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Estimation of Heterosis in Wheat (*Triticum aestivum* L.) under Contrasting Water Regimes

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ABSTRACT

Manipulation of heterosis is considered to be a vital approach to enhance the yield potential of wheat and is as accepted to be a safe strategy to overcome barriers in wheat yield. Twelve diverse Pakistani wheat genotypes were crossed to obtain a series of crosses to estimate the level of heterosis and heterobeltiosis among F_1 hybrids along with their parents under two contrasting environments: normal irrigation and water stress (withholding 50% water). Estimates revealed a significant relationship between the mean performance of F_1 hybrids and their parents under water stress regime only. The presence of significant heterosis for grain yield was also accompanied by heterosis for yield components, particularly length-based traits such as plant height, peduncle length and spike length. The cross Pasban-90 × Sehar-06 was an elite cultivar and showed significant heterobeltiosis. The study suggests that the obtained hybrids surpassed their better parents' effects, indicative of commercial heterosis, and are thus candidates for the commercial production of hybrid wheat.

Keywords: climate, commercial production, elite, heterosis, heterobeltiosis

INTRODUCTION

Wheat has always been considered to be a staple food, particularly in Pakistan, as it is a cheap source of nutrition. Over the years, yield has made significant gains around the world. Rauf *et al.* (2011) noted 248% gains in yield in the top 10 wheat-producing countries over the past 48 years while in Pakistan yield increased by 198%. It is widely considered that wheat yield potential has now reached a plateau and therefore will result in low gains despite significant efforts to increase yield through transgressive breeding and selection. In recent years, wheat production has largely been improved through manipulation of resistance against biotic and abiotic stresses and improved crop management strategies (Noorka and Afzal 2009; Noorka and Haidry 2011).

Manipulation of heterosis is an important strategy for increasing the yield potential of wheat (Rauf *et al.* 2012). Studies have shown that the exploitation of heterosis has the potential to overcome the yield plateau in wheat. Heterosis is the increase or decrease in vigour of hybrids when compared with that of its parents (Sharif *et al.* 2001). Exploitation of heterotic effects is mainly accredited to cross-pollinated crops but now-a-days the incidence is common in self-pollinated crops such as wheat (Singh *et al*. 2004; Akbar *et al*. 2010; Kumar *et al*. 2011), providing an option for commercially utilizing wheat (Matuschke *et al*. 2007). The magnitude of heterosis varies depending on the choice of parents and local conditions. However, wheat hybrids yielded 13.5% more than their parents (Rauf *et al*. 2011a) due to hybrid stability, responsiveness to farm input (Bruns and Peterson 1998; Matuschke *et al*. 2007) and better tolerance to abiotic stress (Bruns and Peterson 1998). Some benefits have also been noted in terms of the yield and quality of wheat hybrids. In India, hybrid wheat was planted over 60,000 acres in various parts of the country and yielded 351 kg/acre more than traditional obtained potential (OP) cultivars while in China, 10 hybrid wheat cultivars have been commercialized following an increase in yield of 20% (Matuschke *et al*. 2007; Sun *et al*. 2008). Furthermore, wheat hybrids would out-yield pure line varieties under abiotic stresses (Bruns and Peterson 1998). Water stress is considered to be the prime factor restricting wheat yield and the level of severity depends on the critical stage (Chowdhry *et al.* 1999; Noorka *et al.* 2009). However, data regarding the exploitation of heterosis under water stress is limited and requires confirmation (Ahmed *et al*. 2007).

This study was conducted to ascertain heterotic effects using various biometric tools and to search promising combinations among a number of wheat genotypes under cultivation to ascertain future breeding programmes to boost yield. Our objectives were to estimate the level of heterosis and heterobeltiosis for different quantitative traits among F_1 hybrids and their parents under two contrasting conditions (normal irrigation and water stress), and to estimate the relationship between F_1 hybrids and their parents.

