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Research paper

Inheritance of agronomic and physiological characteristics of spring wheat (*Triticum aestivum* L.) lines at normal and salinity-stress conditions

Mehri Abbaszadeh[1], Mohammad Moghaddam[1,2*], Majid Norouzi[1], and Ali Bandeh-Hagh[1]

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[1]Department of Plant Breeding and Biotechnology, Faculty of Agriculture, University of Tabriz, Tabriz, Iran
[2]Center of Excellence for Cereal Molecular Breeding, University of Tabriz, Tabriz, Iran
*Corresponding author; Email: mmoghaddam@tabrizu.ac.ir

Abstract
Inheritance of several physiological and agronomic traits in 92 F_4 lines derived from the cross between two wheat (*Triticum* a*estivum* L.) cultivars (Arg and Moghan3, tolerant and sensitive to salinity, respectively) was studied in a greenhouse at normal and salinity stress conditions using a hydroponic system in 2018. The experiment was carried out as a split-plot design based on randomized complete blocks with two replications. The two salinity levels (control and application of 150 mM NaCl at the three-leaf stage) were arranged in the main plots and the lines in the subplots. Analysis of variance showed significant differences among lines for all of the investigated characteristics, except the K^+/Na^+ ratio. The line × salinity interaction was significant for the majority of the traits including grain yield. Salinity stress increased leaf temperature, electrolyte leakage, 1000-grain weight, and Na^+ content, and decreased other traits significantly. Transgressive segregation was detected for some traits at both normal and salinity stress conditions. At both normal and salinity stress conditions, broad-sense and narrow-sense heritability for the studied traits were estimated high (0.72 to 0.99) and moderate to low (0.11-0.62), respectively. The lowest broad-sense (0.72 and 0.66 at normal and salinity-stress conditions, respectively) and narrow-sense heritability (0.13 and 0.11 at normal and salinity-stress conditions, respectively) belonged to the grain yield. At both conditions, the magnitude of dominance genetic variance was higher than the additive genetic variance for the majority of the traits investigated. The average degree of dominance for all traits at both conditions was greater than one, which showed the existence of over-dominance gene action in controlling these traits. This research highlights the necessity of exploiting dominance gene effects in breeding programs of wheat at salinity stress conditions.

Keywords: additive genetic variance; broad-sense heritability; degree of dominance; dominance genetic variance; narrow-sense heritability

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Introduction

The greatest challenge of the present century is to increase the yield in the environmental-stress conditions including salinity (Koyro *et al*. 2012). Salinity causes the accumulation of ions such as sodium, sulfate, and chloride in the *rhizosphere*, which disrupts plant growth and development (Ashraf and McNielly 2004). The extent of yield loss under salinity stress rests on the type of species and variety, salt concentration, types of ions, and culture conditions (Cicek and Cakirlar 2002). The growth and yield of bread wheat are adversely affected by salinity stress (Munns 2005; Ghogdi *et al.* 2012), which results in reduced germination, oxidative stress, declined growth, disturbed photosynthesis, hormonal imbalance, etc. (Hasanuzzaman *et al*. 2017). The adverse effects of

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salinity are often due to the reduction of osmotic potential in the root environment, the effect on the water balance of plants, and the decline in turgor pressure (Munns 2005). Salinity stress reduces wheat grain yield through the impact on yield components (Munns 2005). Reduction in the number of leaves and tillers and the root length and area by salinity stress have been expressed (Asish Kumar and Bandhu Das 2005). In the study of Tammam *et al.* (2008), sodium content increased significantly in the shoots and spikes at saline conditions in wheat but the amount of increase was different among these organs. Also, salinity reduced the K^+/Na^+ ratio and the accumulation and distribution of K^+, Mg^{2+}, and Ca^{+2}. Ouhaddach *et al.* (2018) showed that salt stress decreases K^+/Na^+ ratio, leaf area, number of leaves, and plant height, but increases Na^+ content, relative water content (RWC), membrane stability index, chlorophyll ‘a’ and ‘b’ content, and the plant dry weight. However, based on Ghogdi *et al.* (2012), salinity stress decreased RWC, K^+, K^+/Na^+ ratio, and grain yield, and increased Na^+ in all tolerant and sensitive genotypes at both tillering and flowering stages. Chlorophyll content increased at the tillering stage but decreased at the flowering stage. Tolerant genotypes had higher amounts of K^+, K^+/Na^+ ratio, and RWC in the saline conditions at the tillering stage. Sensitive cultivars showed higher sodium content at both stages. They indicated that the salinity tolerance in the tolerant cultivars was associated with lower sodium accumulation and higher K^+/Na^+ ratio compared to the sensitive cultivars.

Based on Colmer *et al.* (2006), wheat was placed in the semi-tolerant group, with a salinity tolerance threshold of 6 dS/m. But in the study of Steppuhn and Wall (1997) with other genotypes, the tolerance threshold for wheat was estimated as 2 dS/m, which located the wheat as a semi-sensitive plant. In contrast, according to Francois *et al.* (1986), the tolerance threshold of wheat was estimated as 8 dS/m, which located this crop among the tolerant plant species.

