Response of wheat genotypes to osmotic stress in terms of seed germination and growth of seedling

Efecto del estrés osmótico en la germinación y crecimiento de plántulas en distintos genotipos de trigo

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ABSTRACT

To compare the wheat genotypes in terms of seed germination and growth of seedling under osmotic stress conditions, a laboratory experiment was conducted using a completely random design with factorial arrangement. The wheat genotype (G) consisted of eight genotypes numbered as (G1) 9103, (G2) 9116, (G3) 9203, (G4) 9205, (G5) 9207, (G6) 9212, (G7) C-81-10 and (G8) cross-shahi. The osmotic potential factor (Ψ s) consisted of five levels (-1.2, -0.9, -0.6, -0.3 and 0 MPa). Genotypes G2, G6 and G7 prevailed in terms of germination percentage (GP) up to Ψ s = -1.2, while genotype G8 and genotype G6 were only prevalent at Ψ s = 0 and up to Ψ s = -0.9, respectively. The two genotypes of G1 and G4 had lower GPs at Ψ s = 0 compared to other genotypes but these two genotypes had no significant difference with resistant genotype G₇ in terms of GP at Ψ s = -0.3. This trend continued in case of genotype G1 up to Ψ s = -1.2, while genotype G₄ had the lowest GP value next to G8 cultivar from Ψ s = -0.6 to Ψ s = -1.2. Interaction effect of Ψ s $\times$ genotype was significant for Coleoptile Length (CL), Radicle Length (RL), Plumule Length (SL). G7 prevailed in terms of CL with a significant difference at Ψ s = -1.2 while G₁ lost its dominance. The same trend was observed in interaction effect of Ψ s $\times$ genotype for SL. According to GP and CL and SL values, modern genotype G7 was the most resistant genotype to osmotic stress while old genotype G8 was the most sensitive one.

Key words: wheat, germination, seedling growth, osmotic stress.

RESUMEN

El estudio tuvo como objetivo comparar, bajo condiciones de laboratorio, la germinación de semillas y el crecimiento de plántulas bajo condiciones de estrés osmótico de distintos genotipos de trigo. El diseño experimental fue de bloques completamente al azar con arreglo factorial y tres repeticiones. Se evaluaron ocho genotipos de trigo (G): 9103 (G1); 9116 (G2); 9203 (G3); 9205 (G4); 9207 (G5); 9212 (G6); C-81-10 (G7) y, cross-shahi (G8). El potencial osmótico (Ψ s) fue evaluado en cinco niveles (-1.2, -0.9, -0.6, -0.3 y 0 MPa). Los genotipos G2, G6 y G7 obtuvieron un mayor porcentaje de germinación (PG) a -1.2 MPa. Los genotipos G1, G4 y G5 tuvieron el menor porcentaje de germinación con Ψ s = 0. El efecto de la interacción de Ψ s $\times$ genotipo fue estadísticamente significativa para longitud de coleóptilo (CL), longitud de radícula (RL) y longitud de la plúmula (SL), según genotipo. De acuerdo con los análisis de resultados el genotipo G7 fue el más resistente al estrés osmótico y G8 fue el genotipo más sensible.

Palabras clave: trigo; germinación; crecimiento de las plántulas; estrés osmótico.

Introduction

Both seed germination and establishment properties of seedlings are regarded as applied attributes that are used to evaluate the wheat genotypes under osmotic stress (Hubbard *et al.*, 2012; Rauf *et al.*, 2007). The germination percentage and

establishment of seedlings considerably decrease when the soil water potential is less than -1.5 MPa (Qayyum *et al.*, 2011). Gonzalez *et al.*, (2005) and Almansouri *et al.*, (2001) reported a reduction in the lengths of radical, plumule and coleoptile as well as a decrease in germination percentage due to the increase in intensity of moisture stress while