MATERIALS AND METHODS

The study was conducted in an experimental area of the University College of Agriculture, University of Sargodha during the 2009-2011 crop seasons. Twelve wheat genotypes were selected due to their high genetic distance, namely 'Sehar-06', 'Pasban-90', 'C-273', 'Pari-73', 'SA-42', 'Fsd-08', 'Chenab-70', 'Blue Silver', 'Lasani-08', 'Pak-81', 'Uqab-2000', and 'Pothowar-73'. The genotypes were sown during the 15^{th} of October, 2010 under normal field conditions. There was a single line per genotype, sown with a hand drill. Plants were raised according to a production package adopted in the province of Punjab, Pakistan. Weeds were controlled with recommended herbicides while insect and diseases were considered to be absent. At the flowering stage (110 days after sowing (DAS)) the crosses were made by hand emasculation of anthers, bagging the spikes of the female lines and subsequent fertilization with the pollen from male breeding lines. During 2010, seed was collected from 10 randomly selected plants of all the derived crosses, together with that of their parents and kept in separate bags to avoid mixing seeds. Three seeds were sown in the next cropping season (2010-2011) in three pots with three replica-

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tions under two contrasting water regimes (Chowdhry *et al*. 1999). Pots in the non-stressed regime were irrigated to maintain the moisture content close to field capacity (17% moisture content, w/w) while water stress in the stress regime was created by cutting the amount of irrigation by half relative to the non-stress regime during the reproductive phase (80 DAS).

Measurement of yield and yield components

At the maturity stage (163 DAS), the following traits were recorded in 2011 within the replications and treatments for selected plants: plant height (PH), peduncle length (PL), spike length (SL) in cm, number of spikelets/spike (NSS), number of productive tillers/plant (NPTP) were counted manually. A productive tiller was considered as one bearing an intact spike. PH was assessed from the main tiller of selected plants. Measurements were made from the base of plants to the tip of the spike, excluding awns. Similarly, the length of the main spike of the mother shoot was measured in cm at maturity from the base to the tip of the spike, excluding awns. To assess grain yield/plant (GYP; g), each selected plant was harvested manually, threshed and grains obtained were kept in separate bags which were labeled to avoid mixing of grains of different plants. Grains were weighed with an electronic balance.

Biometrical procedures

1. Analysis of variance

To estimate significant differences among parents and hybrids, data was subjected to statistical analysis by using analysis of variance (ANOVA) in a completely randomized design with two factors i.e., genotypes and water regimes (Steel *et al.* 1997). Significant differences between means were further assessed using least significant difference (LSD) at $P < 0.05$.

2. Estimation of heterosis

The percentage increase or decrease of F_1 hybrids over mid parents as well as better parent value was calculated to estimate possible heterotic effects for the above-mentioned parameters by following the equation of Fonseca and Patterson (1968).

Heterosis% = $(F_1\text{-MP}/F_1\text{-MP})*100$

where F_1 = mean performance of the F_1 hybrid; MP = mid-parent value.

MP = (P1+P2)/2

where P_1 = Parent 1 and P_2 = Parent 2.

3. Potency ratio

The potency ratio (PR) was calculated according to Griffing (1950):

$$\frac{F1-MP}{BP-MP}$$

where BP = is better parent value.

RESULTS

Significant differences were noted among genotypes, including parents and crosses ($P \leq 0.01$) for all traits, except for NPTP which showed non-significant differences for parents (**Table 1**). The differences between parents and crosses were significant ($P \geq 0.05$) for PH, PL and SL while non-significant differences were observed for GY, NSS and NPTP (**Table 1**). Similarly, highly significant differences were found between water regimes ($P \leq 0.01$) and between the interaction of genotypes with water regimes and their components. The genotype × water regime interaction was not significant for NPTP and NSS (**Table 1**).