Genetics of various traits has been studied in wheat by different researchers at normal and salinity and drought stress conditions. Farooq *et al.* (2019) used the line × tester mating scheme to assess the additive and dominance genetic variances for yield and its components in wheat at normal conditions. They reported the involvement of both additive and dominance types of gene action in controlling the measured traits, however, the dominance variance was higher than the additive variance for all traits. The average degree of dominance for grain yield was above one, which indicated the over-dominance gene action in controlling this trait. Novoselovic *et al.* (2004) estimated gene effects of several quantitative traits in two winter wheat crosses by generation mean analysis under normal conditions. The additive-dominance model explained the variation among generations for plant height and grain weight per main spike but in most cases, a digenic epistatic model explained the variation in the generation means. On the other hand, for grain yield per plant and single grain weight, the digenic epiststic model was not sufficient due to significant chi-square, and higher-order interactions was proposed. Dominance effects were more important than additive effects. They concluded that the importance of genetic components for the traits under investigation depended on the type of cross and environmental conditions in the experimental sites. Safari *et al.* (2018) used the Bayesian inference to study the nature of gene action for yield and yield components at drought and normal conditions and reported the existence of additive, dominance, and epistatic gene actions in governing the inheritance of agronomic traits at both drought and normal conditions. Shayan *et al.* (2019) studied the inheritance of some agronomic and physiological traits at drought stress and normal conditions using the generations produced from the cross of Arg and Moghan3 varieties in wheat. For most traits, including grain yield, the six-parameter model fitted the generation means and the dominance genetic variance was more important than the additive genetic variance at both conditions. They reported over-dominance type of gene action for all traits at both normal and drought-stress conditions and suggested taking advantage of non-additive gene action through improving hybrid varieties in wheat.

According to Dehdari *et al.* (2007), additive and dominance effects were sufficient for governing Na^+ and K^+/Na^+ ratio in a cross between Shorawaki and Niknejad cultivars using a generation mean analysis under salinity conditions. Dashti *et al.* (2010) reported that characters such as Na^+, K^+, K^+/Na^+ ratio, chlorophyll content, heading date, number of tillers per plant, and plant height were controlled by additive, dominance, and epistatic effects in the saline environment. Dashti *et al.* (2012) studied the gene action of biomass, heading date, plant height, K^+, Na^+, K^+/Na^+ ratio, the total number of tillers per plant, and the ratio of fertile tillers to the total number of tillers in the vegetative stage in the wheat at salinity conditions using the generation mean analysis. They reported the involvement of both additive and non-additive types of gene actions in governing most of the traits investigated. In all three studies above (Dehdari *et al.* 2007; Dashti *et al.* 2010; Dashti *et al.* 2012), the dominance effect was more important than the additive effect in most cases at saline conditions.

Although both additive and dominance genetic effects have been reported to control the physiologic and agronomic traits in wheat, the more important role of dominance effects has been advocated by several authors at both normal (Novoselovic *et al.* 2004; Farooq *et al.* 2019; Safari *et al.* 2018; Shayan *et al.* 2019) and salinity- and water-stress conditions (Dashti *et al.* 2010; Abbasi *et al.* 2013; Safari *et al.* 2018; Shayan *et al.* 2019).

The present investigation aimed to investigate the inheritance of physiological and agronomic characteristics in 92 F4 lines of wheat at salinity-stress and normal conditions and also the effect of salinity on these characteristics.

Materials and Methods

Plant materials and experimental conditions

Plant materials consisted of two spring bread wheat varieties of Moghan3 (sensitive to salinity) and Arg (tolerant to salinity), and the 92 F_4 lines derived from the cross of these two parents. The parents' seeds were obtained from the Seed and Plant Improvement Institute, Karaj, Iran. The experiment was conducted in a greenhouse of the University of Tabriz, Iran at a relative humidity of 50% during the day and 60% at night, 14 h light, and 25 ± 2 °C temperature during the day and night. The seeds were sterilized by benomyl fungicide (1:1000) and cultured in a hydroponic system with sterilized Hoagland's solution (Hoagland and Arnon 1950) using a split-plot design based on randomized complete blocks with two replications. The main plots included two salinity conditions (0 and 150 mM NaCl) and sub-plots consisted of the two parents and 92 F_4 lines. The salt treatment was applied at the three-leaf stage and continued till harvest. The amount of salt needed per each tank was calculated with the following equation and added to the solution inside each feed tank separately:

$$M1V1 = M2V2$$

where M_1 and V_1 represent the stock solution molarity and volume and M_2 and V_2 represent the desired molarity and volume.

