Plant Archives Vol. 17 No. 2, 2017 pp. 851-860 ***ISSN 0972-5210***

HETEROSIS, INBREEDING DEPRESSION AND COMBINING ABILITY ANALYSIS FOR YIELD AND ITS COMPONENT TRAITS IN BARLEY (*HORDEUM VULGARE* L.)

Moti Ram*[1] and A. S. Shekawat[2]

[1]Department of Plant Breeding and Genetics, Rajasthan Agricultural Research Institute, (SKNAU, Jobner), Durgapura (Rajasthan), India.

[2]In-charge, AICRP Wheat & Barley, Rajasthan Agriculture Institute, Durgapura, Jaipur (Rajasthan), India.

Abstract

The present experiment was under taken in six rowed barley (*Hordeum vulgare* L.) to analyze heterosis, combining ability and gene action, for yield and yield contributing traits in Barley using Half diallele analysis. The Sufficient degree of heterosis and heterobeltiosis was observed for all the characters. Among top three crosses for grain yield per plant in all the environments, the crosses RD2786 x RD 2035 and RD2786 x RD2715 showed desirable heterosis and heterobeltiosis for one or more characters in all the environments (Table 3). In present experiment significant inbreeding depression was reported for different traits in all the three environments. However, BH946 x JYOTI and BH902 x RD2715 for grain yield per plant in E_2 and E_3 exhibited significant negative inbreeding depression (Table 2), i.e. a significant increase in F_2 over F_1. On the basis of *per se* performance, SCA effects, heterosis and heterobeltiosis, the cross RD2786 x RD2715 emerged as good cross for grain yield per plant in all the environments. The magnitude of general combining ability variances was higher than the specific combining ability variances for all the characters which indicated preponderance of additive gene action in the inheritance of these traits. The GCA / SCA variance ratio was less than unity indicated the importance of non-additive gene action for all the characters under investigation. On the basis of GCA effects and *per se* performance over the environments, an overall evaluation showed that the parents RD2786, RD2715 and RD 2035 in E_1, E_2 and E_3; emerged as good general combiners for grain yield with simultaneous consideration of other characters (Table 5). Therefore, these parents could be intensively used in the hybridization programme to develop lines with several desirable characters for further tangible advancement of barley yield. On the basis of SCA effects and *per se* performance, some crosses *viz*., RD2786 x RD2715 for F_1, RD2786 x BH946 for F_2 in E_1;RD 2786 x RD 2715 and RD 2786 x BH 946 for F_1 and F_2 in E_2 and in E_3 appeared as good specific cross combinations for grain yield and some associated traits (Table 6). These crosses have great potential for improvement of barley and may be utilize in multiple crossing programme.

Key words : Barley, heterosis, combining ability, inbreeding depression, diallel analysis, gene action.

Introduction

Barley (*HordiumVulgare* L. 2n = 2x = 14) is the worlds' fourth most important cereal crop after wheat, maize and rice. It is one of the widely grown *Rabi* cereals in the temperate and tropical regions of the world. It occupies fourth position in acreage and third position in terms of crop production. Today barley is grown in 49781 thousand ha. The world production of barley is about 144755 thousand tons with Europe largest of producer, due to the highest yield (Anonymous, 2014). The major barley producing countries of world are Canada, USA, Germany, France, Spain, Turkey, UK, Denmark, Russia, Central Asian States and Australia. Barley has also been very important winter cereal crop in India. In India, it is grown on more than 671 thousand ha with the production of more than 1626 thousand tonnes with productivity of 2.5 q/ha (Anonymous, 2014). Barley is an important Rabi cereal next to wheat in acreage and production in Rajasthan also. In Rajasthan, it is grown over an area about 393 thousand ha with annual production of 942 thousand tonnes with an average yield of 30.00q/ha (Ministry of Agriculture GOR, 2014). Barley cultivation in India is now becoming oriented towards industrial

****Present address:*** Technical Assistant, Krishi Vigyan Kendra, Dausa - 303 303 (Rajasthan), India. E-mail: motiram758@gmail.com

Table 1 : Name, source, pedigree, and important morpho-physiological characters of the parental materials.