Average mean performance of parents and hybrids

On average, parents showed a 22, 44, 23, 28 and 76% decrease for PH, NPTP, SL, NSS and GYP, respectively while hybrids showed a 21, 13, 31, 17 and 68% decrease for the same traits under water stress (**Table 2**). The increase in GYP by developing hybrids was 21 and 42% less than the normal and water stress treatments, respectively (**Table 2**). For PL, the parents showed a 33% increase over hybrids under normal irrigation while hybrids showed a 13% decrease under water stress. The highest range of heterosis (4.81 to 56.76 and -15.15 to 246.67) was manifested in GYP under normal and water stress treatments, respectively relative to other yield components (**Table 2**).

Table 1 Analyses of variance for various traits i.e. plant height (PH), peduncle length (PL), number of productive tillers/plant (NPTP), spike length (SL), number of spikelets/spike (NSS), grain yield/plant (GYP).

S.O.V.	d.f.	Mean sum of squares					
		PH	PL	NPTP	SL	NSS	GYP
Genotypes (G)	27	155.15**	18.60**	0.73*	4.18**	13.59**	0.10**
Parents (P)	11	141.32**	17.82**	0.59 NS	1.53**	19.38*	0.11**
Crosses (Cr)	15	127.65**	19.37**	0.82*	4.94**	9.79*	0.09**
P vs. Cr	1	719.65**	15.47**	1.10 NS	21.88**	7.02 NS	0.04 NS
Water Regimes (W)	1	5170.38**	814.00**	51.48**	256.29**	192.86**	17.53**
G × W	27	43.33*	6.98*	0.37 NS	2.28**	3.29 NS	0.11**
P × W	11	43.03*	4.89*	0.36 NS	1.80**	3.89 NS	0.09**
Cr × W	15	46.42*	8.85*	0.34 NS	2.24**	3.01 NS	0.13**
P vs. Cr × W	1	0.21 NS	1.85 NS	0.92 NS	8.25**	0.83 NS	0.08*
Error	112	22.83	2.43	0.32	0.99	2.83	0.02

Table 2 Mean parental and hybrid performance under normal irrigation and water stressed conditions.

Traits	Parent		Hybrid		Heterosis range	
	Normal	Water stress	Normal	Water stress	Normal	Water stress
Plant height (PH)	47.99	37.42	53.66	42.42	3.27-6.89	0.27-29.03
Peduncle length (PL)	9.78	14.63	11.19	9.78	-5.19-30.10	2.49-34.31
Number of productive tillers per plant (NPTP)	1.89	1.05	2.13	1.85	-33.24-39.94	-
Spike length (SL)	8.05	6.21	9.26	6.39	-13.09-37.5	-13.11-24.02
No. of spikelets per spike (NSS)	9.09	6.54	12.13	10.05	-2.4-27.22	-
Grain yield per plant (GYP)	0.88	0.21	1.11	0.36	4.81-56.76	-15.15-246.67

Least significant differences among the mean value of parents and hybrids ± 2.72

Individual mean performance of parents and crosses for grain yield

The individual comparisons of means (**Table 3**) revealed that the parent ‘Pothowar-73’ had the highest value for GYP while ‘Lasani-08’ has the lowest mean value under normal conditions. Among the F_1 hybrids, the cross ‘Pak-81’ × ‘Pasban-90’ showed the highest mean GYP value whereas under water stress condition ‘Pak-81’ showed the highest mean GYP value. Among the F_1 hybrids, cross ‘SA-42’ × ‘Fsd-08’ has the highest GYP value and ‘Pasban-90’ × ‘Sehar-06’ and ‘Fsd-08’ × ‘SA-42’ has lowest mean value under water stress.

