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# Characterizing waterlogging tolerance using multiple selection indices in bread wheat (*Triticum aestivum*)

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Waterlogging affects more than 10% of arable land including 25% of the worldwide area planted with wheat resulting in 15-80% yield reduction (Powell *et al.* 2012). Waterlogging is common in areas that receive high rain intensity with other related factors, *i.e.* heavy textured soil, abrupted slopes and poorly drained soils, even in drought regions (Setter *et al.* 2009). Waterlogging creates poor aerobic condition resulting in reduced growth, delayed plant development and ultimately reduced total grain yield (Dickin and Wright 2008). Wheat is well documented as sensitive to waterlogging particularly in seedling, flowering and grain filling stages showing negative impact on plant height, days to heading, reduced tiller number, kernel number and grain yield as well (Singh *et al.* 2018a). The duration and intensity of waterlogging, as well as the developmental stage at which the waterlogging happens, determine the reduction percentage in the total grain yield (Arguello *et al.* 2016). The grain yield reduction was observed in winter wheat at waterlogged conditions for 10, 20 and 30 days, respectively, at the 4-5 leaf stage (Rasaei *et al.* 2012). Similarly, grain yield reductions of 7.1–11.2% depending on the growth stage at the time of treatment, with the largest reductions observed at pre-anthesis (Shao *et al.* 2013). Therefore, the development of waterlogging tolerant varieties is an effective and economical approach to improve grain yield under waterlogging conditions. Direct selection for yield under complex environments could be misleading as it is a complex trait and therefore, a successful selection will depend upon the information on the genetic variability and correlation among component traits as well as with grain yield. To identify stress tolerant cultivars, several selection indices, viz. mean productivity (MP), harmonic mean (HM), stress tolerance index (STI), yield index (YI) and yield stability index (YSI) (Singh *et al.* 2018a) have been have been reported to be more potent for selecting waterlogging tolerant genotypes. Therefore, the present study was focused to identify the phenotypic trait as a criterion to select for waterlogging tolerance, and their inter-relationships among various yield components.

A set of 320 recombinant inbred lines (RILs) derived from cross DBW 17/BH 1146 were selected, where DBW 17 is sensitive to waterlogging stress but better performing variety for timely sown irrigated conditions, while BH 1146 had potential for contrasting performance under waterlogging conditions. The experiment was conducted during 2015-16 under normal conditions (non-waterlogged conditions) and waterlogging (WL) conditions at two locations ICAR- IIWBR, Karnal (Latitude 29° 4'N; Longitude 76° 59'E) and NDUAT, Faizabad (Latitude 26° 32.67'N; Longitude 81° 49.48'E) in an augmented design. Each genotype was planted in a two row plot of 1.0 m length maintaining spacing of 23 cm between rows and 10 cm between plants within a row. In all, there were five blocks, and each block comprised 64 RILs and parents (wherein set of two parents was replicated in each block). Recommended agronomic practices were followed to raise good crop under normal and WL conditions. In order to create WL condition, the water stagnation was allowed for a week time at four defined growth stages of the crop, viz. 21 DAS (at crown root initiation stage), 40 DAS (at tillering stage), 60 DAS (at flowering stage) and 75 DAS (at grain-filling stage). The observations were recorded on days to heading (DTH), days to maturity (DTM), plant height (PH), tillers per meter (TPM), spike weight (SW), biological yield per plot (BY), and grain yield per plot (GY) under both the conditions. The estimates of genetic variability, correlation coefficients among yield components and various selection indices under normal and WL conditions were calculated by utilizing adjusted mean as per statistical software SAS version 9.3 (2011). The various yield based selection indices, representing mathematical relationships between yield under normal and stress conditions, have been used for characterizing waterlogging tolerance, viz. Percentage reduction (PRGY) = (Yp-Ys)/Yp×100 by (Choukan *et al.* 2006); Yield Stability Index (YSI)=Ys/Yp by (Bouslama M and Schapaugh WT 1984); mean productivity (MP)

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= (Ys+Yp)/2 by (Hossain *et al.* 1990); stress tolerance index (STI) = (Ys×Yp)/$(Xp)^2$ by (Fernandez G C J 1992); harmonic mean (HM) = 2(Yp×Ys)/(Yp+Ys) by (Kristin *et al.* 1997); where, Yp and Ys represent grain yield of a given genotype under normal and WL conditions, respectively and Xp represent mean of grain yield of all genotypes under normal conditions. The larger values of STI, HM, MP and YSI while, smaller values of PRGY are desirable and represent relatively more tolerance to WL stress condition. Therefore, the indices MP, HM, YSI and STI should have positive values, whereas PRGY, with negative values for the selection of superior genotypes under WL conditions.

