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Genetic variation in wheat upon water deficit stress to a range of low temperature regime at high altitude

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Abstract

The performance of seven improved cultivars of wheat genotypes were examined on field trials at cool climatic conditions of high hills (2100 m above mean sea level) under normal and water deficit stress situations during 2003-04 and 2005-06, respectively. Results revealed that highest yielding genotypes at stress situation did not produce higher yield under normal condition. Variation in heritability was observed between two environments. Low heritability and low gains from selection in stress environment made it difficult to identify suitable genotypes for high grain yield and greater harvest index. Drought susceptibility index was associated with grain yield differences of a cultivar between two environments and was failed to detect superior genotypes. Additive gene effect of biomass under normal situation and non-additive gene effect of seed weight and grain yield, respectively, in stress and non-stress condition could be utilized for the improvement of wheat cultivars suitable for higher elevation of hills. Two genotypes (*viz.*, SKW 196 and VL 738) were preferred for cultivation as they performed well both in stress and non-stress conditions.

Key words: Wheat cultivars, high altitude, low temperature, water deficit stress

Introduction

Wheat is cultivated in vast areas of Uttarakhand state in relatively infertile lands of hills under rainfed condition [1]. At high altitude climate remains cool but limited rainfall or no rainfall induces water deficit stress to cultivars, which affects the plant growth and appears as major constraints of wheat production. Improved wheat cultivars often fail to exhibit total yield potential when subject to grow in areas with low moisture availability under cool environmental situation at high hills. Relative improvement of cultivars, therefore, depends on the availability of genetic variability exist within wheat population. The development of cultivars with stress tolerance becomes more necessary to bring stable yield under sustainable agricultural system of wheat cultivation at high altitude areas of this region. Drought in this region is categorized as intermittent system where rain fall and drought can occur at any time during growing seasons. Various morpho-physiological characteristics have been used to determine genotypes exhibiting consistence performance across stress treatments [2, 3], however, necessary evidence to support their use as selection criteria is often lacking [4]. Selection of suitable genotypes requires a thorough knowledge on variation in genetic parameters of characters. Drought intensity index (DII) appears as effective in selection process to quantify the degree of stress when equipment and resources are not available for soil analysis [5]. In this investigation relative performance of cultivars were examined under water deficit stress at near optimum growing condition at high hills at an exposure to low atmospheric temperature on the basis of DII and seed yield means.

Materials and methods

Seeds of 7 wheat genotypes (*viz.*, HS 240, HS 365, HS 473, SKW 196, Sonalika, VL 738 and VL 832), including four standard checks for high hills and three recommended cultivars for north western hill region of India were obtained from All India Coordinated Research Project. Field experiments were conducted at an altitude of 2100m above mean sea levels at Hill Campus, G.B.P.U.A.&T., Ranichauri under rainfed condition. The prevailing climatic condition does not always permit double cropping at this elevation on same land because of prolong growing season, for both *kharif* and *rabi* crops, which overlaps each other. Planting of seeds of wheat cultivars early to mid October are found suitable for existing cropping pattern at high altitude. Seeds were sown on October 7 and 19, respectively, for the year 2003 and 2005 on field at the rate of 100 kg/ha. The trial conducted on 2004-05 was not considered due to late planting of seeds as it affects the planting of fellow crop in rotation although it had experienced high (492.4mm) and regular rainfall almost in every week with little exception during this period. Experiments were laid out in a randomized block design with three replications. The distance between two rows and the length of single rows was maintained 0.23 and 3.0 meters, respectively, with a plot size of 3.0 x 0.92 m^2. Recommended doses of fertilizers were applied and other agronomic practices were employed to maintain the normal growth and development of plant at experimental fields. Rainfall along with maximum and minimum temperature were recorded daily during cropping season of wheat (Table 1). Significant variation of environment was determined by employing t-test on weekly averaged data of temperature and rainfall experienced during 2003-04 and 2005-06. Differences in temperature and rain fall were compared between two years (i) from first day of October to mean date of 50% heading, (ii) time interval of 40^{th} to 5^{th} (correspond to 50% heading date in 2003-04) and (iii) 40^{th} to 9^{th} meteorological weeks (correspond to 50% heading date in 2005-06). Environment with limited rainfall on 2005-06 was categorized as water deficit stress condition of drought for wheat cultivation at high hills while 2003-04 was designated as normal and stress free situation. Influence of water deficit stress on wheat cultivars in this investigation was examined by comparing the performances on field trials [5] conducted during 2003-04 and 2005-06. Pre-sowing rainfall on September (i.e., 36^{th} to 39^{th} meteorological weeks) was conducive for good germination of seeds (90%) and seedling establishment. Observations were recorded for days to 50% heading (days), plant height (cms.), days to maturity (days), 1000 seed weight (g), grain yield (g/plot), straw yield (i.e., biomass; g/plot) and harvest index (%). Standard statistical procedures were employed for the computation of analysis of variance on individual environment and combined over two environments. Mean performance of characters were estimated for each environment separately. Estimation of variance components [6], coefficient of variation [7], broad sense heritability [8], genetic advance and genetic gain [9] were evaluated separately for each character both in stress and non-stress environment. Influence of drought effect on plant characters were observed by estimating drought intensity index (DII) by employing the formula : DII= 1-