Heterosis, heterobeltiosis and potency ratio for grain yield

Nine crosses showed a significantly higher ($P \leq 0.05$) value in PR than their respective mid-parents (**Table 4**) under normal conditions. Heterosis ranged from 26.21% (‘Pak-81’ × ‘Pasban-90’) to 56.76% (‘Pak-81’ × ‘Lasani-08’). Regarding heterosis over better parents, three crosses showed an increase over the better parent. The range of positive heterobeltiosis ranged from 25% (‘Pak-81’ × ‘Pasban-90’) to 44.12% (‘SA-42’ × ‘Fsd-08’). The PR for GYP (**Table 4**) showed that hybrids’ heterosis was generally due to over dominance. The PR ranged from 0.33 (‘Pari-73’ × ‘C-273’) to 31.00 (‘SA-42’ × ‘Fsd-08’). The magnitude of PR ratio determines the type of dominance. A PR ratio greater than unity is interpreted as overdominance and the condition for

Table 3 Mean performance of parental lines and hybrids under contrasting water regimes for grain yield.

Crosses	Normal Maternal	Water stress Maternal	Normal Paternal	Water stress Paternal	Normal F_1	Water stress F_1
Sehar-06 × Pasban-90	0.91	0.47	1.04	0.11	1.03	0.51
Pasban-90 × Sehar-06	1.04	0.11	0.91	0.47	1.08	0.62
C-273 × Pari-73	1.20	0.21	0.87	0.15	1.12	0.34
Pari-73 × C-273	0.87	0.15	1.20	0.21	1.09	0.32
SA-42 × Fsd-08	0.66	0.09	0.68	0.13	0.98	0.23
Fsd-08 × SA-42	0.68	0.13	0.66	0.09	0.94	0.17
Fsd-08 × Chenab-70	0.68	0.13	1.10	0.17	1.23	0.29
Chenab-70 × Fsd-08	1.10	0.17	0.68	0.13	1.17	0.52
Sehar-06 × Blue Silver	0.91	0.47	0.70	0.18	0.98	0.59
Blue Silver × Sehar-06	0.70	0.18	0.91	0.47	1.02	0.28
Lasani-08 × Pak-81	0.47	0.15	1.01	0.28	1.07	0.33
Pak-81 × Lasani-08	1.01	0.28	0.47	0.15	1.16	0.29
Uqab-2000 × Pothowar-73	0.58	0.20	1.24	0.18	1.19	0.24
Pothowar-73 × Uqab-2000	1.24	0.18	0.58	0.20	1.31	0.30
Pasban-90 × Pak-81	1.04	0.11	1.01	0.28	1.14	0.31
Pak-81 × Pasban-90	1.01	0.28	1.04	0.11	1.30	0.39

Table 4 Estimation of percent heterosis and heterobeltiosis and potency ratio for grain yield per plant (g) in wheat.

Crosses	Heterosis		Heterobeltiosis		Potency ratio	
	Normal	Water stress	Normal	Water stress	Normal	Water stress
Sehar-06 × Pasban-90	5.10 NS	75.86*	-0.96 NS	8.51 NS	0.85	1.22
Pasban-90 × Sehar-06	10.20 NS	113.79*	3.85 NS	31.91*	1.62	1.83
C-273 × Pari-73	7.69 NS	88.89*	-6.67 NS	61.90 NS	0.52	5.33
Pari-73 × C-273	4.81 NS	77.77*	-9.17 NS	52.38 NS	0.33	4.56
SA-42 × Fsd-08	46.27*	109.09*	44.12*	76.92 NS	31.00	6.00
Fsd-08 × SA-42	40.30*	54.55 NS	38.24*	30.77 NS	26.67	3.17
Fsd-08 × Chenab-70	38.20*	93.33*	11.82 NS	70.59 NS	1.62	7.00
Chenab-70 × Fsd-08	31.46*	246.67*	6.36 NS	10.64 NS	1.33	1.16
Sehar-06 × Blue Silver	20.99 NS	78.79 NS	7.69 NS	25.53 NS	1.67	1.83
Blue Silver × Sehar-08	25.93 NS	-15.15 NS	12.09 NS	-40.43*	2.05	-0.31
Lasani-08 × Pak-81	44.59*	50.00 NS	5.94 NS	17.86 NS	1.22	1.77
Pak-81 × Lasani-08	56.76*	31.82 NS	14.85 NS	3.57 NS	1.57	1.15
Uqab-2000 × Pothowar-73	30.77*	26.32 NS	-4.03 NS	20.00 NS	0.85	5.00
Pothowar-73 × Uqab-2000	43.96*	57.89 NS	5.65 NS	50.00 NS	1.21	10.67
Pasban-90 × Pak-81	10.68 NS	55.00 NS	9.62 NS	10.71 NS	7.67	1.35
Pak-81 × Pasban-90	26.21*	95.00*	25.00*	39.29 NS	18.11	2.29

Table 5 Response of wheat crosses showing significant heterosis for grain yield and yield components.

