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IDENTIFICATION OF DROUGHT TOLERANT SPRING WHEAT GENOTYPES BASED ON SOME OF THE PHYSIOLOGICAL TRAITS

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SUMMARY

Drought is one of the most important abiotic stresses causing wheat grain losses. The aim of this study was to identify wheat genotypes for tolerance to water stress under rainfed condition. Twenty-nine advanced spring wheat genotypes along with a standard cultivar (Prodip) were grown for consecutive two years using alpha lattice design with three replications, and evaluated for drought tolerance on the basis of several morpho-physiological traits-flag leaf chlorophyll content, canopy temperature, early ground coverage, thousand grain weight and grain yield. Heritability, genetic advance, selection differential and character association between traits was used as selection criteria to identify high yielding drought tolerant lines. Six lines were selected for further evaluation in the drought affected area of the country to release as new drought tolerant wheat variety. Significant variation ($P < 0.01$) was found among the 30 wheat genotypes for all the morpho-physiological traits except flag leaf chlorophyll content. Early ground coverage, thousand grain weight and chlorophyll content showed a significant association with grain yield and were accounted for 28.1, 28.8, and 28.2% yield variation. Canopy temperature at grain filling stage was more imperative than canopy temperature at vegetative stage in relation with grain yield. From this study, it was concluded that early ground coverage, chlorophyll content and 1000-grain weight are the most drought tolerance influencing traits in wheat. Selected wheat genotypes had potential for crossing in future breeding program especially for gene pyramiding as well as breeding cultivars to fill the gap between cultivars under irrigated and rainfed conditions.

Key words: Correlation, drought tolerance, genetic advance, heritability, physiological traits, selection differential, wheat

Key findings: Early ground coverage, chlorophyll content, 1000-seed weight and canopy temperature found to be the most important selection criterion in identifying drought tolerant in bread wheat genotypes. This study has identified six entries namely 2, 6, 19, 21, 28 and 30 which will be used in the future programs for developing drought resistant high yielding genotypes.

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INTRODUCTION

Wheat is one of the three major cereals across the globe because of its acreage, high productivity, wide adaptation and prominent position in the international food grain trade. In Bangladesh, wheat is the second most important staple crop occupying 4% of the total cropped area and producing 7% of the total consumable cereals (Hossain and da-Silva, 2013). The land area of Bangladesh is 130,172 square kilometres with current population (2017) of ~164 million (Source: http://www.worldometers.info/world-population/bangladesh-population/-accessed on 22 February 2017). Wheat along with other cereal plays a vital role in providing food security to this people. Future wheat production has to increase to ensure food security for the ever-increasing population. Wheat is subject to several biotic (Malaker and Reza, 2011; Malaker *et al*., 2016) and abiotic (Khan *et al*., 2014; Rahman *et al*., 2016) stresses in a country like Bangladesh. Abiotic stresses such as drought and heat affect wheat production at different growth stages from seedling to grain-filling stage resulting serious grain yield loss (Jain *et al*., 2014). In Bangladesh, moisture and heat stress during grain-filling stage are major constraints affecting wheat productivity in approximately 5-20% of total cultivation as well as future climate change projections suggest that wheat production could fall by 32% as early as 2050 (Hossain and da-Silva, 2013). Visible signs of plants exposed to drought in the vegetative phase include leaf wilting, reduction of plant height, leaf area and number, and delay in initiation of buds and flowers (Boyer, 1982). The stress factor especially drought negatively affects plant growth and genetic gains in wheat yield under moisture stress (Richards *et al*., 2001). Under dry environmental conditions, identifying drought tolerance mechanism is of great significance in the process of developing high yielding varieties (Rajaram *et al*., 1996).

As a major crop, wheat has gained special attention in respect of morphological and physiological characters affecting drought tolerance worldwide. Earlier, the physiological traits were not intensively used in breeding program however advances in wheat physiology has offered the breeders to incorporate adaptive traits in variety development program (Richards *et al*., 2001). Consequently, focused and integrated breeding program based on physiological traits breeding are now used to enhance drought stress tolerance in wheat (Olivares-Villegas *et al*., 2007). Breeding for drought resistance is complicated lacking fast and reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions when a large amount of genotypes are evaluated efficiently (Ramirez and Kelly, 1998). In recent time, the availability of a number of handy and portable instruments such as infrared thermometer, chlorophyll meter, hand-held porometer, field spectrometers and so on allow precise and easy large scale field screening under stress condition (Pask *et al*., 2014). These instruments have made phenotyping quicker and as such breeders can identify important traits leading to faster genetic gain for complex traits like drought and heat tolerance. Some agronomic traits, such as grain yield and its components have also served as criteria for drought tolerance (Dencic *et al*., 2000) but physiological traits can be used to dissect stress adaptation into some of its components. Early ground cover, chlorophyll content, canopy temperature at vegetative and grain filling stages and 1000 grain-weight were considered to increase grain yield in rainfed condition (Lopes *et al*., 2012). Drought has become a recurrent phenomenon in Bangladesh due to the changes of precipitation and distribution pattern (Shahid and Behrawan, 2008). Wheat Research Centre (WRC), BARI uses conventional breeding strategy on selecting high yielding advanced lines under optimum growing conditions. It is imperative to increase wheat yield by developing stable and high yielding genotypes for unpredicted climatic condition such as drought. Previously several traits had been suggested by Rahman *et al*. (2016), for the improvement of wheat yield under rainfed conditions.

