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Water Stress Tolerance, Its Relationship to Stem Reserve Mobilization and Potence Ratio in Spring Wheat

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ABSTRACT

Twelve wheat (*Triticum aestivum* L.) cultivars and their sixteen direct and reciprocal crosses were evaluated for heterosis, heterobeltiosis and potence ratio to determine the potential of wheat genotypes under contrasting water regimes. The highest positive heterosis and heterobeltiosis was observed in cross combination Sehr-06 × Pasban-90 under both water regimes for the trait stem reserve mobilization (SRM). While in trait 1000-grain weight the cross- combination Pari-73 × C-273 (Normal irrigation) and Fsd-08 × SA-42 (water stress) showed highest heterosis and Pari-73 × C-273(Normal irrigation) and Fsd-08 × Chenab-70(water stress) showed highest value of heterobeltiosis. The potence ratio in both traits expressed overdominance estimates exhibiting the presence of transgressive segregants, may be exploited for on-ward selection in the bread wheat improvement. The genotypes showing better SRM based 1000-grain weight in the absence of photosynthesis indicates relative water stress tolerance. This procedure paved an indirect way to screen the wheat genotypes to withhold water stress situation and sustain wheat production.

Keywords: Stem; Reserve; Mobilization; Direct; Reciprocal

1. Introduction

Wheat is ranked as a staple food of most of world parts particularly in Pakistan due to cheap source nutrition since decades. The major part of wheat grain is consumed by humans and livestock while remaining parts for other by products. Twenty percent diet calories of the world is provided by wheat grain [1]. It pertains 70% carbohydrates, 12% protein, 22% crude fibers, 2% fat, 12% water and 1.8% minerals [2]. Its diverse cultivation in geographic center of origins has evidences for more than 10,000 years as described by Sleper and Poehlman [3]. So, in Pakistan wheat is considered as a versatile crop due to its quantum contributions of 14.4 percent agricultural value addition and 3.1 percent to country GDP. The area and production targets of wheat since last year have shown a decline of 0.04 percent. The estimated size of wheat crop is 23,864 million tons showing 0.7% downward trend than last year [2]. Employment of heterosis isconsidered as an effective strategy to overcome the stagnant yield barrier to feed the burgeoning population [4]. Heterosis is considered as the increase or decrease in vigour of hybrids as compared to their parents. Sharif *et al.* [5], Kumar *et al.* [6] concluded that heterosis is not only limited to cross pollinated crops but can be employed in self-pollinated crop like wheat to exploit its potential. Under the changing climatic situation, water is expected to be limited and it will be the prime factor to produce food security [7-10]. The development and growth of wheat grain mainly depends on current assimilates that are partitioned in to the grains [11,12]. Stem reserve mobilization is also an important index of drought. A genotype having higher capacity to mobilize its reserves may be considered to show good performance under drought stress. Gupta *et al.* [13] showed that drought tolerant genotypes of wheat have the higher capacity to mobilize its nutrients under drought stress. In wheat, it is pertinent to improve the grain filling capacity by stem and spike reserves to combat the water stress as breeding strategy [14,15]. Water always have the prime importance in our food security system and its proper management leads to water saving [16]. Ourprincipal objective was to estimate the level of heterosis and heterobeltiosis for grain weight as well as stem reserve mobilization among F_1 hybrids andrespective parents under two different, normal irrigation and water stress condition. Other objective was to devise a possible screening

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methodology for the stem reserve mobilization trait to address the water stress tolerance in wheat.

2. Materials and Methods

2.1. Purpose of Study

The present study was carried out to estimate the magnitude of heterosis for grain weight and stem reserve mobilization to reckon the level of water stress tolerance in wheat.

2.2. Study Site

The research was initiated in the experimental area of University College of Agriculture, University of Sargodha during the crop season 2009-2011.