S. no.	Variety	Source	Parentage	Characteristics
1.	RD 2786	RARI Durgapura	RD2634/NDB1020//K425	Timely normal sown, medium tall, high tillering capacity, resistant to yellow and brown rust, 45-50 qtl/ha yield.
2.	RD 2832	RARI Durgapura	RD2552/PL512//RD2552	Medium tall, high tillering capacity, bent ear, kernel yellowish, resistant to yellow rust.
3.	RD 2878	RARI Durgapura	RD2618/RD2620//RD2552	Dwarf in height, medium tillering capacity and dirty yellow kernel, resistant to yellow rust, 40-45 qtl/ha yield.
4.	BH 946	DWR KARNAL	BHM 522A/BH949//RD2552	Tall in height, long duration, high tillering, 45-50 qtl/ha yield.
5.	BH 902	DWR KARNAL	BH495/RD2552	Tall variety, high in tillering, long duration, 45-50 qtl/ha yield.
6.	RD 2715	RARI Durgapura	RD387/BH602//RD2035	Dual purpose variety, medium tall, resistant to yellow rust and aphid, 26-28 qtl/ha yield.
7.	RD 2035	RARI Durgapura	RD137/PL101	Medium tall, high tillering capacity, bent ear, kernels dirty yellow in colure resistant to CCN and brown rust.
8.	RD2592	RARI Durgapura	RD2035/UBL9	Medium tall, light yellow and medium hard grain, resistant to yellow rust,40-45 qtl/ha yield.
9.	PL751	DWR KARNAL	K226/PL226	Tall in height, low tillering capacity, 35-40 qtl/ha yield.
10.	JYOTI	PAU LUDHIYANA	K12/C251	Medium tall, yellow srinked hard grain, late maturity time, low tillering capacity, yellow srinked 40-45 qtl/ha yield.

utilization. Though, presently only 12-15% of total produce is being utilised for malting/brewing, but it is projected that by 2020 the demand will be more than double. Challenge to the breeders to breed varieties with high yield potential along with high malt requirement and greater stability for industrial utilisation. The improved malt genotypes with early maturing and better tillering can further bridge the yield gap and can be helpful to meet the demand of quality grain for malting purpose.

However, grain yield as well as component characters are highly influenced by environmental fluctuations thus the study based on solitary environment may not be much useful because of genotype × environment interactions.

Materials and Methods

The experiment was conducted at RARI Durgapura, Jaipur is situated at latitude of 26^0 49' north longitude of $75^0$48' east and altitude of 450 meters above sea label in Jaipur district of Rajasthan This region falls under agro climatic zone. III a (semi-arid eastern plain) of the state. Durgapura Jaipur has semi-arid type of climate with an average annual rainfall of about 400 mm, most of which received between July to early September. Weather parameters play an important role in affecting plant growth and development of crop. Ten genetically diverse parents namely RD 2786, RD 2832, RD 2878, BH 946, BH 902, RD 2715, RD 2035, RD 2592, PL 751 and JYOTI, were selected for present study. The ten parents and their resulting 45 F_1's and 45 F_2's were grown in a randomized block design with three replications under normal, late and very late sown conditions during *Rabi* 2015-2016. Each plot was consisting of 3 m long two rows for non-segregating material *i.e.* parents and F_1's and six rows in F_2's. Row to row and plant to plant distance were kept at 30 cm and 10 cm, respectively under all the three environments. Twenty competitive plants in parents and F_1's and 60 plants in F_2's progenies were selected randomly for recording observations for following characters *i.e.* spike area, spikelets per spike, number of grains per spike, 1000-grain weight, harvest index, grain yield per plant and malt percent under three environments (dates of sowing) separately.

Results and Discussion

The superiority of hybrids particularly over better parent (heterobeltiosis) is more important and useful in determining the feasibility of commercial exploitation of heterosis and also indicating the parental combinations capable of producing the highest level of transgressive segregants.

Three best heterotic and heterobeltiotic crosses for grain yield per plant are presented in table 2. Perusal of this table indicated that the crosses PL 751 × JYOTI, RD 2832 × RD 2035 and RD 2832 × RD 2715 in E_1, E_2 and E_3 emerged as good heterotic as well as heterobeltiotic crosses for grain yield per plant. Among top three crosses for grain yield per plant in all the environments, the crosses PL 751 × JYOTI, RD 2832 × RD 2035 and RD 2832 × RD 2715 showed desirable heterosis and heterobeltiosis for one or more characters in all the environments. Hence, these crosses may be considered as promising type for tangible advancement of six rowed barley yield under normal sown and thermal stress condition.

Assessment of table 3 divulged an interesting relation between heterosis and heterobeltiosis of grain yield per plant and other yield attributing traits. The parents, which, showed desirable heterosis and heterobeltiosis for grain yield per plant, also exhibited desirable heterosis and heterobeltiosis at least for one or more yield attributing traits. Such as, heterosis for grain yield per plant was mainly contributed by number of spike length, 1000 grain weight and spikelets per spike in E_1 and E_2, while heterobeltiosis by spikelets per spike, spike length, number of grains per spike and 1000 grain weight in all the three environments. Findings of this investigation supported the contentions of Grafius (1959), who suggested that there could be no separate gene system for yield *per se* as yield is an end product of the multiplicative interactions among its various contributing attributes. Thus, heterobeltiosis for various yield contributing characters might be result in the expression of heterobeltiosis for grain yield. However, the crosses showing heterotic expression for grain yield per plant were not heterotic for all the characters. It was also noted that the expression of heterosis and heterobeltiosis was influenced by the environments for almost all the characters. This was because of significant G × E interaction.

