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Germplasm characterization and selection indices in bread wheat (*Triticum aestivum*) for waterlogged soils in India

GYANENDRA SINGH[1], M K SINGH[2], B S TYAGI[3], J B SINGH[4] and PRADEEP KUMAR[5]

ICAR-Indian Institute of Wheat and Barley Research, Karnal, Haryana 132 001

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ABSTRACT

In a study, field screening of 109 elite Indian and exotic lines was carried out under normal and waterlogged soil conditions for two consecutive years (2012-13 and 2013-14). Results revealed high GCV along with high heritability and genetic advance for plant height and 1000-grain weight and these two traits were found most desirable in germplasm characterization for waterlogging tolerance. The geometric mean productivity (GMP), harmonic mean (HM), stress tolerance index (STI) and mean productivity (MP) were positively correlated with grain yield under stress (Ys) and non-stress conditions (Yp). There was a negative association between stress susceptible index and yield under normal conditions (Yp), whereas tolerance index (TOL) was positively correlated with Yp and negatively with yield under waterlogged conditions (Ys) during both the years (2012-13 and 2013-14). The promising lines, viz. BH 1146, DBW 39, DBW 52, NW 1014, NW 1067, NW 4081, PBW 621, PBW 631, PBW 590, RW 3684, HD 2967, HD 2997 and NW 4083 were selected on the basis of GMP, STI, MP, HM, and STS and rated as highly tolerant for waterlogged soils. However, the lines identified on the basis of stress susceptible index (SSI) and tolerance index (TOL) only could be suitable for normal and waterlogged conditions. The lines thus identified included; Perenjori, PBW 343, PBW 636, KRL 268, RAJ 4201, RAJ 4205 and WH 1094. It is anticipated that these lines will be utilized as donors for incorporation of waterlogging tolerance genes. The research findings also imply that tolerant lines eventually would lead to higher production and productivity under, heavy rainfall and prolonged stagnant water situations (adversely affect the wheat crop). These lines may also be utilized in hybridization programme for developing next generation mapping (MAGIC and NAM) populations for fine QTLs scanning for waterlogging tolerance.

Key words: Bread wheat, Waterlogging tolerance, Germplasm characterization, Selection indices

Wheat is second most important cereal crop in context of global food and nutritional security. In India, the wheat crop occupies 31.2 million ha area with the production of 95.9 million tonnes and average yield of 3.11 tonnes/ha, during 2013-14 (Anonymous 2015). Globally, anticipated climate change could cause frequent occurrence of heavy rainfalls, reduction in freshwater availability and saltwater intrusion close to the coastal area that can adversely affect agricultural production worldwide (Climate Change 2007).

Waterlogging is a precondition of the soil where, excess water limits gas diffusion; while, waterlogging tolerance is specified as a survival or the maintenance of high growth rates, biomass accumulation or grain yield under waterlogging relative to non-waterlogged conditions (Setter and Waters 2003). It was proposed that waterlogging tolerance is often a product of tolerance to anaerobiosis and to element toxicities as Mn, Fe, Na, Al and B (Khabaz-Saberi *et al.* 2006). It is necessary to develop wheat cultivars with high yield potential along with disease resistance and tolerance to excessive water conditions. For identifying stress-tolerant cultivars, several selection indices described hereunder have been proposed along the basis of mathematical relationships between stress and non-stress conditions (Huang 2000). Tolerance (TOL; Clarke *et al.* 1992), mean productivity (MP; Mccaig and Clarke 1982), stress susceptibility index (SSI; Fischer and Maurer 1978), geometric mean productivity (GMP) and stress tolerance index (STI; Fernandez 1992) and many of these have been employed under various stress conditions.

The traits namely; MP, GMP, HM and STI were reported as preferred selection criteria for selecting drought-tolerant barley genotypes (Baheri *et al.* 2003). Selection for MP is likely to increase yield in both stress and non-stress environment, while selection for tolerance will result in reduced yield in both stress and non-stress conditions (Dodig *et al.* 2008). It was also reported that under moderate stress conditions the mean productivity, geometric mean productivity, harmonic mean and stress

[1]Principal Scientist (e mail: gysingh@gmail.com), IIWBR, Karnal. [2]Breeder-Barley (e mail: drmksinghgene@gmail.com) Group Limagrain, Alwar 301 001, Rajasthan. [3]Principal Scientist (e mail: bs.bstknl@gmail.com), IIWBR, Karnal. [4]Senior Scientist (e mail: jangbsingh@gmail.com) IARI, Indore. [5]Senior Research Fellow (e mail: pradeeptaliyan231@gmail.com), IIWBR, Karnal.

tolerance index were the most effective stress indices for identifying promising bread wheat cultivars with high yield potential under both stress and non-stress conditions (Sio-Se Mardeh *et al.* 2006).To improve the efficiency of STI, a modified stress tolerance index (MSTI) was suggested, which corrects the STI as a weight (Farshadfar and Sutka 2002). High yield along with stability of a genotype is an important consideration in breeding programmes (Kang 2002), where stringent phenotypic selection has to be imposed for identifying suitable plant type comprising desirable agronomic traits for waterlogging tolerance. Keeping above in view, present study was conducted with the objectives to estimate genetic parameters for phenological traits and correlation between selection indices and eventually select better performing elite lines for waterlogging stress tolerance.

