and economic parents, while inbreeding depression in F_2 generation for grain yield and its contributing characters to isolate superior cross combinations that may be remunerative for future wheat improvement programs.

The experimental material for the present investigation comprised of a total of 100 treatments including 10 parents *viz.*, HD3086, K1314, DBW88, K1601, DBW39, K0307, K0402, K8962, HD2733 and HD2967 (**Table 1**), which were crossed to get F_1 seeds following half diallel mating design during 2018-19. In the same year, F_1s were advanced to get F_2 seeds. The experiment was conducted at Crop Research Farm of CSAUA&T, Nawabganj, Kanpur during *Rabi*, 2019-20. All the F_1s and F_2s were raised along with the 10 parents and were sown in 3m rows with 23x10 cm spacing in a Randomized Block Design with three replications. All the essential cultural activities were adopted to develop a good crop population. The data were documented from 10 randomly selected plants per row in each population for all characters *viz.,* days to 75 percent heading, number of productive tillers per plant, spike length, 1000-grain weight, number of spikelets per spike, grain yield per plant, number of grains per spike, biological yield per plant, 1000-grain weight, harvest index, protein content and days to maturity. The estimates of inbreeding depression and heterosis were computed as per the procedure suggested by Fonseca and Patterson, 1968.

Heterosis is measured as the superiority of F_1 mean over the economic parent; the better parent is thus, an important parameter in such studies. Heterosis breeding plays a crucial role in crop improvement programs to obtain higher yields. The first important step in exploiting heterosis is knowing its magnitude and direction. Self-pollinated crops have not largely used hybrid vigor as much as cross-pollinated crops, due to the lack of commercially available stable male sterile lines. However, heterosis in wheat has been extensively studied as a means of increasing productivity, as reported by Vrik *et al.* (1971), Jatasra and Paroda (1979). In the present study, the heterosis of F_{IS} in percentage over Better Parent, economic parent and Inbreeding

Table 1. Description of parent/genotype involved in the study

	Genotype	Pedigree	Source of Origin	Characters
1	HD 3086	DBW 14/HD 2733//HUW 468	IARI, New Delhi	Suitable for irrigated, timely sown conditions, resistant to yellow and brown rust. Average yield is 54.6q/h
2	DBW 88	KAUZ//ALTR84/AOS/3/ MILAN/KAUZ/4/HUITES	IIWBR, Karnal Hariyna	Suitable for irrigated, timely sown conditions, resistance to yellow and brown rust. Average yield is 54.20q/h
3	HD 2733	Attila/3/Tui/Carc//Chen/ Chto/4/Atila	IARI. New Delhi	Suitable for timely sown conditions, average seed yield is 50.00q/ ha, with medium early maturity. Resistance against all the three rusts and more especially against leaf rust and leaf blight.
4	DBW 39	ATTILA/HUI	IIWBR, Karnal Hariyna	Resistant to black rust, brown rust and leaf blight. Average yield is 44.60q/ha
5	K 0307	K8321/UP2003	CSAUA&T, Kanpur	Suitable for irrigated, timely sown conditions, resistant to all the three rusts and leaf blight. Tolerant to terminal heat stress and average yield is 45.60q/h
6	HD 2967	ALD//COC//URES/ HD2160M/HD2278	IARI, New Delhi	Suitable for irrigated, timely sown conditions, resistance to yellow and brown rust. Average yield is 50.4 q/h.
7	K 0402	HP173/UP 2425	CSAUA&T, Kanpur	Suitable for irrigated, timely sown conditions, resistant to major disease, namely, brown, yellow, black rusts and leaf blight. Tolerance to terminal heat and average yield is 43. 10q/h
8	K 1601	K 9107/DBW 14	CSAUA&T, Kanpur	Suitable for irrigated timely sown condition and resistance to yellow, brown, black rust along with leaf blight
9	K 8962	K7401/HD 2160	CSAUA&T, Kanpur	Suitable for rainfed timely sown condition, resistant to brown and yellow rust. Average yield is 52.40q/h
10	K 1314	HD 2402/K 8565	CSAUA&T, Kanpur	Suitable for irrigated late sown condition and resistant to yellow, brown, black rust along with leaf blight.

depression of F_{2S} over F_{IS} for twelve traits were analysed and the results are presented in **Table 2**

The extent of heterosis for Days to 75% heading over better parent ranged from -9.18 (HD 2733 X HD 2967)

Table 2. Estimation of heterosis over better parent, economic parent and inbreeding depression in percent for 12 characters in a 10 parent diallel cross in wheat.

