Indian J. Genet., 80(4) 365-374 (2020)
DOI: 10.31742/IJGPB.80.4.1

Genetic variation of stem characters in wheat and their relation to physiological characters and yield under drought

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(Received: August 2020; Revised: October 2020; Accepted: November 2020)

Abstract

Stem characters such as stem solidness and stem carbohydrates (water soluble carbohydrates and non-structural carbohydrates estimated as fructan) play an important role in stabilizing grain yield in stressful environments. Ten wheat genotypes were screened for carbohydrate content (Water soluble sugars and fructan) in peduncle along with other stem parameters namely, stem solidness, grain growth rate and stem osmotic potential under irrigated and drought conditions. Data was analyzed for correlation among these parameters along with biomass and yield. The results of present study indicated that stress-tolerant genotype, RIL-S1-38 and WH 1235 accumulated higher fructan content in stem and contributed in grain growth rate, reduced osmotic potential and further imparted drought tolerance. Clear differences in stem solidness and fructan content exhibited lesser grain yield reduction under drought condition.

Key words: Drought tolerance, fructan, stem solidness, water soluble sugars

Introduction

Bread wheat (*Triticum aestivum*, 2n=6x=42, genome AABBDD) is cultivated all over the globe and nearly one third of world population consume it as a staple food. It is the second largest food grain crop and contributes nearly 55% carbohydrates and protein to the world diet which is more than any other cereal crop (Abd-El-Haleem et al. 2009). Due to increasing population, the demand of wheat is expected to increase many fold in coming decades which cannot be fulfilled with the present production scenario. Presently, global wheat production is around 760 million metric tonnes. According to an estimate the world population will be around 9 billion in 2050 and to feed such a huge population, wheat production must be increased by 60% (Tilman et al. 2011). To achieve this target, the rate of annual wheat production must be increased from the current level (below 1%) to at least 1.6% (Tadesse et al. 2016). But various abiotic stresses like drought, high temperature, frost, salinity etc. are serious challenges of the present time which hampers the wheat production. Out of these environmental factors drought which is caused by low rainfall and less irrigation water supply is considered to be the most widespread abiotic stress experienced by crop plants and becoming a severe problem in many wheat producing regions of the world (Demirevska et al. 2009). A plant is said to be under drought condition when its water demand exceeds the water supply. Drought is a very complex trait and its effect depends on crop species, variety, duration and stage of occurrence. The competition for fresh water in agriculture industry increases due to population explosion, urbanization and industrialization (Tilman et al. 2011). According to reports by National Science Foundation (NSF) in the next 30 years, drought will affect crop yield more badly (Zhang et al. 2014). More than 50% area under wheat cultivation is affected by periodic drought conditions (Liu et al. 2011). This situation is expected to be more severe due to global warming as high temperature also leads to water stress in plants. It is very difficult for the crop plants to achieve their potential yield under such conditions. Drought severely impacts the performance of crop plants, limits its production more than any other environmental stress (Almeselmani et al. 2011).