MATERIALS AND METHODS

A set of 109 elite Indian and exotic bread wheat lines including five standard checks. Among the cheks DBW 14, DBW 16, DBW 17 are better performing under non-stress conditions while HD 2009 and KRL 3-4 have potential for contrasting performance under waterlogged conditions. The experimental material comprised three types of genetic material, i) set of 16 elite exotic lines (Amery, Brookton, Bt-Schomburgk, Camm, Chara, Cunderdin, Ducula 4, Gamenya, Gutha, Kalannie, Krichauff, Perenjori, Schomburgk, Spear, Tincurrin, Westonia), obtained from Australia, ii) set of released Indian varieties coupled with elite lines under testing in trials and genetic stocks from India and iii) set of advanced lines selected for better yield in northern India.

The experiment was laid out in augmented design with replicated checks and unreplicated elite lines within an environment (Federer 1956). This design requires only seeds for one replicate per test line for each environment, while four replications of each check were used for local error control (Stringer and Cullis 2002). The experiments were conducted during 2012-13 and 2013-14 under non-waterlogged and waterlogged conditions at ICAR-Indian Institute of Wheat and Barley Research (erstwhile Directorate of Wheat Research- DWR), Karnal. Each genotype was planted in four-row plot of 2.0 m length keeping row spacing of 23 cm and 10 cm between plants within a row. There were four blocks, and each block consisted of 26 elite lines. The same set of checks was randomly planted in each block with test entries. Recommended agronomic practices were followed to raise good crop under normal and waterlogging conditions. In case of waterlogged field, the stagnant water was allowed for a week at different growth stages of the crop, viz. 10 days after sowing (DAS) at emergence stage, 21 DAS (at seedling stage), 35 DAS (at tillering stage), 50 DAS (at reproductive stage) and 70 DAS (at grain-filling stage).

Observations were recorded for plant height (cm), spike length (cm), 1000-grain weight (g) and grain yield/plot (g) to assess performance of genotypes under normal or non-waterlogged (NWL) as well as waterlogged (WL) soils. For measuring plant height, observations were taken from base of soil surface to terminal of spike on five randomly selected plants from each plot; spike length was measured from base of spike to terminal awns; for 1000-grain weight random sample of 1000-grains from each plot was taken with help of automatic seed counter and weighed, and grain yield/plot (g) was taken from one m long four-rowplot in each block. The data recorded were then subjected to analysis.

The adjusted mean of test lines calculated as per statistical procedure (Johnson *et al.*1955) was used for analysis of variance (ANOVA) with the help of Statistical software (Genstate 14^{th} Edition). The estimates of genetic variability and correlation coefficients were calculated by utilizing adjusted mean as per statistical software SAS version 9.3 (SAS Institute 2011).

Various indices were estimated by using following mathematical formulae, given by different researchers.

1. Percentage reduction = (Normal - Waterlogged) /Normal*100 (Choukan *et al.* 2006).
2. Stress susceptible index (SSI) = {(1-Ys/Yp)/ (1- (Ys/Yp)} (Fischer and Maurer 1978).
3. Modified stress tolerance index (MSTI)= (A) $K_1STI= [(Yp)^2/(Yp)^2]$(B) $K_2STI= [(Ys)^2/(Ys)^2]$ (Farshadfar and Sutka 2002).
4. Tolerance (TOL)= (Yp-Ys) (Hossain *et al.* 1990).
5. Geometric mean productivity (GMP) = $(Ys+ Yp)^{0.5}$ (Fernandez 1992).
6. Mean productivity (MP) = (Ys+Yp)/2 (Hossain *et al.* 1990).
7. Harmonic mean (HM) = 2(Yp×Ys)/ (Yp+Ys) (Kristin *et al.* 1997).

where, Yp and Ys represent yield under normal and waterlogged environment. To calculate stress tolerance score, following equation was proposed by Abdolshahi *et al.* (2013).

Stress tolerance score (STS) = $GMP^1+STI^1+HM^1+MP^1-TOL^1-SSI^1$

Considering waterlogging tolerance or sensitivity equation, large value for geometric mean productivity, stress tolerance index, harmonic mean and mean productivity would be preferable, while smaller value would be preferred for a stress susceptible index and tolerance that represent relatively more tolerant to waterlogging stress. This way, parameters namely; MP^1, STI^1, GMP^1 and HM^1should have positive value, while SSI^1 and TOL^1should have negative value for finding superior lines. Indeed, it should be kept in mind that the above equation is not accurate for raw values of stress indices thereby all the indices were standardized as per equation given below (Abdolshahi *et al.* 2013).

$$Z_{ij}=[(X_{ij}-X_i)/S_i]$$

where,Z_{ij}=Represent standard score for $_j$th entry in the $_i$th index; X_{ij}=Raw value of $_j$th entry in the $_i$th index; and X_i=Mean of $_i$th index, and S_i =Standard deviation of the $_i$th index. After doing standardization of all the indices values, calculated the stress tolerance score by deployment of above equation.

RESULTS AND DISCUSSION

Analysis of variance

Results indicated that material under study showed wide genetic variation as evident from analysis of variance (ANOVA) for all the four important traits, viz. plant height, spike length, 1000-grain weight and grain yield. The genotypes, including checks and also excluding checks, showed high significant differences under both non-waterlogged and waterlogged environments, over both the years, i.e. 2012-13 and 2013-14 (Table 1).