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also suggesting that the germination percentage in resistant reaction of wheat cultivars to drought stress may not be considered an appropriate indicator for selection of resistant cultivars. The initial growth strength in modern short-statured wheat cultivars is less compared to that of the old long-statured wheat cultivars, with the length of coleoptile and leaf surface area having decreased during the initial stages of growth (Pereira *et al.*, 2002). The decrease in length of coleoptile leads to poor germination and the subsequent low establishment of plant, thus making it impossible to cultivate at lower depths in order to utilize the soil moisture storage, the increase in length of coleoptile would result in larger sizes of initial leaves and accelerate the germination rate (Hakizimana *et al.*, 2002;). A highly positive and significant correlation was reported between the germination percentage and the lengths of radical, plumule, coleoptile as well as the dry weights of radical and plumule (El-Moneim *et al.*, 2008). These properties were evaluated during the course of this test in order to compare the seed germination and seedlings growth of seven modern wheat genotypes with those of an old local genotype (cross-shahi) under osmotic stress conditions in order to determine the resistant and sensitive genotypes to osmotic stress in terms of each one of the aforesaid properties and to compare the modern cultivars and old cultivar in terms of seed germination and growth of seedling under osmotic stress conditions.

Materials and Methods

Test Scheme

This study was conducted using a completely random design with factorial arrangement with 3

replications. The wheat genotype (G) consisted of eight genotypes numbered as (G1) 9103, (G2) 9116, (G3) 9203, (G4) 9205, (G5) 9207, (G6) 9212, (G7) C-81-10 and (C8) cross-shahi. The osmotic potential factor (Ψ s) consisted of five levels (–1.2, –0.9, –0.6, –0.3 and 0 MPa). The pedigree of genotypes is presented in Table 1.

Applying osmotic stress treatments

Osmotic stress treatments were applied through adding polyethylene glycol osmotic solution to petri dishes containing 20 seeds of each genotype placed on two filter papers. Seeds of Genotypes were disinfected by agitating in a solution of sodium hyp Chlorite for 5 minutes, prior to application of osmotic stress treatments (Sapra *et al.*, 1991). Then, the amount of polyethylene glycol required for preparation of –0.3, –0.6, –0.9 and –1.2 MPa osmotic solutions was determined through equation (1) as follows (Michel & Kaufmann, 1973):

$$T WP = - (1.8 e^{-2}) C - (1.8 e^{-4}) C^2 + (2.67 e^{-4}) CT + (8.39 e^{-7}) C^2 \quad (\text{eq. 1})$$

Where WP is the osmotic potential of polyethylene glycol in bars, C is polyethylene glycol concentration in terms of g per kg water, and T is the temperature in Celsius. The amounts of polyethylene glycol required to prepare –0.3, –0.6, –0.9 and –1.2 MPa osmotic solutions at 20 degrees Celsius were 143.18, 213.64, 267.97 and 313.88 grams of polyethylene glycol per 1 liter of distilled water, respectively.

The petri dishes containing two layers of filter paper were placed in autoclave for 4 hours prior to application of osmotic stress treatments.

Table 1. Studies genotypes.

Genotype abbreviation	Pedigree	Genotypes
G1	MV17/Zrn	ARWYT-D1-83-9103
G2	Viking/5/Gds/4/Anza/3/Pi/...	ARWYT-D1-83-9116
G3	Bkt/90-Zhong87	ARWYT-D2-83-9203
G4	Alvd/90-Zhong87	ARWYT-D2-83-9205
G5	Apollo/Alvd/4/Spn/Mcd//Cama/...	ARWYT-D2-83-9207
G6	MV17/Bcn88	ARWYT-D2-83-9212
G7	1-27-6275/Cf1770/5/Ghds/Anza/...	C-81-10
G8	Local genotype	Cross-shahi*

* "Cross-shahi" is an old local genotype with not specified pedigree.

Then, a number of 20 seeds of genotypes that had already been disinfected by 10% sodium hypochlorite solution were placed in each petri dish and the osmotic stress treatments were applied through osmotic solutions. Then, the petri dishes were placed in the germinator at temperature of 20 degrees Celsius in darkness.

Measured properties

In order to determine the germination percentage, the germinated seeds were counted on a daily basis. The seeds with radical lengths about 3 mm were considered as germinated seeds (Sapra *et al.*, 1991). The percentage of germination was ultimately derived from the ratio of germinated seeds to the number of seeds (20) in the petri dish. The ultimate lengths of radical and coleoptile and their respective dry weights as well as the dry weight of shoot parts and ratio of shoot parts to the root were measured and calculated after heating them in the oven at 85 degrees for 24 hours.