	Days to 75% heading			Days to maturity			Plant height (cm)		
	F1		F2	F1		F2	F1		F2
	BP	Ec. P.	IBD	BP	Ec. P.	IBD	BP	Ec. P	IBD
HD-3086 X DBW88	-1.59 ns	-9.52 **	-3.64*	-4.52 **	-10.11**	-0.59	-3.13 ns	-3.69 *	-2.03
HD-3086 X HD-2733	-1.97 ns	-8.79 **	-2.81	-5.85 **	-10.11**	-1.18	-4.36 *	-4.91 **	-3.11
HD-3086 X DBW39	-3.07 *	-7.33 **	0.00	-4.44 **	-8.51 **	-2.33	-6.98 **	-5.71 **	-1.40
HD-3086 X K0307	-4.09 **	-5.49 **	3.88*	-6.52 **	-8.51 **	-0.58	-4.32 *	-4.88 **	4.62**
HD-3086 X HD-2967	-5.49 **	-5.49 **	3.88*	-9.31 **	-9.31 **	0.29	-5.54 **	-5.54 **	-2.36
HD-3086 X K0402	-4.85 **	-6.59 **	-0.78	-10.64 **	-10.64**	-2.08	-3.16 ns	-3.73 *	1.12
HD-3086 X K1601	2.80 ns	-5.86 **	3.11	-6.18 **	-11.17**	0.60	-2.81 ns	-3.38 ns	-1.44
HD-3086 X K8962	5.76 **	-5.86 **	3.11	-4.60 **	-11.70**	-2.41	-12.90 **	-1.18 ns	-1.02
HD-3086 X K1314	5.69 **	-4.76 **	0.00	-5.03 **	-9.57 **	-0.59	-2.87 ns	-3.43 ns	6.33**
DBW88 X HD-2733	1.97 ns	-5.13 **	1.16	-2.79 *	-7.18 **	-0.57	-3.64 ns	-8.26 **	-0.42
DBW88 X DBW39	-2.30 ns	-6.59 **	0.39	-3.33 **	-7.45 **	-1.15	-5.26 **	-3.97 *	0.44
DBW88 X K0307	-4.46 **	-5.86 **	1.95	-5.71 **	-7.71 **	-2.02	-5.51 **	-10.03 **	1.67
DBW88 X HD-2967	-3.66 **	-3.66 **	5.32**	-7.71 **	-7.71 **	-1.44	-5.05 **	-5.05 **	-1.32
DBW88 X K0402	7.84 **	5.86 **	8.65**	-7.45 **	-7.45 **	0.57	-4.24 *	-7.25 **	-2.70
DBW88 X K1601	15.14 **	5.86 **	12.46**	-2.81 *	-7.98 **	0.29	-4.38 *	-7.11 **	-2.70
DBW88 X K8962	12.75 **	3.66 **	14.49**	-2.82 *	-8.51 **	-0.58	-12.13 **	-0.31 ns	1.68
DBW88 X K1314	7.97 **	-0.73 ns	7.38**	-3.35 **	-7.98 **	-1.16	-5.81 **	-9.02 **	0.08
HD-2733 X DBW39	0.00 ns	-4.40 **	4.98**	-2.50 *	-6.65 **	0.57	-8.18 **	-6.93 **	-2.40
HD-2733 X K0307	-4.83 **	-6.23 **	-1.17	-4.35 **	-6.38 **	-0.85	-4.17 *	-15.16 **	-0.70
HD-2733 X HD-2967	-9.52 **	-9.52 **	-5.26**	-5.85 **	-5.85 **	-1.13	-10.73 **	-10.73 **	-1.60
HD-2733 X K0402	-4.85 **	-6.59 **	0.78	-7.45 **	-7.45 **	-2.01	-11.80 **	-14.56 **	-0.49
HD-2733 X K1601	-1.18 ns	-8.06 **	0.00	-1.95 ns	-6.38 **	-2.27	-8.61 **	-11.22 **	-1.06
HD-2733 X K8962	0.39 ns	-6.59 **	-0.39	-4.18 **	-8.51 **	0.00	-17.75 **	-6.69 **	0.67
HD-2733 X K1314	0.79 ns	-6.23 **	-0.39	-1.95 ns	-6.38 **	-0.57	-7.00 **	-10.17 **	1.36
DBW39 X K0307	2.23 ns	0.73 ns	-0.73	-2.72 *	-4.79 **	-0.56	-14.27 **	-13.10 **	-1.60
DBW39 X HD-2967	3.30 *	3.30 *	4.61*	-4.79 **	-4.79 **	-1.12	-2.37 ns	-1.05 ns	1.20
DBW39 X K0402	2.99 *	1.10 ns	1.45	-7.45 **	-7.45 **	-0.57	-6.26 **	-4.98 **	-1.98
DBW39 X K1601	5.75 **	1.10 ns	0.72	-3.89 **	-7.98 **	-0.29	-4.85 **	-3.55 ns	-1.63
DBW39 X K8962	4.21 **	-0.37 ns	8.46**	-3.33 **	-7.45 **	-1.72	-11.24 **	0.70 ns	-2.73
DBW39 X K1314	3.45 *	-1.10 ns	6.30**	-1.11 ns	-5.32 **	-1.12	-8.46 **	-7.21 **	-0.94
K0307 X HD-2967	-6.59 **	-6.59 **	3.14	-3.72 **	-3.72 **	-1.10	-14.39 **	-14.39 **	-3.17
K0307 X K0402	-5.20 **	-6.59 **	2.35	-3.99 **	-3.99 **	-1.39	-14.03 **	-16.72 **	-0.73
K0307 X K1601	-5.58 **	-6.96 **	3.54*	-2.72 *	-4.79 **	0.00	-10.65 **	-13.21 **	-2.57
K0307 X K8962	-5.20 **	-6.59 **	2.35	-3.26 **	-5.32 **	-0.56	-22.11 **	-11.64 **	-3.04
K0307 X K1314	-4.83 **	-6.23 **	4.30*	-2.45 *	-4.52 **	-0.56	-7.50 **	-10.66 **	-0.31
HD-2967 X K0402	-4.03 **	-4.03 **	5.73**	-3.46 **	-3.46 **	-0.83	-6.03 **	-6.03 **	-0.44
HD-2967 X K1601	-5.49 **	-5.49 **	4.26*	-3.72 **	-3.72 **	-1.66	-5.47 **	-5.47 **	-1.66
HD-2967 X K8962	-2.93 *	-2.93 *	7.55**	-3.99 **	-3.99 **	-1.94	-16.49 **	-5.26 **	-1.58
HD-2967 X K1314	-2.93 *	-2.93 *	9.06**	-3.19 **	-3.19 **	-0.55	-8.33 **	-8.33 **	-0.61
K0402 X K1601	-1.87 ns	-3.66 **	3.04	-5.05 **	-5.05 **	-0.84	-2.69 ns	-5.47 **	-0.74
K0402 X K8962	-3.36 *	-5.13 **	0.00	-3.99 **	-3.99 **	1.11	-15.25 **	-3.86 *	-1.98
K0402 X K1314	-3.36 *	-5.13 **	0.77	-4.26 **	-4.26 **	-2.22	-5.83 **	-8.78 **	0.53
K1601 X K8962	8.40 **	-0.73 ns	3.69*	-2.53 *	-7.71 **	-1.44	-16.22 **	-4.95 **	-0.29
K1601 X K1314	8.40 **	-0.73 ns	4.06*	-2.79 *	-7.45 **	0.57	-4.16 *	-6.90 **	0.41
K8962 X K1314	-3.25 *	-12.82 **	-7.14**	-6.98 **	-11.44**	-1.50	-6.28 **	6.33 **	-0.70