Genetic parameters

The estimates of mean, range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability (h^2) in broad sense and genetic advance (GA) as a percentage of mean for four traits, under non-waterlogged and waterlogged environment, in the year 2012-13 (Y1) and 2013-14 (Y2) are presented in Table 2. It is noteworthy that during both the years, the mean values were higher under non-waterlogged environment than waterlogged environment, while range is similar in both environments for all the traits. Under waterlogged environment, higher estimates of PCV, then GCV were observed over both the years for spike length and grain yield comparable to non-waterlogged one, indicating a major role of environmental effects in genotypic performance and governing the behavior of these two traits.

Under waterlogged conditions, the genotypic coefficient of variation for plant height (10.20, Y1 and 13.52, Y2) was much higher along with high heritability (87%, Y1 and 94%, Y2) and moderate to high genetic advance (19.61 Y1 and 27.01 Y2) as percent of mean, during both the years. Similarly, for 1000-grain weight higher GCV (14.40, Y1 and 15.61, Y2) with high heritability (94%, Y1 and 96%,

Table 1 Analysis of variance (ANOVA) for plant height, spike length, thousand grain weight, and grain yield under non-waterlogged and waterlogged conditions over the year 2012-13 and 2013-14

Source of variation	Degree of Freedom	Year	Condition	Calculated F-value			
				Plant height (cm)	Spike length (cm)	1000-grain weight (g)	Grain yield/plot (g)
Blocks (excluding checks and entries)	3	2012-13	NWL	1.01	0.46	2.51	0.41
		2013-14	NWL	1.75	1.36	0.89	0.48
		2012-13	WL	2.55	0.58	0.38	0.24
		2013-14	WL	1.86	0.34	0.80	0.56
Entries (including checks and excluding blocks)	108	2012-13	NWL	26.04**	2.80*	35.79**	18.43**
		2013-14	NWL	32.41**	2.73*	30.51**	13.24**
		2012-13	WL	10.52**	3.85**	33.44**	6.78**
		2013-14	WL	24.10**	3.81**	38.24**	3.90**
Checks	4	2012-13	NWL	78.36**	5.15*	88.37**	59.60**
		2013-14	NWL	183.50**	4.11*	69.28**	69.96**
		2012-13	WL	61.04**	3.78*	31.60**	12.44**
		2013-14	WL	135.19**	3.88*	71.66**	26.90**
Entries (excluding checks)	103	2012-13	NWL	22.65**	2.51*	31.62**	16.90**
		2013-14	NWL	24.19**	3.21*	29.26**	10.89**
		2012-13	WL	18.91**	2.72*	32.37*	6.06**
		2013-14	WL	19.46**	3.68**	37.31**	4.03**
Checks vs. Entries	1	2012-13	NWL	165.82**	15.89**	7.48*	11.22**
		2013-14	NWL	274.85**	16.13**	7.16*	28.77**
		2012-13	WL	134.10**	14.58**	4.09	57.54**
		2013-14	WL	257.46**	17.18**	2.01	65.69**
Error	12	2012-13	NWL	(4.29) ^{MS}	(0.85) ^{MS}	(0.32) ^{MS}	(4403.37) ^{MS}
		2013-14	NWL	(3.41) ^{MS}	(0.44) ^{MS}	(0.83) ^{MS}	(6834.08) ^{MS}
		2012-13	WL	(10.07) ^{MS}	(0.57) ^{MS}	(1.78) ^{MS}	(12574.44) ^{MS}
		2013-14	WL	(8.15) ^{MS}	(0.35) ^{MS}	(1.05) ^{MS}	(25107.72) ^{MS}

*, **Significant at 5% and 1% probability level, respectively. F table values as degree of freedom of 12/3 (3.49 and 5.95); 12/108 (2.34 and 3.49); 12/4 (3.26 and 5.41); 12/103 (2.35 and 3.46) and 12/1 (4.75 and 9.33) at 5% and 1% probability level respectively. MS= Mean sum of square.

Table 2 Estimates of genetic parameters for plant height, spike length, 1000-grain weight and grain yield under non-waterlogged and waterlogged conditions during 2012-13 and 2013-14

Trait (s)	Year	Environment/ condition	Range	Mean	PCV	GCV	h^2	GA
Plant height (cm)	2012-13	NWL	50	85.41	10.73	10.45	94	20.98
	2013-14	NWL	49	93.93	8.99	8.78	95	17.64
	2012-13	WL	50	81.12	10.92	10.20	87	19.61
	2013-14	WL	66	84.08	13.94	13.52	94	27.01
Spike length (cm)	2012-13	NWL	6	10.70	13.10	9.85	56	15.24
	2013-14	NWL	4	9.56	9.97	7.11	50	10.45
	2012-13	WL	6	10.43	11.45	8.85	59	14.08
	2013-14	WL	5	9.91	10.89	8.09	49	15.64
1000-grain weight (g)	2012-13	NWL	21	33.26	8.94	8.77	96	17.74
	2013-14	NWL	24	35.57	12.94	12.68	96	25.60
	2012-13	WL	11	32.84	14.99	14.40	94	16.67
	2013-14	WL	21	31.96	15.86	15.61	96	31.66
Grain yield/plot (g)	2012-13	NWL	1324	1039.62	24.64	23.79	93	47.30
	2013-14	NWL	1313	1043.18	24.71	23.37	89	45.54
	2012-13	WL	1256	809.39	32.04	28.89	81	53.66
	2013-14	WL	1210	810.39	32.46	25.89	63	42.55

R= Range (highest - lowest value); M= Mean of the adjusted values of 104 entries; PCV= Phenotypic coefficient of variance, GCV= Genotypic coefficient of variation, h^2 = Heritability in broad sense and GA%= Genetic advance as percentage of mean.