In response to drought, plants develop stress

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tolerance mechanisms at morphological, physiological and molecular levels (Farooq et al. 2009; Passioura 2012). Among physiological mechanisms, stem solidness and non-structural carbohydrate are important traits which protect the plant from drought and other abiotic stresses. Furthermore, osmotic adjustment, mobilization of carbohydrates helps plants survive and have better growth, yield under drought condition (Farooq et al. 2009). Enhancement in activity of enzymatic and non-enzymatic antioxidants of plants helps it to protect the cellular membranes and macromolecules from drought induced oxidative stress. Under such circumstances, reserved photosynthates of leaves and stem is remobilized and translocated to the developing grains (Blum 2016). In wheat, water-soluble carbohydrates (WSCs) accumulates in the stem and leaf sheath from early jointing stage to anthesis, which are then remobilized and translocated to the developing grains during grain filling stage (Xue et al. 2008; Zhang et al. 2013). The accumulation of WSCs varies with both the genotype and environmental conditions (Dreccer et al. 2009). Among various WSCs, glucose, fructose, sucrose and fructan are most common and accumulates largely inpeduncle and penultimate internode (Gebbing 2003; Joudi et al. 2012). Fructan and starch are the principal carbohydrates for storage reserve of the grain and their remobilization in the wheat plant play an important role in grain yield and drought tolerance. When grain filling demands are high and sucrose is limited, fructan degrades to release more fructose and sucrose. The hydrolysis of fructan is required for the mobilization of stored carbohydrates which involves enzyme fructanexohydrolases (FEHs), mainly fructan 1-exohydrolases (1-FEHs) and it is stated that 1-FEH is up-regulated at around 20-25 days post anthesis in wheat stems under terminal drought (Zhang et al. 2014, 2015). The level of expression of stem solidness is highly heritable, but is affected by environment. Stem tends to be more solid when plants were exposed to high temperature during stem elongation (Reynolds et al. 2009). Therefore, breeding drought tolerant wheat genotypes with relevant agronomic and adaptive traits which include more remobilization of carbohydrates is one of the key components to enhance productivity and food security among wheat growing communities (Chen et al. 2015). The present study therefore, mainly focussed on these important physiological parameters of stress tolerance mechanism in wheat.

Material and methods

Materials, research area and experimental design

The present study was conducted at the Research Farm of Wheat and Barley Section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar during the *rabi* 2018-19. This location is situated in North-Western region of India at 29°10' N latitude and 75°46' E longitude at about 215.2 meter amsl. The material comprised of ten wheat genotypes namely, NIAW 3170, C 306, RIL-S1-38, BRW 3806, MACS 6696, K1317, MP 3288, HD 3237, WH 1235 and HI 1620. The selection of genotypes for this experiment was on a random basis and included both drought tolerant and susceptible genotypes. The experiment was conducted in Complete Randomized Block Design (CRBD) with three replications. Each genotype was grown in three rows of 3m length with a spacing of 20cm (between rows) and 5cm (between plants). The genotypes were sown under two water regimes viz., irrigated and drought condition. In irrigated condition, all the recommended six irrigations (22, 45, 65, 85, 105 and 120 days after sowing) were applied while in drought condition only one irrigation was applied at crown root initiation stage (22 days after sowing). All other standard package and practices were followed equally for both the environments.

Measurement of morphological, physiological and stem characters

All the physiological and morphological observations were taken from ten randomly selected plants. Under both environments, ten plants of each genotype within every replication were randomly selected and tagged after 90 days of sowing. Observations on osmotic potential, stem solidness, grain growth rate, plant biomass and yield were estimated/recorded from these plants and their average was taken for statistical analysis.

The osmotic potential of stem was estimated by the method of Morgan (1980) with psychrometric technique using a model VAPRO 5520 vapour pressure osmometer (Wescor INC., Lorganan, Utah, USA). The osmometer was calibrated by using standard solutions of NaCl. Osmotic potential value obtained from the osmometer was in mmol kg^{-1}, which was converted to MPa (pressure unit) according to the equation:

$$\text{OP (-MPa)} = (-R \times T \times \text{osmometer reading})/1000$$

Where: R is the gas constant (0.008314) and T is the laboratory temperature measured on the Kelvin scale (T = 298K).

The observations for stem solidness were taken three times i.e. 90, 100 and 110 days after sowing. Based on pith fill plants can be divided into six categories from complete pith fill to completely hollow (Fig. 1).

structural carbohydrate present in wheat stem is in form of fructans. Fructan was estimated by method suggested by McCleary and Blakeney (1999).

Statistical analysis

Standard statistical programme was used for analysis of the data. In the present study means and ranges of all the parameters were calculated. To find out

Fig. 1. Variations in stem solidness; fully solid (1) to complete hollow (6)

relationship among various traits with grain yield, correlation analysis was also calculated. The analysis of variance was carried out and significant differences among genotypes were calculated using the standard protocol of Fisher (1934). For correlation analysis, method given by Al-Jibouri et al. (1958) was used.