However, no remarkable progress has been made in the past to develop drought tolerant variety in Bangladesh, as the primary focus of the scientists were concentrated on developing wheat genotypes under irrigated conditions. In recent years, emphasis is being paid on the dissection of phenology and physiology related traits for drought tolerance to identify the suitable genotypes that can withstand adverse climatic conditions, particularly the soil moisture stress in order to produce satisfactory yield per unit area (Rahman *et al.*, 2013). In this study, 29 wheat genotypes selected from nurseries distributed by International Maize and Wheat Improvement Centre (CIMMYT) for the rainfed regions along with one local cultivar were evaluated under rainfed condition to identify high yielding genotypes by evaluating early ground coverage, canopy temperature at the vegetative and grain filling stage, flag leaf chlorophyll content, relative water content, spike m^{-2} and 100-grain weight for future use in breeding programs as well as for further evaluation in drought affected area of the country to identify new drought tolerant wheat variety.

MATERIALS AND METHODS

The study was conducted at the experimental field of the Regional Wheat Research Centre (RWRC), Rajshahi, Bangladesh Agricultural Research Institute (BARI) during 2011-12 and 2012-13 (24.37^o N and 88.52^o E, 14 m above sea level) in the Agro Ecological Zone of High Ganges Flood Plain (AEZ-11).The soil of the experimental field was silty clay loam with a pH of 7.1, low in organic matter and fertility level, deficient in boron but high in iron content. The experiment was conducted in the same research centre in different areas over two seasons to maintain soil health following crop rotation. Weather data of the experimental location are presented in Table 1.

Table 1. Weather data of experimental location RWRC, BARI Rajshahi during November-March/2011-12 and 2012-13.

Month	Temperature (^{0}C)				Rainfall (mm)		Relative humidity (%)		Soil pH	Soil Texture	Organic carbon (%)
	2011-12		2012-13		2011-12	2012-13	2011-12	2012-13			
	Max	Min	Max	Min							
Nov.	29.1	17	28.2	16.5	0.03	3.4	81.6	76.1	6.40	Silty clay loam	1.60
Dec.	24.2	12.5	23	11.8	3.3	0.03	84.1	85.16			
Jan.	23.4	11.5	23.3	9.3	0.18	0	79.5	84.35			
Feb.	28.4	12.2	27.9	13.6	0.02	0.79	66.2	76.68			
March	33.9	17.5	33.9	18.2	0.21	0.19	59.6	69.98			

Source: Meterological Station, Rajshahi, Bangladesh

The moisture content of the experimental field was determined by gravimetric method (Singh and Vittal, 1997). Soil samples were collected randomly from all three replications at 12 days interval starting from 50 days after sowing (DAS) and continued up to grain filling period. Soil moisture was calculated using the formula:

$$\text{Soil moisture} = \frac{\text{Weight of soil moisture}}{\text{Weight of oven dry soil}} \times 100$$

Soil moisture readings were taken at 50, 62, 74 and 86 DAS.At the time of crown root initiation (CRI) stage (17-21 DAS), 3.74 mm and 4.41mm rainfall were recorded in the first and second cropping seasons, respectively. No supplementary irrigation was applied during both cropping seasons.

The spring wheat genotypes were chosen on the basis of their differences in yield along with the performance of several physiological traits under the semiarid condition (Table 2). The experiment was laid out in an alpha lattice design with three replications. Each genotype was sown in 6-rows of 5-meter length with row to row spacing of 20 cm. Recommended crop husbandry practices were followed as recommended by Wheat Research Centre (WRC), BARI.

Table 2. List and pedigree of spring wheat genotypes used in the experiment.