Table 2: Contd…..

	Number of productive tillers per plant			Spike length (cm)			No. of spikelets/spike		
	F1		F2	F1		F2	F1		F2
	BP	Ec. P	IBD	BP	Ec. P	IBD	BP	Ec. P	IBD
HD-3086 X DBW88	10.05 ns	20.20 **	5.39**	-1.94 ns	-0.60 ns	-1.80**	-2.14 ns	-0.44 ns	-0.73
HD-3086 X HD-2733	7.89 ns	22.69 **	8.54**	6.69 ns	-5.06 ns	-2.82**	-8.07 *	-7.27 ns	2.19
HD-3086 X DBW39	-1.83 ns	7.23 ns	-5.35**	4.25 ns	-1.49 ns	-9.67**	1.01 ns	-5.52 ns	-0.92
HD-3086 X K0307	-14.18 **	23.19 **	9.92**	-0.12 ns	-2.50 ns	-5.62**	0.80 ns	-8.43 *	-10.16**
HD-3086 X HD-2967	6.85 ns	16.71 **	6.28**	-1.79 ns	-1.79 ns	-7.88**	0.87 ns	0.87 ns	1.73
HD-3086 X K0402	14.54 **	29.68 **	-0.50	8.45 ns	-4.46 ns	-7.17**	1.36 ns	-2.33 ns	-0.60
HD-3086 X K1601	-12.97 **	37.16 **	6.18**	0.63 ns	-5.36 ns	-14.78**	-5.73 ns	-12.79 **	-17.67**
HD-3086 X K8962	-3.65 ns	5.24 ns	23.55**	11.54 *	-5.06 ns	-7.21**	-1.66 ns	-5.38 ns	-0.77
HD-3086 X K1314	-2.28 ns	6.73 ns	-12.90**	16.13 **	-0.60 ns	-3.59**	6.82 ns	-8.94 *	-10.77**
DBW88 X HD-2733	21.93 **	38.65 **	19.42**	-0.18 ns	1.19 ns	-7.65**	-0.43 ns	1.31 ns	-3.59*
DBW88 X DBW39	11.32 ns	19.70 **	11.63**	3.93 ns	5.36 ns	-5.93**	1.50 ns	3.27 ns	0.63
DBW88 X K0307	-16.96 **	19.20 **	-1.63**	5.08 ns	6.52 ns	3.88**	1.29 ns	3.05 ns	8.32**
DBW88 X HD-2967	12.24 *	20.70 **	6.94**	9.81 *	11.31 **	2.94**	1.57 ns	3.34 ns	1.83
DBW88 X K0402	14.98 **	30.17 **	27.09**	-1.06 ns	0.30 ns	-2.97**	1.14 ns	2.91 ns	0.56
DBW88 X K1601	-19.94 **	26.18 **	18.46**	0.29 ns	1.67 ns	8.67**	-0.86 ns	0.87 ns	4.90**
DBW88 X K8962	3.43 ns	11.22 ns	14.80**	1.00 ns	2.38 ns	-0.29	5.57 ns	7.41 *	15.56**
DBW88 X K1314	1.58 ns	9.23 ns	-3.79**	-1.35 ns	0.00 ns	-2.98**	-7.00 ns	-5.38 ns	-3.23*
HD-2733 X DBW39	2.63 ns	16.71 **	3.72**	5.83 ns	0.00 ns	-5.95**	-3.03 ns	-2.18 ns	15.60**
HD-2733 X K0307	-11.40 **	27.18 **	14.12**	8.23 ns	5.65 ns	1.13*	-0.43 ns	0.44 ns	9.41**
HD-2733 X HD-2967	3.51 ns	17.71 **	0.42	2.98 ns	2.98 ns	-4.05**	-2.45 ns	-1.60 ns	2.22
HD-2733 X K0402	-12.72 *	-0.75 ns	-12.21**	7.89 ns	-3.99 ns	-9.11**	-1.87 ns	-1.02 ns	2.20
HD-2733 X K1601	-23.73 **	20.20 **	6.02**	-0.32 ns	-6.25 ns	-2.86**	-5.91 ns	-5.09 ns	-4.13**