The heterotic expression normally decreases in F_2 generation as the dominance or dominance interaction effects dissipate in this generation due to reduced heterozygosity, resulting into inbreeding depression. In present experiment, significant inbreeding depression was reported for different traits in all the three environments (table 2). The crosses BH 946 × BH 902 for days to heading in E_1, plant height in E_1 and spike area in all the three environments; spike length in E_3 and harvesting index in E_2; RD 2786 × PL 751 for days to heading in E_1 and E_2 and for malt per cent in E_1; RD 2832 × RD 2878 for days to heading in E_1 and E_2; RD 2715 × JYOTI for days to heading E_2 and E_3, peduncle area E_1 and E_2, spike area E_1, number of grain per spike E_3, 1000 grain weight E_2, grain yield per plant E_2; RD 2786 × RD 2878 for days to maturity E_1, plant height E_2 and tillers per plant E_1; RD 2786 × RD 2832 for days to maturity E_1, plant height E_2 and malt per cent E_2; BH 946 × RD 2592 for days to maturity E_2 and grain yield per plant E_3; BH 946 × RD 2035 for days to maturity E_2, spike length E_2, spikelets per spike E_2 and number of grain per spike E_1 and E_2; RD 2832 × JYOTI for days to maturity E_3, tillers per plant E_1, E_2 and E_3, grain yield per plant E_1; RD 2878 × BH 946 for days to maturity E_3 and plant height E_2; RD 2786 × RD 2715 for tillers per plant E_2 and E_3 and flag leaf area E_1 and E_2; BH 946 × JYOTI for tillers per plant E_2 and E_3 and 1000 grain weight E_2; RD 2035 × JYOTI peduncle area E_3, spikelets per spike E_1 and number of grain per spike E_1; RD 2715 × RD 2035 for flag leaf area E_1 and E_2 and malt per cent E_3; RD 2715 × PL 751 for spike area E_1, E_2 and E_3, spike length E_1 and E_2 and E_3, spikelets per spike E_2 and E_3, number of grain per spike E_2, 1000 grain weight E_2 and E_3; BH 946 × BH 902 for spike length E_1 and E_3 and harvest index E_2 and E_3; BH 902 × RD 2715 for spike length E_2, spikelets per spike E_2, number of grain per spike E_2 and grain yield per plant E_1, E_2 and E_3; RD 2035 × RD 2592 number of grain per spike E_3 and malt per cent E_1, E_2 and E_3; BH 946 × PL 751 for grain yield per plant E_2 and E_3 and malt per cent E_2 and E_3 exhibited desirable (significant negative or positive) inbreeding depression in one or more environment *i.e.* a significant increase in F_2 over F_1. Such results were also reported for different crosses and characters. Similar findings were also reported by Ved Prakash (2003).

The negative inbreeding depression may result from the advantage of population buffering, which may occur in F_2 generation due to the segregation of genes or sometimes because of formation of superior gene combinations, such a situation is valuable in conventional breeding programme.

The significant mean square due to GCA and SCA in all the three environments indicated that all the characters were controlled by both additive and non-additive gene effects (table 4). Kakani *et al*. (2007), Singh *et al*. (2007), Bornare *et al*. (2013), Patial (2016) also obtained similar results in barley having influence of both additive and non-additive gene effect for the characters used in their study. This might be possible due to the parental line involved in the present investigation possessed high selection history for these traits. However the GCA/SCA ratio being less than unity for days to heading, days to maturity, plant height, tillers per plant, flag leaf area, peduncle area, spike length, spike area, number of spiklets per spike, number of grain per spike,

Table 2 : Top three of estimates of heterosis, heterobeltiosis and inbreeding depression in individual environments for different characters.