Mean germination time (M.G.T) was calculated through equation (2) (Sapra *et al.*, 1991).

$$\text{M.G.T} = (\sum Dn) / N \quad (\text{eq. 2})$$

Where D is the number of days during which the germinated seeds were counted, n is the number of germinated seeds in each day and N is the ultimate number of germinated seeds. Having obtained the M.G.T, the germination rate would be derived from equation 3 (Sapra *et al.*, 1991).

$$\text{GR} = 1 / \text{M.G.T} \quad (\text{eq. 3})$$

12 hours of light were also alloted to the incubator environment from day 4 onward so that the coloration of leaves occurs, making them distinct from the coleoptile. Using 5 random seedlings from each petri dish and a scale ruler, the length of coleoptile was measured and its mean value was recorded. All the petri dishes were removed from the germinator after 10 days and the lengths of radical and plumule were measured using 10 random seedlings. Both radical and plumule were detached from the seed and placed in separate envelopes and then heated at 76 degree Celsius for 24 hours. When dried, the samples were weighed through a highly sensitive laboratory scale (0.0001g accuracy) and their mean values were calculated and recorded.

Variance analysis was performed through application of SAS software based on the hypotheses of factorial test and Duncan's Multiple Range Test was applied in order to compare the mean values through interaction effects slicing while the EXCEL software was used in order to plot and process the data. Angular conversion was used in case of values that were calculated in percentage.

Results and Discussion

Germination Percentage (GP) and Germination Rate (GR)

GP and GR showed significant reduction as the osmotic potential (Ψ_s) was decreased (Table 2). The decrease thresholds of GP and GR were $\Psi_s = -0.3$ and $\Psi_s = -0.6$, respectively (Table 2). There was a significant difference between all Ψ_s treatments in terms of GP (Table 2).

The GP decreased from 93.1% at $\Psi_s = 0$ to 88.5% and 55.8% at $\Psi_s = -0.3$ and $\Psi_s = -1.2$, respectively (Table 2). Genotypes were significantly different in terms of GP (Table 2). The GP of genotypes varied from 84.0% for G7 to 71% for G8 (Table 2). There was no significant difference in GP of G1, G2, G6 and G7 genotypes (Table 2).

The GR decreased from 33.3 (percentage of daily germinated seeds) at $\Psi_s = 0$ to 20.7 (percentage of daily germinated seeds) at $\Psi_s = -1.2$ (Table 2). Interaction effect of $\Psi_s \times$ genotype was significant for GP (Table 2). At $\Psi_s = 0$, the genotypes G2, G5, G6, G7 and G8 had higher GPs than the other three genotypes (Table 3). Genotypes G2, G6 and G7 prevailed in terms of GP up to $\Psi_s = -1.2$, while genotype G8 and genotype G6 were only prevalent at $\Psi_s = 0$ and up to $\Psi_s = -0.9$, respectively (Table 3). The decreasing trend of GP due to reduction of Ψ_s was not identical in case of three genotypes of G2, G6 and G7 in that germination did not decrease as a result of Ψ_s reduction from -0.3 to -0.6 in G7 which reflects the higher resistance of this genotype (Table 3). The two genotypes of G1 and G4 had lower GPs at $\Psi_s = 0$ compared to other genotypes but these two genotypes had no significant difference with resistant genotype G7 in terms of GP at $\Psi_s = -0.3$ (Table 3). This trend continued in case of genotype G1 up to $\Psi_s = -1.2$, while genotype G4 had the lowest GP value next to G8 cultivar from $\Psi_s = -0.6$ to $\Psi_s = -1.2$ (Table 3). According to GP values, genotypes $G7 > G6 = G2$ were resistant to osmotic stress while

Table 2. The simple effect of osmotic stress and Genotype on seed germination and growth of seedling in wheat.

