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Germplasm characterization, association and clustering for salinity and waterlogging tolerance in bread wheat (*Triticum aestivum*)

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ABSTRACT

A study was conducted for characterizing germplasm, estimating interrelationship of traits and clustering of wheat genotypes in five environments covering salinity, waterlogging and neutral soils using, 100 elite but diverse genotypes with eight checks of bread wheat (*Triticum aestivum* L.). These genotypes were planted under five distinct environments during *rabi* 2009-10 under augmented design in four blocks wherein each check was repeated twice. The genetic variance, correlation coefficients and cluster analysis were carried out for assessment of lines through seven metric traits, namely, plant stand, plant height, days to heading, days to maturity, tillers/meter, 1000-grain weight and grain yield. Analysis of variance revealed wide variability for most of the traits under study. The phenotypic coefficient of variation (PCV) was high for tillers/meter and grain yield, while high heritability coupled with high genetic advance were found for tillers/meter, 1000-grain weight and grain yield under all five environments. At phenotypic level, positive and significant correlation coefficients revealed that under all the normal and stressed environments used here, grain yield is directly influenced by plant stand, tillers/meter and thousand grain weights. Significant and positive correlations were estimated between tillers/meter (r = 0.31 to 0.66), and 1000 grain weight (r = 0.24 to 0.61) with grain yield under all five environments. Under waterlogged conditions there were significant negative correlations of plant height to grain yield (r = –0.38 to –0.39) across two sites. These results, thereby suggests that yield improvement in bread wheat could be possible by emphasizing these traits through selection in these diverse environments. On the basis of D^2 values of pooled data, 108 genotypes were grouped into four clusters. In all, only 26 lines were found common in cluster III under two waterlogging environments (Faizabad and Karnal), while only 15 lines were common in cluster I under non waterlogging (Faizabad, CSSRI and DWR) conditions. These results indicate different constraints exist in waterlogged and non-waterlogged condition at these sites. Genetic diversity available for these traits may be utilized for yield improvement in bread wheat under different soil conditions through planned hybridization and selection in target environments.

Key words: Bread wheat, Correlation coefficient, Cluster analysis, Genetic variability, Salinity, Waterlogging

Wheat (*Triticum aestivum* L. emend. Fiori & Paol.) is the second most important cereal crop for food and nutritional security of India relative to rice. It is grown over 29.5 million hectares area with total production of 85.93 million tonnes (2010-11) and average yield of 2.9 tonnes/ha (Singh *et al.* 2011). Growth rate in wheat productivity has come down to less than one per cent as compared to much higher growth rate of 1.8 per cent in human population. For achieving the projected demand of 100 million metric tonnes of wheat by 2030, there is need to accelerate the overall wheat production in the country annually by 3 per cent (Anonymous 2011). This appears to be a difficult task but not impossible to develop high yielding wheat varieties utilizing the available useful variability in germplasm. Among abiotic factors, salinity and waterlogging stresses are the major yield limiting factors influencing wheat production, especially in the eastern parts, central and peninsular regions of India (Anonymous 2011). In view of the changing climate, erratic distribution of rainfall, may often lead to waterlogging, especially in alkaline soil where there is low hydraulic conductivity. Therefore, it is necessary to develop cultivars with high yield, disease resistance and

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tolerance to excessive moisture conditions. This type of uncertainty of waterlogging during the crop growth period, calls for climate resilient genotypes suitable for erratic water and temperature conditions (Richards *et al.* 2002, Setter *et al.* 2011).

It is now well recognized that wheat is very sensitive to waterlogging particularly during seeding, flowering and grain filling periods. The water-logging for about 30 days during any of these stages can cause 50-70% grain yield loss due to poor seed set and less effective tillers per unit area. The decrease in yield supports the findings of Setter *et al.* (2001) for wheat grown in Australia. The impact of changing climate is likely to affect abiotic stresses (waterlogging and salinity) that will become more important in many areas because of variable rainfall (FAO 2000). The work being carried out on multifactorial importance of crop improvement, crop management and physiological intervention to address issues related to abiotic stresses particularly waterlogging and salinity in India and Australia is very relevant to enhancing wheat production under a changing climate (Setter *et al.* 2011)

Characterizing the germplasm and modifying the selection criterion particularly for suppressive soils (waterlogging, element toxicity and salinity tolerance) and widening the adaptability in future wheat genotypes is necessary for resilience to diverse environments. The success of any breeding programme will depend upon the magnitude of genetic diversity existing in germplasm, heritability index and harnessing genetic advance present in different yield associated parameters.