Characters	Env.	Heterosis	Heterobeltiosis	Inbreeding depression
Days to heading	E_1	RD2035xRD2592	RD2035xRD2592	BH946xBH902
		RD2832xRD2715	RD2832xRD2035	RD2786xPL751
		RD2832xRD2035	PL751xJYOTI	RD2832xRD2878
	E_2	RD2035xRD2592	RD2035xJYOTI	RD2715xJYOTI
		RD2832xRD2592	RD2832xRD2592	RD2878xBH946
		RD2832xRD2035	RD2832xRD2035	RD2832xRD2878
	E_3	RD2832xRD2592	RD2832xRD2592	RD2786xPL751
		PL751xJYOTI	RD2035xJYOTI	RD2878xBH946
		PL751xRD2592	RD2786xRD2878	RD2715xJYOTI
Days to maturity	E_1	RD2786xRD2035	RD2786xRD2878	RD2786xRD2878
		RD2786xRD2878	RD2786xRD2832	RD2786xRD2832
		RD2786xRD2832	RD2786xRD2035	RD2786xRD2832
	E_2	RD2878xRD2715	RD2786xRD2878	RD2878xRD2592
		RD2786xRD2035	RD2715xRD2035	BH946xRD2592
		RD2715xRD2035	RD2786xRD2832	BH946xRD2035
	E_3	RD2786xRD2832	RD2786xRD2832	RD2832xJYOTI
		RD2786xBH946	RD2786xBH946	RD2878xBH946
		RD2786xRD2878	RD2786xRD2878	RD2832xPL751
Plant height (cm)	E_1	RD2832xPL751	RD2832xJYOTI	RD2878xJYOTI
		RD2832xJYOTI	RD2832xPL751	BH946xBH902
		RD2786xRD2035	RD2786xPL751	RD2786xRD2035
	E_2	RD2832xJYOTI	RD2832xJYOTI	RD2786xRD2878
		RD2832xPL751	RD2786xRD2592	RD2786xRD2832
		RD2786xRD2715	RD2832xBH946	RD2878xBH946
	E_3	RD2832xJYOTI	RD2832xJYOTI	RD2786xBH946
		RD2832xPL751	RD2832xPL751	RD2786xRD2832
		RD2786xRD2715	RD2832xBH902	RD2832xBH902
Tillers per plant	E_1	RD2786xRD2715	RD2786xRD2715	RD2832xJYOTI
		PL751xJYOTI	PL751xJYOTI	RD2786xRD2878
		RD2832xRD2878	RD2832xRD2878	RD2786xRD2715
	E_2	RD2786xRD2715	RD2786xRD2715	RD2786xRD2715
		RD2832xRD2878	RD2832xRD2878	RD2832xJYOTI
		RD2786xBH902	PL751xJYOTI	BH946xJYOTI
	E_3	RD2786xRD2715	RD2832xRD2878	RD2832xJYOTI
		RD2832xRD2878	PL751xJYOTI	BH946xJYOTI
		PL751xJYOTI	RD2786xRD2715	RD2786xRD2715

Table 2 continued....

Table 2 continued....

Peduncle area (cm^2)	E_1	RD2786xRD2832	RD2786xRD2832	RD2878xRD2715
		RD2786xBH946	RD2786xBH946	RD2715xJYOTI
		RD2832xJYOTI	RD2832xJYOTI	RD2832xPL751
	E_2	RD2786xRD2832	RD2786xRD2832	RD2878xRD2715
		RD2786xBH946	RD2786xBH946	RD2715xJYOTI
		RD2832xJYOTI	RD2832xJYOTI	RD2832xPL751
	E_3	RD2786xRD2832	RD2786xRD2832	RD2035xJYOTI
		RD2786xBH946	RD2786xBH946	RD2592xPL751
		RD2786xRD2715	RD2786xRD2715	RD2715xRD2035
Flag leaf area (cm^2)	E_1	BH902xRD2715	BH902xRD2715	RD2715xRD2592
		RD2592xJYOTI	BH902xRD2715	RD2715xRD2035
		RD2878xRD2715	RD2786xRD2715	RD2786xRD2715
	E_2	RD2715xRD2035	BH902xRD2715	RD2715xRD2592
		RD2715xPL751	RD2715xRD2035	RD2786xRD2715
		RD2786xRD2715	BH902xRD2035	RD2715xRD2035
	E_3	RD2715xRD2035	RD2715xRD2035	RD2832xRD2035
		RD2878xRD2035	BH902xRD2035	RD2715xRD2592
		RD2786xRD2035	BH902xRD2715	RD2786xRD2035
Spike area (cm^2)	E_1	RD2878xRD2715	RD2832xRD2715	BH946xBH902
		RD2832xRD2878	RD2878xRD2715	RD2715xJYOTI
		RD2878xRD2035	RD2786xRD2715	RD2715xPL751
	E_2	RD2832xRD2878	RD2832xRD2878	BH946xBH902
		RD2878xRD2035	RD2786xRD2832	RD2715xPL751
		RD2878xRD2715	RD2832xRD2715	RD2878xPL751
	E_3	RD2832xRD2878	RD2832xRD2878	BH946xBH902
		RD2878xRD2035	RD2786xRD2832	RD2715xPL751
		RD2878xRD2715	RD2832xRD2878	RD2878xPL751
Spike length (cm)	E_1	PL751xJYOTI	PL751xJYOTI	BH946xBH902
		RD2786xRD2715	RD2786xRD2715	RD2715xPL751
		RD2786xRD2035	RD2786xRD2035	RD2715xJYOTI
	E_2	PL751xJYOTI	PL751xJYOTI	BH946xRD2035
		RD2786xRD2715	RD2786xRD2715	BH902xRD2715
		RD2786xRD2035	RD2786xRD2035	RD2715xPL751
	E_3	RD2786xRD2715	RD2786xRD2715	BH946xBH902
		RD2786xRD2035	RD2786xRD2035	RD2715xPL751
		PL751xJYOTI	PL751xJYOTI	RD2878xPL751
Spikelet’s per spike	E_1	RD2592xPL751	RD2592xPL751	BH946xRD2035
		RD2786xRD2715	RD2786xRD2715	BH902xRD2715
		RD2035xRD2592	RD2786xRD2035	RD2035xJYOTI