HD-2733 X K8962	7.89 ns	22.69 **	20.00**	5.35 ns	-6.25 ns	-2.22**	-2.16 ns	-1.31 ns	6.63**
HD-2733 X K1314	-5.26 ns	7.73 ns	7.41**	5.02 ns	-6.55 ns	4.78**	-4.76 ns	-3.92 ns	4.99**
DBW39 X K0307	-16.96 **	19.20 **	2.26**	11.59 **	8.93 *	18.31**	8.94 *	1.89 ns	6.42**
DBW39 X HD-2967	12.25 *	14.21 *	14.85**	-0.30 ns	-0.30 ns	5.07**	0.00 ns	0.00 ns	9.30**
DBW39 X K0402	3.52 ns	17.21 **	7.66**	7.72 ns	1.79 ns	0.29	6.49 ns	2.62 ns	7.37**
DBW39 X K1601	-22.15 **	22.69 **	4.76**	1.10 ns	-4.46 ns	-6.54**	-1.17 ns	-7.56 *	-1.57
DBW39 X K8962	7.84 ns	9.73 ns	11.68**	8.35 ns	2.38 ns	7.85**	9.21 *	5.09 ns	8.71**
DBW39 X K1314	11.48 ns	16.21 **	5.02**	7.09 ns	1.19 ns	10.00**	9.71 *	2.62 ns	16.71**
K0307 X HD-2967	-20.08 **	14.71 *	-10.09**	-1.79 ns	-1.79 ns	2.12**	-5.09 ns	-5.09 ns	-6.13**
K0307 X K0402	-13.48 **	24.19 **	13.82**	0.00 ns	-2.38 ns	-0.30	-1.81 ns	-5.38 ns	2.61
K0307 X K1601	-0.32 ns	57.11 **	6.03**	6.40 ns	3.87 ns	4.01**	1.81 ns	-5.81 ns	1.54
K0307 X K8962	-20.43 **	14.21 *	-10.04**	-0.91 ns	-3.27 ns	-3.69**	-3.63 ns	-7.27 ns	5.17**
K0307 X K1314	-11.05 *	27.68 **	19.14**	0.30 ns	-2.08 ns	-7.60**	2.72 ns	-6.69 ns	-6.23**
HD-2967 X K0402	-3.96 ns	8.73 ns	4.91**	2.68 ns	2.68 ns	-3.48**	-3.34 ns	-3.34 ns	-2.26
HD-2967 X K1601	-25.63 **	17.21 **	17.74**	-1.19 ns	-1.19 ns	1.51*	-7.56 *	-7.56 *	-4.40**
HD-2967 X K8962	9.73 ns	9.73 ns	15.64**	3.27 ns	3.27 ns	12.97**	-0.29 ns	-0.29 ns	9.91**
HD-2967 X K1314	20.10 **	25.19 **	1.87**	-10.71 *	-10.71 *	-6.67**	-15.26 **	-15.26 **	-9.78*
K0402 X K1601	-12.97 **	37.16 **	18.80**	4.75 ns	-1.49 ns	2.11**	-6.33 ns	-9.74 **	-8.53**
K0402 X K8962	0.88 ns	14.21 *	11.14**	3.72 ns	-8.63 *	-18.57**	1.36 ns	-2.33 ns	2.23
K0402 X K1314	12.33 *	27.18 **	22.24**	13.85 **	0.30 ns	-3.56**	-2.87 ns	-6.40 ns	0.00
K1601 X K8962	-0.32 ns	57.11 **	5.56**	2.53 ns	-3.57 ns	-2.16**	3.32 ns	-0.58 ns	7.60**
K1601 X K1314	5.38 ns	66.08 **	5.41**	2.53 ns	-3.57 ns	-4.32**	-5.42 ns	-12.50 **	-2.33
K8962 X K1314	10.53 ns	15.21 *	7.58**	15.79 **	-0.89 ns	-9.91**	1.21 ns	-2.62 ns	15.52**
SE±	0.41	0.52		0.16		0.63	0.79		1.55

