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Bread wheat responds salt stress better than einkorn wheat does during germination

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Abstract: Salt stress during germination degenerates crop establishment and declines yield in wheat (*Triticum* subsp.). Against salt (NaCl) stress, we investigated 12 bread (*Triticum aestivum* L.) and 10 einkorn wheat (T. *monococcum* subsp. *monococcum*) entries for germination rate, germinating power, coleoptile length, shoot length, root length, shoot/root length ratio, root fresh weight, root dry weight, and root fresh/dry weigh ratio. An effective blocking in variance analysis improved statistical significance and differentiation between germination stages and wheat entries. Salt total and salt ranking tolerance indices grouped the wheat entries into tolerant (Bayraktar 2000, Gerek 79, İkizce 96, Gün 91, Demir 2000, and Momtchil) and susceptible ones (Population-4, Population-14, Population-15, Population-9, Population-11, and Population-10). The best coleoptile length and root fresh weight developments occurred between 0 and 0.15 M and root length between 0 and 0.10 M salt doses. Coleoptile length, root fresh weight, and root dry weight started decreasing at 0.20 M. Pearson linear correlation coefficients were significant at different levels for coleoptile length, root fresh weight, and root dry weight. Spearman correlation coefficients were not significant between the worst salt affected characters of coleoptile length, shoot length, root length, root fresh weight, and root dry weight characters under the control treatment but were significant under salt stress. A significant PC value of 0.356 was recorded for root dry weight, 0.335 for root length, 0.310 for shoot root length ratio, and 0.309 for root fresh weight in PC 1. The first three PCs accounted for 90.52% of total variation. The highest PC was PC1 (71.946%), followed by PC2 (11.098%), and PC3 (7.481%). The dendrogram of all wheat entries clearly differentiated bread and einkorn wheats as both salt indices did. Here, it seemed, then, that those bread wheat cultivars were more salt tolerant than einkorn populations, most likely because of their geographic origin differences.

Key words: Bread wheat, dendrogram, einkorn, germination stages, principal component analysis, salt stress

1. Introduction

Wheat, the second most important agricultural crop amongst the cereals on a global scale (Rahaie et al., 2013), was the first cultivated one thousands of years ago and has kept providing staple nutrition for humans since then (Braun et al., 2001; Goutam et al., 2013; Shahzad et al., 2013). Today's global wheat production of about 670.8 million tons per year directly influences human survival and life quality (Shahzad et al., 2013) by being involved in the production of various foods, including bread, pasta, noodles, cakes, and biscuits (Eren et al., 2015).

Many abiotic factors affect wheat (Braun et al., 1998; Rahaie et al., 2013), reduce productivity (Mostek et al., 2015), and produce stress responses, 31.56% by heat, 26.61% by drought, and 23.38% by salt (Kamal et al., 2010). Salinity, drought, or cold adversely worsens crop yield and quality (Verslues et al., 2006; Li et al., 2010; Izadi et al., 2014; Mostek et al., 2015; Richter et al., 2015), limits water absorption (Pierik and Testerink, 2014), decreases soil osmotic potential (Izadi et al., 2014), induces water deficit, and causes morphological, physiological and biochemical deteriorations, and finally restricts yield (Mehrotra et al., 2014).

Salinity, today, affects nearly 7% (950 million ha) of overall (Shavrukov et al., 2011), 23% of cultivated, and 20% of irrigated land (Vardar and Çifci, 2014) in the world. A worrying 10% annual increase (El-Hendawy et al., 2005; Huang et al., 2006) and 30% expected land loss within the next 25 years are anticipated (Radi, 2013). To combat this problem, new genetic resources (Karagöz et al., 2010) including salt against abiotic stresses and efficient testing and screening techniques are urgently required (Munns and James, 2003; Mostek et al., 2015). Among new genetic resources, emmer (*Triticum dicoccum* Schrank.) and einkorn (*Triticum monococcum* L. subsp. *monococcum*) are expected to play a very significant role

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(Karagöz and Zencirci, 2005; Zencirci and Karagöz, 2005; Munns et al., 2012). New techniques for salt tolerance are drought and salinity responsive zinc finger proteins (Li et al., 2010), water loss durable embryo development in the final maturation (Masmoudi et al., 2009), and genotype testing against salt tolerance at different growth stages (El-Hendawy et al., 2005). Testing wheat at different growth stages or against different salt responsive characters results in different salt tolerance indices and differentiates tolerant and susceptible genotypes effectively (Zencirci et al., 1990; Askari et al., 2016; Oyiga et al., 2016).