The heritability index alone, that also reflects transmissibility is not enough for selection in advance generations under stress conditions. It must simultaneously be accompanied with substantial amount of genetic advance and interrelationship among yield traits. Grain yield is a complex trait and highly influenced by many environmental factors, biotic and abiotic stresses including waterlogging, salinity etc. In any crop breeding programme,

Table 1 Characterization of environments, top ranking genotypes and traits affecting grain yield under each environment

Environment	Feature of environments				Date of sowing	Top ranking genotypes with grain yield (g) per plot in order of merit	Traits showing correlation with grain yield
	Latitude and longitude	Soil conditions	pH	Redox potential (mV)*			
Env.1 (WL) = NDUA&T, Faizabad, waterlogged	26^0 47' N and 82^0 14' E	Salinity with 15 days waterlogging	8.5	120.2.	25 Nov 2009	DBW 59 (480), HI 1563 (449), NW-3069 (413), KRL 268 (387), KRL 19 (387), K 0807 (375), KRL 283 (371), RSP 561 (371), KRL 3-4 (365) and HD 2733 (364).	Tillers/meter and 1000-grain weight
Env.2 = NDUA&T, Faizabad, non-waterlogged	26^0 47' N and 82^0 14' E	Salinity	8.5	415.8	25 Nov 2009	NW (S)-6-5 (790), WESTONIA (691), NWL-7-4 (684), DUCULA 4 (678), DBW 60 (676), DBW 59 (665), KRL 105 (653), AMERY (620), BT-SCHOMBURGK (613) and NW-4092 (592).	Plant stand, days to maturity, tillers/meter and 1000-grain weight
Env.3 (WL) = CSSRI, Karnal, waterlogged	29^0 42' N and 77^0 02' E	Salinity with 15days waterlogging	9.3	165.3	30 Nov 2009	KRL 3-4 (553), KRL 259 (552), Kharchia 65 (519), KRL 240 (480), KRL 105 (477), KRL 268 (466), HD 3028 (450), KRL 238 (449), KRL 283 (435) and HD 2985 (434).	Plant stand, plant height, days to heading, days to maturity, tillers/meter and 1000-grain weight
Env.4 = CSSRI, Karnal, non-waterlogged	29^0 42' N and 77^0 02' E	Salinity	9.3	415.5	30 Nov 2009	KRL 259 (664), KRL 3-4 (628), NW-4035 (605), KRL 210 (599), KRL 240 (595), NW-4081 (593), KRL 283 (589), NW-4018 (585), KRL 229 (582) and GUTHA (580).	Plant stand, tillers/meter and 1000-grain weight
Env.5 = DWR, Karnal, normal	29^0 42' N and 77^0 02' E	Normal	7.2	453.5	04 Dec 2009	PBW 621 (583), DBW 52 (579), HD 3027 (571), KRL 213 (569), RW 3684 (560), NW-1014 (553), CBW 38 (552), DBW 60 (546), NW-4081 (544) and DBW 58 (544).	Plant stand, days to heading, tillers/meter and 1000-grain weight

*Measured after 15 days waterlogging at 10 cm soil depth direct selection for yield under complex environments could be misleading, and therefore, a successful selection will depend upon the information on the genetic variability and association of morpho-agronomic traits with grain yield is a pre-requisite. Correlation coefficients provide a better understanding of the association of different trait(s) with grain yield. The study of associations among various traits is useful to breeders in selecting genotypes possessing groups of desired traits. Keeping all this in view, diverse and elite genotypes (high yielding, disease resistant, abiotic stress tolerant) were included to generate information on genetic variability, relationships of yield and its components and their implication in selection of better genotypes of wheat for suppressive soils in India.

MATERIALS AND METHODS

The experimental material used here consists of 100 diverse but elite genotypes of wheat (high yielding, disease resistant, abiotic stress tolerant) from India and Australia and eight checks. These were planted in an augmented design under five environments during *rabi* season of 2009-2010. The experimental material was planted at two locations, i.e. Karnal (Haryana) and Faizabad (Uttar Pradesh), three sites namely, Narendra Dev University of Agriculture & Technology (NDUA&T), Faizabad; Central Soil Salinity Research Institute (CSSRI), Karnal and Directorate of Wheat Research (DWR), Karnal. The environments included two waterlogging (WL) and two non-waterlogging (NWL) conditions at CSSRI-Karnal and NDUA&T-Faizabad, while a fifth environment was under neutral soil conditions at Directorate of Wheat Research (DWR), Karnal. The distinctive features (latitude, longitude, soil type, pH and date of sowing) of all five environments along with duration for waterlogging at NDUA&T and CSSRI are presented in Table 1. Each entry was planted in a four-row plot of 2.5 m length with 23 cm row to row spacing and 10 cm spacing between plants and within rows. The experiments under five environments were laid out across the three blocks following augmented design wherein the eight checks were repeated twice to generate precise information for economic traits. All the recommended cultural practices were followed to raise normal crop and have proper expression of genotypes. The following observations on seven important metric traits, viz. plant stand, plant height, days to 50 per cent heading, days to maturity, tillers/meter, 1000-grain weight (TGW) and grain yield/plot were recorded at appropriate crop growth stage.