For measurement of this character, stem of plant was excised from peduncle part. The upper stem internode diameter (Internode-D) and pith fill was determined with Yammoyo digimatic external screw-type micrometer (vernier caliper). The calculation for stem solidness (%) was done by using formula:

Stem solidness (%) = (Stem diameter/pith fill) x 100

For grain growth rate (mg/day) calculations, two ears were harvested from each genotype at 10 days after anthesis with ten days interval. It was continued up to physiological maturity. The harvested ears were oven dried at 70°C for 72 hours. Ten grains of each genotype were separated from the middle of each spike and then weight was taken with analytical balance. Grain growth rate (mg/day) was calculated by following formula:

Grain growth rate (mg/day) = $(W_2 – W_1) / (T_2"T_1)$

Where: W_1 = grain weight at initial time, W_2 = grain weight at final time, T_1 = initial time and T_2 = final time

For biomass yield, plants from one square meter area were harvested at maturity, sun dried and weighted. These plants were threshed using a thresher. The grains of threshed plants were weighted for grain yield.

Estimation of water soluble carbohydrates and non-structural carbohydrates

The water soluble carbohydrate of stem was estimated by the method of Dubois (1990). The main non-

Results

Analysis of variance (ANOVA) used to partition the total variance into its causal components, showed highly significant differences among the wheat genotypes for all the traits at $p>0.01$ level of significance (Tables 1 and 2). Further the genotypes were evaluated for the association of various traits with grain yield. Performance of different genotypes with respect to various physiological parameters and grain yield is discussed in the below section.

Stem solidness (%) at 90, 100 and 110 days after sowing (DAS)

The average stem solidness in irrigated and drought condition at 90 DAS was in a range of 14.93% to 28.79% in irrigated condition and 13.31% to 15.95% in drought condition (Tables 3 and 4). The maximum stem solidness was shown in RIL-S1-38 (28.79%) in irrigated condition while in drought condition maximum solidness was shown in WH 1235 (15.95%). The minimum stem solidness at 90 DAS (days after sowing) was shown in K 1317 (14.93% and 13.31%) in both irrigated and drought condition. At 100 DAS the average range of stem solidness in irrigated condition was 14.52% to 27.05% while in drought

Table 1. Mean sum of squares for different traits under irrigated condition

Source of variation	Degree of freedom	Mean sum of squares									
		SS1	SS2	SS3	OP	WSCPd	WSCPe	NSC	GGR	BY	GY
Treatment	9	74.14*	41.11*	13.42*	1.44*	14.58*	111.66*	14.45*	880.69*	120721.39*	29408.31*
Replication	2	0.38	0.18	0.07	0.20	1.19	0.45	0.53	234.55	22918.74	6853.74
Error	18	0.03	0.02	0.01	0.01	0.08	0.03	0.32	9.61	769.13	437.77
CD		0.30	0.23	0.11	0.19	0.45	0.29	0.91	5.04	45.06	34.00

*Significant at p = 0.01 level of significance, SS1: Stem solidness (90 DAS); SS2: Stem solidness (100 DAS); SS3: Stem solidness (110 DAS); OP: Osmotic potential; WSCPd: Water soluble carbohydrate in peduncle; WSCPe: Water soluble carbohydrate in penultimate; NSC: Non-structural carbohydrate; BY: Biological yield; GY: Grain yield

Table 2. Mean sum of squares for different traits under drought condition

Source of variation	Degree of freedom	Mean sum of squares									
		SS1	SS2	SS3	OP	WSCPd	WSCPe	NSC	GGR	BY	GY
Treatment	9	4.48*	6.49*	9.16*	0.39*	5.07*	47.97*	25.15*	1361.82*	23273.64*	32338.13*
Replication	2	0.30	0.06	0.08	0.07	0.22	1.08	0.06	120.34	16777.22	2499.56
Error	18	0.03	0.01	0.01	0.01	0.02	0.12	0.02	7.56	883.93	22.16
CD		0.30	0.13	0.11	0.20	0.21	0.55	0.21	4.47	48.31	7.65