Y2) and moderate to high genetic advance (16.67, Y1 and 31.66, Y2), were observed as compared to non-waterlogged environment. The moderate estimates of heritability (81%, Y1 and 63%, Y2) along with high GCV (28.89, Y1 and 25.89, Y2) and also with higher genetic advance (53.66, Y1 and 42.55, Y2) were found for grain yield under waterlogged conditions than non-waterlogged one (Table 2).

Correlation coefficients among indices

To determine the most desirable indices for waterlogging tolerance, the correlation coefficients between Yp, Ys and other quantitative indices were calculated for both the years and presented in Table 3. It is apparent from the results that for grain yield GMP, HM and STI had positive and significant correlation with Yp and Ys, whereas, SSI and TOL indices exhibited a highly significant negative correlation and thus were better predictors of Yp and Ys comparable to other indices for non-waterlogged and waterlogged conditions. Correlation analysis showed that tolerance (TOL) had a significant and positive correlation (r=0. 41, Y1 and 0.36 Y2) with Yp but negative correlation (r = -0.50 Y1 and 0.48 Y2) with Ys during both the years. Similarly, stress susceptible index showed a significant but negative association (r = -0.64 Y1 and -0.66Y2) with the yield under waterlogged conditions (Ys) and non-significant correlation with yield under non-waterlogged conditions (Yp). The geometric mean productivity showed a highly significant association (0.81 with Yp and 0.94 with Ys) during first year and (0.85 with Yp and 0.95 with Ys) during the second year. Harmonic mean (HM) also had significant correlation with Yp and Ys) during both the years.The modified stress tolerance index (MSTI) exhibited a positive and significant correlation with grain yield under non-waterlogged conditions and waterlogged conditions over the year one and two (Table 3). It is apparent from the results (Table 4) that the five selection indices, namely; SSI, GMP, TOL, HM and STI could be used while selecting the best performing genotypes under waterlogged conditions, and accordingly these indices could also be used for identifying stable potential lines for waterlogging tolerance.

Identification of elite lines

It was observed that the patterns of correlation between different indices were significant with Yp and Ys and has been used for selecting the waterlogging tolerant genotypes. All the six indices were derived based on grain yield of a particular line under non-waterlogged and waterlogged conditions during the years 2012-13 and 2013-14 and supported by mean grain yield. It has been earlier reported that higher tolerance (TOL) value could lead to yield reduction under stress conditions and thus show higher sensitivity for waterlogged stress conditions. Conversely, selection based on minimum yield reduction under stress in comparison to non-stress conditions, did not help in identifying the most tolerant lines (Rizza *et al.* 2004). It was noted that greater tolerance and stress susceptible index values lead to greater sensitivity to stress and therefore smaller value for these two indices would be favorable.The estimates of SSI and TOL for 104 test lines and 5 checks were compared and presented in ascending order while GMP, K1STI and K2STI are presented in descending order. Top ten elite lines along with their indices value and those better

Table 3 Correlation coefficients among the selection indices for grain yield during 2012-13 (above diagonal) and 2013-14 (below diagonal) in wheat

Selection indices	Yp	Ys	PRPH	PRSL	PRTGW	SSI	GMP	TOL	HM	K_1STI	K_2STI
Yp	-	0.58**	0.09	0.06	0.15	0.23	0.81**	0.41**	0.75**	0.99**	0.61**
Ys	0.64**	-	-0.12	-0.04	0.06	-0.64**	0.94**	-0.50**	0.97**	0.57**	0.98**
PRPH	-0.13	-0.14	-	-0.02	-0.04	0.25	-0.06	0.23	-0.09	0.08	-0.07
PRSL	-0.14	-0.08	0.15	-	-0.04	0.09	-0.01	0.11	-0.03	0.07	-0.01
PRTGW	-0.07	0.04	-0.10	-0.08	-	0.06	0.09	0.10	0.08	0.14	0.05
SSI	0.12	-0.66**	0.05	0.00	-0.13	-	-0.36**	0.96**	-0.45**	0.23	-0.56**
GMP	0.85**	0.95**	-0.15	-0.11	0.01	-0.41**	-	-0.19	0.99**	0.80**	0.93**
TOL	0.36**	-0.48**	0.02	-0.06	-0.13	0.95**	-0.18	-	-0.29	0.42**	-0.45**
HM	0.80**	0.97**	-0.15	-0.10	0.02	-0.48**	1.00**	-0.26	-	0.74**	0.94**
K_1STI	0.98**	0.62**	-0.12	-0.11	-0.07	0.13	0.83**	0.37**	0.78**	-	0.60**
K_2STI	0.65**	0.98**	-0.13	-0.05	0.02	-0.60**	0.93**	-0.45**	0.94**	0.64**	-