The adjusted mean values were subjected to analysis of variance to test the level of significance. Analysis of variance (ANOVA) for estimating phenotypic and genotypic coefficient of variation, heritability and genetic advance as per cent of mean for all seven traits was performed by adjusted values as suggested by Panse and Sukhatme (1984) and coefficient of variations, heritability, correlation coefficient analysis and cluster analysis was done as per latest available software (SAS version 9.2).

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) for individual environment and also on pooled data indicated significant differences for all the traits except days to heading under waterlogged condition at Faizabad and days to maturity under waterlogged condition at CSSRI, Karnal and also under neutral soils at DWR, Karnal (Table 2). The estimates of genetic parameters, viz. mean, range, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability in broad sense and genetic advance (GA%) are presented in Table 3.

Table 2 ANOVA for seven metric traits based on 108 entries under five environments in wheat

Environment	Source of variation	D F	Mean sum of squares for seven metric traits						
			Plant stand	Plant height	Days to heading	Days to maturity	Tillers /meter	1000-grain weight (g)	Grain yield/ plot (g)
Env.1	Total entries	107	49.6**	96.2**	7.2*	7.6*	242.7**	15.9**	1939.8**
	Error	8	1.6	7.8	3.8	1.8	4.8	0.5	8.9
Env.2	Total entries	107	49.7**	114.5**	7.7*	9.1*	425.1**	12.8**	4377.8**
	Error	8	8.4	7.2	0.3	1.7	17.1	0.5	18.2
Env.3	Total entries	107	935.4**	167.2**	8.1*	7.5*	13768.7**	19.6**	14278.9**
	Error	8	5.2	6.9	2.7	7.1	14.3	0.3	16.7
Env.4	Total entries	107	379.7**	138.9**	25.5**	3.6*	14058.0**	17.3**	4896.8**
	Error	8	3.6	1.8	1.9	0.6	27.4	0.1	17.3
Env.5	Total entries	107	120.7**	108.7**	8.1*	4. 5*	684.5**	26.6**	10062.4**
	Error	8	3.4	3.6	0.9	3.1	4.7	0.9	29.2
Pooled	Total entries	107	92.5**	93.2**	7.4*	2.8	2649.4**	11.5**	1810.4**
	Error	8	0.3	0.8	0.3	1.1	2.5	0.1	5.4

Where, Env.1, Waterlogged condition at NDUA&T, Faizabad; Env.2, Non-waterlogged condition at NDUA&T, Faizabad; Env.3, Waterlogged condition at CSSRI, Karnal; Env.4, Non-waterlogged condition at CSSRI, Karnal; Env.5, Normal conditions at DWR, Karnal and Pooled=Data pooled over five environments. *,** Significant at 5% and 1% level, respectively. Table F value with 107 and 8 degree of freedom at 5% and 1% is 2.95 and 9.45

Table 3 Estimates of mean, range, heritability, variability and genetic advance of bi-plot experiment under all five environments and pooled data over location (108 entries)