Table 2 continued....

Table 2 continued....

	E_2	RD2592xPL751	RD2592xPL751	BH946xRD2035
		RD2786xRD2715	RD2786xRD2715	BH902xRD2715
		RD2832xRD2592	RD2786xRD2035	RD2715xPL751
	E_3	RD2592xPL751	RD2592xPL751	RD2715xPL751
		RD2786xRD2715	RD2786xRD2715	BH902xRD2592
		RD2832xRD2592	RD2786xRD2035	RD2715xJYOTI
Number of grain/spike	E_1	RD2592xPL751	RD2592xPL751	BH946xRD2035
		RD2786xRD2715	RD2786xRD2715	BH902xRD2715
		RD2035xRD2592	RD2786xRD2035	RD2035xJYOTI
	E_2	RD2592xPL751	RD2592xPL751	BH946xRD2035
		D2786xRD2715	RD2786xRD2715	BH902xRD2715
		RD2832xRD2592	RD2786xRD2035	RD2715x PL751
	E_3	RD2592xPL751	RD2592xPL751	RD2035xRD2592
		D2786xRD2715	RD2786xRD2715	BH902x RD2592
		RD2832xRD2592	RD2786xRD2035	RD2715 xJYOTI
1000 grain weight (g)	E_1	PL751 xJYOTI	RD2715 xRD2035	RD2592xJYOTI
		RD2786xRD2035	RD2786xRD2715	BH946x PL751
		RD2715 xRD2035	RD2786xRD2035	RD2715 xJYOTI
	E_2	PL751 xJYOTI	PL751 xJYOTI	RD2715 xPL751
		BH946x PL751	BH946x PL751	BH946xJYOTI
		RD2786xRD2035	RD2786xRD2035	RD2715 xJYOTI
	E_3	PL751 xJYOTI	PL751 xJYOTI	BH946x PL751
		RD2832xRD2592	RD2786xRD2715	RD2715 xPL751
		RD2786xRD2035	RD2832xRD2592	BH902xJYOTI
Harvesting index (%)	E_1	RD2786xRD2832	RD2786xRD2832	RD2832xBH902
		RD2786xRD2878	RD2786xRD2878	RD2878xPL751
		PL751 xJYOTI	RD2786xRD2715	RD2786xJYOTI
	E_2	RD2786xRD2832	RD2786xRD2832	RD2832xBH902
		RD2786xRD2878	RD2786xRD2878	BH946xBH902
		PL751 xJYOTI	PL751 xJYOTI	RD2878xPL751
	E_3	RD2786xRD2832	RD2832xRD2715	BH946xBH902
		RD2786xRD2832	RD2786xRD2832	RD2832xBH902
		RD2786xRD2035	RD2786xRD2878	RD2878xPL751
Grain yield(g)	E_1	PL751xJYOTI	PL751xJYOTI	BH902xRD2715
		RD2832xRD2035	RD2786xRD2715	RD2786xJYOTI
		RD2832xRD2715	RD2786xRD2035	RD2832xJYOTI
	E_2	PL751xJYOTI	PL751xJYOTI	BH946xPL751
		RD2832xRD2035	RD2786xRD2715	RD2715xJYOTI
		RD2786xRD2715	RD2786xRD2035	BH902xRD2715

Table 2 continued....

Table 2 continued....