** Significant at 0.001 probability level ($p < 0.001$), Yp= Grain yield under normal environment, Ys= Grain yield under waterlogging environment, PRPH= Percentage reduction in plant height; PRSL= Percentage reduction in spike length; PRTGW= Percentage reduction in 1000-grain weight; SSI= Stress susceptibility index; GMP= Geometric mean productivity, TOL=Tolerance, HM= Harmonic mean; and MSTI (K_1STI & K_2STI) = Modified stress tolerance index.

performing than best checks for each indices under year one, two and based on mean of two years are presented in Table 5. Based on SSI index, it was observed that only 06 lines out of the 30 best lines that were common over year one or two or in both the years included Perenjori; PBW 343; PBW 636; Raj 4201; Raj 4205 and WH 1094. Whereas, 07 lines were selected based on lower TOL values while, 06 lines were same as selected based upon SSI and another one more line KRL 268 was shortlisted. Higher value of geometric mean productivity and stress tolerance index has been reported as a selection criterion for identifying high yielding and stable waterlogging tolerant genotypes. The promising lines, namely; BH 1146; DBW 52; PBW 631 and RW 3684 exhibited higher value than best checks for GMP and K1 and K2STI, whereas NW 1014, was better for GMP; DBW 39 and PBW 621 for K1STI and PBW 590 for the K2STI (Table 5).The better performing and stable lines for waterlogging tolerance under both non-waterlogged and waterlogged conditions were also selected by other mathematical relationship. The GMP, MP and STI were the better predictors of Yp and Ys than other indices under both non-waterlogged and waterlogged conditions. The earlier reports have also demonstrated that these indices were found most suitable criterian for selecting high yielding and stable lines for stress prone areas (Sio-Se Mardeh *et al.* 2006).

The elite lines were classified into three groups and from each group top ten lines were shortlisted and are presented for individual year and also over the years (Table 5). In group ‘A’, summation of GMP, MP and STI value for each line have been taken, than sorted the values in descending order to get top ten lines. In group ‘B’ best performing lines were sorted based on lower to higher SSI values. The lines of this group exhibited poor performance under both non-waterlogged and waterlogged conditions. Group ‘C’, is the most important group where sorting of genotypes was done based on higher values of stress tolerance score (STS) and thus top ten elite lines were selected. In group ‘A’, eight elite lines, viz. BH 1146, DBW 39, DBW 52, NW 1014, NW 4081, PBW 631, PBW 590 and RW 3684 were common in individual year and also over bot the years. On the other hand group ‘B’, included six lines, viz. Perenjori, PBW 343, PBW 636, RAJ 4201, RAJ 4205 and WH 1094 which showed poor performance under both non-waterlogged and waterlogged conditions. The most important group ‘C’ included nine best performing lines namely; BH 1146, DBW 52, HD 2967, HD 2997, NW 4081, NW 4083, PBW 631, PBW 590 and RW 3684 which showed high score for STS and the results were confirmatory as most of these lines were also found in group ‘A’.

Phenotypic variation and genetic estimates

It is noteworthy from the present study that plant height and 1000-grain weight are more desirable traits for identifying promising lines, and therefore selection based on these two traits will be rewarding for germplasm improvement under waterlogging conditions. Spike length and grain yield exhibited moderate to low heritability and thus could be used for simultaneous improvement being component traits of economic value. It may be concluded here that planned hybridization followed by selecting desirable transgressive segregants will be a better choice for yield improvement under waterlogging conditions. Similar results to the findings of present study highlighting plant height and 1000-grain weight having high heritability together with high genetic advance were also observed by Gulnaz *et al.* (2011). Heritability of traits has been found associated with waterlogging tolerance through plant grain weight at 15 days of waterlogging in the field at tillering stage (74%) and booting stage (80%) as reported (Bao1997). It has been reported that waterlogging tolerance is often highly

Table 4 Better performing elite lines then best check for different selection indices, over the year 2012-13, 2013-14 and pooled