	GR%	SG (seeds day ⁻¹)	CL (cm)	RL (cm)	SL (cm)	RL/SL	RDW (mg)	SDW (mg)	SLDW (mg)	RDW/SDW	RDW/SLDW	SDW/SLDW
Ψ_s	**	**	**	**	**	**	**	**	**	**	**	**
G	**	NS	**	**	**	**	**	**	**	**	**	**
$\Psi_s \times G$	*	NS	*	**	**	NS	**	**	**	**	**	**
Ψ_{s_1}	93.1 ^a	33.3 ^a	4.34 ^a	4.80 ^a	11.0 ^a	0.43 ^c	7.57 ^b	11.33 ^a	18.9 ^a	0.66 ^c	0.40 ^e	0.59 ^a
Ψ_{s_2}	88.5 ^b	32.0 ^a	3.62 ^b	4.81 ^a	8.52 ^b	0.56 ^d	7.82 ^a	7.56 ^b	15.38 ^b	1.03 ^d	0.50 ^d	0.49 ^b
Ψ_{s_3}	81.8 ^c	27.9 ^b	3.24 ^c	4.18 ^b	6.11 ^c	0.68 ^c	7.08 ^c	5.85 ^c	12.94 ^c	1.21 ^c	0.54 ^c	0.45 ^c
Ψ_{s_4}	73.9 ^d	22.5 ^c	2.33 ^d	3.63 ^c	4.19 ^d	0.86 ^b	6.05 ^d	3.82 ^d	9.88 ^d	1.58 ^b	0.61 ^b	0.38 ^d
Ψ_{s_5}	55.8 ^e	20.6 ^d	1.40 ^e	2.77 ^d	1.85 ^e	1.49 ^a	4.83 ^c	1.99 ^e	6.82 ^c	2.44 ^a	0.70 ^a	0.29 ^e
G ₁	81.0 ^{ab}	27.3 ^a	3.05 ^a	4.36 ^a	6.62 ^a	0.81 ^{bc}	6.60 ^b	6.32 ^{ab}	12.9 ^{cd}	1.36 ^c	0.54 ^c	0.45 ^a
G ₂	82.3 ^a	27.3 ^a	2.98 ^b	4.50 ^a	6.42 ^a	0.90 ^a	6.62 ^b	6.44 ^a	13.0 ^c	1.29 ^d	0.54 ^c	0.45 ^a
G ₃	75.6 ^c	26.7 ^a	2.66 ^c	3.80 ^c	6.22 ^b	0.80 ^{bc}	6.34 ^c	5.84 ^{cd}	12.1 ^c	1.43 ^{ab}	0.55 ^b	0.44 ^b
G ₄	76.0 ^c	27.2 ^a	3.03 ^{ab}	3.74 ^c	6.24 ^b	0.77 ^c	6.46 ^{bc}	5.87 ^{cd}	12.3 ^c	1.39 ^{bc}	0.55 ^b	0.44 ^b
G ₅	78.3 ^{bc}	27.7 ^a	3.02 ^{ab}	3.86 ^{bc}	6.28 ^b	0.78 ^c	6.64 ^b	6.00 ^c	12.65 ^d	1.46 ^a	0.56 ^{ab}	0.43 ^{bc}
G ₆	81.0 ^{ab}	28.2 ^a	2.98 ^b	4.02 ^b	6.34 ^b	0.78 ^c	7.23 ^a	6.20 ^b	13.4 ^b	1.45 ^{ab}	0.57 ^a	0.42 ^c
G ₇	84.0 ^a	27.4 ^a	3.19 ^a	4.54 ^a	6.60 ^a	0.86 ^{ab}	7.34 ^a	6.49 ^a	13.8 ^a	1.42 ^{ab}	0.56 ^{ab}	0.43 ^{bc}
G ₈	71.0 ^d	26.3 ^a	2.99 ^b	3.50 ^d	6.03 ^c	0.74 ^c	6.14 ^d	5.74 ^d	11.8 ^f	1.28 ^d	0.54 ^c	0.45 ^a

P:

 Ψ_s and G: osmotic stress and genotype, respectively. Ψ_{s_5} to Ψ_{s_1} : -1.2, -0.9, -0.6, -0.3 and 0 MPa.

Genotypes: (G1) 9103, (G2) 9116, (G3) 9203, (G4) 9205, (G5) 9207, (G6) 9212, (G7) C-81-10 and (G8) cross-shahi.