	E_3	PL751xJYOTI	PL751xJYOTI	BH946xRD2592
		RD2832xRD2035	RD2786xRD2715	BH902xRD2715
		RD2832xRD2715	RD2786xRD2035	BH946xPL751
Malt percent	E_1	RD2832xRD2715	RD2786xRD2715	RD2035xRD2592
		RD2786xRD2878	RD2715xRD2592	RD2786xPL751
		RD2715xRD2592	RD2786xRD2035	RD2786xJYOTI
	E_2	RD2832xRD2715	RD2786xRD2715	RD2035xRD2592
		RD2786xRD2878	RD2715xRD2592	BH946xPL751
		RD2786xRD2715	RD2786xRD2035	RD2786xRD2832
	E_3	RD2832xRD2715	RD2786xRD2715	RD2035xRD2592
		RD2786xRD2878	RD2786xRD2035	BH946xPL751
		RD2832xRD2592	RD2715xRD2592	RD2715xRD2035

Table 3 : Crosses possessing with high heterosis and heterobeltiosis for grain yield per plant (g) along with desirable (+) heterotic expression for other characters in different environments.

Particulars	Environments	Crosses	Days to heading	Days to maturity	Plant height (cm)	Tillers per plant	Peduncle area (cm^2)	Flag leaf area (cm^2)	Spike area (cm^2)	Spike length (cm)	Number of spike lets per spike	Number of grains per spike	1000 grains weight (g)	Harvest index(%)	Malt Percent
Heterosis	E2	**RD2786xRD2715**	-	-	+	+	-	-	-	+	+	+	-	-	+
		RD2786xRD2035	-	+	-	-	-	-	-	+	-	-	+	-	-
	E3	**RD2786xRD2715**	-	-	+	+	+	+	-	+	+	+	-	-	-
		RD2786xRD2035	-	-	-	-	-	-	-	+	-	-	+	+	-
Heterobeltiosis	E1	**RD2786xRD2715**	-	-	-	+	-	+	+	+	+	+	+	+	+
		RD2786xRD2035	-	+	-	-	-	-	-	+	+	+	+	-	+
	E2	**RD2786xRD2715**	-	-	-	+	-	-	-	+	+	+	-	-	+
		RD2786xRD2035	-	-	-	-	-	-	-	+	+	+	+	-	+
	E3	**RD2786xRD2715**	-	-	-	+	+	-	-	+	+	+	+	-	+
		RD2786xRD2035	-	-	-	-	-	-	-	+	+	+	-	-	+
	F_1	**RD2786xRD2715**	-	-	+	+	-	-	-	+	+	+	-	-	+
	F_2	**RD2786xRD2035**	-	+	-	-	-	-	-	+	-	-	+	-	-

Table 4 : Analysis of variance showing mean squares in individual environment for parents, F_1's and F_2's for combining ability in individual environment for different characters.

S. no.	Characters	Sources	GCA (df=9)	SCA (df=45)	Error (df=110)	GCA/ SCA	GCA (df=9)	SCA (df=45)	Error (df=110)	GCA/ SCA
		Env/ generation	F_1				F_2			
1	Days to heading	E_1	17.57**	14.29**	0.85	0.10	12.05**	13.77**	0.90	0.072
		E_2	15.42**	13.37**	0.80	0.096	8.24**	19.33**	0.56	0.078

Table 4 continued....

Table 4 continued...