ENTRY	CROSS/PEDIGREE
1 (Prodip)	BARI Gom-24
2	W15.92/4/PASTOR//HXL7573/2* BAU/3/WBLL1 PTSS02B00I02T-0TOPY-0B-0Y-0B-11Y-0M-0SY
3	MILAN//PRL/2*PASTORI4/CROC_1/AE.SQUARROSA (213)//PGO/3/CMSA02M00435T-040M-040P0Y-040ZTM-040SY-040M- 18ZTY-04M-0Y
4	CNO79//PF70354/MUS/3/PASTOR/4/BAV92/5/FRET2/KUKUNA//CMSA05Y01011T-040M-040ZTP0Y-040ZTM-040SY-5ZTM-01Y-0B
5	GK ARON/AG SECO 7846//2180/4/2*MILAN/KAUZ//PRINIA/3/CMSA05Y00954T-040M-040ZTP0Y-040ZTM-040SY-12ZTM-01Y-0B
6	MILAN/KAUZ//PRINIA/3/BAV92/4/WBLL1*2/KUKUNACMSA04M00040S-040ZTB-040ZTY-040ZTM-040SY-2ZTM-03Y-0B
7	ACHTAR*3//KANZ/KS85-8-5/4/MILAN/KAUZ//PRINIA/3/BAW92/5/CMSA05M00661T-050Y-040ZTM-040ZTY-33ZTM-02Y-0B
8	QG 78.5//2*INQALAB 91*2/TUKURUCMSA05M00713T-050Y-040ZTM-040ZTY-13ZTM-02Y-0B
9	QG 78.5//2*INQALAB 91*2/TUKURUCMSA05M00713T-050Y-040ZTM-040ZTY-33ZYM-01Y-0B
10	QG 78.5//2*INQALAB 91*2/fIJKURUCMSA05M00713T-050Y-040ZTM-040ZTY-33ZTM-02Y-0B
11	HUANIL//2*WBLL1*2/KUKUNACMSA05M00752T-050Y-040ZTM-040ZTY-28ZTM-01Y-0B
12	SERI*3//RL6O1O/4*YR/3/PASTOR/4/BAV92/5/WBLL1*2/TUKURU/CMSA05M00790T-050Y-040ZTM-040ZTY-22ZYM-02Y-0B
13	SERI*3//RL6010/4*YR/3/PASTOR/4/BAV92/5/WBLL1*2/TUKURU/CMSA05M00790T-050Y-040ZTM-040ZTY-30ZTM-01Y-0B
14	NSM*4/ 14-2/FRTL/2*PIFED/3/VORBCMSA05M00650T-050Y-040ZTM-040ZTY-10ZTM-03Y-0B
15	NSM*4/ 14-2/FRTL/2*PIFED/3/VORBCM SA05M00650T-050Y-040ZTM-040ZTY-20ZTM-01Y-0B
16	NSM*4/ 14-2//FRTL/ 2*PIFED/3/VORBCMSA05M00650T-050Y-040ZTM-040ZTY-21ZTM-02Y-0B
17	BABAX/LR42//BABAX/3/BABAX/LR42//BABAX/4/CM SA05M00772T-050Y-040ZTM-040ZTY-14ZTM-02Y-0B
18	ONIX/4/MILAN/KAUZ//PRINIA/3/BAV92CMSA05Y00338S-040ZTP0Y-040ZTM-040SY- I 2ZTM-03Y-0B
19	BOW/VEE/5/ND/VG9144//KAL/BB/3/YACO/4/CHIL/6/CASKOR/3/CMSA04M01201T-050Y-040ZTP0M-040ZTY-040ZTM-040SY-6ZTM-03Y-0B
20	CN079//PF70354/MUS/3/PASTOR/4/BAV92/5/FRET2/KUKUNA//CMSA05Y01011T-040M-040ZTPOY-040ZTM-040SY-4ZTM-03Y-0B
21	CN079/ /PF70354/MUS/3/PASTOR/4/BAV92/5/FRET2/KUKUNA//CMSA05Y0 1011T-040M-040ZTPOY-040ZTM-040SY-5ZTM-01Y-0B
22	CN079//PF70354/MUS/3/PASTOR/4/BAV92/5/FRET2/KUKUNA//CMSA05Y01011T-040M-040ZTP0Y-040ZTM-040SY-14ZTM-02Y-0B
23	SOKOLL//PBW343*2/KUKUNA/3/ATTILA/PASTORCMSA05Y0 1188T-040M-040ZTPOY-040ZTM-040SY- I 7ZTM-02Y-0B
24	GK ARON/AG SECO 7846//2180/4/2*MILAN/KAUZ//PRINIA/3/CMSA05Y00954T-040M-040ZTP0Y-040ZTM-040SY-9ZTM-04Y-0B
25	GK ARON/AG SECO 7846//2180/4/2*MILAN/KAUZ//PRXNIA/3/CMSA05Y00954T-040M-040ZTP0Y-040ZTM-040SY-I2ZTM-01Y-0B
26	GK ARON/AG SECO 7846//2180/4/2*MILAN/KAUZ//PRINIA/3/CMSA05Y00954T-040M-040ZTP0Y-040ZTM-040SY-I5ZTM-01Y-0B
27	MILAN/KAUZ//PRINIA/3/BAV92/4/WBLL1* 2/KUKUNACMSA04M00040S-040ZTB-040ZTY-040ZTM-040SY- 2ZTM-3Y-0B
28	CNO79//PF70354/MUS/3/PASTOR/4/BAV92/5/FRET2/KUKUNA//CMSA05Y01011T-040M-040ZTP0Y-040ZTM-040SY-2ZTM-03Y-0B
29	ACHTAR*3//KANZ/KS85-8-5/4/MILAN/KAUZ//PRINIA/3/BAV92/5/CMSA05M00661T-050Y-040ZTM-040ZTY-33ZTM-02Y-0B
30	W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1PTSS02B00102T-0T0PY-0B-0Y-0B-11Y-0M-0SY