Year	SSI (Lower to higher)	GMP (Higher to lower)	TOL (Lower to higher)	K_1STI (Higher to lower)	K_2STI (Higher to lower)
	Top ten elite lines along with their values for each indices, based on desirability of the indices				
2012 - 2013	NW(S)2-4 (0.006)	HUW635 (1477)	KRL213 (1.10)	HUW635 (2.54)	NW1012 (2.87)
	NW1012 (0.008)	NW1012 (1432)	GUTHA (1.90)	NW4083 (2.20)	HUW635 (2.64)
	AMERY (0.010)	NW1014 (1368)	NW4082 (1.90)	NW1012 (2.07)	NWL9-22 (2.47)
	UP2003 (0.011)	NWL9-22 (1367)	CUNDERDIN (2.10)	NW1014 (2.04)	NW1014 (2.43)
	K9107 (0.013)	KRL283 (1287)	DBW59 (2.10)	NWL9-22 (1.99)	K0808 (2.36)
	PBW343 (0.014)	NW1076 (1253)	NW (S)6-5 (2.40)	DBW46 (1.99)	HUW638 (2.33)
	RAJ4205 (0.014)	K0808 (1246)	NWL7-4 (3.90)	KRL283 (1.87)	DBW52 (2.33)
	KRL233 (0.016)	HUW638 (1241)	DBW52 (3.90)	HI1563 (1.83)	NW4092 (2.29)
	KRL283 (0.019)	DBW52 (1238)	KRL268 (3.90)	RAJ3765 (1.77)	NW1076 (2.27)
	PBW634(0.020)	KRL19 (1228)	K0807 (4.90)	KRL105 (1.73)	CBW38 (2.16)
	DBW14 © (0.669)	DBW17© (996)	DBW14 © (214)	DBW16 © (1.67)	DBW17 © (1.90)
2013 -2014	SCH. (0.010)	DBW52 (1453)	PBW550 (2.25)	DBW52 (2.56)	PBW631 (3.01)
	PBW550 (0.011)	RW3684 (1429)	SCH. (2.25)	NW1067 (2.29)	RW3684 (2.95)
	WH1094 (0.024)	PBW631 (1428)	WH1094 (5.25)	BH1146 (2.09)	PBW590 (2.65)
	PBW634(0.036)	BH1146 (1411)	PERENJORI (8.25)	RW3684 (1.98)	BH1146 (2.65)
	PERENJORI (0.036)	DBW17© (1339)	PBW634 (9.25)	PBW631 (1.94)	DBW52 (2.44)
	PBW636 (0.039)		RAJ4201 (9.25)	PBW621 (1.93)	NW4081(2.33)
	RAJ4201(0.048)		RAJ4205 (9.25)	DBW39 (1.89)	DBW17 © (2.31)
	NWL9-24 (0.050)		PBW636 (10.25)	DBW17 © (1.87)	
	RAJ4205 (0.059)		NWL924 (13.25)		
	PBW343 (0.072)		PBW343 (15.25)		
	DBW16 © (0.400)		DBW16 © (151)		
Mean of year (2012-13 and 2013-14)	WH1094 (0.018)	DBW52 (1465)	WH1094 (3.67)	DBW52 (2.55)	BH1146 (2.76)
	PBW636 (0.025)	BH1146 (1422)	RAJ4201 (5.68)	NW1067 (2.25)	PBW631 (2.73)
	RAJ4201 (0.033)	RW3684 (1399)	PBW636 (6.33)	BH1146 (2.08)	RW3684 (2.69)
	PBW343 (0.042)	PBW631 (1398)	RAJ4205 (7.18)	RW3684 (2.01)	DBW52 (2.54)
	PERENJORI (0.049)	PBW590 (1280)	PBW343 (8.18)	PBW631(1.97)	PBW590 (2.40)
	RAJ4205 (0.052)	DBW39 (1276)	PERENJORI (10.33)	PBW621 (1.96)	NW4081 (2.35)
	NW4081 (0.076)	NW4081 (1250)	NW2036 (18.58)	DBW39 (1.88)	NW4083 (2.27)
	HD 2997 (0.080)	NW1014 (1235)	NW4018 (18.58)	PBW639 (1.81)	HD2997 (2.23)
	NW 2036 (0.080)	NW4083 (1235)	HD3024 (20.08)	KRL266 (1.75)	HD2967 (2.23)
	NW4091(0.086)	HUW636 (1226)	KRL268 (20.58)	NWL925 (1.74)	HUW636 (2.14)
	DBW17© (0.810)	DBW17 © (1168)	KRL34 © (250)	DBW17 © (1.72)	DBW17 © (2.13)

heritable under field or different soil conditions (Collaku and Harrison 2005). It is important to mention here that grain number has been found as the most sensitive traits to waterlogging stress resulted higher grain yield (Collaku and Harrison 2002).

Correrlation between selection indices

Correlations showed that tolerance has positive association with yield under non-waterlogged conditions, while it was negatively associated under waterlogged conditions as reported by Clarke *et al.* (1992). The stress susceptibility index has been widely used by various researchers to identify the sensitive and tolerant genotypes (Clarke and Duncan 1993) and several published reports suggested that these indices will prove to be the most suitable criterian for selecting the best stable genotypes for stress-prone areas (Sio-Se Mardeh*et al.* 2006). Some reports of estimating negative association of grain yield under non-saline conditions (Mohammadi *et al.* 2011). Nevertheless, negative correlation between Ys and Yp has also been reported (Sio-Se Mardeh *et al.* 2006). The better responsive performance by some cultivars under stress conditions could be ascribed to adaptation mechanisms (Clarke *et al.* 1992). Earlier reports emphasized that STI

Table 5 Selected top ten elite lines along with their values for each group A (higher values), group B (lower values) and group C (higher values) based on stress tolerance score during 2012-13, 2013-14 and pooled one, two and based on mean of both the years