Trait	Environment	Estimate					
		Range	Mean	h^2	PCV	GCV	G A
Plant stand	Env.1(WL)	60-90	74.57	53	7.90	6.68	10.77
	Env.2	59-90	73.13	51	8.21	6.09	7.89
	Env.3 (WL)	40-90	49.13	58	44.87	42.63	14.18
	Env.4	30-100	81.18	58	18.88	16.72	17.98
	Env.5	22-62	42.80	54	19.15	17.64	11.34
	Pooled	42-86	64.16	59	12.52	10.48	13.93
Plant height (cm)	Env.1(WL)	48-102	76.06	75	11.20	10.06	12.63
	Env.2	39-97	65.48	78	11.24	9.61	14.16
	Env.3 (WL)	65-129	88.67	72	12.54	10.11	11.68
	Env.4	75-140	98.14	71	10.67	8.30	16.09
	Env.5	71-116	87.47	66	9.24	7.53	11.07
	Pooled	69-113	83.17	68	9.23	8.16	13.89
Days to heading	Env.1(WL)	73-85	79.34	61	1.81	1.58	15.52
	Env.2	76-90	83.11	52	4.52	2.42	13.80
	Env.3 (WL)	95-110	101.69	50	2.28	1.62	12.40
	Env.4	85-105	95.65	56	5.87	3.60	16.57
	Env.5	74-96	84.43	50	3.51	2.25	10.50
	Pooled	83-97	88.84	52	3.21	2.13	11.74
Days to maturity	Env.1(WL)	102-119	110.57	62	1.87	1.48	12.77
	Env.2	110-129	115.04	68	2.09	1.73	13.27
	Env.3 (WL)	136-149	142.60	62	1.89	1.32	15.16
	Env.4	135-145	139.51	63	1.03	0.78	12.17
	Env.5	110-126	119.55	59	2.63	1.72	12.79
	Pooled	121-133	125.45	53	1.11	0.62	11.23
Tillers/meter	Env.1(WL)	31-134	72.41	80	24.89	22.44	12.02
	Env.2	18-111	47.87	88	20.60	19.79	28.26
	Env.3 (WL)	103-276	131.38	83	30.77	30.33	24.63
	Env.4	115-360	228.56	89	19.48	18.45	27.20
	Env.5	186-241	196.36	88	14.93	13.83	27.72
	Pooled	86-329	208.79	89	17.47	17.15	35.87
1000-grain weight	Env.1(WL)	25-42	34.78	87	9.14	8.87	45.55
	Env.2	21-40	31.34	92	7.39	7.12	24.92
	Env.3 (WL)	19-43	33.32	91	9.47	9.44	46.31
	Env.4	25-44	34.68	96	8.55	8.39	35.88
	Env.5	26-40	28.49	93	12.99	12.57	37.15
	Pooled	23-41	32.52	95	7.48	7.35	44.90
Grain yield	Env.1(WL)	161-395	203.25	72	27.11	26.99	31.34
	Env.2	141-238	199.33	79	24.24	23.15	35.78
	Env.3 (WL)	90-275	175.81	71	27.69	26.66	47.75
	Env.4	165-331	245.43	79	11.05	10.02	20.39
	Env.5	214-581	416.41	89	18.09	17.04	34.48
	Pooled	208-399	305.62	89	10.84	9.82	30.70

Where, h^2, Heritability in broad sense; PCV, Phenotypic coefficient of variation; GCV, Genotypic coefficient of variation; GA, Genetic advance as per cent of mean. Environments 1 to 5 as per Table 1.

Genetic variability

The results revealed that genotypic variability was high (Table 3) and that prompted for further analysis. The performance under waterlogged conditions for seven metric traits revealed that tillers/meter ranged between 31-134 (with mean value of 72) at Faizabad environment; 106-552 (with average of 266) at CSSRI, Karnal soil conditions (Table 3). While performance under drained conditions was different as the range for tillers/meter varied from 18-111 at Faizabad; 330-647 with 411 mean value at CSSRI, Karnal conditions; and 186-241 with mean of 133 at DWR, Karnal environment, respectively (Table 3). The range for thousand kernel weight (g) under waterlogged conditions varied from 25-42 (with mean value of 34) at Faizabad location and from 19-43 at CSSRI, Karnal location, while the range for this trait under normal condition was 21-40 at Faizabad;

25-44 at CSSRI and 26-40 (with mean value of 28) in DWR, Karnal (Table 3). The grain yield widely fluctuated over the five environments as evident by its range under waterlogging conditions (Faizabad and CSSRI), with lowest mean value of 203 for waterlogging condition at Faizabad and 303 for waterlogging condition at CSSRI, Karnal. While, values were much higher under normal condition with mean value (491 and 416) at CSSRI, Karnal and at DWR, Karnal locations respectively. It is clearly indicated that the yield recorded in most of the genotypes was adversely affected by waterlogging conditions (Table 3) at CSSRI, Karnal, while at Faizabad the yield under waterlogged conditions was numerically higher than the non-waterlogged conditions.

The phenotypic coefficient of variation was higher than genotypic coefficient of variation for all traits under all five environments (Table 3). Higher phenotypic coefficient of variation and genotypic coefficient of variation indicate that high variability exists among the genotypes.

The PCV was higher for tillers/meter and grain yield per plot than other seven studying traits under all five the environments. The magnitude of phenotypic and genotypic coefficient of variability (PCV and GCV) for different parameters under stressed conditions (waterlogged) were higher than their counterparts under normal, i.e. non-waterlogged conditions, which indicated that wide variability is manifested under waterlogged stress for exercising the selection. The coefficient of variation estimated (PCV and GCV) under neutral soil conditions and also of the pooled data showed similar pattern thereby revealing opportunity of improvement in these traits through direct selection under normal, waterlogged and non-waterlogged (Sodic and alkaline) soils conditions. A close observation of estimates of GCV and PCV suggested that environment had little role in the expression of traits like plant height, day to maturity and thousand grain weight under normal and waterlogged conditions based on two locations data. Whereas, traits like plant stand, days to heading, tillers/meter and grain yield were having moderate to high influence of the environment (waterlogged, non-waterlogged and neutral) at three locations.