Table 2: Contd…..

	No. of grain/spike			1000-grain weight (g)			Grain yield (g)		
	F1		F2	F1		F2	F1		F2
	BP	Ec. P	IBD	BP	Ec. P	IBD	BP	Ec. P	IBD
HD-3086 X DBW88	-9.20 **	-12.21 **	1.55	5.53 **	31.73 **	6.62**	3.69 *	-2.02 ns	3.18**
HD-3086 X HD-2733	-7.55 **	-6.34 *	6.77**	1.27 ns	26.41 **	0.79	7.77 **	1.83 ns	1.80**
HD-3086 X DBW39	1.65 ns	-8.65 **	4.41**	1.14 ns	26.25 **	0.92	5.24 **	-0.55 ns	1.66**
HD-3086 X K0307	-8.71 **	-6.76 **	4.01**	0.81 ns	25.83 **	0.83	13.20 **	6.97 **	7.20**
HD-3086 X HD-2967	-9.72 **	-9.72 **	4.66**	-2.72 ns	21.43 **	-1.50	7.52 **	7.52 **	6.66**
HD-3086 X K0402	-13.85 **	-11.14 **	1.80	8.92 **	35.96 **	5.56**	2.33 ns	-3.30 *	1.90**
HD-3086 X K1601	5.41 ns	-7.53 **	4.42**	-0.06 ns	24.75 **	-0.27	9.13 **	3.12 *	1.60**
HD-3086 X K8962	-0.56 ns	-15.59 **	5.13**	-7.02 **	16.06 **	-3.41**	0.58 ns	-4.95 **	2.70**
HD-3086 X K1314	1.14 ns	-15.59 **	4.71**	0.27 ns	25.16 **	1.92	2.91 *	-2.75 *	2.64**
DBW88 X HD-2733	3.69 ns	5.04 *	6.77**	-6.39 **	4.98 *	4.27**	3.13 *	-9.36 **	3.44**
DBW88 X DBW39	9.99 **	6.34 *	6.13**	1.26 ns	-0.00 ns	1.77	-2.02 ns	-11.19 **	2.69**
DBW88 X K0307	4.99 *	7.23 **	7.96**	5.98 *	6.06 **	2.66*	-4.11 **	-10.09 **	2.65**
DBW88 X HD-2967	6.64 **	6.64 **	2.67	1.91 ns	1.91 ns	0.81	-9.36 **	-9.36 **	4.05**
DBW88 X K0402	6.03 *	9.37 **	4.50**	-7.19 **	8.31 **	3.68**	-5.13 **	-11.74 **	3.74**
DBW88 X K1601	4.41 ns	0.95 ns	3.46*	26.88 **	24.67 **	1.53	5.59 **	-9.91 **	3.67**
DBW88 X K8962	3.19 ns	-0.24 ns	10.04**	-14.81 **	-6.40 **	-5.50**	-1.72 ns	-16.15 **	3.50**
DBW88 X K1314	3.37 ns	-0.06 ns	4.57**	2.21 ns	3.49 ns	2.42*	4.30 **	-11.01 **	3.92**
HD-2733 X DBW39	3.69 ns	5.04 *	3.84**	5.16 *	17.94 **	1.90	1.01 ns	-8.44 **	3.61**
HD-2733 X K0307	0.75 ns	2.90 ns	7.60**	9.83 **	23.17 **	2.90*	-0.39 ns	-6.61 **	3.54**
HD-2733 X HD-2967	2.40 ns	3.73 ns	7.66**	2.79 ns	15.28 **	4.61**	-5.69 **	-5.69 **	2.33**
HD-2733 X K0402	0.80 ns	3.97 ns	7.53**	8.54 **	26.66 **	7.41**	-2.56 ns	-9.36 **	2.02**
HD-2733 X K1601	3.63 ns	4.98 *	5.03**	0.59 ns	12.82 **	4.37**	1.67 ns	-10.64 **	4.93**
HD-2733 X K8962	-2.81 ns	-1.54 ns	5.84**	-4.02 ns	7.64 **	7.79**	3.76 *	-8.81 **	8.25**
HD-2733 X K1314	1.58 ns	2.90 ns	10.60**	3.58 ns	16.17 **	9.77**	2.51 ns	-9.91 **	4.28**
DBW39 X K0307	-4.29 ns	-2.25 ns	3.52*	5.06 *	5.15 *	6.56**	-0.20 ns	-6.42 **	2.94**
DBW39 X HD-2967	3.26 ns	3.26 ns	5.45**	2.79 ns	2.79 ns	5.46**	-3.49 *	-3.49 *	5.51**
DBW39 X K0402	-2.24 ns	0.83 ns	3.23*	-10.75 **	4.15 ns	1.99	-0.79 ns	-7.71 **	3.18**
DBW39 X K1601	8.97 **	-2.07 ns	5.39**	4.37 ns	3.07 ns	5.00**	2.63 ns	-6.97 **	3.75**
DBW39 X K8962	7.39 **	-3.50 ns	5.90**	-11.41 **	-2.66 ns	0.77	1.82 ns	-7.71 **	8.95**
DBW39 X K1314	3.69 ns	-6.82 **	2.80	-0.30 ns	0.95 ns	9.66**	-0.61 ns	-9.91 **	4.07**
K0307 X HD-2967	6.50 **	8.77 **	0.76	3.15 ns	3.24 ns	0.00	1.47 ns	1.47 ns	5.42**
K0307 X K0402	8.51 **	11.91 **	1.75	-3.64 ns	12.44 **	4.49**	5.09 **	-1.47 ns	5.21**
K0307 X K1601	4.88 *	7.11 **	2.55	6.19 **	6.28 **	2.55*	4.89 **	-1.65 ns	3.73**
K0307 X K8962	-1.92 ns	0.18 ns	2.90*	-10.28 **	-1.41 ns	3.54*	2.54 ns	-3.85 **	8.21**
K0307 X K1314	-2.61 ns	-0.53 ns	3.81**	3.77 ns	5.07 *	4.66**	3.91 **	-2.57 ns	2.82**
HD-2967 X K0402	4.71 ns	8.00 **	4.34**	-8.22 **	7.10 **	3.53*	7.34 **	7.34 **	3.59**
HD-2967 X K1601	4.21 ns	4.21 ns	1.54	3.65 ns	3.65 ns	7.91**	5.32 **	5.32 **	3.48**
HD-2967 X K8962	-0.95 ns	-0.95 ns	1.62	-13.19 **	-4.61 *	-2.92*	-2.94 *	-2.94 *	1.51**
HD-2967 X K1314	2.79 ns	2.79 ns	6.00**	1.79 ns	3.06 ns	2.72*	3.30 *	3.30 *	2.31**
K0402 X K1601	4.77 ns	8.06 **	2.03	5.05 *	22.59 **	3.46*	4.73 **	-2.57 ns	2.45**
K0402 X K8962	-0.86 ns	2.25 ns	3.77**	-1.64 ns	14.78 **	5.43**	1.58 ns	-5.50 **	4.27**
K0402 X K1314	1.84 ns	5.04 *	4.97**	1.74 ns	18.73 **	2.27*	2.37 ns	-4.77 **	5.01**
K1601 X K8962	5.20 ns	-7.71 **	2.25	-18.39 **	-10.32 **	-8.36**	6.88 **	-8.81 **	5.23**
K1601 X K1314	12.91 **	-0.95 ns	3.59*	-4.84 *	-3.65 ns	8.02**	5.38 **	-10.09 **	6.73**
K8962 X K1314	2.51 ns	-12.98 **	4.36**	-8.75 **	0.27 ns	-1.06	6.28 **	-25.50 **	7.39**
SE±	3.37		1.44	0.94		1.16	0.25		0.49

Table 2. Contd…..