Data were recorded for early ground cover (ground covered with plant canopy was estimated visually at 21 DAS. Canopy temperature (CT) was measured at vegetative and grain filling stages using a hand held infrared thermometer (Model LT-300, Sixth sense) held at 0.5-1 m from the edge of the plot and approximately 50 cm above the canopy at a 30° angle from the horizon. The presented data are means of three sets of measurements, which was taken in the late morning: from two hours before solar noon(Pask *et al*., 2012) . Leaf chlorophyll content (LCC) was measured at 50% anthesis using a self-calibrating chlorophyll meter (Minolta SPAD model 502). Five leaves were randomly selected, measured and averaged for each plot and the SPAD values were recorded. The relative water content was calculated using the following formula (Schonfeld *et al.*, 1988):

$$\text{RWC}\,(\%) = \frac{\text{Fresh weight - Dry weight}}{\text{Turgid weight - Dry weight}} \times 100$$

Where, five flag leaves for each genotype were collected from the base of lamina during the grain filling stages and fresh weights were determined. Turgid weight was taken after leaves were soaked in distilled water after 18 hours at room temperature (20 ± 2^{o}C) and 60% relative humidity under low light conditions. The leaves were then taken out of water, blotted on tissue papers and turgid weight was obtained. Dry weights were taken after oven drying the turgid leaves at 70^{o}C for 48 hours.

At physiological maturity (80% of the plants of each plot lost green colour in their peduncle), data were collected from four central rows on the following traits: plant height (cm), peduncle length (recorded from the base of spike to bottom flag leaf node in cm), spikes m^{-2}, grains spike^{-1}, TGW (g), total dry matter at 86 days after sowing (g m^{-2}) and grain yield (kg ha^{-1}).

Statistical analysis

All the analysis were performed using ‘R’ platform (Team, 2016). Correlation analysis was performed using 'Agricolae’ package (Mendiburu, 2016) and graphical visualization of regression was done using ‘ggplot2’ package (Wickham, 2009) in R platform (Team, 2016).

Broad-sense heritability for all the characters was computed as per formula suggested by Lush (1949). The genetic advance (GA) and genetic gain were computed following the procedure reported by Singh and Chaudhary (1985): $GA = k \times \delta^2p \times h^2b$; while Genetic Gain (%) = (GA/Mean) × 100 where k = 1.4 at 20% selection intensity, δ^2p = phenotypic variance for a trait and H^2b= broad-sense heritability for a trait and Selection differential for a trait = Mean of top 20% selected lines – population mean.

RESULTS AND DISCUSSION

The analysis of variance revealed significant variation ($P < 0.01$) among the 30 wheat genotypes for all the phenology and physiology related traits studied apart from flag leaf chlorophyll content (Table 3). The wide range of variations were observed for early ground cover (EGC), Leaf chlorophyll content (SPAD value), thousand grain weight (TGW), grain yield ranged from 10-30%, 38.2-47.2, 30.9-47.6 g and 4024-5053 kg ha^{-1} respectively. Variations obtained among genotypes can be used in selecting genotypes for drought stress. Significant genetic difference for plant height, number of effective tillers, 100-grain weight (TGW), grain yield and relative water content (RWC) among 9 bread wheat genotypes have previously been reported by Bayoumi *et al.*, 2008. Days to maturity (DM), early ground cover (EGC), canopy temperature at the vegetative and grain filling stage (CTvg and CTgf) as well as Leaf chlorophyll content (SPAD value) were found to be significant at different location (Lopes *et al*., 2012). In another study, Kilic and Yagbasanlar (2010) found significant differences between days to heading, days to maturity (DM), plant height (PH), number of spike per m^2, chlorophyll content (CC), peduncle length (PL) and1000-grain weight under drought stress.

EGC, DM, PH, spike m^{-2}, PL, CTvg and CTgf, RWC, yield and TGW exhibited high to moderate heritability with the range being 0.50-0.96 while low estimate of heritability was observed for CC (Table 3). High heritability of traits indicated that these traits are less affected by environment and genetic improvements can be achieved for these traits. High genetic advance (GA) or selection response was estimated for yield, TGW and RWC. High to moderate genetic gain was recorded for yield, TGW, spike m^{-2}, EGC, PL and CTgf. High GA for grain yield was 648.63 kg ha^{-1} indicating the best 20% high yielding genotypes using as parents could improve yield by 648.63 kg ha^{-1} in their progenies. Therefore, mean genotypic value of the new population for grain yield can be improved from 4567.89 to 5216.52 kg ha^{-1} Likewise, high GA for other traits can contribute on mean genotypic value of the new population.