		E_3	6.69**	6.98**	0.67	0.079	7.73**	10.80**	0.66	0.058
2	Days to Maturity	E_1	105.80**	40.10**	1.46	0.225	119.39**	76.47**	1.19	0.131
		E_2	75.79**	38.55**	0.66	0.165	48.33**	44.90**	1.00	0.089
		E_3	20.63**	9.90**	0.80	0.182	15.58**	7.01**	0.46	0.192
3	Plant height(cm)	E_1	85.94**	24.95**	0.32	0.290	84.58**	25.51**	0.43	0.280
		E_2	87.19**	22.94**	0.19	0.319	91.30**	24.36**	0.30	0.315
		E_3	83.29**	22.23**	1.00	0.323	90.98**	21.68**	1.06	0.363
4	Tillers per plant	E_1	35.07**	3.63**	0.33	0.878	24.20**	3.42**	0.47	0.671
		E_2	31.57**	4.17**	0.30	0.674	23.48**	3.56**	0.49	0.625
		E_3	32.26**	3.28**	0.34	0.906	24.34**	3.18**	0.48	0.735
5	Flag leaf area(cm^2)	E_1	89.47**	49.94**	0.45	0.403	61.78**	49.54**	0.51	0.255
		E_2	62.13**	49.39**	0.47	0.312	109.71**	53.43**	0.56	0.199
		E_3	92.37**	49.42**	0.47	0.307	69.63**	49.77**	0.54	0.280
6	Peduncle area(cm^2)	E_1	42.06**	25.15**	0.08	0.121	42.94**	24.46**	0.09	0.167
		E_2	38.51**	26.60**	0.08	0.121	48.54**	24.28**	0.09	0.167
		E_3	40.39**	26.31**	0.06	0.128	39.91**	24.75**	0.17	0.135
8	Spike area (cm^2)	E_1	6.28**	1.27**	0.18	0.465	6.91**	1.07**	0.15	0.612
		E_2	6.67**	1.48**	0.18	0.414	6.67**	1.48**	0.15	0.615
		E_3	6.32**	1.47**	0.17	0.394	6.38**	1.10**	0.15	0.546
9	Number of spike lets per spike	El	115.31**	21.12**	0.46	0.472	96.65**	15.35**	0.87	0.551
		E_2	113.34**	21.81**	0.68	0.444	95.73**	15.15**	0.76	0.549
		E_3	127.20**	24.29**	0.77	0.447	104.95**	16.83**	0.80	0.541
10	Number of grain per spike	El	11.39**	3.00**	0.30	0.342	11.89**	3.05**	0.42	0.363
		E_2	12.24**	3.04**	0.40	0.374	12.01**	3.04**	0.43	0.370
		E_3	13.34**	2.85**	0.34	0.432	11.14**	2.13**	0.33	0.501
11	1000-grain weight (g)	E_1	410.00**	107.87**	10.67	0.342	428.06**	109.78**	15.04	0.363
		E_2	440.80**	109.58**	14.45	0.374	432.36**	109.55**	15.66	0.370
		E_3	480.28**	102.43**	12.11	0.432	401.12**	76.64**	11.84	0.501
12	Harvest index (%)	E_1	153.66**	27.04**	1.05	0.489	66.51**	16.56**	0.98	0.350
		E_2	165.08**	27.57**	1.08	0.516	91.75**	20.38**	1.02	0.390
		E_3	189.08**	29.97**	0.95	0.540	160.69**	56.81**	1.04	0.239
13	Grain yield per plant (g)	E_1	72.64**	29.36**	2.14	0.215	34.43**	11.61**	2.95	0.302
		E_2	71.70**	32.02**	2.09	0.193	31.14**	14.81**	3.61	0.204
		E_3	86.00**	38.11**	2.04	0.193	49.02**	17.19**	2.27	0.261
14	Malt per cent	E_1	288.04**	84.39**	0.84	0.286	317.50**	83.31**	0.71	0.319
		E_2	323.61**	87.72**	0.58	0.308	339.58**	82.44**	0.59	0.345
		E_3	334.65**	89.85**	0.22	0.310	371.50**	92.30**	0.37	0.336

Table 5 : Best parents possessing high GCA effects along with their per performance for grain yield per plant and significant desirable (+) GCA effects for other characters in different environments in F_1's and F_2's.

Environments	Generation which exhibited high GCA	Best parents based on desirable GCA effects and per se performance for grain yield per plant	Day to heading	Days to maturity	Plant height (cm)	Tillers per plant	Peduncle area (cm^2)	Flag leaf area (cm^2)	Spike area (cm^2)	Spike length (cm)	No. of spikelets per spike	No. of grains per spike	1000 grain weight (g)	Harvest index (%)	Malt percent
E_1	F_1	RD2786	-	-	-	+	-	-	-	-	+	+	+	+	+
	F_2	RD2786	-	-	-	+	-	-	-	-	+	+	+	+	+
	F_1	RD2715	-	+	-	+	-	-	+	-	+	+	+	+	-
	F_2	RD2715	+	-	-	+	-	-	+	+	+	+	+	+	-
	F_1	RD2035	-	-	+	+	-	-	+	+	+	+	+	+	+
	F_2	RD2035	-	-	+	+	-	-	+	+	+	+	+	+	+
E_2	F_1	RD2786	-	-	-	+	-	-	-	-	+	+	+	+	+
	F_2	RD2786	-	+	-	+	-	-	-	-	+	+	+	+	+
	F_1	RD2715	-	-	-	+	-	-	+	+	+	+	+	+	+
	F_2	RD2715	-	-	-	+	-	-	+	+	+	+	+	+	+
	F_1	RD2035	-	-	+	+	-	-	+	+	+	+	+	+	-
	F_2	RD2035	-	-	+	+	-	-	+	+	+	+	+	+	+
E_3	F_1	RD2786	-	-	-	+	-	-	-	+	+	+	+	+	+
	F_2	RD2786	-	+	-	+	-	-	-	+	+	+	+	+	-
	F_1	RD2715	-	+	-	+	-	-	+	+	+	+	+	+	-
	F_2	RD2715	-	-	-	+	-	-	+	+	+	+	+	+	-
	F_1	RD2035	-	+	+	+	-	-	+	+	+	+	+	+	-
	F_2	RD2035	-	+	+	+	-	-	+	+	+	+	+	+	+

Table 6 : Best crosses possessing high SCA effects along with their per se performance for grain yield per plant and significant desirable (+) SCA effects for other characters in different environments in F_1's and F_2's.