High PCV (44.9%) and GCV (42.6 %) were observed for plant stand under waterlogged conditions at CSSRI, Karnal. Similarly, high PCV for tillers per meter and grain yield (30.8%, 27.7 %) was recorded under waterlogged conditions. Besides, moderate PCV (18.1%) and GCV (17.0 %) for grain yield under neutral soils conditions at DWR, Karnal was observed which indicated that even under normal conditions yield improvement is feasible putting due emphasis on higher yield while selecting promising genotypes. Higher PCV than GCV indicated that the visible variation in the expression of traits was not only due to genotypes alone but also due to varying influence of environment.

Heritability and genetic advance

The estimates of high heritability (broad sense) and high genetic advance (GA% of mean) indicate additive gene action and hence improvement in these traits could be possible by direct selection (Panse 1957). The traits included grain yield and to some extent tillers/meter in both normal and stressed (waterlogged) conditions and plant stand under non-waterlogged and neutral conditions at Karnal. The higher heritability (more than 70%) along with higher genetic advance (more than 20%) was recorded for tillers/meter, thousand kernel weight and grain yield/plot under all environments. Moderate heritability with moderate genetic advance was recorded for plant height under all the environments. The heritability along with genetic advance was lower under waterlogging conditions for tillers/meter, thousand kernel weight and grain yield/plot comparable to drained conditions (Table 3). Singh *et al.* (2006) however reported high heritability under waterlogging for most of the traits except days to maturity and grains/ear. This might be due to different set of genotypes used in the study.

In general, plant height and thousand grain weight across all environments and grain yield under stressed environment and also under neutral soils conditions revealed moderate estimates of heritability. Moderate to high estimates of genetic advance were recorded for thousand grain weight, grain yield and tillers/meter under normal as well as stressed environment (waterlogged). Whereas, high values of heritability coupled with moderate to low estimates of genetic advance for traits like plant stand, plant height, days to heading and days to maturity indicated role of non additive gene action in the expression of these traits. In case of traits showing moderate values of heritability and genetic advance, slight improvement through direct selection could be possible. For non-waterlogged sites the results here confirm to the earlier reports of Pawar *et al.* (2002). Gupta *et al.* (2004) who also reported high heritability for days to heading, plant height, tillers/plant, spike length and spikelets/spike, spike weight, seeds/plant and leaf blight. Sardana *et al.* (2007) suggested that high heritability may not necessarily lead to increase genetic gain, unless sufficient genetic variability existed in the germplasm and low heritability has been achieved for the grain number/spike as reported by Ayciceck and Yildirim (2006). Some authors reported moderately high heritability for spikelets per spike (Kashif and Khaliq 2004). The highest heritability coupled with high genetic advance for plant height and 1000-grain weight whereas, lowest heritability and expected genetic advance for grain yield and test weight was reported by Oguz *et al.* (2011). For plant height and number of tillers/plant, high heritability along with high genetic advance was reported by Gulzaz *et al.* (2011). High heritability along with high genetic advance for some metric traits was reported by Singh *et al*. (2011).

High heritability coupled with high genetic advance and high coefficient of variability for grain yield/plot and plant height showed scope for improvement following selections. However, in case of characters like days to heading, spike length and spike weight showing high heritability but moderate to low genetic advance, which

Table 4 Phenotypic correlation coefficients based on108 elite lines for seven traits under five environments and pooled data over the location in case of bread wheat (*Triticum aestivum*)