In the first week after transplanting due to the limited nutritional needs of the seedlings and the possibility of food poisoning, the seedlings were fed with a Hoagland's solution of half strength, and with the onset of salt stress treatment in the second week a full- strength solution was used. The pH of the tanks was controlled every two days during the experiment to keep them in the optimal range of wheat growth (i.e. 6.5 ± 0.5). Hydrochloric acid was used to adjust the pH. Since there was always some evaporation from the surface of the culture medium and transpiration from the plants, to avoid the increase in the concentration of nutrients and sodium chloride in the culture medium, the water level of the feed tanks was checked every day and compensated for the reduced amount. To ensure the stability of the salt stress, the EC of the solution was measured regularly to add water if the EC was higher and NaCl if the EC was lower than expected.

All necessary care was made during the growth and development period. To estimate the within-lines variance, data were obtained from all individual plants within a plot for all traits, except for Na^+ and K^+ content.

Measurement of the variables

The following traits were measured during the growing season: flag leaf length (FLL), flag leaf width (FLW), flag leaf area (FLA), leaf temperature (LT), electrolyte leakage (EL), RWC, chlorophyll index (Chl), plant height (PH), peduncle length (PL), number of grains per spike (NS), spike length (SL), head weight (HW), 1000-grain weight (1000GW), biomass (Bio), straw weight (STW), grain yield (GY), harvest index (HI), Na^+, K^+, and K^+/Na^+ ratio. To measure FLL and FLW, the maximum length and width of the selected main tillers were measured, respectively. Then, FLA was computed as FLL× FLW × 0.74 (Muller 1991). RWC was measured through three disks with a diameter of 2 cm^2 at both normal and salinity stress conditions by the method of Weatherley (1950). The leaf chlorophyll index was determined using a SPAD chlorophyll meter according to James *et al.* (2002). Leaf temperature was measured by a hand-held thermometer as described by Reynolds *et al.* (1998) from 12:00 to 14:00. EL was calculated according to the formula: $EL= L_1/L_2$, where L_1 was the electric conduction of leaf disks after putting into the deionized water at 25 °C and L_2 was the electric conduction of the samples at 120 °C for 20 minutes (Nayyar 2003). The leaf concentration of Na^+ and K^+ was determined using a flame photometer. For this purpose, the dried leaves at 70 °C temperature for 48 hours were used. The concentration of these ions was calculated in the leaves of the control and salt-stressed plants (Chaparzadeh *et al*. 2003).

Statistical analysis

Before conducting univariate analysis of variance (ANOVA) for each trait, multivariate analysis of variance (MANOVA) was performed to control the type I error rate. Four statistics were used to test the effects of factors and their interaction in MANOVA (i.e. Wilks Lambda, Pillai Trace, Hotelling-Lawley Trace, and Roy's Greatest Root). Before ANOVA, assumptions of homogeneity of error variances, normal distribution of residuals, and independence of errors were verified. Means were compared by Duncan's multiple range test at $p \leq 0.05$. Also, the traits with transgressive segregation were detected under normal and salinity-stress conditions.

Additive (A) and dominance (D) variance components for each trait were estimated separately for the two environmental conditions by the least-squares method according to the components' coefficients in Table 1. Then, additive variance (V_A) and dominance variance (V_D) was calculated as follows (Mather and Jinks 1982):

$$V_A = \frac{A}{2}, \quad V_D = \frac{D}{4}$$

Environmental variance (V_E), genetic variance (V_G), narrow sense (h^2_{bs}) and broad sense (h^2_{bs}) heritability, and average degree of dominance ($\bar{a}$) were estimated by the following formulae (Mather and Jinks 1982):

$$V_{E} = \sqrt{V_{P_1} \times V_{P_2}}$$

$$V_G = V_A + V_D$$

$$h^2_{bs} = \frac{V_G}{V_G + \frac{V_E}{r}}$$

$$h^2_{ns} = \frac{V_A}{V_G + \frac{V_E}{r}}$$

$$\bar{a} = \sqrt{\frac{2V_D}{V_A}}$$

Where, r= number of replications, V_{P_1} and V_{P_2}= variances within the first and second parents, respectively.

All statistical analyses were carried out by Excel, SPSS, and MSTAT-C software.

Results and Discussion

Tests for all assumptions of ANOVA indicated the validity of all assumptions for the studied characteristics (data not shown).

Analyses of variances and means comparison

MANOVA showed that the effects of salinity, line, and line × salinity interaction were significant for all traits, indicating the significant effect of salinity, line, and their interaction on at least one of the studied traits. Also, ANOVA revealed significant differences among lines for all of the characteristics, except the K^+/Na^+ ratio, indicating the existence of appropriate diversity among the

Table 1. Coefficients of the genetic variance components for the generation under investigation

Variance of generations	$A = 2V_A$	$D = 4V_D$
V_{P1} (variance within the first parent)	0	0
V_{P2} (variance within the second parent)	0	0
$V_{\overline{F4}}$ (variance among F4 lines)	0.75	0.046875
$\bar{V}_{F4}$ (variance within F4 lines)	0.125	0.0625

A: additive variance component; D: dominance variance component wheat F4 lines under investigation. There were significant differences between salinity conditions for all of the studied traits. Line × salinity interaction was significant for SL, FLL, FLW, FLA, LT, NS, HW, STW, Bio, GY, and Na^+. The significance of this interaction illustrates that differences among lines were not similar across the normal and salinity-stressed conditions (Table 2).