Environments	Generation which exhibited high GCA	Best crosses based on desirable GCA effects and per se performance for grain yield per plant	Day to heading	Days to maturity	Plant height (cm)	Tillers per plant	Peduncle area (cm^2)	Flag leaf area (cm^2)	Spike area (cm^2)	Spike length (cm)	No. of spikelets per spike	No. of grains per spike	1000 grain weight (g)	Harvest index(%)	Malt percent
E_1	F_1	RD2786xRD2715	-	-	-	+	-	-	-	+	+	+	-	-	-
E_2	F_2	RD2786xBH946	-	-	-	+	-	-	-	-	-	-	-	-	-
	F_1	RD2786xBH946	-	-	-	+	-	-	-	+	+	+	-	-	-

Table 4 continued...

Table 4 continued...

	F_2	RD2786xBH946	-	-	-	+	-	-	-	+	-	-	-	-	-
	F_1	RD2786XRD2715	-	-	-	+	-	-	-	+	+	+	-	-	-
	F_2	RD2786xRD2715	-	-	-	+	-	-	-	-	+	+	-	-	-
E_3	F_1	RD2786xBH946	-	-	-	-	-	-	-	+	+	+	-	-	-
	F_2	RD2786xBH946	-	-	-	+	-	-	-	-	-	-	-	-	-
	F_1	RD2786xRD2715	-	-	-	+	-	-	—	+	+	+	-	-	-
	F_2	RD2786xRD2715	-	-	-	+	-	-	-	-	+	+	-	-	-

1000 grain weight, harvest index and grain yield per plant and malt per cent exhibited preponderance of non-additive gene actions in all the three environments. These results are the supported with Chaudhary *et al*. (1974), Madic (1996), El-seidy (1997a and b). It is thus evident that both additive and non-additive gene effects controlled different characters including grain yield and associate characters. Nature and magnitude of combining ability effects provide an idea of about the relative role of fixable and non-fixable gene effects in the inheritance of different characters. Thus, in turn, helps in identifying suitable parents for crossing programme.

References

Anonymous (2014). *AICWB improvement annual project report, 2014*. AICWB project, RARI, Durgapura, Jaipur (Rajasthan).

Bornara, S. S., L. C. Prasad, J. P. Lal and Jaswant Singh (2013). Heterosis and combining ability for yield and its contributary traits in crosses of two row and six row barley under rain fed environment. *Crop Imp*., **40(1)** : 81-86.

Choudhary, B. D., R. K. Singh and S. N. Kakar (1974). Estimation of genetic parameters in barley (*Hordeum vulgare* L.). *Theoritical and applied Genetics*, **45 (5)** : 192-196.

El-Seidy, E. S. H. (1997a). Inheritance of earlyness and yield in some barley crosses. *Annals of Agril. Sci*., Moshtohor. **35(2)** : 715-730.

El-Seidy, E. S. H. (1997b). Inheritance of Plant height, grain yield and components in three barley crosses (*Hordeum vulgare* L.). *Annals of Agril. Sci*., Moshtohor. **35(1)** : 63-76.

Grafius, J. E. (1959). Heterosis in barley. *Agron. J*., **51(9)** : 551-554.

Kakani, R. K., Yogendra Sharma and S. N. Sharma (2007). Combining ability analysis in barley (*Hordium vulgare* L.). *SABRAO Journal of Breeding and Genetics*, **39(2)** : 17-126.

Madic, M. (1996). Inheritance of spike traits and grain yield in barley (*Hordeum vulgare* L.) hybrids. *Review of research work at the faculty of Agri. Belgrade*. **41(1)** : 53-65.

Patial, M., D. Pal and J. Kumar (2016). Combining ability and gene action studies for grain yield and its component traits in barley (*Hordeum vulgare* L.). *SABRAO J. Breed. Genet*., **48(1)** : 90-96.

Singh, H., S. N. Sharma, R. S. Sain and D. L. Singhania (2003). The inheritance of production traits in bread wheat by diallel analysis. *SABRAO J. Br. Genet*., **35** : 1-9.

Prakash, Ved and P. Joshi (2003). Genetics of metric traits in spring wheat under normal and late sown environments. *Crop Improv*., **30** : 177-187.