Among the growth stages, germination is an important one as it particularly determines the good start of crop establishment in saline soils. Several plants (Colmer et al., 1995; Moud and Maghsoudi, 2008), including cereals (Vardar and Çifci, 2014), are sensitive to higher salinity (Abdoli and Saeidi, 2012) during yield determining germination stages. This study, therefore, aimed to investigate the reactions of 12 bread wheat (*Triticum aestivum* L.) cultivars and 10 einkorn (T. *monococcum* subsp. *monococcum*) wheat populations for germination rate, germinating power, coleoptile length, shoot length, root length, shoot/root length ratio, root fresh weight, root dry weight, and root fresh weight/root ratio under salt (NaCl) stress.

2. Materials and methods

2.1. Materials

2.1.1. Plant material

The plant material was 12 bread wheat (*Triticum aestivum* L.) cultivars and 10 einkorn wheat (*Triticum monococcum* subsp. *monococcum*) populations (Table 1). The bread wheat cultivars were Gerek 79, İkizce 96, Kıraç 66, Kenanbey, Flamura 85, Momtchill, Bayraktar 2000,

Table 1. Twelve bread wheat cultivars and 10 einkorn populations with their code numbers and origins.

Code number	Cultivars/Populations	Origins
1	Gerek 79	ARI[2]
2	İkizce 96	CRIFC[1]
3	Kıraç 66	ARI[2]
4	Kenanbey	CRIFC[1]
5	Flamura 85	TARI[3]
6	Momtchill	TARI[3],
7	Bayraktar 2000	CRIFC[1]
8	Tosunbey	CRIFC[1]
9	Pandas	CARI[4]
10	Pehlivan	TARI[3]
11	Demir 2000	CRIFC[1]
12	Gün 91	CRIFC[1]
13	Population-1	Bolu, Seben, Haccağız Village
14	Population-2	Bolu, Seben, Boğaz Region
15	Population-4	Bolu, Seben, Kavaklı Yazı Village, Field # 1
16	Population-5	Bolu, Seben, Kavaklı Yazı Village, Field # 2
17	Population-6	Bolu, Seben, Kavaklı Yazı Village, Field # 3
18	Population-9	Kastamanonu, İhsan Gazi, Çatalyazı Village
19	Population-10	Kastamanonu, İhsan Gazi, Uzunoğlu District
20	Population-11	Kastamanonu, İhsan Gazi, Çay District
21	Population-14	Kastamanonu, İhsan Gazi, Center
22	Population-15	Kastamanonu, İhsan Gazi, Center

[1]CRIFC: Central Research Institute for Agricultural Research, Ankara; [2]ARI: Anatolian Research Institute, Eskişehir; TARI[3:] Thrace Agricultural Research Institute, Edirne; CARI[4]: Çukurova Agricultural Research Institute, Adana.

Tosunbey, Pandas, Pehlivan, Demir 2000, and Gün 91, and the einkorn (*Triticum monococcum* subsp. *monococcum*) wheat populations were Population-1, Population-2, Population-4, Population-5, Population-6, Population-9, Population-10, Population-11, Population-14, and Population-15. The bread wheat cultivars were kindly provided by research institutes in Turkey and the einkorn wheat (*Triticum monococcum* subsp. *monococcum*) populations by the Quality Feed Company, Bolu (Table 1).

2.2. Methods

2.2. 1. Salt stress tests

First 3 × 30 wheat seeds (of each wheat entry per treatment) were surface sterilized in 96% ethanol for 30 s and 10% sodium hypochlorite for 15 min, and rinsed twice in distilled water. Then 10 × 3 seeds were germinated on wet filter paper under salt stress of 1 control and 6 salt (NaCl) doses of 5 mL: 0 (control), 0.05 M, 0.10 M, 0.15 M, 0.20 M 0.25 M, and 0.30 M. pH in each concentration was adjusted to 5.9 ± 1. Wheat seeds were germinated for 8 days at 23 ± 1 °C in a dark growth room. After 4 days germination rate (%) and after 8 days germination power (%), coleoptile length (cm), shoot length (cm), root length (cm), shoot root length ratio, fresh root weight (mg), dry root weight (mg), and root fresh dry weight ratio were measured. Salt total tolerance indices based on genotype character measurements and salt rank tolerance indices based on genotype character rankings (Zencirci et al., 1990; Askari et al., 2016; Oyiga et al., 2016) were calculated and salt tolerant and susceptible wheat genotypes were determined.