Table 1. Weekly averaged data of rainfall (RF), maximum temperature (MxT) and minimum temperature (Mn T) experienced during 2003-04 and 2005-06 at experimental site (2100 m above m.s.l.)

Year		Meteorological week															
		36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
2003-04	Mx T	21.8	21.9	23.2	21.5	23.0	22.0	22.3	20.3	20.5	19.5	14.3	16.7	15.7	15.3	13.0	11.7
	Mn T	13.8	14.5	13.8	11.8	9.4	8.3	8.1	7.0	7.1	5.3	3.5	2.7	1.8	2.4	2.1	0.0
	RF	25.0	15.4	7.9	10.6	0.0	0.0	0.0	0.0	0.0	0.0	14.8	2.6	0.0	0.0	48.4	3.3
2005-06	Mx T	22.8	21.8	21.1	20.5	22.5	21.3	21.3	19.1	18.4	19.4	19.7	18.9	15.9	17.1	15.8	15.7
	Mn T	15.4	13.6	13.4	11.2	11.8	9.3	8.2	9.3	7.1	6.0	5.9	5.7	3.9	3.7	2.7	2.9
	RF	7.3	62.4	174.1	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4
Year		Meteorological week															
		52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2003-04	Mx T	10.2	12.0	13.3	12.5	8.3	9.1	12.2	15.4	17.4	19.4	20.2	21.8	25.1	22.7	24.7	26.2
	Mn T	-0.6	-0.1	1.0	1.2	-0.9	1.3	2.9	5.3	5.9	7.9	8.3	11.4	13.3	9.9	11.9	13.4
	RF	8.6	0.0	0.0	5.2	86.3	30.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1
2005-06	Mx T	13.5	12.7	16.8	11.7	13.0	19.2	17.4	18.5	22.1	18.9	18.5	13.8	19.4	19.0	23.4	23.4
	Mn T	2.2	2.9	3.5	4.2	1.7	7.7	6.0	7.9	10.4	6.8	7.6	4.9	8.1	7.8	10.2	10.7
	RF	1.4	30.6	0.0	7.7	0.0	0.0	0.0	0.0	0.0	5.2	34.6	22.4	1.2	5.0	0.9	0.0

Calculated t-value : Maximum temperature (7.8996**, 5.0917**, 3.5038**), minimum temperature (6.2152**, 3.9599**, 2.0643), average temperature (5.5523**, 4.0623**, 2.4976*), diurnal temperature (2.1330*, 2.5056**, 3.5099**) and rainfall (–2.1192*, 2.0657*, –1.1026). The first figure under parentheses indicated difference of 40^{th} to 5^{th} meteorological weeks between 2003-4 and 2005-06 ; the second figure indicated a comparison between 40 to 5^{th} with 40^{th} to 9^{th} meteorological weeks of 2003-04 and 2005-06, respectively ; The third figure under parentheses indicated difference of 40^{th} to 9^{th} meteorological weeks between 2003-4 and 2005-06.

X_d / X_p , where X_d is the mean yield averaged across genotypes in the stress (drought) environment and X_p the mean yield averaged across genotypes in the non-stress environment [10]. Accordingly drought susceptibility index (S) was calculated by adopting the formula as follow: S = (1 – Y_d / Y_p) / DII, where Y_d is mean yield of a genotype under stress and Y_p mean yield for the same genotype under non-stress environment. Harvest index was determined by dividing the grain yield by total biomass and was expressed in percent. Correlation coefficients values [11] were estimated for all pair-wise combination of characters including the differences in crop performance between two environments, their mean productivity and drought susceptibility index. Significant association between characters was determined by t-test.