Crosses	GYP^{-1}		PL		NPTP	SL		NSS	PH	
	N	WS	N	WS	AE	N	WS	Average	N	WS
Pasban-90 × Sehar-06	NS	*	*	NS	NS	NS	NS	NS	*	*
Pari-73 × C-273	NS	*	*	*	NS	NS	NS	NS	*	NS
SA-42 × Fsd-08	*	*	NS	NS	NS	NS	NS	*	NS	*
Fsd-08 × SA-42	*	NS	NS	NS	NS	*	*	NS	NS	*
Fsd-08 × Chenab-70	*	*	NS	NS	NS	NS	NS	*	*	NS
Chenab-70 × Fsd-08	*	*	NS	NS	NS	NS	NS	NS	*	*
Lasani-08 × Pak-81	*	NS	NS	NS	NS	*	NS	*	*	*
Pak-81 × Lasani-08	*	NS	*	NS	NS	NS	NS	*	*	NS
Uqab-2000 × Pothowar-73	*	NS	*	NS	NS	*	NS	NS	*	NS
Pothowar-73 × Uqab-2000	*	NS	*	NS	*	*	NS	NS	NS	NS
Pak-81 × Pasban-90	*	*	*	NS	NS	*	*	NS	NS	NS

* = Significant ($P \leq 0.01$), NS = Non-significant; GYP = grain yield per plant, PL = peduncle length; NPTP = number of productive tillers per plant, SL = spike length, NSS = number of spikelets per spike, PH = plant height