Trait	Environment	Plant height	Days to heading	Days to maturity	Tillers/ meter	1000–grain weight	Grain yield
Plant stand	Env.1(WL)	0.15	0.09	0.21*	0.27**	–0.31**	0.14
	Env.2	0.38**	0.11	0.36**	0.51**	–0.04	0.60**
	Env.3 (WL)	0.12	–0.36**	–0.65**	0.53**	0.12	0.42**
	Env.4	0.24*	–0.09	–0.28**	0.37**	–0.05	0.26**
	Env.5	0.20*	–0.23*	–0.16	0.21*	–0.20*	0.31**
	Pooled	0.19*	–0.18	–0.15	0.43**	0.33**	0.39**
Plant height	Env.1(WL)		–0.06	0.08	0.42**	0.22*	–0.39**
	Env.2		–0.01	0.31**	0.33**	0.14	0.39**
	Env.3 (WL)		–0.14	–0.12	0.43**	0.20*	–0.38**
	Env.4		0.03	–0.03	0.39**	0.19*	0.22*
	Env.5		–0.03	0.08	–0.31**	0.12	0.28**
	Pooled		0.01	0.09	0.39**	0.23*	0.27**
Days to heading	Env.1(WL)			0.44**	–0.22*	0.01	0.13
	Env.2			–0.60**	0.07	–0.31**	–0.08
	Env.3 (WL)			0.43**	–0.18	–0.35**	–0.20*
	Env.4			–0.25**	0.29**	–0.40**	–0.03
	Env.5			–0.47**	–0.21*	–0.12	–0.37**
	Pooled			0.64**	0.21*	–0.31**	–0.39**
Days to maturity	Env.1(WL)				0.11	–0.14	–0.09
	Env.2				0.40**	–0.41**	–0.26**
	Env.3 (WL)				–0.43**	–0.16	–0.44**
	Env.4				–0.04	–0.10	–0.18
	Env.5				0.45**	0.21*	0.52**
	Pooled				0.18	–0.14	–0.15
Tillers/meter	Env.1(WL)					–0.30**	0.33**
	Env.2					–0.16	0.38**
	Env.3 (WL)					–0.31**	0.66**
	Env.4					–0.22*	0.31**
	Env.5					–0.30**	0.42**
	Pooled					–0.21*	0.40**
1000–grain weight	Env.1(WL)						0.42**
	Env.2						0.25**
	Env.3 (WL)						0.44**
	Env.4						0.24*
	Env.5						0.61**
	Pooled						0.31**

*, **, Significant at 5% and 1% level respectively.

may be due to non-additive gene action and presence of G × E interaction, simple selection may not be rewarding (Singh *et al*. 2003). Different researchers like Ansari *et al*. (2005) and Inamullah *et al*. (2006) in their studies have reported the presence of high heritability and genetic advance in different yield related attributes in wheat.

Correlation coefficients

The phenotypic correlation coefficients among seven traits were also worked out to see the association between these traits (Table 4). The yield is the end product of contributions made by several component traits that are directly or indirectly associated with grain yield. If the association is positive, improvement in one character will simultaneously bring about an improvement in other. However, the negative association between two economic traits is useful for characteristics, like plant height, maturity duration and days to heading.

The significant and positive correlation co-efficient were found between tillers/meter and 1000-grain weight with grain yield/plot under all environments. While, tillers per meter was significantly and negatively correlated with thousand kernel weight under all environments. The days to heading was significantly and positively correlated with days to maturity under waterlogging conditions in Faizabad and CSSRI, whereas, it showed significant but negative correlation with days to maturity under non-waterlogging conditions. The plant stand was significantly and positively correlated with plant height in drained condition, while in waterlogging conditions non- significant correlations were found with plant height. The plant height was significantly and positively correlated with 1000 grain weight in waterlogging, while not in drained conditions. It is evident that shorter plant height is desirable for higher grain yield. The plant height was significantly and negatively correlated with grain yield/plot in waterlogging conditions.

At phenotypic level, positive and significant correlation coefficients revealed that under all the normal and stressed environments used here, grain yield is directly influenced by plant stand, tillers/meter and thousand grain weight. While, significant but negative correlation of grain yield with plant height under stressed (waterlogged) conditions at both locations (Karnal and Faizabad) indicated that height alone is not the contributor to yield under stressed environment but may be through some other traits which are tillers/meter, days to maturity and thousand grain weight. It was interesting to note that 1000-grain weight was having negative association with tillers/plant but both these traits were direct contributors of yield under all environments. Khan *et al*. (2004) also reported significant and positive correlation between grains/spike, effective tillers/plant and spike weight with yield/plant, thus supporting our results. Khan *et al.* (2003) reported positive correlation of grain yield with plant height, number of tillers/plant, grains/spike and 100 grain weight both at genotypic and phenotypic levels. Similar to our findings, the number of effective tillers/plant, number of spikelets/panicle and harvest index gave significant positive correlation with grain yield/plant both at genotypic and phenotypic level as reported by (Kotal *et al.* 2010). Some authors also reported that grain yield/plant showed highly significant and positive correlation with biological yield/plant, grains/spike, spike weight, tillers/ plant and ear length whereas, plant length has significant and positive association with grain yield (Singh *et al.* 2010).

The grain yield was positively and significantly correlated with gain weight, grains/spike, test weight, plant height, spikelets/spike, 1000-grain weight and spike length whereas, negatively correlated with days to 50% flowering as reported by Oguz *et al*. (2011). Significant and positive correlations were also estimated between tillers/meter and 1000-grain weight with grain yield/plot by Singh *et al.* (2012).