*Significant at p = 0.01 level of significance, SS1: Stem solidness (90 DAS); SS2: Stem solidness (100 DAS); SS3: Stem solidness (110 DAS); OP: Osmotic potential; WSCPd: Water soluble carbohydrate in peduncle; WSCPe: Water soluble carbohydrate in penultimate; NSC: Non-structural carbohydrate; BY: Biological yield; GY: Grain yield

condition it was 12.51% to 17.27%. The maximum stem solidness at 100 DAS follow the same pattern as in 90 DAS which was RIL-S1-38 (27.05%) in irrigated and WH 1235 (17.27%) in drought. The minimum stem solidness at 100 DAS in irrigated condition was found in MP 3288 (14.52%) and in drought it was found in MACS 6696 (12.51%). At 110 DAS the average range of stem solidness was 14.30% to 21.29% in irrigated condition and 11.09% to 17.27% in drought condition. The maximum stem solidness was found in WH 1235 (21.29% and 17.27%) under both conditions and the minimum stem solidness was found in MP 3288 (14.30% and 11.09%) under both conditions. Significant difference was observed between genotypes and environment at 90, 100 and 110 DAS. Also there was a decrease in stem solidness at 110 DAS as compared to 90 and 100 DAS.

Osmotic potential (MPa)

Stem osmotic potential was strongly affected by imposition of drought. Drought stress decreased osmotic potential at anthesis (Table 3 and 4, Fig. 2). Average osmotic potential for irrigated and drought

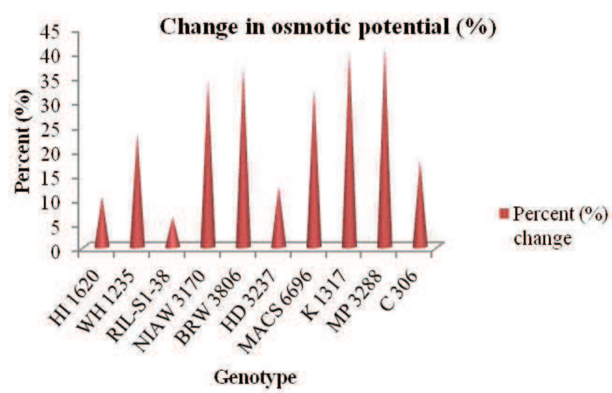

Fig. 2. Per cent change in osmotic potential (MPa) from irrigated to drought conditions

condition ranged from -3.90 to -1.46 MPa and -2.30 to -1.37MPa respectively. Based on F-test, osmotic potential showed significant difference among different genotypes in irrigated and drought condition at p>0.01 level of significance. The maximum osmotic potential was found in RIL-S1-38 (-1.46MPa in irrigated and -1.37 MPa in drought condition). The minimum osmotic potential was found in MP3288 in both conditions

Table 3. Mean value of different physiological traits of wheat genotypes under irrigated condition