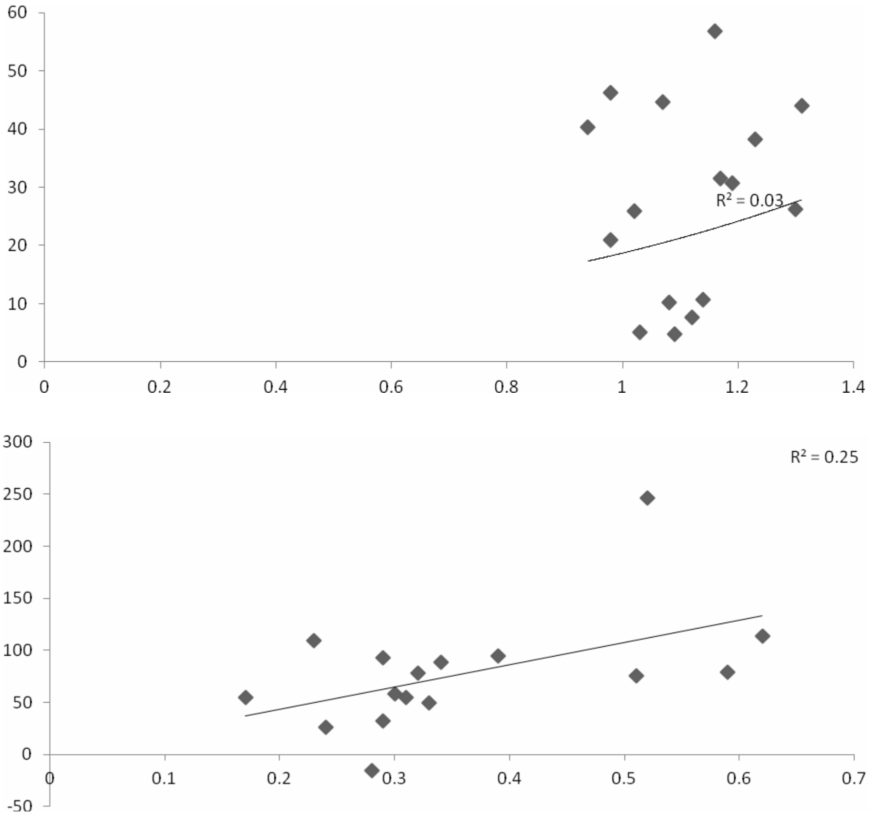

Fig. 1 Response of heterosis to the variation in grain yield per plant under normal conditions (top) and water stress (bottom).

the development of a hybrid is only fulfilled in the presence of overdominance. Similar results have been reported by Saeed *et al.* (2011).

Under water stress, eight crosses showed an increase over their mid-parent values and heterosis ranged from 75.86% ('Sehar-06' × 'Pasban-90') to 246.67% ('Chenab-70' × 'Fsd-08') (**Table 4**). Two crosses showed a significant ($P \leq 0.05$) increase over their respective better parents: the range of heterobeltiosis was from -40.42% ('Blue Silver' × 'Sehar-06') to 31.91% ('Pasban-90' × 'Sehar-06'). Under water stress, all crosses showed heterosis due to the over dominance effect except for 'Blue Silver' × 'Sehar-06'. The highest value for the over dominance effect was shown by 'Pothowar-73' × 'Uqab-2000'.

Response of crosses showing significant heterosis for grain yield with respect to heterosis in yield components

Generally, significant heterosis was also correlated with significant heterosis for other yield components (**Table 5**). For instance, hybrids resulting from cross between 'Pasban-81' × 'Sehar-06' showed significant heterosis for GYP under water stress; it also showed significant heterosis for PH under non-stressed and stressed conditions (**Table 5**). On the other hand, cross 'Pak-81' × 'Pasban-90', which showed significant heterosis for GYP, also showed significant heterosis for the traits SL and PL. Thus, heterosis of GYP in this cross may be due to the manifestation of heterosis in SL under water stress and due to PL and SL under non-stressed conditions (**Table 5**).

The relationship between heterosis and GYP of crosses was also estimated. There was a positive relationship between GYP and heterosis under water stress. Thus, hybrids with higher mean values for GYP also showed higher heterosis% values under water stress (**Fig. 1**). Mid-parental GYP was regressed against their hybrid yield, and the coefficient of determination (i.e., R^2 values) were 0.26 and 0.37 under non-stressed and stressed conditions, respectively (**Fig. 2**). These coefficients of determination values showed that parents with high GYP values produced hybrids with high grain yield. Therefore, a breeding line with high yield potential may be selected in a wheat hybrid breeding programs.

DISCUSSION

Increasing GY potential is an ultimate breeding objective of a wheat breeder. Therefore, wheat breeders have intensified their efforts to increase the yield potential of commercial cultivars under both stressed and non-stressed conditions (Araus *et al.* 2008). Hybrid breeding in wheat has occupied a central position to overcome the yield plateau. The present study has clearly showed the benefits of producing hybrids under water stressed and non-stressed conditions. The yield benefits were even higher under water stress due to a higher magnitude of heterosis. This may be due to the heterozygous nature or due to the broad genetic base of wheat hybrids or due to crossing of those parents having a diverse nature of tolerance against water stress. The superiority of hybrids under severe drought has also been mentioned in other crop species by various authors (Rao *et al.* 1999; Bruce *et al.* 2002; Noorka 2009; Kato *et al.* 2011). The genetic basis of heterosis has also been explored and was shown to have an overdominance type of gene action while quantitative trait loci (QTLs) for heterosis in various crop species have shown an additive × additive epistatic type of interaction (Larièpe *et al.* 2012).