GR (germination percentage); SG (speed of germination); CL, RL and SL: coleoptile, radical and plumule length, respectively; RDW, SDW and SLDW: radical, plumule and seedling dry weight, respectively.

genotypes G1 and G8 were sensitive. The genotypes did not differ significantly in terms of GR (Table 2). Interaction effect of $\Psi_s \times$ genotype was insignificant for GR (Table 2). Thus, the germination rate is not a proper characteristic for comparison of genotype resistance to osmotic stress. The G8 genotype which is a long-statured and old cultivar was anticipated to yield better germination percentage and rate under osmotic stress conditions compared to the other seven short-statured and modern genotypes, but the results proved the opposite. Ghodsi (2004) reported that wheat cultivars under various osmotic potentials differ with each other in terms germination characteristics in that the medium-statured Mexican cultivars have higher percentage and rate of germination and are thus more resistant to drought during germination stage, an assertion that is consistent with the results of this study.

Coleoptile Length (CL), Radicle Length (RL), Plumule Length (SL)

Effect of Ψ_s on CL, RL and SL was significant (Table 2). Osmotic stress had more effect on SL

decrease than that of the CL. Moreover; RL reaction to Ψ_s stress was different than those of CL and SL. There was a significant difference in CL and SL among all Ψ_s treatments while there was no significant difference in RL between $\Psi_s = 0$ and $\Psi_s = -0.3$ (Table 2). Reduction thresholds due to osmotic stress were at $\Psi_s = -0.3$ for CL and SL and at $\Psi_s = -0.6$ for RL (Table 2). As the osmotic potential decreased from $\Psi_s = 0$ to $\Psi_s = -1.2$, the CL, RL and SL decreased up to 67.7%, 42.2% and 83.1%, respectively (Table 2). This decrease was respectively 18.2% and 22.5% for CL and RL at $\Psi_s = -0.3$ while it was 12.9% for RL at $\Psi_s = -0.6$ (Table 2). There was a significant difference between genotypes in terms of SL, CL and RL (Table 2). Genotypes G1 and G7 had the highest CL, SL and RL while genotype G8 had the lowest SL and RL with genotype G3 having the lowest CL (Table 2). Interaction effect of $\Psi_s \times$ genotype was significant for CL, SL and RL (Table 2 and 3). As the osmotic potential reduced, CL decreased up to 47.0% and 49.2% at $\Psi_s = -0.1$ in genotypes G7 and G1, respectively (Table 3). With Ψ_s decreasing from $\Psi_s = -0.1$ to $\Psi_s = -1.2$, the CL respectively reduced

to 25.0% and 40.8% for G7 and G1 so that G7 prevailed in terms of CL with a significant difference at $\Psi_s = -1.2$ while G1 lost its dominance (Table 3).

The CL in genotype G8 was higher than other genotypes up to $\Psi_s = -0.3$ but as the Ψ_s s decreased, the CL in this genotype dropped lower than that

Table 3. The interaction effect of osmotic stress and Genotype on seed germination and growth of seedling in wheat.