Genotypes	Stem Solidness (%)			Stem osmotic potential (MPa)	Water soluble carbohydrates (mg glucose/g dry wt.)		Stem non-structural carbohydrates (mg fructan/g dry wt.)
	90 DAS	100 DAS	110 DAS		Peduncle	Penultimate	
HI 1620	25.63±0.07	19.62±0.13	18.25±0.07	-2.32±0.005	27.5±0.215	45.0±0.095	5.7±1.81
WH 1235	26.67±0.03	22.09±0.48	21.29±0.060	-1.84±0.305	29.8±0.160	48.6±0.160	6.4 ±0.29
RIL-S1-38	28.79±0.08	27.05±0.02	19.93±0.13	-1.46±0.050	28.6±0.215	49.4 ±0.000	5.6±0.07
NIAW 3170	16.13±0.14	16.37±0.16	16.48±0.07	-2.16±0.245	26.3 ±0.975	39.5±0.445	5.9±0.02
BRW 3806	17.63±0.13	17.55±0.03	17.44±0.14	-2.84±0.100	24.2±0.090	36.5±0.470	7.0±0.01
HD 3237	19.62±0.67	17.27±0.27	16.19±0.00	-2.58±0.115	24.5 ±0.165	41.2 ±0.215	10.2 ±0.04
MACS 6696	17.95±0.15	15.48±0.04	16.41±0.10	-3.16±0.340	25.4±0.440	32.9±0.050	10.5±0.01
K 1317	14.93±0.21	17.55±0.09	15.40±0.23	-2.97±0.130	23.8 ±0.049	33.5 ±0.055	9.5 ±0.02
MP 3288	15.88±0.32	14.52±0.12	14.30±0.03	-3.90±0.070	23.2 ±0.170	34.3±0.430	11.0±0.02
C 306	18.62±0.14	16.67±0.02	16.15±0.07	-2.54±0.100	25.0 ±0.510	43.2±0.205	6.5±0.01
Mean	20.18	18.42	17.18	-2.58	25.80	40.41	7.80
RANGE	14.93-28.79	14.52-27.05	14.30-21.29	-3.90–(-1.46)	23.20–29.80	32.90–49.40	5.60–11.00
CD	0.30	0.23	0.11	0.19	0.45	0.29	0.91

Table 4. Mean value of different physiological traits of wheat genotypes under drought condition

Genotypes	Stem Solidness (%)			Stem osmotic potential (MPa)	Water soluble carbohydrates (mg glucose/g dry wt.)		Stem non-structural carbohydrates (mg fructan/g dry wt.)
	90 DAS	100 DAS	110 DAS		Peduncle	Penultimate	
HI 1620	25.63±0.07	19.62±0.13	18.25±0.07	-2.32±0.005	27.5±0.215	45.0±0.095	5.7±1.81
HI 1620	14.96±0.03	15.98±0.04	13.20±0.07	-2.08±0.02	17.50 ±0.06	32.70 ±0.37	8.70 ±0.02
WH 1235	15.95±0.41	17.27±0.00	17.27±0.06	-1.41±0.19	18.60±0.06	38.60 ±0.73	9.80 ±0.01
RIL-S1-38	13.56±0.25	13.51±0.12	15.94±0.13	-1.37±0.37	19.80 ±0.05	36.10 ±0.38	10.50 ±0.08
NIAW 3170	12.48±0.56	13.34±0.07	13.73±0.06	-1.42±0.02	18.40 ±0.31	35.90 ±0.02	7.50±0.09
BRW 3806	15.13±0.13	13.40±0.29	13.05±0.14	-1.79±0.02	16.90 ±0.13	29.50 ±0.15	9.40±0.03
HD 3237	15.77±0.14	14.57±0.04	12.90±0.00	-2.26±0.01	17.40± 0.40	31.00 ±0.23	10.40 ±0.02
MACS 6696	13.77±0.04	12.51±0.05	12.63±0.10	-2.13±0.03	15.20 ±0.01	25.80 ±0.08	3.40 ±0.01
K 1317	13.31±0.03	13.40±0.07	13.09±0.23	-1.77±0.28	16.80 ±0.06	27.80 ±0.11	5.50 ±0.44
MP 3288	13.13±0.10	13.01±0.08	11.09±0.03	-2.30±0.01	16.20 ±0.24	31.50 ±1.09	2.40 ±0.01
C 306	15.28±0.03	13.90±0.04	14.00±0.06	-2.09±0.02	17.80 ±0.15	29.90 ±0.12	8.50 ±0.05
Mean	14.33	13.99	13.69	-1.86	17.50	31.90	7.60
RANGE	13.31-15.95	12.51-17.27	11.09-17.27	-2.30–(-1.37)	15.20–19.80	25.80–38.60	2.40–10.50
CD	0.30	0.13	0.11	0.20	0.21	0.55	0.21

DAS: days after sowing

(-3.90 in irrigated condition and -1.37 in drought condition).