2.2.2. Statistical analyses

The experiment was set up in a 3 replicate randomized complete block design with factorial restriction. Analysis of variance (ANOVA), Fisher's protected test (F), least significant difference (LSD) for mean separation (Gomez and Gomez, 1984), Pearson linear correlations among the higher number sample characters (Kalaycı, 2006), salt total tolerance indices based on genotype character measurements (Zencirci et al., 1990; Askari et al., 2016; Oyiga et al., 2016), salt tolerance indices (Zencirci et al., 1990; Askari et al., 2016; Oyiga et al., 2016), and Spearman correlations among characters both under salinity or control were calculated by EXCEL. Then further statistical evaluations were carried out on salt tolerant and susceptible wheat entries (Zencirci and Kün, 1996). Principal component analysis (PCA) for variation components and dendrograms for grouping wheat entries based on multicharacters were performed by SPSS (Zobel et al., 1988).

3. Results

Salinity disturbs crops especially during germination, worsens crop establishment, and reduces yield. Better understanding salt stress is a good way to overcome its damage on wheat. Twelve bread wheat (*T. aestivum* L.) cultivars and 10 einkorn wheat (*T. monococcum* subsp. *monococcum*) populations provided the following results.

3.1. Differences among germination stages, among and within bread wheat cultivars and einkorn populations

We ran analysis of variance (Table 2) after we determined the most salt decreased (%) characters (Table 3): coleoptile length (95.11%), shoot length (100.00%), root length (100.00%), root fresh weight (92.24%), and root dry weight (85.94%), and evaluated them by further analyses. The highest decrease in bread wheat cultivars under salt stress was in coleoptile length (48.34%) and the highest decrease in einkorn populations was in shoot length (52.05%). ANOVA revealed that blocking was effective ($P < 0.01$), cultivars and salt doses differed ($P < 0.01$), and all wheat entries and salt doses were highly different for all most decreased characters ($P < 0.01$). No wheat entry by dose interaction existed for any of the characters.

Differences between coleoptile length, shoot length, root length, root fresh weight, and root dry weight under salt stress (Table 2), as observed by F test in ANOVA, existed and were discriminated by least significant difference (LSD) to the greatest extent. Control (0 salt)

Table 2. Sources of variation, degrees of freedom (DF), and Fisher's protected F values in analysis of variance for GR, GP, CL, SL, RL, SRLR, FW, RDW, and RFDWR under salt stress.

Sources of variation	DF	Coleoptile length	Shoot length	Root length	Root fresh weight	Root dry weigh
Blocks	2	6.75**	8.87**	7.90**	0.42ns	3.65*
Treatment	153	27.50**	17.26**	15.83**	18.15**	5.29**
Cultivar	21	2.21*	4.00**	1.04^{ns}	5.22**	3.12**
Doses	6	210.13**	124.36**	61.22**	129.64**	24.42**
Cultivar *Doses	126	0.76^{ns}	0.40^{ns}	0.51^{ns}	0.30^{ns}	0.46^{ns}
Error	306					

Table 3. Differences among coleoptile length, shoot length, root length, root fresh weight, and root dry weight under stress.

Salt doses (M)	Coleoptile length	Shoot length	Root length	Root fresh weight	Root dry weight
Control	4.09^{A}	12.35^{A}	7.70^{A}	76.24^{A}	7.11^{A}
0.05	3.88^{AB}	10.00^{B}	5.70^{AB}	65.88^{AB}	6.12^{AB}
0.10	$2.96^{A–C}$	5.47^{C}	$4.00^{A–C}$	$48.34^{A–C}$	$4.81^{A–C}$
0.15	$2.06^{A–D}$	2.16^{D}	$2.39^{B–D}$	$32.30^{A–D}$	$3.52^{A–D}$
0.20	$1.11^{C–E}$	0.50^{E}	$1.30^{B–E}$	$19.36^{B–E}$	$2. 37^{B–E}$
0.25	$0.44^{C–F}$	0.07^{E}	$0.75^{C–F}$	$12.03^{C–F}$	$1.66^{C–F}$
0.30	$0.24^{C–G}$	0.00^{E}	0^{E}	$5.92^{C–G}$	$1.00^{C–G}$
% Decrease	95.11	100.00	100.00	92.24	85.94

treatment always led to the highest values. The highest coleoptile length and root fresh weight were seen between 0 and 0.15 M and root length between 0 and 0.10 M. Coleoptile length, root fresh weight, and root dry weight decreased starting at 0.150 M (Table 3).