This result suggested that some of the genotypes performed well under water stress condition. It refers to the potential of these genotypes could be utilized to get high yield in drought prone areas. High heritability accompanied with high genetic advance was due to additive gene effects and selection may be effective for these traits (Abinasa *et al*., 2011). However, high heritability for DM, PH, CTvg and CC relatively lower estimates for genetic advance and lower genetic gain indicated non-additive gene effect. Therefore, there seemed a limited scope for improvement in these traits. Lopes *et al*. (2012) also reported high heritability estimates for grain yield, TGW, DM, PH, EGC, CTvg and CTgf under water stress environment which supported the present findings. High and high to moderate genetic advance for grain yield, TGW, RWC and CC were reported by Said (2014) suggesting direct selection for these traits. Significant increase in Yield, TGW, EGC and PL of 20% top selected genotypes was noticed on comparison with population mean (Table 3). In contrast, non-significant reduction was observed for traits canopy temperature at vegetative and grain filling stages (CTvg and CTgf) and there was a positive increase in RWC.

Significant positive correlations were observed for traits EGC, TGW, CC and Leaf area index at 86 days after sowing (LAI86) with yield while number of plants m^{-2} (NP) showed strong negative association with GY (Table 4). Canopy temperature at grain filling (CTgf) stage, PL, HD and MD showed non-significant negative correlation with yield. RWC, PH, SPM and TDM86 were found to be positively correlated with yield. CT at both stages showed positive strong correlation with each other as well as positive correlation with HD, MD, SPAD and LAI86 while CTgf was found to be negatively associated with TGW. EGC was found to be positively correlated with RWC, TGW, SPM, SPAD and PH while negatively correlated with CT at both stages. PL showed positive association with RWC, LAI86 and TDM86 but negative association with SPAD and both stages of CT. Correlation coefficient among traits has big impact in selection process for breeders, and therefore it would help selecting traits to increase yield under certain environmental conditions. Genetic correlations sharpened the cohesion of traits under variation, due to environmental effects, are eliminated and were the basis for the indirect selection (Van-Ginkel *et al*., 1997). CT particularly at reproductive stage has been reported to be the most important, an inexpensive and efficient tool for predicting high grain yield under drought condition (Olivares-Villegas *et al*., 2007; Pask *et al*., 2014). In our study, decreased CTgf and increased EGC were found to be associated with increased yield. This result is supported by other studies (Lopes *et al*., 2012; Olivares-Villegas *et al*., 2007). It indicated that higher EGC reducing weed and evaporation from the soil surface will led to higher biomass which offers production of more photosynthates and it finally reflected in TGW and grain yield.

A positive association was observed between CT and MD this is accordance with the findings of Lopes and Reynolds (2011). As mentioned above, increased PH and TGW were positively correlated with improved grain yield. This finding is consistent with previous results (Naghavi *et al*., 2015; Ahmadizadeh and Shahbazi, 2012). Increased early vigour is correlated with increased specific leaf area (Rebetzke and Richards, 1999). This explains the expected increase in chlorophyll content (SPAD reading) though the association was negative in this present study. However, positive and strong association was noticed for the trait CC (SPAD) at grain filling stage with grain yield and LAI86. Moreover, positive correlation was found for the traits CT with CC. This may have been because of high production of photosynthates and delayed leaf senesces, which is widely used as a selection criterion in breeding program for drought and heat tolerance (Reynolds *et al*., 2001; Kumar *et al*., 2010). Identical results were obtained by Kumari *et al*. (2013), they have reported strong positive association for the traits CT and grain yield with stay green. Non-significant positive association was reported by others between CC (SPAD reading) and yield under drought condition (Pask *et al*., 2014; Guendouz and Maamari, 2012; Olivares-Villegas *et al*., 2007). Week positive association wasobserved between RWC and grain yield whereas significance difference was noticed among the genotypes

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Table 3. Population mean, mean values of top 20% (6) selected genotypes, genotypic variance (δ^2g), phenotypic variance (δ^2p), heritability, Selection response, percentage genetic gain over mean, coefficient of variation (CV), least significance difference (LSD at $p<0.05$) and level of probability for yield, days to maturity (DM), plant height (PH), spikes per square metre, thousand grain weight (TGW), early ground coverage (EGC/GC), peduncle length (PL), canopy temper measured at vegetative and grain filling stages (CTvg, CTgf), relative water content (RWC) and leaf chlorophyll content (CC) measured by SPAD under rainfed condition.