The results of correlation coefficients of inter-relationship of traits under normal and stressed environment showed that tillers/plot had positive correlations with plant stand and plant height under all environments except plant height with tillers/plot in neutral conditions. This is quite possible due to the fact that initial crop establishment and biomass production is directly influenced by plant stand and plant height, particularly under stressed environment where number of effective tillers as well as plant height are adversely affected.

Cluster analysis

The cluster analysis based on pooled data over five environments indicated that 108 genotypes were grouped in four clusters having 41, 22, 11 and 34 genotypes, respectively (Table 5). The grouping of genotypes and their possible classification for use in hybridization programme as donors for economic traits is very clear, and largely parents selection for stressed environment (salinity and waterlogging), based on present study might give transgressive segregants for desired traits. The genotypes were grouped while subjecting the similarity values to clustering pattern based on dendrogram involving seven traits based on 108 genotypes (Fig 1). From the clustering pattern and genetic relationship, breeders can identify the diverse genotypes from different clusters and utilize them in future hybridization programmes. Besides, the information generated on variability, inter-relationship and clustering may be useful for developing strategies to improve wheat yields under abiotic stress particularly salinity and waterlogging conditions. The results clearly indicated that the performance of genotypes under each environment showed variation, thereby revealing the roll of genotype *x* environment.

The top ranking genotypes and their grain yield in order of merit presented (Table 1), clearly indicates that the grain yield under waterlogged situations was as expected lower than non-waterlogged conditions except Faizabad

Table 5 Cluster-wise distribution of bread wheat genotypes under pooled (waterlogging and non-waterlogging) conditions

Cluster	Total genotypes	Genotype
I	41	NW 3069, UP 2003, WESTONIA, PBW 343, NWL -9-23, KRL 240, NW 1067, PBW 621, HD 3024, NW 4098, NWL-9-24, GUTHA, HUW 636, NW 4092, HD 3027, KRL 266, NW 4018, DUCULA 4, KRL 105, DBW 52, K 9107, NW 4035, K 0808, NW 1014, KRL 238,NW 4081, KRL 35, DBW 60, SPEAR, CBW 38, NW 1076, BT-SCHOMBURGK, DBW 58, KRL 259, KRL 268, KRL 283, KRL 1-4, RW 3684, DBW 59, KHARICHIA 65 and KRL 3-4.
II	22	CAMM, GAMENYA, NW 1012, CHIRYA 7, CHARA, DBW 51, KRL 104, KRL 99, DBW 55, CUNDERDIN, KALANNIE, DBW 50, PERENJORI, AMERY, PBW 590, NW 3087, NW 4099, KRICHAUFF, BH 1146, BROOKTON, KRL 236 and SCHOMBURGK.
III	11	PBW 639, PBW 642, PBW 635, NWL-9-22, HD 2997, NWL-9-25, PBW 634, PBW 636, HD 2009, DBW 14 and RAJ 4205.
IV	34	KRL 229, KRL 19, HD 2985, NW (S)-2-4, HUW 635, NW-4082, KRL 210, DBW 46, NW-4091, TINCURRIAN, KRL 213, RSP 561, UP 262, DBW 39, HD 3028, WH 1094, RAJ 4201, HUW 638, K 0807, HI 1563, KRL 233, KRL 227, RAJ 3765, NW 4083, NW (S)-6-5, NWL-7-4, PBW 550, HD 2733, NW 2036, PBW 631, KRL 249, DBW 17, KRL 261 and HD 2967.