	Biological yield (g)			Harvest index (%)			Protein content (%)		
	F_1		F_2	F_1		F_2	F_1		F_2
	BP	Ec. P	IBD	BP	Ec. P	IBD	BP	Ec. P	IBD
HD-3086 X DBW88	-4.35 **	-0.42 ns	1.26*	1.20 ns	-1.73 ns	1.93**	-4.32 **	-0.79 ns	-0.54**
HD-3086 X HD-2733	7.78 **	5.88 **	0.08	-1.28 ns	-4.13 **	1.52*	0.78 ns	-2.71 **	0.98**
HD-3086 X DBW39	0.84 ns	0.92 ns	-0.42	1.43 ns	-1.51 ns	1.26**	-4.13 **	-2.33 *	1.28**
HD-3086 X K0307	3.77 **	4.11 **	0.24	5.79 **	2.73 **	7.32**	-4.19 **	3.31 **	0.97**
HD-3086 X HD-2967	3.69 **	3.69 **	0.57	3.66 **	3.66 **	7.52**	0.63 ns	0.63 ns	0.00
HD-3086 X K0402	-7.11 **	-1.34 ns	0.26	1.35 ns	-1.58 ns	2.15	-1.99 *	7.32 **	0.47**
HD-3086 X K1601	7.63 **	6.55 **	0.55	-0.53 ns	-3.40 **	0.98**	0.26 ns	-3.21 **	1.30**
HD-3086 X K8962	-2.06 ns	-0.42 ns	1.26*	-1.73 ns	-4.57 **	1.53**	1.58 ns	1.50 ns	1.11**
HD-3086 X K1314	6.20 **	3.53 **	0.32	-3.38 **	-6.17 **	2.33	0.37 ns	3.31 **	0.24**
DBW88 X HD-2733	4.19 **	8.48 **	3.02**	-6.75 **	-16.51 **	0.44**	1.33 ns	5.07 **	1.36**
DBW88 X DBW39	2.18 ns	6.38 **	-0.63	-8.26 **	-16.95 **	2.89**	4.30 **	8.15 **	0.23**
DBW88 X K0307	2.66 *	6.88 **	0.24	-10.12 **	-16.00 **	2.43**	3.56 **	11.66 **	2.76**
DBW88 X HD-2967	2.98 *	7.22 **	0.70	-16.22 **	-16.22 **	2.61**	5.54 **	9.43 **	1.97**
DBW88 X K0402	-0.24 ns	5.96 **	1.35**	-5.39 **	-16.81 **	1.58**	1.97 *	11.66 **	0.85**
DBW88 X K1601	4.52 **	8.82 **	0.85	-4.06 **	-17.32 **	2.91**	3.94 **	7.77 **	0.05
DBW88 X K8962	-2.50 *	1.51 ns	-2.81**	-0.35 ns	-17.53 **	6.01**	2.66 **	6.44 **	-0.35**
DBW88 X K1314	2.74 *	6.97 **	2.35**	0.51 ns	-16.82 **	1.65**	3.70 **	7.52 **	1.82**
HD-2733 X DBW39	1.17 ns	1.26 ns	-0.91	0.19 ns	-9.30 **	4.90**	-0.30 ns	1.58 ns	1.28**
HD-2733 X K0307	2.34 ns	2.69 *	1.72**	-2.71 **	-9.08 **	1.92**	-3.72 **	3.81 **	1.52**
HD-2733 X HD-2967	3.02 *	3.02 *	0.57	-8.57 **	-8.57 **	1.75**	4.51 **	4.51 **	0.19*
HD-2733 X K0402	-5.61 **	0.25 ns	0.00	0.95 ns	-9.62 **	2.15**	-3.11 **	6.09 **	-2.15**
HD-2733 X K1601	-0.08 ns	-1.09 ns	1.10*	0.81 ns	-9.74 **	3.95**	7.85 **	4.06 **	1.57**
HD-2733 X K8962	-2.89 *	-1.26 ns	0.51	3.09 **	-7.70 **	7.81**	0.50 ns	0.43 ns	2.25**
HD-2733 X K1314	2.36 ns	0.55 ns	0.22	0.00 ns	-10.47 **	4.56**	-1.90 *	0.98 ns	1.79**
DBW39 X K0307	0.00 ns	0.34 ns	0.84	-0.27 ns	-6.80 **	2.13**	1.70 *	9.65 **	0.75**
DBW39 X HD-2967	1.26 ns	1.34 ns	1.82**	-4.86 **	-4.86 **	3.75**	2.44 **	4.36 **	2.09**
DBW39 X K0402	-6.32 **	-0.50 ns	0.84	2.45 *	-7.26 **	2.51**	1.05 ns	10.66 **	0.91**
DBW39 X K1601	-0.25 ns	-0.17 ns	0.76	2.87 **	-6.88 **	3.07**	1.53 ns	3.44 **	1.55**
DBW39 X K8962	-2.81 *	-1.18 ns	1.10*	3.09 **	-6.68 **	7.96**	1.53 ns	3.44 **	2.55**
DBW39 X K1314	-0.17 ns	-0.08 ns	0.50	0.76 ns	-8.79 **	4.79**	0.97 ns	3.94 **	2.61**
K0307 X HD-2967	3.51 **	3.86 **	1.70**	-2.46 **	-2.46 **	3.81**	-0.93 ns	6.82 **	-1.36**
K0307 X K0402	-2.13 ns	3.95 **	1.29**	1.31 ns	-5.33 **	3.97**	1.97 *	11.66 **	0.74**
K0307 X K1601	1.92 ns	2.27 ns	1.31**	2.04 *	-4.64 **	1.76**	0.47 ns	8.32 **	0.69**
K0307 X K8962	0.45 ns	2.14 ns	0.86	0.64 ns	-5.95 **	7.36**	-0.35 ns	7.45 **	1.28**
K0307 X K1314	1.61 ns	1.95 ns	1.09*	2.20 *	-4.49 **	1.83**	-0.05 ns	7.77 **	1.93**
HD-2967 X K0402	-2.69 *	3.36 **	1.30**	3.85 **	3.85 **	2.35**	-2.11 *	7.20 **	1.52**
HD-2967 X K1601	1.09 ns	1.09 ns	0.75	4.18 **	4.18 **	2.87**	11.33 **	11.33 **	8.15**
HD-2967 X K8962	-2.81 *	-1.18 ns	-2.80**	-1.73 ns	-1.73 ns	4.15**	1.43 ns	1.43 ns	2.10**
HD-2967 X K1314	0.81 ns	0.81 ns	-0.03	3.77 **	3.77 **	3.33**	0.10 ns	3.03 **	1.44**
K0402 X K1601	1.74 ns	8.06 **	1.32**	2.49 *	-9.89 **	1.21*	4.49 **	14.42 **	1.93**
K0402 X K8962	-0.95 ns	5.21 **	1.60**	1.99 ns	-10.32 **	2.68**	5.91 **	15.97 **	3.89**
K0402 X K1314	-1.42 ns	4.70 **	1.60**	3.31 **	-9.16 **	3.45**	6.30 **	16.40 **	2.20**
K1601 X K8962	2.81 *	4.53 **	2.01**	1.10 ns	-12.87 **	3.26**	-4.27 **	-4.34 **	1.83**
K1601 X K1314	3.73 **	2.69 *	1.06	0.68 ns	-13.24 **	5.14**	-8.04 **	-5.34 **	-1.38**
K8962 X K1314	5.28 **	7.05 **	3.06**	-11.34 **	-30.50 **	4.40**	0.07 ns	3.01 **	1.41**