Genetic components	Yield (kg ha^{-1})	DM (days)	PH (cm)	Spikes m^{-2}	TGW (g)	EGC (%)	PL (cm)	CTvg (^{0}C)	CTgf (^{0}C)	RWC (%)	CC (SPAD)
Population mean	4567.9	114.9	101.8	361.4	38.5	25.8	36.5	18.9	24.0	86.0	43.1
Mean (top 20% selected lines)	4983.3	114.2	101.2	355.9	42.5	30.0	35.7	18.6	23.7	87.8	44.8
Maximum	5053.0	118.0	112.0	514.0	47.6	30.0	40.0	21.6	26.6	97.3	47.2
Minimum	4024.0	112.0	95.0	320.0	30.9	10.0	32.0	17.3	21.6	70.9	38.2
Δ^2g	111438.2	1.8	12.5	966.9	19.7	26.4	5.9	0.7	1.3	30.1	2.6
δ^2p	125260.2	2.0	13.8	1599.1	20.1	32.1	6.0	1.4	1.5	34.4	17.1
Heritability	0.88	0.88	0.87	0.60	0.96	0.82	0.95	0.50	0.87	0.87	0.15
Genetic advance	648.6	2.6	6.9	49.8	9.1	6.5	4.9	1.3	2.2	10.6	1.3
Selection differential	415.43	-0.7	-0.6	-5.5	4.0	4.2	-0.8	-0.3	-0.3	1.8	1.7
CV%	2.57	0.4	1.1	7.0	1.5	9.3	1.0	4.3	1.7	2.4	8.9
LSD 5%	207.38	0.9	2.0	44.4	1.0	3.9	0.6	1.4	0.7	3.6	6.7
F-Value	**	**	**	**	**	**	**	**	**	**	*NS*

** Significant at 1% level of probability

Table 4. Correlation in percent increase or decrease between yield and physiological traits for elite wheat lines grown under rainfed condition.

	NP	HD	MD	PH	TGW	EGC	PL	CTv	CTgf	RWC	SPAD	LAI86	TDM86
HD	40*												
MD	25	64**											
PH	-4	32	5										
TGW	-45	-49	-33	5									
EGC	-40	-22	-30	12	55**								
PL	-25	-9	-1	-11	-18	-27							
CTv	46*	32	21	17	7	-42	-19						
CTgf	45*	55**	34	-1	-39	-31	-2	54**					
RWC	-13	14	2	6	-8	16	24	-51	-31				
SPAD	-17	24	23	13	4	26	-13	16	2	27			
LAI86	5	3	19	-3	4	-13	24	37*	43*	-32	33*		
TDM86	5	21	-2	14	-2	-13	26	9	14	-2	3	70**	
Yield	-54	-18	-25	15	69**	53**	-14	7	-6	9	53**	28*	8

Table 5. Co-efficient of determination and probability (*P*) of different primary and secondary traits on yield.

	Primary yield contributing traits	Secondary yield contributing traits
Initial Model	Yield ~ NP + HD + MD + PH + TGW	Yield ~ EGC + PL + CTvg + CTgf + RWC + SPAD + LAI86 + TDM86
Adjusted r^2	0.55	0.44
P-value	0.0001	0.0063
Final Model	Yield ~ NP + HD + MD + TGW	Yield ~ EGC + RWC + SPAD
Adjusted r^2	0.57	0.48
P-value	0.00003	0.00017

Under water stress condition a positive and significant association between RWC and yield was reported by Bayoumi *et al*. (2008). RWC has been recommended as a drought tolerance trait and genotypes maintaining more RWC under water stress are considered to be better tolerance to drought and giving more yield (Keyvan, 2010; Lugojan and Ciulca, 2011).

Stepwise (both forward and backward) regression was done following the multiple regression model to find out the most important traits for grain yield variation. The primary and secondary yield contributing traits all together were accounted for 55.7% and 43.9% yield variation respectively (Table 5), which clearly indicated that secondary traits is also important for selection of suitable genotypes under water stress. The final regression model with reduced traits contributed 57.4% and 47.6% for primary and secondary yield contributing traits, to the final yield variation.

NP, TGW, EGC and SPAD showing significant association with grain yield were accounted for 48.1, 28.8, 28.1 and 28.2% yield variation (Figure 1). NP was in opposite direction while others were positive. Higher number of plant often increases the competition for water and sharing for resources which eventually reduce the yield potential of the plant. In contrast, high grain weight is an indication of superior yielding ability. Early ground coverage and chlorophyll content (SPAD) explained a significant yield variation, where those traits indirectly contributed through photosynthetic assimilates translocated to grains. High chlorophyll content has been recognized as a desirable characteristic due to its low degree of photo inhibition of photosynthetic apparatus, therefore reducing carbohydrate losses for grain growth (Farquhar *et al*., 1989). However, Iturbe-Ormaetxe *et al*. (1998) had revealed that water stress condition caused reduction in chlorophyll content and chlorophyll content differed significantly among the genotypes under study. Therefore, primary (NP, HD, MD and TGW) and secondary (EGC, RWC and SPAD) yield contributing traits hold higher importance and selection based on those traits would be beneficial.