		GR%	CL (cm)	RL (cm)	SL (cm)	SDW (mg)	SLDW (mg)	RDW (mg)
Ψ_{s_1}	G ₁	90.0 ^c	4.53 ^{ab}	5.06 ^{ab}	11.4 ^a	11.7 ^a	19.3 ^{bc}	7.56 ^b
	G ₂	93.3 ^{abc}	4.23 ^{bc}	5.00 ^{bc}	11.2 ^{abc}	11.9 ^a	19.4 ^{bc}	7.46 ^b
	G ₃	91.6 ^{bc}	3.80 ^c	4.53 ^{cd}	10.7 ^{cd}	10.7 ^b	17.6 ^c	6.96 ^c
	G ₄	90.0 ^c	4.40 ^{ab}	4.33 ^d	10.5 ^d	10.6 ^b	17.8 ^c	7.20 ^{bc}
	G ₅	93.3 ^{abc}	4.36 ^{ab}	4.60 ^{bcd}	10.8 ^{bcd}	11.5 ^a	18.7 ^{cd}	7.20 ^{bc}
	G ₆	95.0 ^{ab}	4.16 ^{bc}	4.76 ^{bcd}	10.9 ^{abcd}	11.7 ^a	20.0 ^{ab}	8.26 ^a
	G ₇	96.6 ^a	4.53 ^{ab}	5.50 ^a	11.4 ^{ab}	11.9 ^a	20.3 ^a	8.46 ^a
	G ₈	95.0 ^{ab}	4.73 ^a	4.66 ^{bcd}	11.10 ^{abcd}	10.5 ^b	17.9 ^{de}	7.43 ^{bc}
Ψ_{s_2}	G ₁	90.0 ^a	3.66 ^{ab}	5.16 ^{bc}	8.53 ^{bc}	7.96 ^{abc}	15.7 ^{ab}	7.73 ^{ab}
	G ₂	90.0 ^a	3.56 ^b	5.60 ^{ab}	8.40 ^{bc}	8.03 ^{ab}	15.5 ^{bc}	7.50 ^b
	G ₃	86.6 ^{ab}	3.16 ^c	4.30 ^e	7.96 ^c	7.46 ^c	15.1 ^{bc}	7.66 ^{ab}
	G ₄	90.0 ^a	3.76 ^{ab}	4.10 ^e	8.53 ^{bc}	7.50 ^c	15.4 ^{bc}	7.90 ^{ab}
	G ₅	90.0 ^a	3.73 ^{ab}	4.53 ^{de}	8.86 ^{ab}	6.96 ^d	14.8 ^{cd}	7.83 ^{ab}
	G ₆	88.3 ^{ab}	3.53 ^b	4.90 ^{cd}	8.50 ^{bc}	7.53 ^{bc}	15.7 ^{ab}	8.23 ^a
	G ₇	90.0 ^a	3.63 ^{ab}	5.70 ^a	9.13 ^a	8.10 ^a	16.4 ^a	8.30 ^a
	G ₈	83.3 ^b	3.93 ^a	4.23 ^e	8.30 ^{bc}	6.93 ^d	14.3 ^d	7.43 ^b
Ψ_{s_3}	G ₁	86.6 ^{ab}	3.30 ^a	4.66 ^a	6.60 ^a	5.96 ^{ab}	12.6 ^{bc}	6.70 ^d
	G ₂	85.0 ^{ab}	3.33 ^a	4.73 ^a	6.33 ^{ab}	6.00 ^{ab}	12.9 ^b	6.96 ^{cd}
	G ₃	80.0 ^{bc}	3.03 ^a	3.96 ^{bc}	6.53 ^a	5.63 ^{cd}	12.2 ^c	6.63 ^d
	G ₄	75.0 ^{cd}	3.20 ^a	3.90 ^{bc}	6.13 ^b	5.90 ^{bc}	12.7 ^{bc}	6.86 ^{cd}
	G ₅	83.3 ^{abc}	3.26 ^a	3.96 ^{bc}	5.66 ^{cd}	6.00 ^{ab}	13.2 ^b	7.26 ^{bc}
	G ₆	85.0 ^{ab}	3.36 ^a	4.23 ^{abc}	5.96 ^{bc}	5.56 ^d	13.3 ^b	7.73 ^{ab}
	G ₇	90.0 ^a	3.43 ^a	4.36 ^{ab}	6.13 ^b	6.23 ^a	14.1 ^a	7.86 ^a
	G ₈	70.0 ^d	3.03 ^a	3.66 ^c	5.56 ^d	5.56 ^d	12.2 ^c	6.63 ^d
Ψ_{s_4}	G ₁	81.6 ^a	2.40 ^a	3.80 ^{ab}	4.36 ^a	4.00 ^a	10.0 ^{bc}	6.06 ^c
	G ₂	80.0 ^a	2.46 ^a	4.00 ^a	4.26 ^{ab}	3.96 ^a	10.3 ^{ab}	6.36 ^b
	G ₃	66.6 ^{bc}	2.30 ^a	3.46 ^c	4.16 ^{ab}	3.70 ^{ab}	9.56 ^d	5.86 ^{cd}
	G ₄	73.3 ^{abc}	2.26 ^a	3.60 ^{bc}	4.13 ^{ab}	3.40 ^b	9.06 ^c	5.66 ^d
	G ₅	71.6 ^{abc}	2.30 ^a	3.60 ^{bc}	4.20 ^{ab}	3.76 ^a	9.83 ^{cd}	6.06 ^c
	G ₆	76.6 ^{ab}	2.30 ^a	3.60 ^{bc}	4.33 ^{ab}	4.00 ^a	10.7 ^a	6.70 ^a
	G ₇	80.0 ^a	2.30 ^a	3.96 ^a	4.33 ^{ab}	4.06 ^a	10.7 ^a	6.63 ^a
	G ₈	61.6 ^c	2.06 ^a	3.06 ^d	3.73 ^b	3.70 ^{ab}	8.80 ^c	5.10 ^e
Ψ_{s_5}	G ₁	56.6 ^{ab}	1.36 ^{bc}	3.10 ^{ab}	2.16 ^a	1.93 ^c	6.86 ^b	4.93 ^{bc}
	G ₂	63.3 ^a	1.30 ^{bcd}	3.20 ^a	1.86 ^b	2.26 ^a	7.10 ^{ab}	4.83 ^{bc}
	G ₃	53.3 ^{bc}	1.00 ^d	2.73 ^{bc}	1.73 ^b	1.70 ^d	6.30 ^{cd}	4.60 ^c
	G ₄	51.6 ^{bc}	1.53 ^{ab}	2.76 ^{bc}	1.86 ^b	1.96 ^{bc}	6.66 ^{bc}	4.70 ^c
	G ₅	53.3 ^{bc}	1.46 ^{bc}	2.63 ^c	1.83 ^b	1.76 ^{cd}	6.63 ^{bc}	4.86 ^{bc}
	G ₆	60.0 ^{ab}	1.56 ^{ab}	2.63 ^c	1.93 ^{ab}	2.16 ^{ab}	7.40 ^a	5.23 ^{ab}
	G ₇	63.3 ^a	1.80 ^a	3.20 ^a	2.00 ^{ab}	2.16 ^{ab}	7.60 ^a	5.43 ^a
	G ₈	45.0 ^c	1.20 ^{cd}	1.90 ^d	1.46 ^c	1.96 ^{bc}	6.06 ^d	4.10 ^d