** significant at 1% level; * Significant at 5% level
BP = better parent; Ec. P = Economic parent; IBD = Inbreeding depression

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to 15.14 (DBW 88 X K 1601) percent, and heterosis over economic parent (HD 2967) ranged from -9.52 (HD 3086 X DBW 88, HD 2733 X HD 2967) to 5.86 (DBW 88 X K 0402, DBW 88 X K 1601) percent. In respect of days to maturity, better parent heterosis ranged from -10.64 (HD 3086 X K 0402) to -1.11 (DBW 39 X K 1314) percent, and economic heterosis ranged from -3.19 (HD 2967 X K 1314) to -11.70 (HD 3086 X K 8962) percent. Most of the crosses recorded negative heterosis with significant values. Plants with negative heterosis are desirable for breeding short-durational, early-maturity hybrids and varieties. Significantly desirable heterosis for earliness was reported by Gaur *et. al.,* (2014). The inbreeding depression in all the crosses was average for Days to 75% heading and days to maturity, indicating the presence of additive gene action.

Heterosis for plant height over better parent varied from -22.11(K 0307 X K 8962) to -2.81 (HD 3086 X K 1601) percent and over economic parent ranged from -16.72 (K 0307 X K 0402) to 0.70 (DBW 39 X K 8962) percent. Almost all the crosses that expressed significant negative heterosis over better parent and economic parent in F_1 also showed favorable inbreeding depression in their F_{2S}, indicating dwarfness. Hence, selection for dwarfness in all these crosses would be effective in F_2 and subsequent generations. Similar results for dwarfness were reported by Singh *et. al.,* (2008).

Heterosis over better parent for the number of productive tillers per plant ranged from -25.63 (HD 2967 x K 1601) to 21.93 (DBW 88 x HD 2733) and over economic parent ranged from -0.75 (HD2733 x K0402) to 66.08 (K1601 x K1314) percent. Out of the 45 crosses, DBW88 x HD2733, K0307 x K1601, K0402 x K1601, K1601 x K8962 and K1601 x K1314 had higher ranks for desirable heterosis. Similar findings were reported by Vanparia *et al*. (2006a). The cross combinations, like, HD3086 x K1314, HD2733 x K0402, HD2733 x K8962, DBW39 x HD2967 and K0307 x K8962 showed low inbreeding depression. The estimates of better parent heterosis varied from -10.71 (HD2967 x K1314) to 16.13 (HD3086 x K1314) percent for spike length. Among the 45 crosses, HD3086 x K8962, HD3086 x K1314, DBW39 x K0307, K0402 x K1314 and K8962 x K1314 resulted in more spike length than better parent. Economic heterosis ranged from -10.71 (HD2967 x K1314) to 11.30 (DBW88 x HD2967) per cent. Out of the 45 crosses, only two cross DBW88 x HD2967 and DBW39 x K0307 were desirable for spike length. Similar findings were reported by Singh *et al*. (2007). While in F_2 generation the cross combinations, like, HD3086 x K1601, K0402 x K8962, K8962 x K1314, HD2733 x K0402 and HD3086 x DBW39 had low inbreeding depression.

As for the number of spikelets per spike, the crosses, *viz*. DBW39 x K0307, DBW39 x K8962 and DBW39 x K1314 had higher spikelets per spike to better parent. Out of the 45, only one cross, HD2733 x K0402 showed desirable economic heterosis for number of spikelets per spike. In F_2 generation the crosses, like, HD3086 x K0307, HD3086 x K1601, HD3086 x K1314, K0307 x K1314 and K0402 x K1601 were observed to record low inbreeding depression while K0402 x K1314 was observed to record no inbreeding depression for number of spikelets per spike.