2.3. Genetic Material

Twelve wheat genotypes were used to initiate the researchviz; Sehr-06, Pasban-90, C-273, Pari-73, SA-42, Fsd-08, Chenab-70, Blue Silver, Lasani-08, Pak-81, Uqab-2000, and Pothowar-73 with diverse origin wheat genotypes (**Table 1**). The genotypes were sown in crossing block during the 15th of October, 2010 by a hand drill. At the flowering stage, 110 days after sowing (DAS) the F_1 hybrids including direct crosses and their reciprocals were attempted by hand emasculation of anther and covered with butter paper bag to avoid foreign pollen contaminations. The mature bifid stigmas of female lines were pollinated manually with the help of camel brush approximately after three days. Suitable tags were hanged to maintain identity of each cross.

Table 1. Pre-green revolution and post green revolution selected wheat varieties pedigree.

Wheat varieties	Parentage	Research Institute/Station	Year of Release
C273	C209/C591	Punjab.Agri. C.Res.Inst.Lyallpur	1957
Chenab 70	C271-WT(E)//SON 64	AARI.Faisalabad	1970
SA 42	C271-LR64/SON 64	-do-	1971
Blue Silver	II-54-388-AN(YT.54-N 10B/LR 64)	RARI, Bahawalpur	1971
Pothowar	114B-35/NAD 63	-do-	1973
Pari 73	CNO'S'//SON/KL.REND /M.PAK	-do-	1973
Pak-81	KVZ/BUHO//KAL/BB	-do-	1981
Pasban-90	INIA66/A.DISTT//INIA 66/3/GEN81	WRI, Faisalabad	1990
Uqab-2000	CROW'S'/NAC//BOW'S'	WRI, Faisalabad	2000
Lasani-08	LUAN/KOH-97	WRI, Faisalabad	2008
Faisalabad-08	PBW62/2*PASTOR	WRI, Faisalabad	2008
Sehr-06	CHILL/2*STAR/4/BOW/ CROW//BUC/PVN/3/	WRI, Faisalabad	2006

Source. CIMMYAT, 1989.

2.4. Hybridization

The crosses were made by hand emasculation and pollination.The lists of crosses are as given as Sehr-06 × Pasban-90,Pasban-90 × Sehr-06, C-273 × Pari-73, Pari-73 × C-273, SA-42 × Fsd-08, Faisalbad-2008 × SA-42, FS-08 × Chenab-70, Chenab-70 × FS-08, Sehr-06 × Blue Silver, Blue Silver × Sehr-06, Lasani-08 × Pak-81, Pak-81 × Lasani-08, Uqab-2000 × Pothowar-73, Pothowar-73 × Uqab-2000, Pak-81 × Pasban-90, Pasban-90 × Pak-81.

2.5. Water Stress

The seeds of all crosses and respective parents was taken and sown in the next crop season (2010-2011) in pots with three replications using completely randomized design (CRD) in contrasting water regimes in two sets of experiment. The pots were placed under plastic sheet driven belt to save from occasional rains. One set was kept under normal irrigation system by maintaining the soil moisture close to field capacity (17% moisture content w/w), while the second set irrigation was with held up to half during reproductive phase. After 163 DAS, when crop was at maturity, the data were taken.

2.6. 1000-Grain Weight (g)

Fixed number of grains was taken from each plant and 1000-grain weight was estimated by multiplication-method.

2.7. Stem Reserve Mobilization

At maturity the main stem having spike was harvested. Leaves were removed and then dried to constant weight. Afterwards stem reserve mobilization was estimated according to the Formula (1) below [13].

$$\text{Stem reserve mobilization} = \frac{\text{grain yield per plant}}{\text{Dry stem weight}} \qquad (1)$$

2.8. Statistical Analysis

To estimate significant differences among parents and hybrids, the data were subjected to statistical analysis by using the analysis of variance technique in completely randomized design with two factors *i.e.*, genotypes and water regimes [17]. Significant differences were further subjected to least significance difference test (LSD).

2.9. Heterosis and Heterobeltiosis

The percent increase or decrease of F_1 hybrids over mid parent as well as better parent value was calculated to estimate possible heterotic effects following Formulae, (2) and (3) given by Fonceca and Patterson [18].

$$\%\text{age } Ht = \frac{F_1 - M.P}{M.P} \times 100 \quad (2)$$

$$\%\text{age } Hbt = \frac{F_1 - B.P}{B.P} \times 100 \quad (3)$$

where, *Ht* = Heterosis, *Hbt* = Heterobeltiosis, *M.P* = Mid Parent Value, *B.P* = Better parent Value.