Further, 30 genotypes showing different performance under water stress condition were ranked on the basis of 12 traits along with grain yield (Table 6). It is a common consensus that identification of drought tolerance genotypes based on a single criterion was contradictory and considered to be inefficient because of large genotype x environment interactions and complex inheritance (Bolanos and Edmeades, 1996). Hence, ranking method was applied to find out the suitable drought tolerance genotypes. Therefore in light of ranking, entry 30 found in top of the chart (11/13). This entry was followed by entries 19 and 21 (10/13), and 2, 6 and 28 (9/13). In contrast, entry 8 (3/13) was in lower yield category with lower early ground coverage, chlorophyll content, TGW, RWC and MD and PH. So, considering the overall performance and visual grain quality of the genotypes, Entry 2, 6, 19, 21, 28 and 30 were finally selected.

Table 6. Comparison of genotypes (entry 1 is local variety) using mean values for number of plants m^{-2} (NP), early ground coverage (EGC/GC), days to heading (DH), days to maturity (DM), plant height (PH), peduncle length (PL), canopy temper measured at vegetative and grain filling stages (CTvg, CTgf), relative water content (RWC), leaf chlorophyll content (CC) measured by SPAD under rainfed condition,spikes per square metre, thousand grain weight (TGW) and yield. Top mean values ranked from a-h are shown. Rows marked as bold are the six selected genotypes.

Entries	NP (Rank)	EGC (Rank)	DH (Rank)	DM (Rank)	PH (Rank)	PL (Rank)	CTvg (Rank)	CTgf (Rank)	RWC (Rank)	CC (Rank)	SPM (Rank)	TGW (Rank)	Yield (Rank)	Frequency
1(Prodip)	201.3	20d	77d	115.3h	102.7	35	21.7	26.7	75.9	44.1	320.3	43.5b	4844	4/13
2	151.7b	30a	76c	112.7a	99.3f	35	18.3d	23c	75.4	38.5	348	42.7d	5002.7c	9/13
3	228	26.7b	81	115.3h	107.7	34	20.7	23.7e	80.2	41.9	347.3	41.6g	4246	4/13
4	175.7	20d	83	114e	101	38.7f	20.7	24.7h	77.1	44.4	366.7h	40.1	4974.3e	6/13
5	209.3	30a	82	114e	103.7	33.3	20.3	25.7	70.9	45.7g	390.7c	38.7	4969.3f	5/13
6	183	30a	81	116.3	99.7g	37.7h	18.7e	24.3g	89.1h	45.2h	356.3	41.9f	5041b	9/13
7	180	30a	69b	113b	96.7b	38.7f	18c	21.7a	83.1	38.7	343	40.8	4232	7/13
8	205	10e	84	116.7	105.3	37	20h	23.7e	87.4	43.9	355	34.6	4132.3	3/13
9	232	20d	83	114.7g	99.3f	34.7	19.3g	24.3g	88.9	39.4	331	32.2	4393.3	5/13
10	234.7	20d	81	115.7	100.3h	35	19.3g	24.7h	84	41.1	346.7	33.4	4257	4/13
11	179.3	20d	68a	114e	94.7a	36.7	17.3a	23c	83.5	42.4	382.7d	37.5	4319.7	7/13
12	200	20d	83	115.7	97.3c	41.3a	19f	25	88	42.7	352.7	31.9	4351.3	4/13
13	212.3	20d	84	114.3f	103.3	35	19f	25.3	84.8	41.2	372f	32.4	4024	4/13
14	208.7	20d	83	116	102.7	41b	19f	25	83.9	40.1	364.7h	31	4086.7	4/13
15	201.3	26.7b	83	115.3h	103.3	35	18.7e	25	85.8	39.5	355.7	33.5	4071.3	3/13
16	205	30a	84	114.3f	102.3	36	17.7b	25	88.3	42.2	348	32.9	4483.3	3/13
17	195	23.3c	85	117.3	101	39e	18.3d	25	88.2	43.1	326	31.4	4222.7	3/13
18	162d	23.3c	78e	114.7g	98.3e	37.3	18.3d	23.3d	90.9d	40.8	362.7	37.7	4248.7	8/13
19	211.3	30a	77d	114.3f	99.3f	35.3	19f	24f	91.1c	45.9e	362	47.6a	4875.7h	10/13
20	169h	23.3c	81h	115.7	101.7	40.7c	18.7e	23c	88.8	44	355	42.2e	4709	7/13
21	168g	30a	76c	113.7d	97.7d	36.3	19f	25	89.6f	47.3a	345	41.2h	4952g	10/13
22	190	30a	79g	114.3f	101.3	38g	18.7e	23.3d	88.6	47.1b	350.3	43.3c	4521.3	8/13
23	210.7	30a	85	114.7g	99.7g	32	18.3d	24.3g	89.3g	45.8f	367.7g	39.4	4366	8/13
24	198	30a	85	118	103	34	19f	23c	90.5e	44	372f	39.1	4618.3	5/13
25	170	30a	78f	114.7g	106	33.7	18.7e	24f	89.3h	45h	345.3	40	4976d	8/13
26	145.3a	30a	83	117.7	101	33.7	18.3d	24.7h	84.2	46.4d	397.7b	41h	4828.3	7/13
27	168g	30a	69b	112.7a	102.3	37.3	18c	21.7a	83.4	38.3	320.3	43.5b	4652.3	7/13
28	152.7c	30a	79g	113.3c	112.3	37.7h	17.7b	23.3d	88.5	42.9	514.3a	40.4	4894.3h	9/13
29	165.3f	30a	81h	114.3f	106	40d	18.3d	23c	97.3a	45.2h	364	39.1	4691	9/13
30	164.7e	30a	78f	114e	105.3	36	18.3d	22.3b	92.3b	47.1c	378.7e	41.8g	5052.7a	11/13