For the number of grains per spike, the crosses, *viz*, DBW88 x DBW39, DBW39 x K1601, DBW39 x K8962, K0307 x K0402 and K1601 x K1314 were in the order of merit over the better parent. The crosses, DBW88 x K0307, DBW88 x K0402, K0307 x HD2967, K0307 x K0402 and HD2967 x K0402 were observed to be observed superior over economic parent for the number of grains per spike (**Table 2**). Similar observations were recorded by Barot *et al.* (2014) and Desale and Mehta (2013).

The maximum value of desirable heterosis over better parent was observed in HD3086 x K0402 followed by DBW88 x K1601, HD2733 x K0307, HD2733 x K0402 and K0307 x K1601 for 1000-grain weight, while the cross combinations, HD3086 x DBW88, HD3086 x HD2733, HD3086 x DBW39, HD3086 x K0402 and HD2733 X K0402 showed maximum economic heterosis for 1000-grain weight (**Table 2**). Similar result was reported by Barot *et al.* (2014). On the other hand cross K0307 x HD2967 exhibited no inbreeding depression for these characters.

In terms of biological yield per plant, among the 45 crosses, six combinations namely HD3086 x HD2733, HD3086 x K1601, HD3086 x K1314, DBW88 x K1601 and K8962 x K1314 had maximum value over better paren. The cross combinations, DBW88 x HD2967, DBW88 x K1601, DBW88 x K1314, K0402 x K1601 and K8962 x K1314 had the highest economic heterosis for biological yield per plant. While the cross HD2733 x K0402 showed no inbreeding depression for biological yield per plant. A similar result was reported by Barot *et al.* (2014).

As for the harvest index, HD3086 x K0307, HD3086 x HD2967, HD2967 x K0402, HD2967 x K1601 and HD2967 x K1314 were the best combinations over their better parents. The cross combinations, namely, HD3086 x K0307, HD3086 x HD2967, HD2967 x K0402, HD2967 x K1601 and HD2967 x K1314 exhibited better economic heterosis. A similar observation was reported by Desale and Mehta (2013).

The estimates of better parent heterosis ranged from -8.04 (K1601 x K1314) to 11.33 (HD2967 x K1601) percent for protein content. From the 45 crosses, DBW88 x HD2967, HD2733 x K1601, HD2967 x K1601 K0402 x K8962 and K0402 x K1314 occupied the highest rank to better parent, while over economic heterosis the cross combination DBW88 x K0307, DBW88 x K0402, HD2967 x K1601, K0402 x K1601, K0402 x K8962 and K0402 x K1314 were in the order of merit. On the other hand, the cross

Table 3. Superior crosses for grain yield per plant

Genetic parameter	Crosses					
Mean performance	HD 3086 X HD 2967	HD 2967 X K 0402	HD 3086 X K 0307	HD 2967 X K 1601	HD 2967 X K 1314	HD 3086 X K 1601
$\bar{X}_{EP}$	18.17	18.17	18.17	18.17	18.17	18.17
$\bar{X}_{F1}$	19.053	19.50	19.43	19.13	18.77	18.73
$\bar{X}_{F2}$	18.23	18.80	18.03	18.47	18.33	18.43
Heterosis % over economic parents	7.52**	7.34**	6.97**	5.32**	3.30*	3.12*
Inbreeding depression	6.66**	3.59**	7.2**	3.48**	2.31**	1.6**

HD3086 x HD2967 exhibited no inbreeding depression for protein content. High heterosis accompanied by low or no inbreeding depression indicates the predominance of additive gene action of the expression of such traits Fonesca and Patterson (1968).

With regard to grain yield per plant, better parent heterosis ranged from -9.36 (DBW 88 x HD 2967) to 13.20 (HD 3086 x K 0307) percent. The maximum value of desirable heterosis over better parent was observed in HD 3086 x HD 2733 followed by HD 3086 x K 0307, HD 3086 x HD 2967, HD 3086 X K 1601, and HD 2967 X K 0402. Similar findings were reported by Ved *et al.* (2006) and Desale *et al.* (2013). The range of economic heterosis for grain yield per plant varied from -25.50 (K8962 x K1314) to 7.52 (HD 3086 x HD 2967) percent. The maximum value of economic heterosis was observed in HD 3086 x K 0307 followed by HD3086 x HD2967, HD2967 x K0402, HD2967 x K1601, and HD2967 x K1314 for grain yield as well as some other yield-related characters (**Table 3**). Considerable economic heterosis for grain yield was reported by Punia *et al*. (2005) and Singh *et al*. (2008). Inbreeding depression ranged from 1.51 (DH 29767 x K 8962) to 8.95 (DBW 88 x K 8962) percent for grain yield. All the 45 cross combinations showed positive and significant inbreeding depression in F_2 for grain yield per plant. Similar results were observed by Singh *et al*. (2007). In almost all the crosses, high heterosis for grain yield and yield associated characters followed by inbreeding depression in F_2, was observed, suggesting the presence of non-additive (dominant) gene action in controlling the heterosis for grain yield per plant (Paramasivan and Sreerangasamy, 1987).

This study highlights the potential of heterosis breeding for achieving higher yields and improving crop productivity. The results suggest that heterosis breeding can be an effective strategy for crop improvement programs. In this study certain cross combinations showed good heterosis in the terms of number of productive tillers per plant, spike length, the number of spikelets per spike, and the number of grains per spike. Additionally, some cross combinations had the highest economic heterosis for biological yield per plant and the harvest index. Overall, these findings provide important insights into the use of heterosis breeding to address the challenges of food security and sustainable agriculture.

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