Differences between the 12 wheat cultivars and 10 einkorn wheat populations under salt stress, as perceived by F tests in ANOVA, also existed for all decreased germination characters and were distinguished by LSD to the greatest degree (Table 4). Salt total tolerance and salt tolerance indices grouped wheat entries (Table 5) as tolerant (Bayraktar 2000, Gerek 79, İkizce 96, Gün 91, Demir 2000, and Momtchill) and susceptible (Population-4, Population-14, Population-15, Population-9, Population-11, and Population-10). Gerek 79, Momtchill, Demir 2000, Bayraktar 2000, and Pehlivan had the longest coleoptile length, while Population-9 and Population-10 had the shortest ($P < 0.05$). Bayraktar 2000, Demir 2000, and İkizce 96 had the longest shoot length, while Population-10 and Population-14 had the shortest ($P < 0.05$). Bayraktar 2000, Gerek 79, İkizce 96, and Gün 91 had the longest root length, while Population-9 and Population-10 had the shortest ($P < 0.05$). Bayraktar 2000, Gün 91, İkizce 96, Gerek 79, Demir 2000, Tosunbey, Momthcill, Flamura 85, and Population-5 had the heaviest root fresh weight, while Population-11, Population-9, and Population-10 had the lightest ($P < 0.05$). Bayraktar 2000, Gün 91, İkizce 96, Gerek 79, Demir 2000, and Momtchill had the heaviest root dry weight, while Population-15 and Population-11 had the lightest ($P < 0.05$).

3.2. Correlation between characters with and without salt stress

Pearson linear correlation coefficients (r; Kalaycı 2006) between the most salt affected coleoptile length, shoot length, shoot length, root length, root fresh weight, and root dry weight under salt stress resulted in linear correlations at different significance levels (Table 6a). Those higher, of which their r ranged between 0.900 and 1.000, existed between root dry weight and root length and between root dry weight and root fresh weight. Those higher, of which their r ranged between 700 and 0.890, occurred between coleoptile length and root fresh weight, and coleoptile length and root dry weight. No lowest linear relationships, of which their r was between 0.000 and 0.250, existed among any of the character pairs.

Salt most affected coleoptile length, shoot length, shoot length, root length, root fresh weight, and root dry weight characters were also correlated by Spearman correlation (Table 6b) under control (0 NaCl) and salt (0.15 M) conditions. Characters under control treatment were not highly significantly correlated but were under salt stress. Under control traetment, the highest significant correlation was between coleoptile length and shoot length (0.70), followed by root length and root fresh weight (0.66), and shoot length and root dry weight (0.51), ($P < 0.05$). Coleoptile length and root dry weight (–0.36), shoot length and root fresh weight (–0.35), and coleoptile length and root fresh weight (–0.004) were negatively correlated. The highest correlation under salt (0.15 M) stress was between root length and root fresh weight (0.96), followed by root length and root dry weight (0.94), and shoot length and root fresh weight (0.94). All other correlation coefficients between character pairs (Table 6) under salt stress were significant ($P > 0.05$).

3.3. Principal component analysis (PCA)

PCA determines the variation and its contribution by characters into the process and reveals the most important contributors in multicharacter studies. The coefficient of PC is significant if it is ≥0.3 (Hair et al., 1987) although there are no clear-cut guidelines about it. In the present study, root dry weight (0.356), root length (0.335), shoot root length ratio (0.310), and root fresh weight (0.309) formed PC 1; shoot length (0.613) and root fresh dry weight ratio (0.613) PC2; and germination rate (0.779) and

Table 4. Differences among 12 wheat cultivars and 10 einkorn wheat populations under salt stress.