Water soluble carbohydrates (mg glucose/g dry wt.)

Water soluble carbohydrates (WSCs) were estimated both in peduncle and penultimate internode of wheat stem. A significant variability was present among different genotypes for this trait (Table 1 and 2). In peduncle the WSCs range from 23.2 to 29.8 mg/g in irrigated condition and in drought condition it was in a range of 15.2 to 19.8 mg g^1 (Table 3 and 4). The maximum value in irrigated conditions was shown in WH 1235 (29.8 mg/g) and minimum in MP 3288 (23.2 mg/g). In drought condition the maximum value in peduncle was observed in RIL-S1-38 (19.8 mg/g) and minimum was shown in MACS6696 (15.2 mg/g). In penultimate, the water soluble carbohydrate was in a range of 32.9 to 49.4 mg/g in irrigated condition and 25.8 to 38.6 mg/g in drought condition. The maximum value in irrigated condition (in penultimate) was observed in RIL-S1-38 (49.4 mg/g) and in drought it was observed in WH 1235 (38.6 mg/g). The minimum value in penultimate in both conditions was observed in MACS 6696 (32.9 and 25.8 mg/g).

Non-structural carbohydrates

The variation for non-structural carbohydrate in wheat genotypes under drought and irrigated conditions is shown in Table 3 and 4. The range between non-structural carbohydrates in irrigated condition was (5.6-11.0 mg/g-) while in drought condition it was in between (2.4-10.5 mg/g-). The stem non-structural carbohydrate (fructan) content was found minimum in RIL-S1-38 (5.6 mg/g) in irrigated condition while in drought condition it was minimum in MP3288 (2.4 mg/g-). The maximum value of fructan content in drought condition was found in RIL-S1-38 (10.5 mg/g^1) while in irrigated condition it was maximum in MP3288 (11.0 mg/g-).

Grain growth rate (mg/day)

The average grain growth in irrigated condition was obtained in a range of 78.5 to 127.8 mg/day and in drought condition it was observed in a range of 24.5 to 103.0 mg per day (Table 5). The highest grain growth rate in irrigated condition was observed in RIL-S1-38 (127.8 mg/day) and in drought condition it was observed in WH 1235 (103.0 mg/day). The minimum grain growth rate in irrigated condition was observed in MP 3288 (78.5 mg/day) and in drought it was in MACS 6696 (24.5 mg/day).

Biomass (g/m²) and grain yield (g/m²)

The average biomass (g/m²) in irrigated condition was obtained in a range of 991g/m^2 to 1558g/m^2 and in drought condition it was observed in a range of 726g/m^2 to 991g/m² as shown in Table 5. The maximum biomass in irrigated and drought condition was observed in RIL-S1-38 (1588 and 991 g/m^2). The minimum biomass in irrigated condition was observed in MP 3288 (991g/m^2) and in drought it was observed

Table 5. Grain growth rate, biomass and grain yield of different wheat genotypes under irrigated (IR) and drought conditions (DR)

Genotypes	Grain growth rate		Biomass (g/m²)		Grain yield (g/m²)	
	IR	DR	IR	DR	IR	DR
HI 1620	120.2±2.67	82.2±2.26	1282±88.7	941±49.30	560±17.1	434±16.90
WH 1235	121.5±3.69	103.0±4.93	1454±0.0	905±69.00	525±21.6	377±13.90
RIL-S1-38	127.8±7.15	73.8±1.17	1558±80.3	991±61.00	624±28.4	545±13.90
NIAW 3170	94.8±3.44	57.2±5.85	1060±0.0	905±69.00	506±27.3	436±19.50
BRW 3806	92.8±4.65	67.9±9.89	1134±69.0	787±0.00	551±16.1	394±13.90
HD 3237	114.8±6.03	66.4±2.38	1134±51.8	905±69.00	511±20.1	350±18.00
MACS 6696	84.7±9.78	24.5±1.34	1019±49.3	726±49.30	400±25.4	260±7.20
K 1317	91.1±8.92	49.9±3.01	991±28.8	787±0.00	334±27.4	235±25.40
MP 3288	78.5±2.04	46.3±1.03	991±28.8	787±0.00	331±14.2	205±15.10
C 306	104.3±0.06	63.9±2.83	1282±37.0	941±42.50	420±12.6	340±14.30
Mean	103.0	63.5	1191.0	868.0	476.0	358.0
RANGE	78.5-127.8	24.5-103.0	991-1558	726-991	331-624	205-545
CD	5.04	4.47	45.06	48.31	34.00	7.65