A comparison of the means revealed that under normal conditions, the Arg variety and lines No. 17, 48, 74, 76, 78, 86, and 91 had higher values for the majority of the traits under investigation. Also, Arg and lines No. 6, 9, 14, 17, 19, 24, 27, 28, 33, 40, 42, 44, 46, 47, 48, 50, 74, 76, and 78 showed higher values for most of the traits under salinity and therefore, can be suggested to be used in the wheat breeding programs to improve salinity tolerance. Furthermore, the Arg variety and lines No. 17, 48, 74, 76, and 78 were suitable for both normal and salinity conditions (the table was not included).

Effect of salinity stress on the studied traits

Although, the line × salinity interaction was significant, however, comparing the two conditions will provide some insight into the effect of salinity on the measured agronomic and physiological traits in this experiment. Salinity stress increased the magnitude of LT, EL, TGW, and Na^+ and decreased other characteristics significantly compared to the normal conditions (Table 3). Significant reduction of grain yield due to salt stress may be the result of the reduction of the photosynthetic capacity and fertilization through the decline in pollen viability and/or stigma receptivity (Flowers and Yeo 1995). According to Asgari *et al.* (2012), salinity stress reduced grain yield and most of the agronomic characteristics, leaf K^+ concentration, and leaf K^+/Na^+ ratio, and increased leaf Na^+ concentration and chloride concentration of all wheat genotypes. In the study of Hasan *et al.* (2015), the grain yield of wheat declined under saline conditions due to the

Table 2. Summary of the MANOVA for the 92 F4 lines of spring bread wheat and their parents under normal and salinity stress conditions

Sources of variation	Test statistics	Statistics
Salinity	Pillai Trace	0.968**
	Wilks Lambda	0.032**
	Hotelling-Lawley Trace	30.26**
	Roy's Largest Root	30.26**
Line	Pillai Trace	9.588**
	Wilks Lambda	0.000**
	Hotelling-Lawley Trace	55.93**
	Roy's Largest Root	22.37**
Line × Salinity	Pillai Trace	7.357**
	Wilks Lambda	0.000**
	Hotelling-Lawley Trace	28.99**
	Roy's Largest Root	14.26**

**: Significant at 0.01 level of probability; MANOVA: Multivariate analysis of variance

Table 3. Means of normal and salinity conditions for the traits under investigation in the spring wheat

Condition	PH (cm)	PL (cm)	SL (cm)	FLL (cm)	FLW (cm)	FLA (cm^2)	RWC (%)	Chl	LT ℃	EL
Normal	33.79a	17.94a	7.76a	19.85a	0.96a	14.25a	70.18a	31.53a	21.15b	25.27b
Salinity	28.15b	14.04b	7.17b	14.23b	0.61b	6.53b	47.10b	23.26b	24.16a	53.59a

Table 3 continued

Condition	NS	TGW (gr)	HW (gr)	STW (gr)	Bio (gr)	GY (gr)	HI (%)	Na^+	K+	K^+/Na^+
Normal	21.26a	36.03b	1.01a	1.32a	2.33a	0.77a	32.92a	4.70b	27.06a	5.80a
Salinity	12.58b	45.76a	0.81b	1.13b	1.94b	0.58b	29.63b	17.63a	22.22b	1.27b

PH: plant height, PL: peduncle length, SL: spike length, FLL: flag leaf length, FLW: flag leaf width, FLA: flag leaf area, RWC: relative water content, Chl: chlorophyll content, LT: leaf temperature, EL: electrolyte leakage, NS: number of grains per spike, TGW: 1000-grain weight, HW: head weight, STW: straw weight, Bio: biomass, GY: grain yield, HI: harvest index; Means having different letters in each column were significantly different at 0.05 probability level based on the F test.

reduction in spikes per plant, grains per spike, and 100-grain weight.

Transgressive segregation

Transgressive segregation was observed for PH, FLL, FLW, FLA, RWC, Chl, LT, EL, NS, K^+, and K^+/Na^+ ratio at both control and salinity stress, Na^+ at the normal, and PL at the salinity conditions. Histograms of the frequency distribution of several traits with transgressive segregation at both normal and salinity conditions are shown in Figures 1 and 2, respectively. At normal and salinity conditions, some lines had significantly higher values than the two parents for PH, FLL, FLW, FLA, RWC, Chl, NS, K^+, and K^+/Na^+ ratio, respectively and several lines showed significantly lower values than the two parents for LT and EL, respectively. At both conditions, lines No. 17 and 44 showed transgressive segregation for most of these traits, which can be used as promising lines in the crossing programs of the spring wheat.