Results and discussion

Maximum yield potential of crop realize in presence of favourable environment. Threshold, like rain fall and temperature, do always exist to determine the yield in addition to describe physiological and developmental feature of plant characters and to delineate the length of cropping season at growing site. In this investigation significant differences in minimum temperature and rain fall were observed for a time interval of 40th to 5th meteorological weeks and between heading date of two years. The results revealed that atmospheric temperature on 2003-04 remained relatively cooler in comparison to that experienced on 2005-06 while wheat cultivars were exposed to water deficit stress on 2005-06 at high altitude. In stress free condition on 2003-04 wheat genotypes registered flowering and maturity, respectively, at 103.5 and 172.5 days (Table 2), while more number of days was required for flowering and

Table 2. Mean performance of 7 characters under nonstress and stress environments, yield loss (%) at stress environment and drought susceptibility index (DSI) of wheat genotypes at high hills

Genotypes	Environment	Days to flowering	Days to maturity	Plant height (cm)	Seed weight (g)	Bio-mass (g)	Harvest index (%)	Grain yield (g)	Yield loss stress(%)	DSI
Sonalika	Nonstress	99.2	168.0	86.2	36.2	1219.9	37.0	716.6	46.88	1.239
	Stress	121.0	174.0	63.2	30.1	956.7	35.1	384.3		
HS 365	Nonstress	98.0	169.2	82.2	40.2	1337.2	32.3	600.0	16.39	0.438
	Stress	127.1	184.0	67.1	40.6	1156.7	33.2	501.6		
SKW 196	Nonstress	104.0	174.2	90.0	40.2	1525.6	40.1	1033.3	55.33	1.478
	Stress	134.1	177.1	70.2	29.2	1145.5	37.1	462.0		
VL 832	Nonstress	103.2	175.0	96.0	40.8	1420.5	32.1	683.3	37.32	0.997
	Stress	130.0	184.0	77.1	31.0	1121.3	34.0	428.3		
HS 240	Nonstress	103.2	172.0	65.2	40.2	1320.8	30.2	583.3	22.86	0.611
	Stress	158.0	209.0	67.3	40.1	1048.4	36.2	450.0		
VL 738	Nonstress	109.2	176.1	95.1	43.0	1094.0	42.3	800.0	32.96	0.881
	Stress	153.0	204.0	72.0	46.2	1157.6	30.1	536.3		
HS 473	Nonstress	108.0	173.0	103.0	41.0	9248.9	43.2	720.0	37.50	1.002
	Stress	153.0	195.0	70.2	39.0	886.6	34.1	450.0		
Mean	Nonstress	103.5	172.5	88.2	40.2	1263.3	36.7	733.8	35.52	
	Stress	139.4	189.5	69.6	36.6	1067.5	34.3	458.9		
S e m	Nonstress	1.3	1.2	1.7	0.8	26.9	1.1	34.1		
	Stress	1.8	2.3	1.4	0.9	18.7	1.3	22.44		
CD	Nonstress	4.0	3.7	5.4	2.4	83.1	3.6	105.3		
	Stress	5.6	7.3	4.4	3.0	79.0	4.0	69.1		
CV	Nonstress	2.2	1.2	3.4	3.4	3.6	5.5	8.0		
	Stress	2.2	2.1	3.6	4.6	3.0	6.5	8.4		

Drought intensity index (DII) used for the calculation of DSI was 0.374.

maturity in water deficit stress situation at high hills in 2005-06. This indicated that influence of moisture level in soil perhaps exerted its effect on physiology of wheat crops within available range of low temperature regime at this elevation and increased the number of days for flowering on 2005-06. It was, therefore, assumed that low moisture level of soil possibly appeared as one of the major limiting factors and fails to meet the demand for required water potential by the plant to carry out normal physiological function and imposed restriction to survive and grow the cultivars in areas with low moisture availability at high hills. Alternatively it could be stated that improved wheat cultivars performed better even under relatively cooler climatic condition during 2003-04 in presence of available moisture in soil. The results of this investigation, therefore, indicated that plants were subjected to grow under both kinds of environmental stresses (i.e., water deficit stress and cold stress) synchronously but the damage was usually caused by the most severe factors. It was, therefore, presumed that the response of wheat plants to abiotic stress caused by surrounding environment at high hill possibly originated through additive and synergistic effect of multiple stresses [12].