in MACS 6696 (726 g/m²).

The average grain yield (g/m²) in irrigated condition was in a range of 331 g/m^2 to 624 g/m² and in drought condition it was in range of 205 g/m² to 545 g/m² (Table 5). The maximum grain yield was observed in RIL-S1-38 (624 and 545 g/m²) in irrigated and drought condition. The minimum grain yield in both irrigated and drought was obtained in MP3288 (331 and 205 g/m²).

Correlation among different traits

Grain yield is generally associated with several morphological and physiological traits. To determine the degree of association among different traits under drought condition correlation coefficient was calculated using method given by Al-Jibouri et al. (1958). For the present study correlation among yield and other traits is shown in Table 6. It was found that biomass yield (g/m^2) was positively and highly significantly correlated with grain yield (0.790). Similarly biomass was also positively associated with fructan content (0.752). Grain yield was also showing positive correlation with fructan content (0.754). This positive correlation is mainly due to the role of fructan in stem reserve mobilization towards sink. Water soluble carbohydrate content was positively and significantly correlated with grain yield (0.871), biological yield (0.885) and fructan (0.761) whereas it was negatively correlated with osmotic potential (-0.727). Osmotic potential is negatively associated with grain yield (-0.728). Although the physiological traits i.e. stem solidness (90 DAS) trait had a positive correlation with grain yield (0.243), biomass yield (0.268) and fructan content (0.605) but it was not significantly correlated with any of these trait. Grain growth rate is also positively correlated with grain yield (0.697) and biomass yield (0.692).

Table 6. Correlation analysis of wheat genotypes under drought condition

	GY	BY	GGR	Fr	WSCs	OP	SS (90DAS)
GY	1.000	0.790**	0.697*	0.754*	0.871**	-0.728*	0.243^{NS}
BY		1.000	0.692*	0.752*	0.885**	-0.372^{NS}	0.268^{NS}
GGR			1.000	0.786**	0.723*	-0.460^{NS}	0.614^{NS}
Fr				1.000	0.761*	-0.441^{NS}	0.605^{NS}
WSCs					1.000	-0.727*	0.110^{NS}
OP						1.000	0.189^{NS}
SS (90DAS)							1.000

**Significant at p=0.01%, *significant at p=0.05 %, NS: Non significant; GY: Grain yield, BY: Biomass yield; GRR: grain growth rate; Fr: Fructan; WSCs: Water soluble carbohydrates; OP: Osmotic potential; SS: Stem solidness; DAS: Days after sowing