The analysis of variance revealed significant differences among the RILs for all yield components studied under both normal (except SW) and WL conditions (except DTH, DTM) at Karnal location (Table 1). While significant differences were observed among the RILs for all yield components (except DTH and SW) under normal and WL conditions (except DTM) at Faizabad. The trait averages decline numerically under WL conditions as compared to the normal conditions (Table 2). Maximum reduction was recorded in BY, followed by TPM, GY, SW and PH in the lines. In the sensitive genotype DBW17, tillers/meter was the most affected trait followed by biological yield, grain yield, spike weight and plant height whereas, biological yield, followed by tillers/meter, grain yield, spike weight and plant height were the most affected traits in tolerant parent BH1146 under waterlogged conditions at Karnal. Similarly, at Faizabad, the maximum reduction under waterlogging was recorded for grain yield, followed by biological yield, plant height, tillers/meter and spike weight in the RILs whereas, biological yield, followed by spike weight, grain yield, tillers/meter and plant height was affected in DBW 17. Similarly in BH1146, the reduction in biological yield was recorded highest followed by plant height, spike weight, tillers/meter, and grain yield. Reduction in grain yield ranging from 30–50% was reported in spring and winter wheat (Arguello *et al.* 2016, Singh *et al.* 2018b).

The traits like plant height ($r \geq 0.35$), tillers/meter ($r \geq 0.21$), spike weight ($r \geq 0.21$) and biological yield ($r \geq 0.74$) were found to be positively and significantly correlated with grain yield at both the locations under both

Table 1 Analysis of variance for grain yield and component traits in RIL population of bread wheat under normal and waterlogged soil conditions

| Source of variation | D F | Location | Condition | Days to heading (days) | Days to maturity (days) | Plant height (cm) | Tillers/ meter | Spike weight (g) | Biological yield/plot (g) | Grain yield/plot (g) |
|---|---|---|---|---|---|---|---|---|---|---|
| Genotype | 319 | Karnal | Normal | 14.68** | 7.24* | 324.38** | 714.78** | 0.26 | 46555.87** | 3333.72** |
| | | | Waterlogging | 11.33 | 4.83 | 287.60** | 352.05** | 0.19** | 15740.48** | 1497.18** |
| | | Faizabad | Normal | 0.70 | 1.53** | 82.43* | 276.36* | 0.08 | 5892.60* | 1497.86** |
| | | | Waterlogging | 1.62 | 2.91 | 189.12** | 216.63** | 0.12** | 2377.51** | 448.82** |
| Blocks | 4 | Karnal | Normal | 0.60 | 1.90 | 9.25 | 3.10 | 0.27 | 1875.00 | 91.85 |
| | | | Waterlogging | 3.35 | 1.85 | 2.15 | 9.35 | 0.11 | 15740.48 | 34.40 |
| | | Faizabad | Normal | 0.85 | 2.40 | 51.85 | 21.25 | 0.05 | 2875.00 | 435.40 |
| | | | Waterlogging | 2.10 | 0.15 | 0.85 | 13.25 | 0.02 | 71.25 | 4.75 |
| Error | 6 | Karnal | Normal | 0.50 | 0.60 | 1.65 | 6.40 | 0.06 | 1000.00 | 91.85 |
| | | | Waterlogging | 4.15 | 1.15 | 12.35 | 18.65 | 0.01 | 740.00 | 28.40 |
| | | Faizabad | Normal | 0.25 | 0.10 | 9.85 | 53.85 | 0.09 | 8.75.00 | 84.40 |
| | | | Waterlogging | 0.60 | 2.15 | 2.85 | 13.75 | 0.01 | 78.75 | 3.65 |