Mean performances of grain yield (Table 2) showed that the genotype exhibited highest yield potential in non-stress condition has failed to produce highest yielding capacity at stress situation and vice versa. This might be due to differing mechanisms that contribute to yield under the two regimes of moisture treatments at an exposure to low atmospheric temperature at high altitude. Maximum grain yield in non-stress environment was registered for SKW 196 (1033.3 g/plot) followed by VL 738 (800.0 g/plot). Greater biomass content (1525.6, 1145.5 g/plot) and high harvest index (40.1, 37.1) were also recorded for SKW 196 under both treatments. This suggested that physiological mechanism involved in the partitioning of photosynthates for the development of structural and nonstructural carbohydrate was least affected in this cultivar and showed the ability of productive potential at an exposure to moisture stress condition [2] at high hills. Drought intensity index (DII) at this elevation during experimental periods was estimated 0.374. This incurred a loss of 35.52% grain production and seemed to represent a typical water deficit stress situation for higher hills to demonstrate a significant treatment effect in both populations. SKW 196 yielded a maximum of 55.3% less under stress situation. The second highest loss was recorded for Sonalika (46.38%). Contrary, HS 365 and HS 240 showed minimum loss 16.39 and 22.86 % respectively. An inconsistent variability among cultivars illustrated the difficulty in breeding for stress tolerance per se and emphasized the importance of breeding for adaptations as a criterion for drought resistance.

Mean square of the treatment effects for grain yield and other characters, resulting from separate analysis on individual environment and on combined analysis over two environments (Table 3), were significant. These results suggested the existence of genetic variation for grain yield and other characters in the population and showed differential reaction of wheat cultivars [13] in their relative adaptation to water deficit stress environment at high hills. A reduction in heritability (Table 4) estimates of grain yield (0.55, 0.86), harvest index (0.40, 0.86) and plant height (0.73, 0.93) was observed in stress environment than non-stress environments, which were in agreement to Rosielle and Hamblin [14]. The wide range in the values between two treatments emphasizes the difficulty comparing heritability estimates. It seemed to depend upon population structure and size, genetic back ground of experimental materials studied, number of environments and replications. Low heritability and low gains from selection (0.14, 0.07) made it difficult to identify genotypes suitable for grain yield and greater harvest index under stress environment. Contrasts in developmental timing and dissimilarities between stress initiation, intensity and duration [15] might be responsible to constitute higher estimates of heritability in stress environment for days to heading (0.95, 0.74), days to maturity (0.91, 0.61) and 1000 grain weight(0.93, 0.65). Biomass production showed equivalent estimates of heritability (0.93, 0.94) and genetic gain per cycle of selection (0.31, 0.40) between treatments. The efficiency of selection procedure seemed to be improved only when the plants exhibited high variability for the desired characters, which were heritable in nature [7]. Heritability along with genetic gain was more useful than heritability alone [9] in predicting the resultant effects of selection. In this investigation biomass registered higher values for genetic coefficient of variance (15.92), heritability (0.94), genetic advance (403.78) and genetic gain from selection (0.31) under non-stress situation. High genetic advance, as percent of mean, coupled with high heritability suggested the preponderance of additive gene action with low environmental influence could be effective in phenotypic selection of cultivars for high biomass under stress free condition of normal environment. Less variability between phenotypic and genotypic coefficient of variation of biomass under stress environment coupled with high heritability, genetic advance and genetic gain from selection also suggested the influence of additive gene effect on the expression

Table 3. Individual and combined (Comb) analysis of variance for 7 characters in wheat cultivars grown under water deficit stress (ST) and nonstress (NS) environments at high hills

Source	df		Days to flowering	Days to maturity	Plant height	Seed weight	Grain yield	Biomass	Harvest index
Replication	2	NS	1.16	1.23	0.19	0.62	6004.35	578.28	7.08
		ST	1.03	4.21	1.14	0.06	2882.50	3872.35	2.90
	2	Comb	0.01	4.40	0.45	0.19	1446.71	3114.00	9.32
Genotype(G)	6	NS	50.94**	26.54**	449.8**	2.62**	68838.0**	123659.6**	84.19**
		ST	656.15**	537.47**	57.87**	126.73**	7243.72**	94128.0**	15.48**
	6	Comb	492.89**	331.28**	337.32**	95.43**	40348.33**	70687.77**	39.68**
Year (Y)	1	Comb	13575.11**	3065.66**	3637.62**	137.88**	793237.4**	1604834.0**	62.29**
G x Y	6	Comb	214.21**	233.05**	170.40**	43.92**	35733.54**	148275.3**	60.00**
Error	12	NS	5.22	4.53	9.53	1.92	3504.82	2184.51	4.17
		ST	10.20	17.13	6.30	2.95	1510.80	1973.74	5.15
	26	Comb	7.29	10.07	7.37	2.28	2887.22	2026.30	4.35
Total	20	NS	370.67	216.12	284.9	100.07	467095.0	769327.9	569.43
		ST	4061.46	3438.93	425.17	795.99	67357.0	596197.98	115.64
	41	Comb	18007.44	6722.37	6876.71	1033.94	132769.0	2977524	792.37