2.10. Potence Ratio

The potence ratio was calculated by the following Formula (4):

$$\text{Potence ratio} = \frac{F_1 - M.P}{B.P - M.P} \quad (4)$$

"t" Test, The 't' test was manifested to determine whether F_1 hybrid means were statistically different from mid parent and better parent value. The t-value for heterosis was calculated following the Formula (5)

$$t_{ij} = F_{1ij} - M.P_{ij}\left(3/8\ EMS\right)^{1/2} \quad (5)$$

The t-value for heterobeltiosis was calculated following the Formula (6)

$$t_{ij} = F_{1ij} - B.P_{ij}\left(1/2\ EMS\right)^{1/2} \quad (6)$$

where F_{1ij} = The Mean of the *ij*th F_1 cross, $M.P_{ij}$ = The mid parent for the *ij*th cross.

$B.P_{ij}$ = The better parent values for *ij*th cross, *EMS* = Error mean square.

3. Results and Discussions

3.1. 1000-Grain Weight

Highly significant differences ($P \leq 0.01$)among the genotypes, parents and the contrast between parents × crosses have been shown by analysis of variance for 1000-grain weight (**Table 2**) however there were non-significant variations ($P \geq 0.05$) among the crosses. Highly significant differences were also found among water regimes and the contrast between genotypes and water regimes and parent × water regimes and cross whereas the interaction of crosses and water regimes showed non-significant results. (**Table 3**) showed that the parent Lasani-08 has the highest value for this trait while Pari-73 has the lowest mean value for 1000-grain weight under normal condition. Among the F_1 hybrids, the highest mean value was shown by Lasani-08 × Pak-81 and the cross Sehr-06 × Blue Silver showed the lowest mean value for 1000-grain weightwhereas in water stress condition Pak-81 showed highest mean value for 1000-grain weight and SA-42 has lowest mean value among the parents. Among the F_1 hybrids Fsd-08 × Chenab-70 has the highest value for this trait and Pasban-90 × Sehr-06 has lowest mean value for 1000-grain weight under water stress condition.While for heterosis over the mid parent (**Table 3**) three crosses showed an increase over their respective mid parents under normal condition indicating significant heterosis ($P \leq 0.05$). The heterosis ranged from 6.55% (Lasani-08 × Pak-81) to 11.67% (Pari-73 × C-273). As far as heterosis over better parent is concerned only one cross Pari-73 × C-273 showed an increase over the better parent. The potence ratio **Table 2** for 1000-grain weight showed that thirteen hybrids showed heterosis due to over dominance effect. The highest value of over dominance gene action was shown by the cross combination SA-42 × Fsd-08. For heterosis in water stress condition eleven crosses showed an increase over their mid parental values indicating significant heterosis and the range of heterosis was from 9.08% (Sehr-06 × Blue Silver) to 26.60% (Fsd-08 × Chenab-70). Three crosses showed an increase over their respective better parents and showed significant positive heterosis over their respective better parents ($P \leq 0.05$). The range of positive heterobeltiosis was from 9.77% (Blue Silver × Sehr-06) to 13.19% (Sehr-06 × Pasban-90). In case of water stress twelve crosses showed heterosis due to over dominance effect. The highest value for over dominance effect was shown by the cross combination Fsd-08 × Chenab-70. The highest heterosis for this trait was again observed in crosses *i.e.* between post green revolution period and pre-green revolution period (Pari-73 × C-273) under non-stress condition. Pre-green revolution cultivars were indigenous to our area; they were tall and normally lodge at the maturity. On the other hand, post green revolution cultivars were introduced from CIMMYT. Thus because of geographical distance, they may have able to show higher magnitude of hetero-

Table 2. Analyses of variance for 1000-grain weight and Stem reserve mobilization.