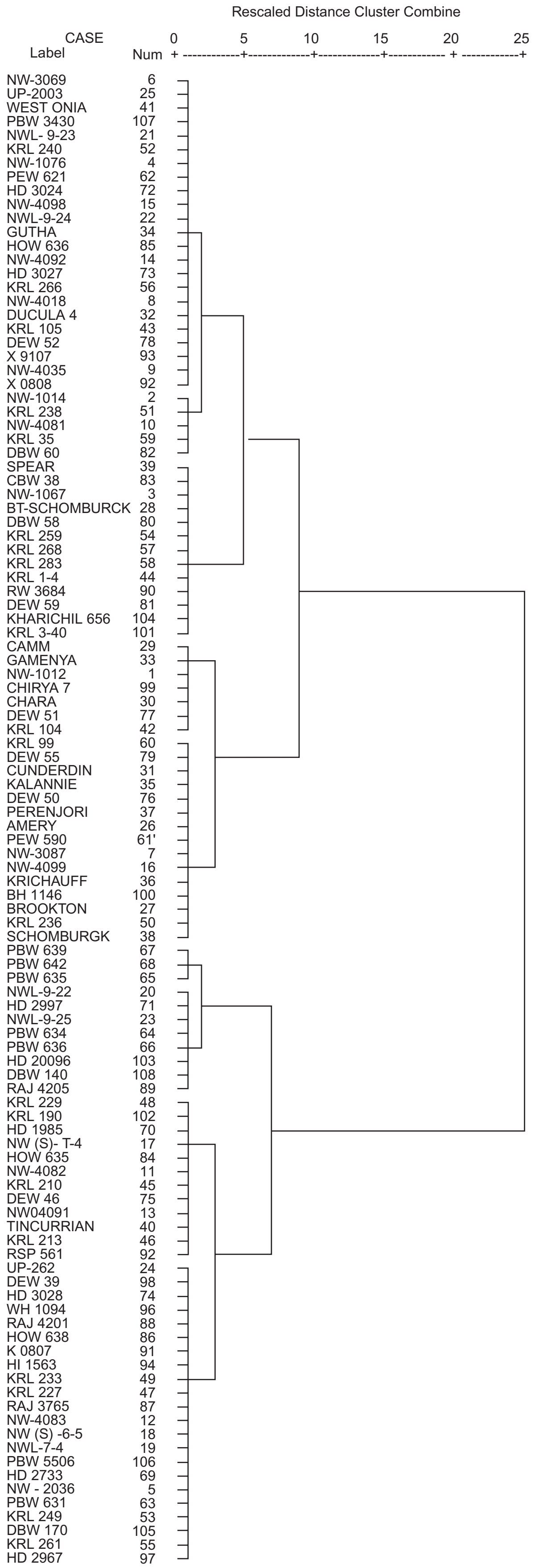

Fig 1 Dendrogram based on pooled data over five environments for 108 wheat genotypes

where numerically higher yield was recorded under waterlogged conditions.

The Faizabad location was found to be superior in term of grain yield realization under waterlogged conditions while at CSSRI, Karnal the yield was higher under non-waterlogged conditions. This finding is also supported by the performance of genotypes for yield attributes and there inter-relationship under varying conditions. The performance of genotypes under neutral soil conditions at DWR, Karnal was in accordance of our assumption for high yield and disease resistance as better performing genotypes like PBW 621, DBW 52, HD 3027, KRL 213, RW 3684 were in the top ranking genotypes and few of these have already been released for commercial cultivation. Genotype KRL 213 which is primarily for saline situation also performed better under neutral soils, thus showing promise for higher yield under reclaimed soils.

The spring wheat Ducula was shown to be very tolerant to waterlogging under North-western Mexican conditions, expressing only 12 per cent leaf chlorosis relative to 71 per cent chlorosis in the sensitive check Seri-82. Shoot weight was severely reduced by waterlogging and also stomata conductance in waterlogging sensitive genotypes, all stomatal activity will cease three days after the onset of waterlogging, while stomatal conductance in tolerant cultivars such as Savannah will continue. It has been reported that waterlogging reduces spike number/m^2 in winter wheat by about 20-50% and that the decrease in spike number/m^2 becomes important after 10 days of waterlogging (Collaku and Harisson *et al.* 2002). It has been reported that selection for responsiveness to increase moisture should be carried out initially under optimum conditions during early generations with higher heterozygosity and then could be applied at low or high moisture levels in the subsequent generations (Kirgiwi *et al.* 2004). They reported that selection under optimum conditions enables the identification of genotypes with responsiveness to increase moisture while selecting under low or high irrigated conditions identifies high yielding lines carrying traits for performance under stress conditions.

In summary, the present study reveals that, wide genetic variability exists in wheat grown in environments limited by abiotic stresses like waterlogging and salinity. Three traits, tillers/metre, thousand grains weight and grain yield per plot showed a high heritability with high genetic advance across five diverse environments used here, indicating a significant scope for improving grain yield through simple hybridization and selection. The high and positive correlations across these diverse environments will help in improving the grain yield through selection and the high heritability and genetic advance will be useful for population improvement through hybridization. Distribution pattern of all the genotypes into various clusters showed the presence of considerable genetic divergence among the genotypes for most of the traits.

Based on the result obtained from present study, it may be concluded that 1) significant genetic variation exists even in this limited population of 100 genotypes, and 2) germplasm characterization, variability assessment, the inter-relationships of traits and clustering pattern under normal, waterlogged and neutral conditions, can be utilized in hybridization to obtain the transgressive segregants for desired traits. Whether these results can be repeated in different environments or seasons; and whether these results relate to other abiotic stresses will need to be confirmed in further research.

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