**,*Significant at 1 and 5 % levels of probability, respectively.

Table 4. Genetic parameters of 7 characters in wheat cultivars grown under nonstress and stress environments at high hills

Genetic parameter	Environment	Days to flowering	Days to maturity	Plant height	Seed weight	Grain yield	Biomass	Harvest index
Phenotypic variance	Nonstress	20.46	11.87	156.30	5.48	25282.50	42676.20	30.84
	Stress	225.52	190.58	23.49	44.21	3421.77	12436.95	8.60
Genotypic variance	Nonstress	15.24	7.33	146.77	3.56	21777.90	40493.65	26.67
	Stress	215.31	173.44	17.18	41.25	1910.97	11379.75	3.44
GCV	Nonstress	3.77	1.58	13.72	4.69	20.11	15.92	14.04
	Stress	10.51	6.94	24.68	17.53	9.52	9.99	5.42
PCV	Nonstress	4.36	2.00	14.16	5.82	21.66	16.35	15.10
	Stress	10.76	7.28	33.73	18.15	12.74	10.44	8.53
Heritability	Nonstress	0.74	0.61	0.93	0.65	0.86	0.94	0.86
	Stress	0.95	0.91	0.73	0.93	0.55	0.93	0.40
Genetic advance	Nonstress	6.94	4.38	24.18	3.13	282.10	403.78	9.89
	Stress	29.53	25.88	7.30	12.78	67.20	349.97	2.43
Genetic gain	Nonstress	0.06	0.02	0.27	0.07	0.38	0.31	0.26
	Stress	0.21	0.13	0.10	0.34	0.14	0.40	0.07

of this character under stress environment. The possible control of non-additive gene effect was observed for plant height (13.72, 0.93, 24.18, 0.27) and grain yield (20.11, 0.86, 282.1, 0.38) in non-stress environment and seed weight (17.53, 18.15, 0.93, 12.78, 0.34) in stress condition. This indicated that indirect selection through these characters would be more effective when exploited under favourable environment while constituted significant relation with desire characters.

Grain yield had significant positive correlation with biomass (0.759) in stress environment but constituted non significant positive association in stress free normal condition (Table 5). This indicated that ability for greater biomass production in stress situation was a good indicator for obtaining high yield. In stress free situation harvest index exhibited significant positive and negative correlation with grain yield (0.591) and biomass (–0.521), respectively. This indicated that effective partitioning of photosynthates had enabled them to establish desired relation of grain yield and biomass with harvest index. Contrary significant inverse association of harvest index both with grain yield (–0.563) and biomass (–0.738) in stress situation explained that physiological deterrence of plants by fall in requirement of optimum moisture level in soil possibly constituted this relation at high altitude.

Table 5. Estimates of correlation coefficient among different characters# of wheat cultivars at high altitude for nonstress (2003-04), stress environments (2005-06) and between two environments

Characters		Non-stress	Stress	Non-stress vs stress	Stress vs non-stress
DF vs	DF	1.000	1.000	0.739**	0.739**
	DM	0.633**	0.868**	0.470*	0.428
	PH	0.499*	0.179	0.488*	–0.096
	SW	0.592**	0.650**	0.377	0.553**
	GY	0.315	0.354	0.378	–0.081
	BM	–0.479*	0.361	0.441*	–0.478*
	HI	0.514*	–0.191	–0.331	0.195
DM vs	DM	1.000	1.000	0.387	0.387
	PH	0.337	0.109	0.571**	–0.265
	SW	0.670**	0.741**	0.083	0.584**
	GY	0.276	0.371	0.394	0.377
	BM	0.024	0.467*	0.413	0.421
	HI	0.293	–0.283	–0.337	0.037
PH vs	PH	1.000	1.000	0.479*	0.479*
	SW	0.305	0.074	–0.089	0.536*
	GY	0.382	0.211	0.027	0.158
	BM	–0.379	0.293	0.244	0.168
	HI	0.680**	–0.064	–0.209	0.053
SW vs	SW	1.000	1.000	0.527**	0.527*
	GY	0.016	0.586**	0.593**	–0.332
	BM	–0.160	0.769**	0.689**	–0.523*
	HI	0.190	–0.455**	–0.293	0.117
GY vs	GY	1.000	1.000	0.011	0.011
	BM	0.239	0.759**	–0.035	–0.113
	HI	0.591**	–0.563**	0.169	0.135
BM vs	BM	1.000	1.000	–0.337	–0.337
	HI	–0.521*	–0.738**	0.461*	0.237
HI vs	HI	1.000	1.000	–0.083	–0.083