Estimates of genetic parameters

Estimates of genetic parameters for each trait at normal and salinity stress conditions are presented in Table 4. The magnitude of dominance genetic variance was higher than the additive genetic variance for all traits, except PL and FLW at the normal and EL at both conditions. Therefore, the dominance genetic effects played an important role in governing these traits. Abbasi *et al*. (2013) also reported similar results for grain yield and some other traits in wheat.

The average degree of dominance was greater than one at both conditions for all of the studied characteristics (Table 4), showing the possibility of over-dominance type of gene action governing these traits. Nonetheless, the estimates may be biased upwardly by the epistasis and/or linkage disequilibrium (especially repulsion type), so that a partial or complete dominance is shown as the pseudo-overdominance type of gene action (Hill and Maki-Tanila 2015).

Broad-sense heritability was high and narrow-sense heritability was moderate to low at both normal and salinity stress conditions. Estimates of

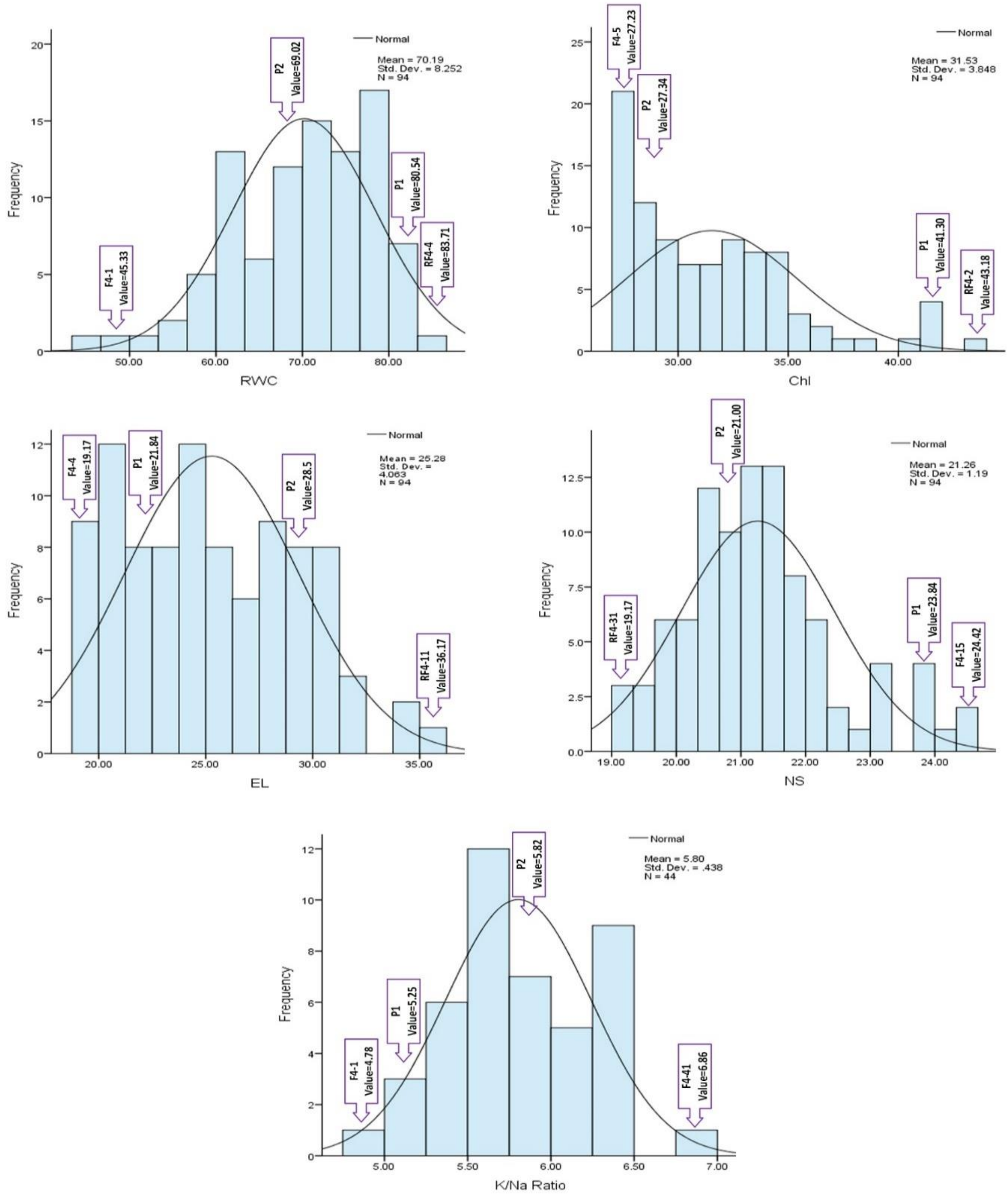

Figure 1. Histogram of the frequency distribution of relative water content (RWC), chlorophyll index (Chl), electrolyte leakage (EL), number of seeds per spike (NS), and K/Na ratio for F4 wheat lines with transgressive segregation at normal conditions