Cultivars/Populations	Coleoptile length	Shoot length	Root length	Root fresh weight	Root dry weight
Gerek 79	3.02a	5.60a - c	47.93a - d	5.00ab	9.56b - l
İkizce 96	2.27b - g	5.30a - e	4.11a - c	48.30a - c	4.65a - d
Kıraç 66	2.06e - j	4.06d - n	3.14b - k	40.29a - j	4.40a - f
Kenanbey	1.94f - l	4.24b - j	3.21b - j	42.32a - i	3.98b - j
Flamura85	1.91f - m	3.81f - p	3.61a - p	43.35a - h	4.79a - c
Momtchill	2.83ab	4.70b - g	3.51b - i	46.90a - g	4.63a - e
Bayraktar 2000	2.79a - d	6.44a	5.09a	52.28a	5.37a
Tosunbey	1,56g - s	3.70f - q	3.93a - g	47.22a - f	4.21a - h
Pandas	1.90f - n	4.22b - k	3.07b - l	34.96b - m	3.50d - o
Pehlivan	2.71a - e	5.10a - f	3.96a - f	38.37a - l	3.76c - l
Demir 2000	2.80a - c	5.66ab	4.06a - d	47.53a - e	4.31a - g
Gün 91	2.51a - f	4.50b - i	4.01a - e	50.05ab	3.93b - k
Population 1	2.12b - I	4.21c - l	2.40h - q	30.01h - o	3.57c - n
Population 2	2.03e - k	4.69b - h	2.56h - o	27.53j - q	2.83i - t
Population 4	1.88f - o	3.88e - o	2.05j - s	27.58j - p	3.11g - p
Population 5	2.13b - h	5.36a - d	3.04b - m	39.57a - k	4.03b - i
Population 6	2.03ek	4.13d - m	2.82c - n	31.82f - n	3.61c - m
Population 9	1.501t	3.38g - t	1.87j - u	24.30k - t	2.89i - r
Population 10	1.55g - t	2.57o - v	1.90j - t	24.05l - u	2.59l - v
Population 11	1.60g - r	3.61g - s	2.55h - p	21.37m - u	2.63l - u
Population 14.	1.66g - p	3.25h - u	2.36h - r	25.72j - s	2.99h - q
Population 15	1.65g - q	3.62g - r	2.36h - r.	25.90j - r	0.64y
% Decrease in Cults	48.34	34.63	39.69	33.13	34.82
% Decrease in Pops.	27.23	52.05	38.49	21.95	35.73
% Decrease in All	50.00	60.09	63.26	59.12	88.08

germination power (0.633) PC3. Cumulative variance of the first three PCs added up to a total of 90.525%. PC1 had a share of 71.946%, PC2 11.098%, and PC3 7.481% in total variation (Table 7).

3.4. Dendrograms

The dendrogram, which groups individuals based on their multicharacter values, is one of the best multiapproaches to group individuals. With the support of other statistical analysis including analysis of variance and comparison tests (i.e. Fisher's protected F) a dendrogram provides meaningful results to group individuals.

3.4.1. Overall dendrogram for bread wheat (*T. aestivum* L.) cultivars and einkorn (*Triticum monococcum* L. subsp. *monococcum*) populations

An overall dendrogram based on the averages of 22 wheat entries of 12 bread wheat (*T. aestivum* L.) cultivars and 10 einkorn *Triticum monococcum* L. subsp. *monococcum* populations) resulted in two main groups (Figure 1a). Each group also had 2 subgroups. The first main group consisted of mostly einkorn populations and bread wheat Pandas in two subgroups. Population-14, Population-15, Population-9, Population-10, Population-2, Population-4, and Population-11 were in the first subgroup 1, while Population-1, Population-6, and Pandas were in the second subgroup. The second main group was mostly bread wheat cultivars with einkorn Population-5. The third subgroup encompassed Kenanbey, Flamura 85, Kıraç 66, Population-16, and Pehlivan, while the fourth subgroup included Gerek 79, İkizce 96, Momtchill, Demir 2000, Tosunbey, Gün 91, and Bayraktar 2000.

3.4.2. Bread wheat (*T. aestivum* L.) cultivars

Bread wheat cultivars, based on the averages of all the characters studied, formed two dendrograms (Figure 1b), which had 7 and 5 of the total 12 cultivars. Gerek

Table 5. Salt total (STTI) and salt rank tolerance indices (SRTI) and standard deviations of bread wheat cultivars and einkorn populations.