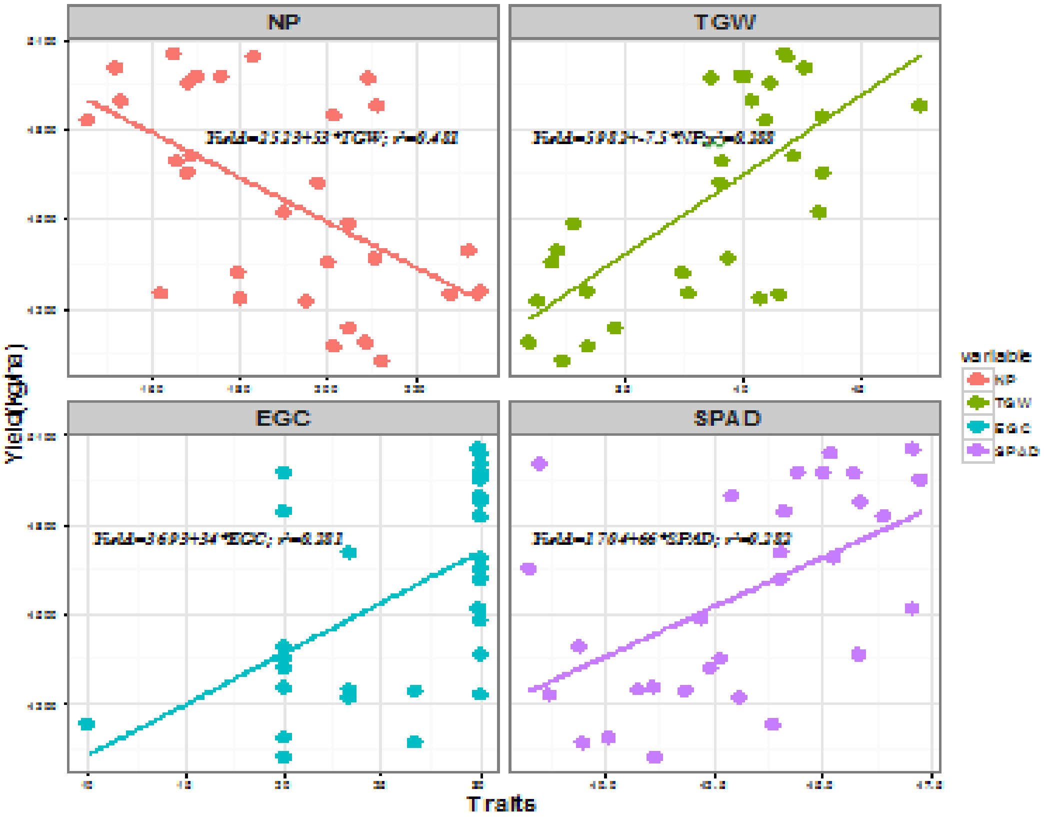

Figure 1. Contribution of number of plants m^{-2} (NP), thousand grain weight (TGW), early ground coverage (EGC) and leaf chlorophyll content (CC) measured by SPAD on grain yield variation and their direction of interaction.

CONCLUSION

The results of this study indicated that some of the spring bread wheat genotypes differently responded to water stress at different growth stages. Heritability estimates for most of the traits were higher under rainfed condition and high genetic advance for studied traits can contribute on mean genotypic value of the new population produced from the selected lines. A total of six high yielding genotypes expressing physiological traits of interest under water stress condition were selected and recommended as high yielding genotypes which would be suitable for the future wheat improvement or as drought tolerant varieties. The conclusive remarks of the study made coverage on the potential grain yield of 30 wheat genotypes were well understood, in addition to the avenue for improving yield by bringing all drought adaptive traits in to a single genotype. The four key traits (early ground coverage, thousand grain weight, chlorophyll content and canopy temperature) were identified in this study and could be targeted to improve grain yield of wheat under moisture stress which is relatively cheaper and convenient to utilize.

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