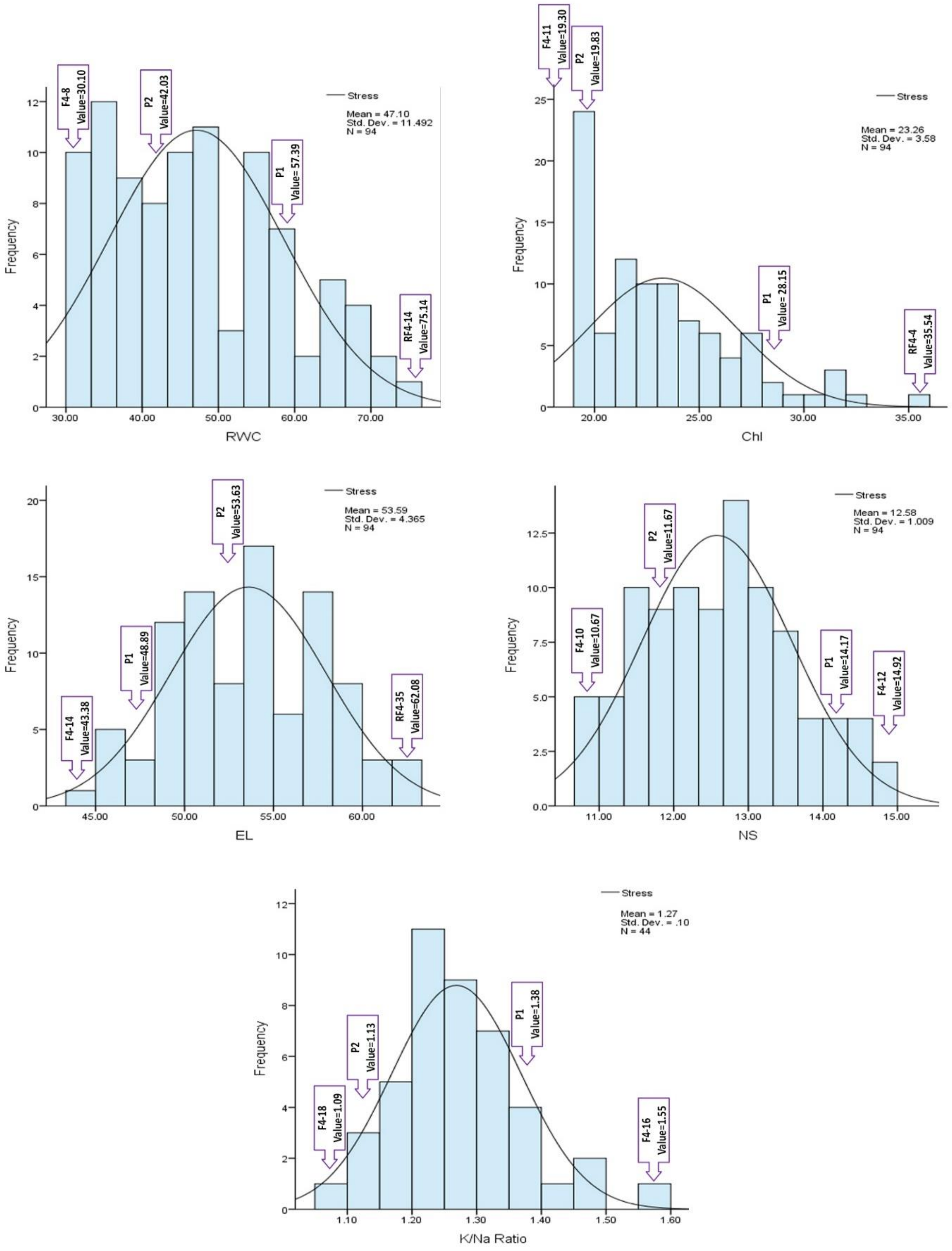

Figure 2. Histogram of the frequency distribution of relative water content (RWC), chlorophyll index (Chl), electrolyte leakage (EL), number of seeds per spike (NS), and K/Na ratio for F4 wheat lines with transgressive segregation at salinity-stress conditions