*, **=Significance at P=0.05, P=0.01, respectively

Table 2 Location-wise percent reduction of yield component traits due to waterlogging at Karnal and Faizabad locations

| Location | Karnal | | | | | | | Faizabad | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Genotype | RILs | | DBW 17 | | BH 1146 | | RILs | | DBW 17 | | BH 1146 | |
| Traits | Mean | Range | Mean | Range | Mean | Range | Mean | Range | Mean | Range | Mean | Range |
| DTH | -0.7 | -10.3-10.4 | 1.5 | -2.2-4.4 | -2.3 | -3.4-1.1 | 0.2 | -6.4-7.6 | 0.3 | -1.6-3.1 | 0.6 | -1.6-3.1 |
| DTM | 2.6 | -7.4-11.0 | 2.9 | 2.3-3.8 | 2.7 | 2.2-3.7 | -0.1 | -5.9-3.9 | -0.2 | -0.9-0.9 | -0.9 | -3.9-0.0 |
| PH | 13.3 | 1.5-92.2 | 10.9 | 6.6-14.9 | 9.1 | 4.7-12.6 | 21.8 | -118.6-62.9 | 9.4 | 1.5-21.5 | 24.2 | 16.5-28.3 |
| TPM | 44.5 | 5.6-82.1 | 37.9 | 34.2-40.0 | 47.9 | 42.6-53.6 | 18.2 | -31.5-59.8 | 15.1 | 6.4-28.6 | 15.2 | 5.6-26.1 |
| SW | 20.2 | -100-82 | 14.9 | -0.2-37.5 | 26.9 | 14.3-50.0 | 14.4 | -116.1-68.8 | 18.4 | 13.3-24.2 | 22.2 | 0.0-42.1 |
| BY | 48.1 | 0.0-85.3 | 24.8 | 16.4-42.9 | 49.7 | 37.5-55.6 | 31.4 | 0.0-75.0 | 31.1 | 23.3-45.0 | 26.4 | 16.7-41.3 |
| GY | 42.9 | 0.0-87.3 | 24.3 | 17.5-38.1 | 39.4 | 33.1-48.3 | 40.2 | 0.0-91.7 | 17.0 | 8.4-30.8 | 14.9 | 2.7-30.0 |