SOV	df	1000-gain weight	SRM
Genotypes (G)	27	3.29^{**}	0.55^{**}
Parents (P)	11	3.97^{**}	0.67^{**}
Crosses (Cr)	15	1.97^{NS}	0.14^{**}
P vs. Cr	1	15.42^{**}	5.54^{**}
Water Regimes(W)	1	13091.18^{**}	43.19^{**}
G × W	27	4.86^{**}	0.38^{**}
P × W	11	7.57^{**}	0.41^{**}
Cr × W	15	1.94^{NS}	0.30^{**}
P vs. Cr × W	1	18.79^{**}	1.15^{**}
Error	112	1.54	0.02

Genotypic differences were highly significant ($P \leq 0.01$). NS = Non significant.

Table 3. Mean performance of parental lines, hybrids and estimation of percent heterosis, heterobeltiosis and potency ratio for 1000-grain weight (g) in wheat.

Crosses	MAT	MAT	PAT	PAT	F1	F1	HT	HT	HB	HB	PR	PR
	N	WS	N	WS	N	WS	N	WS	N	WS	N	WS
Sehr-06 × Pasban-90	31.46	12.36	32.79	11.03	33.24	13.99	3.45^{NS}	19.57^{*}	1.37^{NS}	13.19^{*}	1.68	3.45
Pasban-90 × Sehr-06	32.79	11.03	31.46	12.36	32.93	13.01	2.49^{NS}	11.20^{*}	0.43^{NS}	5.26^{NS}	1.21	1.98
C-273 × Pari-73	29.38	13.64	28.17	12.06	30.55	14.06	6.15^{NS}	9.41^{*}	3.98^{NS}	3.08^{NS}	2.94	1.53
Pari-73 × C-273	28.17	12.06	29.38	13.64	32.14	13.33	11.67^{*}	3.73^{NS}	9.39^{*}	-2.27^{NS}	5.56	0.61
SA-42 × Fsd-08	31.54	10.30	31.21	12.14	32.66	13.71	4.08^{NS}	22.19^{*}	3.55^{NS}	12.93^{*}	7.79	2.71
Fsd-08 × SA-42	31.21	12.14	31.54	10.30	31.99	13.67	1.94^{NS}	21.84^{*}	1.43^{NS}	12.6^{NS}	3.75	2.66
Fsd-08 × Chenab-70	31.21	12.14	29.98	12.52	30.80	15.61	0.65^{NS}	26.60^{*}	-1.31^{NS}	24.7^{NS}	0.34	17.3
Chenab-70 × Fsd-08	29.98	12.52	31.21	12.14	30.89	13.47	0.95^{NS}	9.24^{*}	-1.03^{NS}	7.59^{NS}	0.48	6.00
Sehr-06 × Blue Silver	31.46	12.36	30.73	13.41	30.09	14.06	-3.25^{Ns}	9.08^{*}	-4.35^{NS}	4.85^{NS}	−2.8	2.24
Blue Silver × Sehr-06	30.73	13.41	31.46	12.36	32.27	14.72	3.76^{NS}	14.20^{*}	2.57^{NS}	9.77^{*}	3.22	3.50
Lasani-08 × Pak-81	34.19	11.92	31.49	14.44	34.99	13.51	6.55^{*}	2.50^{NS}	2.34^{NS}	-6.44^{NS}	1.59	0.26
Pak-81 × Lasani-08	31.49	14.55	34.19	11.92	33.29	13.27	1.37^{NS}	0.23^{NS}	-2.63^{NS}	-8.80^{NS}	0.33	0.03
Uqab-2000 × Pothowar-3	30.87	13.61	29.90	13.17	31.31	13.65	3.0^{NS}	1.94^{NS}	1.43^{NS}	0.29^{NS}	1.90	1.20
Pothowar-73 × Uqab-2000	29.90	13.17	30.87	13.61	31.52	14.69	3.72^{NS}	9.70^{*}	2.11^{NS}	7.94^{NS}	2.34	5.89
Pasban-90 × Pak-81	32.79	11.03	31.49	14.44	30.83	13.43	-4.08^{NS}	5.42^{NS}	-5.98^{NS}	-6.99^{NS}	−2.0	0.41
Pak-81 × Pasban-90	31.49	14.44	32.79	11.03	34.48	15.26	7.28^{*}	19.78^{*}	5.15^{NS}	5.68^{NS}	3.60	1.48

MAT = Maternal, PAT = Paternal, F1 = First generation, HT = Heterosis, HB = Heterobeltiosis, PR = Potence Ratio, N = Normal, WS = Water stress, Least significant differences among the mean value of parents and F_1 ± 2.01.