Groups	Year 1 (2012-13)	Year 2 (2013-14)	Both (2012-13&2013-14)
Group A (Elite lines exhibiting good performance under normal and waterlogged conditions)	HUW635 (1094497), NW1012 (1029480), NW1014 (939144), NWL9-22 (937872), KRL283 (831962), NW1076 (788431), K-0808 (778808), HUW638 (772580), DBW52 (768861) and KRL19(756865).	DBW52 (1059597), RW3684 (1025104), PBW631(1022685), BH1146 (999140), PBW590 (893505), DBW39 (802195), NW4081 (790342), NW4083 (775201) and NW1014 (774452).	DBW52 (1077135), BH1146 (1014399), RW3684 (982392), PBW631 (980546), PBW590 (822046), DBW39 (817167), NW4081 (784587), NW1014 (765678), NW4083 (765535) and HUW636 (754584).
Group B (Elite lines exhibiting poor performance yield under normal and waterlogged conditions)	NW(S)2-4 (0.0062), NW1012 (0.0084), AMERY (0.0104), UP2003 (0.0116), K9107 (0.0133), PBW343 (0.0141), RAJ4205 (0.0142), KRL233 (0.0164), KRL283 (0.0196) and PBW634 (0.0207).	SCHOMBURGK (0.0107), PBW550 (0.0117), WH1094 (0.0245), PBW634 (0.0361), PERENJORI (0.0362), PBW636 (0.0387), RAJ4201 (0.0485), NWL9-24 (0.0500), RAJ4205 (0.0598) and PBW343 (0.0720).	WH1094 (0.0185), PBW636 (0.0255), RAJ4201 (0.033), PBW343 (0.042), PERENJORI (0.049), RAJ4205 (0.052), NW4081 (0.077), HD2997 (0.080), NW2036 (0.081) and NW4091 (0.087).
Group C (Elite lines exhibiting high score for stress tolerance score)	HUW635 (13.19), NW1012 (12.89), NWL9-22 (9.30), KRL283 (8.73), NW1014 (8.51), HUW638 (8.49), DBW52 (8.47), NW1076 (8.44), K-0808 (7.77) and NW4092 (7.33).	PBW631 (13.05), RW3684 (12.88), BH1146 (11.56), DBW52 (11.33), PBW590 (10.79), NW4081 (8.78), NW4083 (8.39), HD2967 (7.53), HD2997 (7.51) and PBW636 (7.08).	BH1146 (12.28), DBW52 (12.09), PBW631 (11.90), RW3684 (11.73), PBW590 (9.38), NW4081 (8.90), NW4083 (8.48), HD2997 (8.19), HD2967 (8.19) and HUW636 (7.76).

Group A= (GMP+HM+MP+K_1STI+K_2STI); Group B= SSI;Group C= STS (GMP^1+HM^1+ MP^1+ K_1STI^1+ K_2STI^1- TOL^1-SSI^1).

showed highly correlated response with grain yield under both stress (Ys) as well as non-stress (Yp) environments (Farshadfar *et al.* 2013). Also, grain yield under stress and non-stress conditions was found positively correlated with yield susceptibility indices (YSI), yield index (YI), drought response index (DRI), modified stress tolerance index (MSTI) and relative drought index (RDI) as reported by Farshadfar and Elyasi (2012).

Selected elite lines for waterlogging tolerance

It is well recognized that using high-yielding and waterlogged tolerant elite lines as parents in hybridization for improving tolerance to waterlogging could be very effective for developing wheat cultivars that possessing high-yield potential, as well as better adaptation. In the present study superior lines (BH 1146, DBW 39, DBW 52, NW 1014, NW 1067, NW 4081, PBW 621, PBW 631, PBW 590, RW 3684, HD 2967, HD 2997 and NW 4083) were identified based on selection indices namely; GMP, MP, HM, STI and also based on STS have been found highly waterlogging tolerant. However, the lines that were selected based on SSI and TOL including; Perenjori, PBW 343, PBW 636, HD 3024, KRL 268, RAJ, 4201, RAJ, 4205 and WH 1094 were found moderately susceptible to non-waterlogged and waterlogged conditions. Similar to the present study stress tolerant wheat genotypes were also selected by Sardouie *et al.* (2014) having different germplasm lines. Stress susceptible index in wheat showed year-to-year variation for genotypes and their ranking pattern (Clarke *et al.* 1992). Whereas, selection made based on SSI showed that SSI higher than one indicates above-average susceptibility to stress (Guttieri *et al.* 2001). Indices that showed highly significant correlations with grain yield under stress and non-stress conditions are generally suitable for selecting stress tolerant cultivars (Farshadfar *et al.* 2001).

SSI has been also used to identify stress sensitive and resistant genotypes by several authors (Clarke *et al.* 1992). It was also reported that mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI) values are convenient parameters for selecting high yielding wheat genotypes in both stress and non-stress conditions, whereas for the relative decrease in yield only under stress conditions, tolerance and stress susceptible values were found better indices for determining tolerance levels (Ilker *et al.* 2011). It was anticipated that lines developed using this approach might display superior performance under waterlogging conditions.The clustering pattern of genotypes based on common parentage was found effective as it helped in identifying or grouping tolerant lines that have shown linkage with their primitive lines or landraces in their pedigree such as ATTILA, KAUZ, PASTOR, MILAN or there might be two primitive lines in their parentage. It is clear from present study that genotypes namely; DBW 39 (ATTALIA); DBW 52 (KAUZ/PASTOR); PBW 621 (KAUZ/MILAN); RW 3684 (PASTOR); NW 4083 (MILAN/ATTILA) were rated as tolerant lines, whereas other tolerant lines were having diverse pedigree. In contrast, most of the stress sensitive lines included Raj 3777 (RAJ 4205) or VEERY (PBW 343 and RAJ 4201) or BOW (WH 1094) in their parentage. Whereas, other sensitive lines, namely Perenjori, PBW 636, HD 3024 and KRL 268 have diverse pedigree. It is well recognized that most of KRL series genotypes (Table 6) which normally have Kharchia local as one of the parent in their pedigree, reflects that Kharchia local have genomic region that probably confer tolerance for salinity as well as for waterlogging.