narrow-sense and broad-sense heritability for the characteristics under investigation ranged between 0.72 (GY) - 0.99 (FLW) and 0.13 (GY) - 0.62 (FLW) at the normal conditions and 0.66 (GY) - 0.98 (FLW) and 0.108 (GY)-0.462 (Chl) at the salinity-stress conditions, respectively (Table 4). FLW had the highest broad-sense (at both conditions) and narrow-sense heritability (at the normal conditions), indicating the important role of the genetic factors compared to the environmental factors in governing FLW. In contrast, GY had the lowest broad-sense and narrow-sense heritability at both conditions, indicating that this trait is highly influenced by the environment in which the plants are grown. Therefore, selection for the grain yield indirectly via its components, which have higher heritability than the grain yield, can be more effective in segregating generations. The difference between broad-sense and narrow-sense heritability represents the important role of the dominance effect in the genetic system of these traits. According to Ravari *et al.* (2017), the broad-sense and narrow-sense heritability for plant height, grain yield, Na^+, K^+, K^+/Na^+ ratio, RWC, days to heading, and days to maturity in wheat at normal and salinity stress conditions were relatively high. In the study of Dashti *et al.* (2010), the broad-sense heritability of traits ranged from 0.07 (Na^+) to 0.87 (K^+/Na^+ ratio) in wheat at salinity-stress conditions. Based on Ali *et al.* (2014), narrow-sense heritability was high (> 0.70) for biomass and Na+ in non-saline conditions, for biomass, fertile tillers, 100-grain weight, grain yield, Na^+, Cl^-, and K^+/Na^+ ratio at 10 dS m^{-1} of salinity and for grain yield, fertile tillers, Na^+, K^+, and K^+/Na^+ ratio at 15 dS m^{-1} in wheat.

The importance of dominance genetic variance relative to the additive genetic variance for most of the traits, the over-dominance type of gene action for all traits, and higher values of the broad-sense heritability compared to moderate to low values for the narrow-sense heritability indicates that the dominance genetic effects played an important role in the inheritance of the traits under investigation at both salinity and normal conditions. Therefore, exploiting the non-additive gene action through the production of hybrid varieties will increase the grain yield in wheat if the problems of pollen transfer and male sterility are solved. Hybrid varieties are also more stable than pure lines (Schnable and Springer 2013). Although the cultivation area of the commercial hybrids in wheat is small (Florian Mette *et al*. 2015) it seems that wheat hybrid production will increase soon (Ledbetter 2016) due to the utilization of new technologies in this important crop (Whitford *et al.* 2013).

Conclusions

There was significant diversity among F4 lines derived from the cross between Arg and Moghan3 spring wheat cultivars. Salinity stress during the three-leaf stage decreased the values of all characters except LT, EL, TGW, and Na^+, which increased at the salinity conditions. Transgressive segregation was observed for PH, FLL, FLW, FLA, RWC, Chl, NS, K^+, K^+/Na^+ ratio, LT, and EL at both normal and salinity conditions, and lines No. 17 and 44 were superior to their parents for most of these traits, which can be utilized in the wheat breeding programs. Narrow-sense and broad-sense heritability for all of the investigated traits were moderate to high at both normal and salinity-stress conditions, respectively. In both conditions, the dominance genetic variance was more important than the additive genetic variance for most of the studied traits. Also, the average degree of dominance for all traits was more than one at both normal and salinity stress conditions. These results demonstrate the advantage of exploiting dominance gene action and improving grain yield by producing hybrid varieties if hybridization problems (pollination and male sterility) and other obstacles were solved in wheat.

Acknowledgments

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Conflict of Interest

The authors declare that they have no conflict of interest with any people and/or organization concerning the subject of the manuscript.

Table 4. Estimates of genetic variances, broad-sense and narrow-sense heritability, and average degree of dominance for the agronomic and physiological traits of bread wheat at normal and salinity stress conditions

Trait	Conditions	V_A	V_D	h^2_{bs}	h^2_{ns}	$\bar{a}$
PH	Normal	19.198	24.142	0.91	0.40	1.59
	Salinity	17.916	18.468	0.88	0.44	1.44
PL	Normal	9.185	7.229	0.97	0.54	1.26
	Salinity	3.597	4.039	0.87	0.41	1.50
SL	Normal	1.629	1.705	0.97	0.48	1.45
	Salinity	0.563	0.747	0.96	0.41	1.63
FLL	Normal	40.108	65.026	0.99	0.38	1.80
	Salinity	19.964	23.530	0.96	0.44	1.54
FLW	Normal	0.382	0.230	0.99	0.62	1.10
	Salinity	0.054	0.074	0.98	0.41	1.66
FLA	Normal	35.296	77.246	0.99	0.31	2.09
	Salinity	9.430	22.252	0.96	0.29	2.17
RWC	Normal	31.840	35.808	0.97	0.46	1.50
	Salinity	29.723	34.265	0.95	0.44	1.52
Chl	Normal	13.417	17.395	0.99	0.43	1.61
	Salinity	4.903	5.117	0.94	0.46	1.45
LT	Normal	6.402	12.219	0.97	0.33	1.95
	Salinity	2.761	4.457	0.95	0.36	1.80
EL	Normal	13.881	9.287	0.97	0.58	1.16
	Salinity	8.411	6.053	0.74	0.43	1.20
NS	Normal	7.006	24.486	0.91	0.20	2.64
	Salinity	5.888	10.806	0.91	0.32	1.92
TGW	Normal	20.711	69.079	0.90	0.21	2.58
	Salinity	19.853	61.829	0.79	0.19	2.50
HW	Normal	0.028	0.091	0.97	0.23	2.54
	Salinity	0.007	0.040	0.89	0.14	3.34
STW	Normal	0.057	0.121	0.96	0.31	2.06
	Salinity	0.039	0.066	0.90	0.34	1.84
Bio	Normal	0.169	0.397	0.97	0.29	2.17
	Salinity	0.065	0.200	0.90	0.22	2.47
GY	Normal	0.019	0.086	0.72	0.13	3.01
	Salinity	0.014	0.073	0.66	0.11	3.20
HI	Normal	7.472	28.044	0.96	0.20	2.74
	Salinity	6.169	15.980	0.86	0.24	2.28