sis. Previous findings have also shown positive relationship between genetic distance and heterosis in crop plants as consistent with Tao *et al.* [19]. The hybrid Pari-73 × C-273 showed the highest values for heterosis and heterobeltiosis under normal condition while the hybrid Fsd-08 × Chenab-70 showed the highest values for heterosis in water stress condition. Heterosis and heterobeltiosis for 1000-grain weight in variability values has also been reported by Baric *et al.* [20]; Mahmood *et al.* [21]; Akbar *et al.* [22] and Tuhina-Khatun *et al.* [23].

3.2. Stem Reserve Mobilization

Stem reserves have been shown to supply the nutrient to the developing seed when plants are unable to synthesize their food under severe water shortage [13]. It was noted that drought tolerant genotypes have higher fructan contents in their main stem and they unloaded these nutrients to the sink *i.e.* seed thus providing some sustainability to the yield under water stress conditions. The analysis of variance for stem reserve mobilization (**Table 2**) showed highly significance differences among the genotypes and due to its components *i.e.*, parents, crosses and the contrast of parents × crosses ($P \leq 0.01$). Previous finding have also showed variation within wheat germplasm for stem reserve mobilization [13,24]. Highly significant differences were found between water regimes and all its interactions ($P \leq 0.01$). Individual comparison of means (**Table 3**) showed that the parent Chenab-70 has the highest value for this trait while C-273 has the lowest mean value for stem reserve mobilization under normal condition. Among the F_1 hybrids, the cross Uqab-2000 × Pothowar-73 showed the highest mean value and the cross SA-42 × Fsd-08 showed the lowest mean value for this trait whereas in water stress condition Pari-73 showed the highest mean value and SA-42 has the lowest mean value among the parents. Among the F_1 hybrids C-273 × Pari-73 has the highest value for this trait and Uqab-2000 × Pothowar-73 showed the lowest mean value for stem reserve mobilization in water stress condition. For heterosis over the mid parent twelve crosses showed an increase over their respective mid parents (**Table 4**) under normal condition. Twelve crosses showed significant heterosis ($P \leq 0.05$). The heterosis ranged from −26.11% (SA-42 × Fsd-2008) to 84% (Sehar-06 × Pasban-90). Eight crosses manifested an increase over the better parent. The range of heterobeltiosis was from −37.97% (SA-42 × Fsd-2008) to 83.16% (Sehr-06 × Pasban-90). The potence ratio table for stem reserve mobilization (**Table 4**) showed that almost all hybrids, heterosis was due to over dominance effect except four crosses which showed partial dominance. The range of potence ratio was from −1.37 (SA-42 × Fsd-08) to 94.5 (Sehr-06 × Pasban-90). Under water stress conditions twelve crosses showed increase over their mid parental values and the heterosis values ranged from 2.94% (Lasani-08-08 × Pak-81) to 93.47% (Sehr-06 × Pasban-90). Six crosses showed an increase over their respective

Table 4. Mean performance of parental lines, hybrids and estimation of percent heterosis, heterobeltiosis and potency ratio for stem reserve mobilization in wheat.