Ψ_s s and G: osmotic stress and genotype, respectively.

Ψ_{s_5} to Ψ_{s_1} : -1.2, -0.9, -0.6, -0.3 and 0 MPa.

Genotypes: (G1) 9103, (G2) 9116, (G3) 9203, (G4) 9205, (G5) 9207, (G6) 9212, (G7) C-81-10 and (G8) cross-shahi.

GR (germination percentage); SG (speed of germination); CL, RL and SL: coleptile, radical and pulmule length, respectively; RDW, SDW and SLDW: radical, pulmule and seedling dry weight, respectively.

of the other genotypes to the extent that it attained the lowest CL at $\Psi_s = -1.2$ with only G3 genotype having a lower CL at $\Psi_s = 0$ (Table 3).

According to CL values, genotypes G7 and G1 were thus resistant to osmotic stress while genotypes G8 and G3 were sensitive. The same trend was observed in interaction effect of $\Psi_s \times$ genotype for SL. Genotypes G1 and G7 that were prevalent at $\Psi_s = 0$ in terms of SL maintained this dominance up to $\Psi_s = -1.2$, except for G1 at $\Psi_s = -0.3$ (Table 3).

But genotype G8 lost the dominance it once had at $\Psi_s = 0$ as it showed the least SL compared to other genotypes from $\Psi_s = -0.6$ to $\Psi_s = -1.2$ (Table 3). According to SL values, genotypes G7 and G1 were thus resistant to osmotic stress while genotypes G8 was sensitive. Interaction effect $\Psi_s \times$ genotype was significant for RL (Table 2). The value of RL increased in genotypes G2, G6 and G7 as the osmotic potential dropped to $\Psi_s = -0.3$ while it contrastingly decreased as the osmotic stress increased (Table 3). Genotype G1 and G7 that were dominant in terms of RL at $\Psi_s = 0$ maintained this trend up to $\Psi_s = -1.2$, except for G1 at $\Psi_s = -0.3$ (Table 3). Genotype G2 also showed no significant difference under osmotic potential from $\Psi_s = -0.3$ to $\Psi_s = -1.2$ (Table 3). Genotype G8 had the lowest RL among other genotypes from $\Psi_s = -0.3$ to $\Psi_s = -1.2$ (Table 3). Thus according to RL values, genotypes $G2 < G1 < G7$ were resistant to osmotic stress while G8 was sensitive. Although the height of genotype G7 was less than the long-statured G8 cultivar, but it was longer in terms of CL, RL and SL which is consistent with the report of Calderini *et al.* (1999). Dhanda & Behl (2004) evaluating 30 bread wheat genotypes subject to osmotic stress also reported that the length of coleoptile and plumule decreased subsequent to increase in osmotic stress while the radicle length of cultivars increased up to average levels of osmotic stress. They concluded that the coleoptile and plumule are more sensitive than the radicle under osmotic stress which is consistent with the results obtained in this study. Dhanda & Behl (2004) also suggested that the lesser decrease in length of radicle under stress compared to that of the plumule is a basic mechanism of plant whereby the root system is developed more than the aerial parts in order to attain more soil moisture.