There was a good positive relationship between the mean yield of hybrids and heterosis under drought stress (**Table 2**). Thus, only high-yielding hybrids showed a higher magnitude of heterosis under drought stress. However, under non-stressed conditions, yield was independent of heterosis as indicated from the low regression values, showing that the manifestation of heterosis was due to factors other than yield components and that QTLs for yield and heterosis are independent of each other. Furthermore, mid-parent value was significantly related with the yield of the hybrids under both conditions. Similar results have also been obtained in various crop species in which crosses between high-yielding genotypes with moderately yielding genotypes or between high yielding genotypes with low

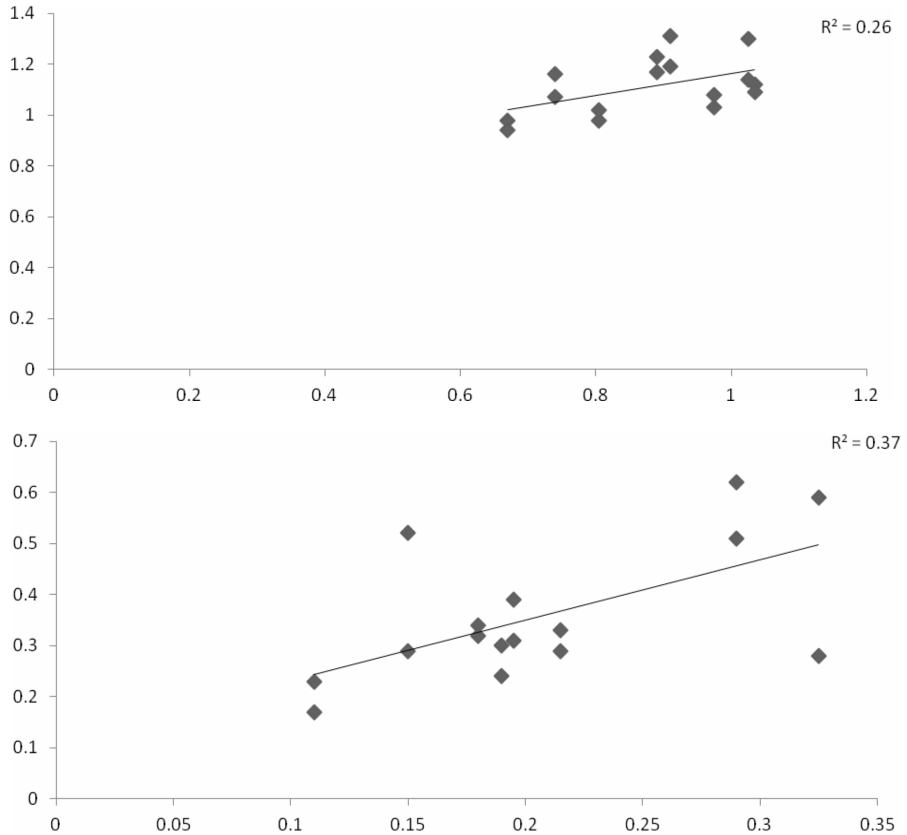

Fig. 2 Response of parental grain yield to the variation in hybrid grain yield per plant under normal conditions (top) and water stress (bottom).

yielding genotypes showed the highest magnitude of heterosis (Tulu 2002; Rauf *et al.* 2009). The presence of significant heterosis for GYP was also accompanied by heterosis for yield components in length-based traits such as PH, PL and SL. Thus, apart from GYP, hybrid vigor was also manifested in traits related to growth. Rauf *et al.* (2011, 2012) and Noorka and Bramawy (2011) also found differences among parents and hybrids for various traits related to growth parameters in wheat, sunflower and faba bean, respectively.

In this study, some elite wheat cultivars were used as parental lines of the hybrids. Thus, hybrids surpassing their better parents, i.e. elite cultivars, were indicative of commercial heterosis and are candidates for the commercial production of hybrid wheat. 'Pasban-90' × 'Sehar-06' were the elite cultivars used as parents, and this cross showed significant heterobeltiosis and it was the highest yielding cross compared with the yield of all other parents and hybrids under drought stress.

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