Crosses	MAT	MAT	PAT	PAT	F1	F1	HT	HT	HB	HB	PR	PR
	N	WS	N	WS	N	WS	N	WS	N	WS	N	WS
Sehr-06× Pasban-90	1.12	0.57	1.13	0.35	2.07	0.89	84.00*	93.47*	83.16*	56.14*	94.5	3.9
Pasban-90 × Sehr-06	1.13	0.35	1.12	0.57	1.91	0.6	69.78*	30.43NS	69.02*	5.26NS	79.0	1.27
C-273 × Pari-73	0.33	0.66	1.89	1.20	1.90	1.22	71.17*	31.18*	0.53NS	1.67NS	1.01	1.07
Pari-73 × C-273	1.89	1.2	0.33	0.66	1.88	1.20	69.40*	29.03*	−0.53NS	0.00NS	0.98	1.00
SA-42 × Fsd-08	1.28	0.32	1.87	0.57	1.16	0.85	−26.11*	93.18*	−37.97*	49.12*	−1.37	3.15
Fsd-08 × SA-42	1.87	0.57	1.28	0.32	1.99	0.70	26.75*	59.09*	6.42NS	22.81NS	1.40	2.00
Fsd-08 × Chenab-70	1.87	0.57	2.14	0.67	2.04	0.66	2.00NS	6.45NS	−4.67NS	−1.49NS	0.28	0.80
Chenab-70 × Fsd-08	**2.14**	0.67	1.87	0.57	2.15	0.95	7.50NS	53.22*	0.47NS	41.79*	1.07	6.60
Sehr-06 × Blue Silver	1.12	0.57	1.37	0.48	1.86	0.74	50.00*	−29.52*	35.77*	29.82NS	4.77	0.64
Blue Silver × Sehr-06	1.37	0.48	1.12	0.57	1.85	0.72	49.19*	−31.43*	35.03*	26.32NS	4.69	0.68
Lasani-08 × Pak-81	0.73	0.54	1.96	0.83	1.89	0.70	41.04*	2.94*	−3.57NS	−15.66NS	0.88	0.13
Pak-81 × Lasani-08	1.96	0.83	0.73	0.54	1.97	0.89	47.02*	30.88*	0.51NS	7.23NS	1.01	1.40
Uqab-2000 × Pothowar-73	1.48	0.72	1.87	0.40	2.59	0.52	55.09NS	−7.14NS	38.50*	−27.78*	4.60	−0.25
Pothowar-73 × Uqab-2000	1.87	0.40	1.48	0.72	1.62	1.04	−2.99NS	85.71*	−13.37*	44.44*	−0.25	3.00
Pasban-90 × Pak-81	1.12	0.35	1.96	0.83	2.08	0.81	35.06*	37.28*	6.12NS	−2.41NS	1.28	0.92
Pak-81 × Pasban-90	1.96	0.83	1.12	0.35	2.53	0.60	64.29*	1.69NS	29.08*	−27.71*	2.36	0.04

MAT = Maternal, PAT = Paternal, F1 = First generation, HT = Heterosis, HB = Heterobeltiosis, PR = Potence Ratio, *=Significant, NS = Non-significant, , Least significant differences among the mean value of parents and F1 ±(0.23).

better parents and showed significant heterosis over their better parents ($P \leq 0.05$). The range of positive heterobeltiosis was from 41.79% (Chenab-70 × Fsd-08) to 56.14% (Sehr-06 × Blue Siver). Under water stress conditions nine crosses showed heterosis due to over dominance effect. The highest value for over dominance effect was shown by the cross Chenab-70 × Fsd-08. Drought depressed the mean values of SRM of many cultivars and their hybrids. When relationship of SRM with yield and its components was established, it showed moderately positive relationship with 1000-grain weight ($R^2 = 0.20$) showing its positive contribution toward yield compo nents of parental genotypes under water stress. This influence over the yield and yield component has also been observed in some previous studies in wheat as revealed by Farhangi and Ghodsi, [24]; Gupta *et al.* [13]. However, these authors were not able to show heterosis manifested as result of crossing of diverse parents. Most of the crosses induced significant heterosis and magnitude of heterosis increased under water stress thus showing the values of heterosis breeding under both conditions. Crosses showing significant positive heterosis may be exploited in both stress and non-stress condition for increasing wheat productivity. The genotypes possessing high mobilization of stem reserves are considered able to withstand sever water stress conditions because they have ability to accumulate sufficient amount of water soluble carbohydrates (WSC) in their stems and then able to shuffle carbohydrates at the presence of light in to grain filling under the limited or non-photosynthesis conditions [25,26]. The genotypes showing less SRM may not be able to withstand the shocks of water stress, and resultantly they will lose their yield potential at the onset of water stress [7,12,27,28].

4. Conclusion

This study reveals that stem reserves mobilization supports grain weight in wheat particularly if the water stress occurs. The elite genotypes like Sehr-06 × Pasban-90, Pari-73 × C-273, Fsd-08 × SA-42 may be used as breeding material to create genetic variation for stem reserves mobilization and to develop promising wheat varieties that will be more adapted to water stressed conditions.

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