It is suggested that for conducting this type of field study, material with diverse parentage is a pre-requisite excepting for those few lines that otherwise are high yielding and normally perform better under field conditions. Breeders are targeting the genomic region having QTLs for waterlogging, salinity and element toxicities tolerance and for this purpose, multi-parent set including high yielding, tolerant and resistant sources from different backgrounds for developing bi-parental (RILs, DH, and NILs) or multi-parent (MAGIC and NAM) populations as next generation populations along with high density molecular markers will be useful for

Table 6 Clustering of elite lines (Indian and Australian) based on common parentage

Primitive/landrace /breeding line	Name of the elite line	Number of line
Elite lines having one parent common in their pedigree		
BODALLIN	AMERY and PERENJORI	2
CRANBROOK	BROOKTON, WESTONIA, CUNDERDIN	3
HALBERD	BT-SCHOMBURGK, KRICHAUF	2
SPEAR	CAMM and SPEAR	2
ATTILA	DBW39, DBW58, HD2733, NW3069, NW3087, NW4082 and NW4083.	7
KAUZ	DBW50, KRL240, NW (S)2-4, DBW52, NW 4018 and PBW 621	6
MILAN	DBW50, DBW51, KRL249, NW4083 and NW4091	5
SITE	DBW51, DBW59 and NW4092	3
PASTOR	DBW51, DBW52, HD2985, KRL238, NW4018, RW3684	6
RAJ-3777	DBW 17, DBW55, HUW638 and RAJ4205	4
TILHI	DBW58, DBW59 and NW4082	3
TUKURU	DBW60 and HD3028	2
GABO	GAMENYA and GUTHA	2
K 9107	K0807, K0808 and NWL9-24	3
AROONA	BT-SCHOMBURGK, KALANNIE and SCHOMBURGK	3
FALCON	KALANNIE and TINCURRIAN	2
KHARCHIA LOCAL	KHARCHIA65, KRL19, KRL35, KRL99,KRL1-4, KRL3-4, KRL9-22, KRL104, KRL105, KRL210, KRL229, KRL266, KRL227, KRL-283, KRL-259, NWL9-25 and NW-4099	17
KTDH	KRL227, KRL233, KRL236 and KRL268	4
HAHN ‘S’	KRL261 and NW1014	2
CPAN 3004	KRL259, KRL283 and KRL268	3
INSIGNIA	SPEAR and TINCURRIAN	2
KRL-20	NW (S)6-5 and NWL9-23	2
VEE#	DBW14, DBW46, HD2985, PBW343, NW1012, NW4018 and RAJ4201	7
RAJ 3765	NW4035 and RAJ 3765	2
BOW	NW2036 and WH1094	2
SERI	DBW52 and NWL7-4	2
Elite lines having two parent common in their pedigree		
WH 594/W 485	PBW 550 and PBW 590	2
Elite lines having similar pedigree		
KAUZ//ALTAR84/ AOS/3/MILAN/KAUZ/4/ HUITES	DBW50 and PBW621	2
WAXWING*2/VIVITSI	HUW 636 and PBW 631	2
Elite lines having no parent common in their pedigree		
CBW 38, CHARA, DUCALA-4, HD 2967, HD 2997, HD 3024, HD 3027, HI 1563, HUW 635, KRL 213, NW 1067, NW 1076, NW 4081, NW 4098, PBW 634, PBW 635, PBW 636, PBW 639, PBW 642, RSP 561, UP 2003, UP 262, DBW 16, HD 2009		24

fine mapping of QTL for waterlogging tolerance. After QTL mapping, the incorporation of desired gene(s) by introgression of tapped genomic region into stringent background would be feasible and rewarding.

Numerous molecular markers are available for various abiotic stresses in wheat (Ribaut *et al.* 2001), however, there are no reports of molecular markers for waterlogging tolerance in cereals, but this might be achieved based on known sequences from genes (candidate genes) of known function. It has also been demonstrated that low rates of alcoholic fermentation and low ATP led to injury of root cells in waterlogging intolerant wheat genotypes that are exposed to anoxia (Waters *et al.* 1991). The activities of pyruvate decarboxylases (PDC) and rates of alcoholic fermentation indicate that the alcoholic fermentation is usually limited in root tips of wheat genotypes, and that might be one factor contributing to wheat crop being more intolerant than to the annexation rice crop (Waters *et al.* 1991). It is necessary that for a faster breeding programme, exploring the potential benefits of marker assisted selection has good scope, whereas, through simple traditional approaches of conventional breeding it is little difficult and time consuming to understand the architecture of complex traits that are responsible for waterlogging tolerance. By deployment of new molecular tools, it would be possible to tap the genomic region, responsible for controlling behavior of the complex traits. Therefore, such field based screening techniques are very useful and feasible in improving stress tolerance and increasing productivity under harsh environments.

Conclusion

Waterlogging tolerance is an important abiotic stress, that limits the yielding potential of wheat genotypes under extreme moisture conditions. Results from the present study confirmed that plant height and 1000-grain weight are desirable traits to characterize germplasm for waterlogging tolerance. The high estimates of correlation of GMP, HM, STI and MP with yield under waterlogging indicated that these selection indices are more potent for selecting waterlogging tolerance elite lines. Besides, selected lines might be identified as potential genotype as such or may be used in hybridization programme for developing next generation mapping populations targeting waterlogging tolerance in wheat to boost productivity under harsh environments.

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