Discussion

Drought stress is one of the major challenges of present time in agriculture. Further the increasing temperature due to global warming is also causing water stress in crop plants. For a crop like wheat which is staple food for a huge population, development of drought tolerant genotypes is major objective of plant breeders. Various physiological processes are disturbed due to the osmotic stress caused by drought and high temperature which can be used as potential selection parameters. In the present study some important physiological parameters are studied to find their relation with drought tolerance. In the genotypes of present study significant genetic variability was recorded for both water soluble carbohydrate and osmotic potential which are important parameters for drought tolerance in crop plants. In earlier studies also significant variability has been reported for WSCs along with other physiological parameters and grain yield in wheat under drought condition (Hou et al. 2018; Kumar et al. 2018). Among various physiological parameters stem reserve assumes great importance for grain filling under both drought and heat conditions because under these stresses photosynthesis is not properly conducted by leaves (Blum et al. 1994). During the period of abiotic stresses like drought and heat, the carbohydrate accumulated in stem and leaves is remobilized towards grains and helps in proper grain filling (Ram et al. 2018). In wheat plant, carbohydrates mainly stored in the form of fructan in peduncle, penultimate and lower part of stem. Fructan, a short-term storage carbohydrate, play a major role to fill gaps between resource availability and demands. However, in grasses they also stimulate quick regrowth (Morvan-Bertrand et al. 2001). Under limited water conditions, plants start accumulation of higher concentrations of WSC, glucose, fructose and fructan in the stem parts with the upregulations of genes associated with enzymes fructan 1-fructosyltransferase B (*1-FFTB*) and fructan 1-exohydrolase w2 (*1-FEHw2*) (Yanez et al. 2017). During flower opening fructans regulates osmosis and during drought and cold stress fructans protect plants through membrane stabilization (Hincha et al. 2000). During grain filling it mobilize towards its sink source in form of sucrose and fructose (Ruuska et al. 2006). Further sugar remobilized from fructan lower the intracellular water potential and helps in continuous expansion of leaves even under drought stress (Livingston et al. 2009). WSCs (Water Soluble Carbohydrates) accumulation and remobilization depends on demand of carbohydrates by developing grain under different environment condition (Wardlaw and Willenbrink 2000). The results in present study indicate that the carbohydrate present in form of NSCs (non-structural carbohydrates) was in range of 0 to 10.0 mg fructan/g dry wt. The maximum percent variation was found in MP 3288 in irrigated condition and RIL-S1-38 in drought condition. It is earlier reported that under drought conditions, wheat genotypes with higher concentration of WSCs in the stems portion before anthesis exhibit higher grain yield than comparison to other genotypes (Michiel et al. 2004). The significance of WSCs can be realized from the fact that under varying environmental condition, stem reserve mobilization has 6 to 100% role in grain filling (Blum, 1998). However in earlier studies it was found that WSCs is either negatively correlated with grain yield or exhibit no relationship with yield. But our study has shown that WSCs are directly associated with grain yield under limited water supply condition. Similar correlation was also noticed by Seslija et al. (2017) and Hou et al. (2018) where wheat genotypes were evaluated for grain yield attributing traits.

A significant variation for stem solidness after 90, 100 and 110 DAS was present among these genotypes. Maximum stem solidness in irrigated condition was obtained in RIL-S1-38 and in WH 1235 and minimum was obtained in MP 3288. Similarly maximum stem solidness in drought condition was obtained in WH1235 followed by HI 1620 and minimum was obtained in MP3288. This variability can be used in wheat breeding for lodging resistance (Qayyum et al. 2018). Even there is no significant correlation between stem solidness and other parameters but earlier studies have reported a positive correlation between this trait and grain yield (Sallam et al. 2015). Stem solidness may be associated with grain yield as it has some role in assimilation of fructan in stem (Pierre et al. 2010). Selection of wheat genotypes for drought conditions requires estimation of various morphological traits associated with grain yield. But various physiological parameters such as osmotic potential, grain growth rate and WSCs has also correlation with grain yield and can be used as essential selection parameter. The present findings suggest that the selection of genotypes with higher fructan content would lead to cultivars with higher grain yield under drought conditions. The wheat genotypes, WH 1235 and RIL-S1-38 possess drought tolerance and may have different physiological mechanisms to deal with drought conditions.

Authors' contribution

Conceptualization of research (RM, So, Su, P); Designing of the experiments (RM); Contribution of experimental materials (RM); Execution of field/lab experiments and data collection (Su, P, So); Analysis of data and interpretation (So, RM, Su, P); Preparation of manuscript (Su, RM).

Declaration

The authors declare no conflict of interest.

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