Plumule Dry Weight (SDW), Radicle Dry Weight (RDW) and Seedling Dry Weight (SLDW)

The effect of Ψ_s and genotype as well as the interaction effect of $\Psi_s \times$ genotype on SDW, RDW and SLDW was significant (Table 2). RDW had a significant increase up to $\Psi_s = -0.3$ (7.57 to 7.82 Kg) and then decreased so that it showed a significant increase of 6.4% and 36.1% at $\Psi_s = -0.6$ and $\Psi_s = -1.2$, respectively (Table 2). An increase of 2.2, 10, 9.7 and 8.7 % in RDW was observed at $\Psi_s = -0.3$ for genotypes G1, G3, G4 and G5, respectively (Table 3). SDW and SLDW had declining trends as the Ψ_s decreases in that SDW was respectively 33.2% and 82.4 % at $\Psi_s = -0.3$ and $\Psi_s = -1.2$, while SLDW underwent significant decreases of 18.6% and 63.9%, respectively (Table 2). Hence, RDW has shown greater response to osmotic stress than SDW and SLDW. The maximum and minimum SDW, RDW and SLDW were observed in Genotypes G7 and G8, respectively (Table 2). G7 had no significant difference with genotypes G2 and G1 in terms of SDW and with genotype G6 in terms of RDW (Table 2). Genotype G8 also had no significant difference with genotypes G3 and G4 in terms of SDW and SLDW (Table 2). Genotypes G6 and G7 maintained their dominance in terms of SDW and SLDW over the entire Ψ_s treatments, except for G6 for SLDW at $\Psi_s = -0.6$ (Table 3).

Genotypes G1, G2 and G7 maintained their dominance in terms of SDW over the entire Ψ_s treatments, except for G1 for SLDW at $\Psi_s = -1.2$ (Table 3). Genotype G8 had the least RDW among other genotypes from $\Psi_s = -0.6$ to $\Psi_s = -1.2$ (Table 3). Genotypes G8, G3 and G4 had the least SDW up to $\Psi_s = -0.6$ and the least SLDW up to $\Psi_s = -1.2$ while genotype G4 and genotypes G5, G4 and G1 had the least SDW at $\Psi_s = -0.9$ and $\Psi_s = -1.2$, respectively (Table 3).

According to the integrated results of RDW, SDW, and SLDW, genotypes G7, G6 and G1 were the most resistant and genotypes G4, G3 and G8 were the most sensitive to osmotic stress.

Radicle length to plumule length ratio (RL/SL), Radicle dry weight to plumule dry weight ratio (RDW/SDW) and plumule dry weight to seedling dry weight ratio (SDW/SLDW) are important characteristic representing the compatibility of

plant to stress conditions. This characteristic is highly correlated with performance and could be considered a criterion for initial selection of cultivars under moisture stress conditions (Dhanda & Behl, 2004). The effect of Ψ_s and genotype on RL/SL and effect of Ψ_s , genotype and interaction effect of $\Psi_s \times$ genotype on RDW/SDW, RDW/SLDW and SDW/SLDW was significant (Table 1). RL/SL, RDW/SDW and RDW/SLDW respectively

increased up to 3.46, 3.69 and 1.75 times from $\Psi_s = 0$ to $\Psi_s = -1.2$ while SDW/SLDW decreased up to 2.03 times (Table 2). Although the effect of genotype on SDW/SLDW was significant (Table 2), its value remained within the limited range of 0.42 to 0.45 (Table 2). The amounts of RL/SL, RDW/SDW and RDW/SLDW were higher in case of the resistant G7 while it was lower in case of sensitive G8 (Table 2).

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