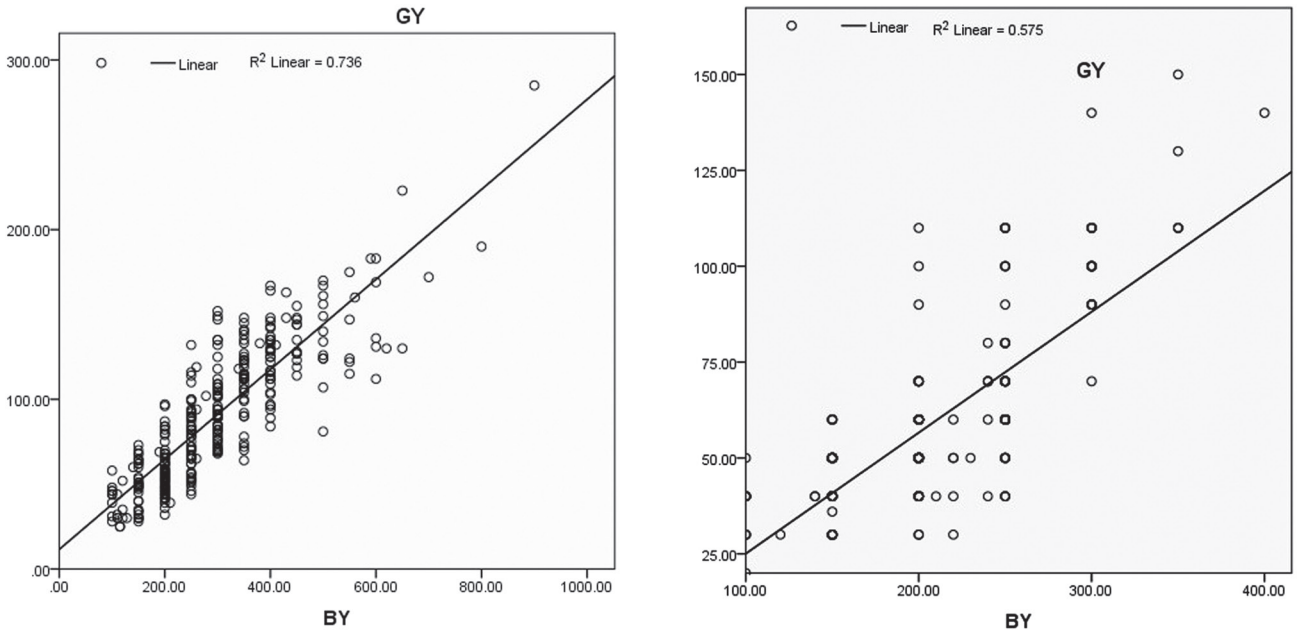


Fig 1 Correlation between grain yield with biological yield (BY) at (a) Karnal and (b) Faizabad locations under waterlogging stress.

conditions. Significant and positive associations were also observed among BY, TPM and PH under WL conditions at both locations. The positive and significant correlation revealed that PH, TPM, SW and BY are the key traits that contribute towards GY under both conditions at both the locations. Regression analysis was carried out to assess the contribution of different traits towards overall grain yield under WL stress. The BY contributed significantly towards grain yield under waterlogged conditions at Karnal ($R^2$= 0.74) and Faizabad ($R^2$=0.57) (Fig 1a & b). Apart from biological yield, traits like days to maturity ($R^2$= 0.02), tillers/meter ($R^2$=0.01) and spike weight ($R^2$=0.01) significantly contributed to grain yield at Karnal, whereas traits like SW ($R^2$= 0.08), DTA ($R^2$=0.01) and PH ($R^2$=0.01) contributed towards grain yield at Faizabad. Regression analysis results indicated that biological yield mainly contributing towards the final grain yield under waterlogged conditions. Under waterlogged conditions, TPM were also found to be significantly associated with GY indicating that TPM is an important contributor to final GY along with BY (Singh *et al.* 2018b). The biological yield is inclusive of number of tillers, spike weight and plant height. Tillers/meter was the trait which was showing good association with yield at both locations under stress conditions may be the trait of choice for field screening of genotypes along with spike weight which was also reported by few studies (Singh *et al.* 2018a).

The correlation coefficient was worked out among grain yield and stress selection indices under both normal conditions and waterlogging conditions. Selection indices, viz. yield stability index ($r \geq 0.38$), mean productivity ($r \geq 0.75$), harmonic mean ($r \geq 0.94$) and stress tolerance index ($r \geq 0.89$) showed significant positive correlation with grain yield under waterlogging whereas percent reduction in grain yield ($r \leq -0.38$) showed significant negative association with grain yield under waterlogging conditions at both the locations. The selection indices HM, MP, YSI and STI with larger values could be useful while selecting the best performing genotypes under WL conditions and accordingly these indices could be used for identifying stable genotypes with high yield potential under waterlogged conditions. In the past several selection criterion including mean productivity, harmonic mean and stress tolerance index have been used for identifying suitable genotypes showing better performance in stress and normal environments (Singh *et al.* 2018a). In the present study it was observed that the YSI, MP, HM and STI revealed positive and significant correlation with GY under waterlogging (Ys) conditions suggesting that any one of them can be used as an alternative to others for the short listing tolerant genotypes. The selection indices that showed highly significant correlations with GY under WL and normal soil conditions are generally suitable for selecting tolerant genotypes. Hence, these indices can be used for selecting best genotypes for WL stress conditions.

## SUMMARY

WL stress significantly affected grain yield, biological yield, tillers per meter, plant height and spike weight. The plant height, tillers per meter, spike weight, and biological yield were found to be positively and significantly correlated with grain yield under WL conditions. Among these traits, biological yield has maximum contribution towards WL tolerance and can be used for selection of tolerant genotypes. Significant and desirable correlation of different selection indices, viz. HM, MP, YSI, STI and PRGY indicated that any one of these can be used interchangeably to select stress tolerant genotypes.

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