PH: plant height, PL: peduncle length, SL: spike length, FLL: flag leaf length, FLW: flag leaf width, FLA: flag leaf area, RWC: relative water content, Chl: chlorophyll content, LT: leaf temperature, EL: electrolyte leakage, NS: number of grains per spike, TGW: 1000-grain weight, HW: head weight, STW: straw weight, Bio: biomass, GY: grain yield, HI: harvest index; V_A, V_D, h^2_{bs}, h^2_{ns}, V_E, $\bar{a}$: additive genetic variance, dominance genetic variance, broad sense heritability, narrow sense heritability, environmental variance and average degree of dominance, respectively.

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وراثت صفات زراعی و فیزیولوژیک در لاین‌های گندم (*Triticum aestivum* L.) بهاره در شرایط نرمال و تنش شوری

مهری عباس‌زاده[۱]، محمد مقدم[۱،۲]، مجید نوروزی[۱] و علی بنده حق[۱]

۱- گروه به‌نژادی و بیوتکنولوژی گیاهی؛ دانشکده کشاورزی، دانشگاه تبریز، تبریز
۲- قطب علمی اصلاح مولکولی غلات، دانشگاه تبریز، تبریز
*مسئول مکاتبه؛ Email: mmoghaddam@tabrizu.ac.ir

چکیده

وراثت چند صفت فیزیولوژیکی و زراعی در ۹۲ لاین F4 حاصل از تلاقی دو رقم گندم (ارگ و مغان ۳، به ترتیب متحمل و حساس به شوری) در گلخانه تحت شرایط نرمال و تنش شوری با استفاده از سیستم هیدروپونیک در سال ۱۳۹۷ مورد بررسی قرار گرفت. آزمایش به صورت کرت‌های خرد شده بر پایه بلوک‌های کامل تصادفی با دو تکرار انجام شد. دو سطح شوری (نرمال و کاربرد ۱۵۰ میلی مولار نمک طعام در مرحله سه برگی) در کرت‌های اصلی و لاین‌ها در کرت‌های فرعی قرار داده شدند. تجزیه واریانس تفاوت معنی‌داری را بین لاین‌ها برای همه صفات مورد بررسی، به جز نسبت K+/Na+، نشان داد. اثر متقابل لاین × شوری برای اکثر صفات از جمله عملکرد دانه معنی دار بود. تنش شوری سبب افزایش معنی‌دار میزان دمای برگ، نشت الکترولیت، وزن هزار دانه و محتوای Na+ و کاهش معنی‌دار سایر صفات شد. تفکیک متجاوز برای برخی صفات در هر دو شرایط نرمال و تنش شوری مشاهده شد. در هر دو شرایط نرمال و تنش شوری، وراثت‌پذیری عمومی و خصوصی صفات مورد مطالعه به‌ترتیب بالا (۰/۷۲ - ۰/۹۹) و متوسط تا کم (۰/۶۲-۰/۱۱) برآورد شد. کمترین میزان وراثت‌پذیری عمومی (۰/۷۲ و ۰/۶۶ به ترتیب در شرایط نرمال و تنش شوری) و وراثت‌پذیری خصوصی (۰/۱۳ و ۰/۱۱ به ترتیب در شرایط نرمال و تنش شوری) مربوط به عملکرد دانه بود. در هر دو شرایط، مقدار واریانس غالبیت بیشتر از واریانس افزایشی برای اکثر صفات مورد مطالعه بود. میانگین درجه غالبیت برای همه صفات در هر دو شرایط بیشتر از یک بود که نشان دهنده وجود عمل فوق غالبیت ژنی در کنترل صفات مورد بررسی بود. این تحقیق ضرورت بهره‌برداری از اثرات ژنی غالبیت در برنامه‌های اصلاحی گندم تحت تنش شوری را نشان می‌دهد.

واژه‌های کلیدی: درجه غالبیت؛ واریانس ژنتیکی افزایشی؛ واریانس ژنتیکی غالبیت؛ وراثت پذیری خصوصی؛ وراثت پذیری عمومی

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