**,*Significant at 1 and 5 percent levels of probability, respectively.
#DF=Days to flowering, DM=Days to maturity, PH=Plant height, SW=Seed weight, GY=Grain yield, BM=Biomass, HI=Harvest index

This suggested harvest index would not be utilized as a good selection criterion for improving grain yield among wheat cultivars in stress situation because it failed to maintain normal physiological function at post-flowering grain filling stage of crop growth to restore the desire relation with grain yield at an exposure to water deficit condition at higher altitude. Moreover the nature of this response upon improved wheat cultivars at high hills appeared to be more complex in nature and were possibly influenced by synergistic effect of multiple stresses of environment, as indicated by the presence of poor relation among grain yield, biomass and harvest index at different combination of stress and non-stress environments (0.011, –0.035, 0.169; –0.113, –0.337, 0.461; 0.135, 0.237, –0.083). Grain yield and biomass for stress environment constituted significant positive correlation with seed weight both in stress (0.586, 0.769) and non-stress (0.593, 0.689) environments. Between stress and non-stress environment seed weight had significant positive association (0.527) but showed an independent behaviour with grain yield in non-stress environment (0.016). It was, therefore, apparent that seed weight [16] could be utilized as an effective selection criterion for the enhancement of grain yield in stress environment at high altitude. High biomass concomitantly increased the number days for maturity (0.467) in stress environment and imposed restriction for desire improvement on grain yield at high altitude among improved cultivars. Non-significant correlation at genotypic and phenotypic levels (Table 6) for grain yield of stress environment with non-stress environment (0.144; 0.047) and yield differential (-0.151, -0.305) indicated that breeding for improved performance in stress condition while maintaining yield potential under non-stress condition was difficult [14] and increased grain yield in stress environment might not be associated with reducing the grain yield differentials between two environments. Identification of desire traits would be more important for yield enhancement under stress condition. Drought susceptibility index (S) was significantly and positively associated with grain yield (0.825) in non-stress environment indicating that small difference in performance between stress and non-stress treatments of agronomically undesirable genotypes were associated with low S values, while, genotypes with a superior yielding capacity under both treatments much more under non-stress condition [17] might have higher S values than the cultivars with low grain yield potential. This suggested that a method of indirect selection related to the expression of dehydration stress inducible gene [18] may prove effective for increasing yield in water deficit stress situation at high altitude.

Table 6. Estimates of correlation coefficient of grain yield for nonstress (GY_{NS}) and stress (GY_S) environments at genotypic, phenotypic levels and with yield differences between two environments (GY_D), average productivity over two environments (GY_A) and on drought susceptibility index (S)

Characters		Genotypic	Phenotypic	Drought susceptibility index (S)
GY_{NS} vs	GY_{NS}	1.000	1.000	1.000
	GY_S	0.144	0.047	0.103
	GY_D	0.956**	0.936**	
	GY_A	0.962**	0.940**	
	S			0.825**
GY_S vs	GY_S	1.000	1.000	1.000
	GY_D	–0.151	–0.305	
	GY_A	0.406	0.383	
	S			–0.442
GY_D vs	GY_D	1.000	1.000	
	GY_A	0.841**	0.762**	
GY_A vs	GY_A	1.000	1.000	
S vs S			1.000	

**,*Significant at 1 and 5 percent levels of probability, respectively.

This result suggested that additive gene effect of biomass in normal situation and non-additive gene effect of seed weight and grain yield respectively in stress and non-stress condition could be utilized for the improvement of wheat cultivars at high altitude; however, indirect selection through modern screening techniques seemed to identify tolerant genotypes more efficiently. In this investigation superiority of SKW 196 and VL 738 was established and likely to be preferred for cultivation both under stress and non-stress condition at high hills.

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