Cultivars/ Populations	Salt total tolerance indices (STTI) ± SD	Salt rank tolerance indices (SRTI) ± SD	Range of coleoptile length (control to 0.30)	Range of shoot length (control to 0.30)	Range of root length (control to 0.30)	Range of root fresh weight (control to 0.30)	Range of root dry weight (control to 0.30)
TOLERANT							
Bayraktar 2000	97.88 ± 15.77	5.44 ± 5.24	3.88–0.26	2.56–0.00	10.26–0.61	88.46–8.47	8.01–0.13
Gerek 79	93.44 ± 14.38	5.44 ± 3.19	4.57–0.63	2.66–0.00	7.35–0.69	73.25–10.75	7.76–1.46
İkizce 96	92.65 ± 14.58	5.89 ± 4.04	3.55–0.19	2.89–0.00	8.72–0.57	93.35–10.56	7.61–1.54
Gün 91	95.66 ± 15.23	6.00 ± 4.95	4.41–0.13	0.87–0.00	8.98–0.64	95.88–8.96	7.11–1.17
Demir 2000	91.62 ± 14.33	6.78 ± 3.89	4.23–0.25	3.43–0.00	8.98–0.46	88.72–8.10	7.29–1.22
Momtchill	90.42 ± 14.16	7.44 ± 3.55	4.09–0.11	0.63–0.00	6.18–0.63	87.65–29.13	7.84–0.85
SUSCEPTIBLE							
Population-4	65.23 ± 8.26	14.11 ± 5.79	4.00–0.19	1.06–0.53	5.23–0.16	59.58–5.08	5.95–0.58
Population-14	62.71 ± 7.76	14.56 ± 5.31	4.54–0.17	3.57–0.09	6.92–0.17	72.29–5.43	5.89–0.93
Population-15	60.32 ± 7.98	17.11 ± 3.82	4.30–0.16	4.01–0.08	6.79–0.15	78.20–3.71	5.92–0.63
Population-9	58.79 ± 7.31	18.44 ± 3.46	3.93–0.22	13.50–0.00	6.27–0.21	75.53–4.64	6.37–0.86
Population-11	56.17 ± 6.40	18.67 ± 2.42	3.90–0.13	3.64–0.00	7.30–0.16	68.73–4.26	5.76–0.72
Population-10	56.79 ± 7.32	20.56 ± 1.43	4.45–0.17	2.70–0.00	6.21–0.15	71.38–3.84	6.04–0.70

Table 6. a - Pearson correlation coefficients among coleoptile length, shoot length, root length, root fresh weight, and root dry weight under salt stress; b - Spearman correlation coefficients under salt stress and under control (no stress).

Characters	Coleoptile length	Shoot length	Root length	Root fresh weight
Root dry weight	0.891	0.579	0.925	0.912
Root fresh weight	0.860	0.671	0.890	
Root length	0.865	0.656		
Shoot length	0.657			
Characters/Salt application				
Under salt	Coleoptile length	Shoot length	Root length	Root fresh weight
Root dry weight	0.91	0.93	0.94	0.80
Root fresh weight	0.87	0.94	0.96	
Root length	0.89	0.87		
Shoot length	0.90	-		
Control (no salt)	Coleoptile length	Shoot length	Root length	Root fresh weight
Root dry weight	–0.36	0.51	0.46	0.24
Root fresh weight	–0.04	–0.35	0.66	
Root length	0.06	0.47		
Shoot length	0.70	-		

a. Pearson correlation coefficients
b. Spearman correlation coefficients

Table 7. First three PC coefficients for germination characters, variations by each of them, and the total variance explained.

Characters	Principal component			Sums of squared	
	1	2	3	% of variance	Cumulative %
Shoot length	–0.210	0.613	–0.052	71.946	71.946
Shoot/root length ratio	0.310	–0.178	–0.031	11.098	83.044
Coleoptile length	0.284	–0.060	–0.075	7.481	90.525
Germination power	–0.200	–0.053	0.633		
Germination rate	–0.294	–0.068	0.779		
Root length	0.335	–0.022	–0.204		
Root dry weight	0.356	–0.154	–0.096		
Root fresh weight	0.309	–0.018	–0.163		
Root fresh/dry weight ratio	–0.210	0.613	–0.052		

79, İkizce 96, Demir 2000, Momtchill, Tosunbey, Gün 91, and Bayraktar 2000 were in the first subgroup. Flamura 85, Kenanbey, Kıraç 66, Pehlivan, and Pandas were in the second.

3.4.3. Einkorn (*T. monococcum* L. subsp. *monococcum*) populations

Einkorn populations based on character averages (Figure 1c) fitted into two subgroups except Population-5. Other populations including Population-14, Population-15, Population-9, Population-10, Population-2, Population-4, and Population-11 were in one subsubgroup with Population-1 and Population-6 in the other.

4. Discussion

Germination is one of the most stress vulnerable growth stages of crops. Biotic or abiotic factors during germination are critical since they worsen crop establishment and reduce yield. Salt, with drought and cold, is the most devastating biotic factor, especially on salt sensitive plants during germination and early seedling stages. The higher

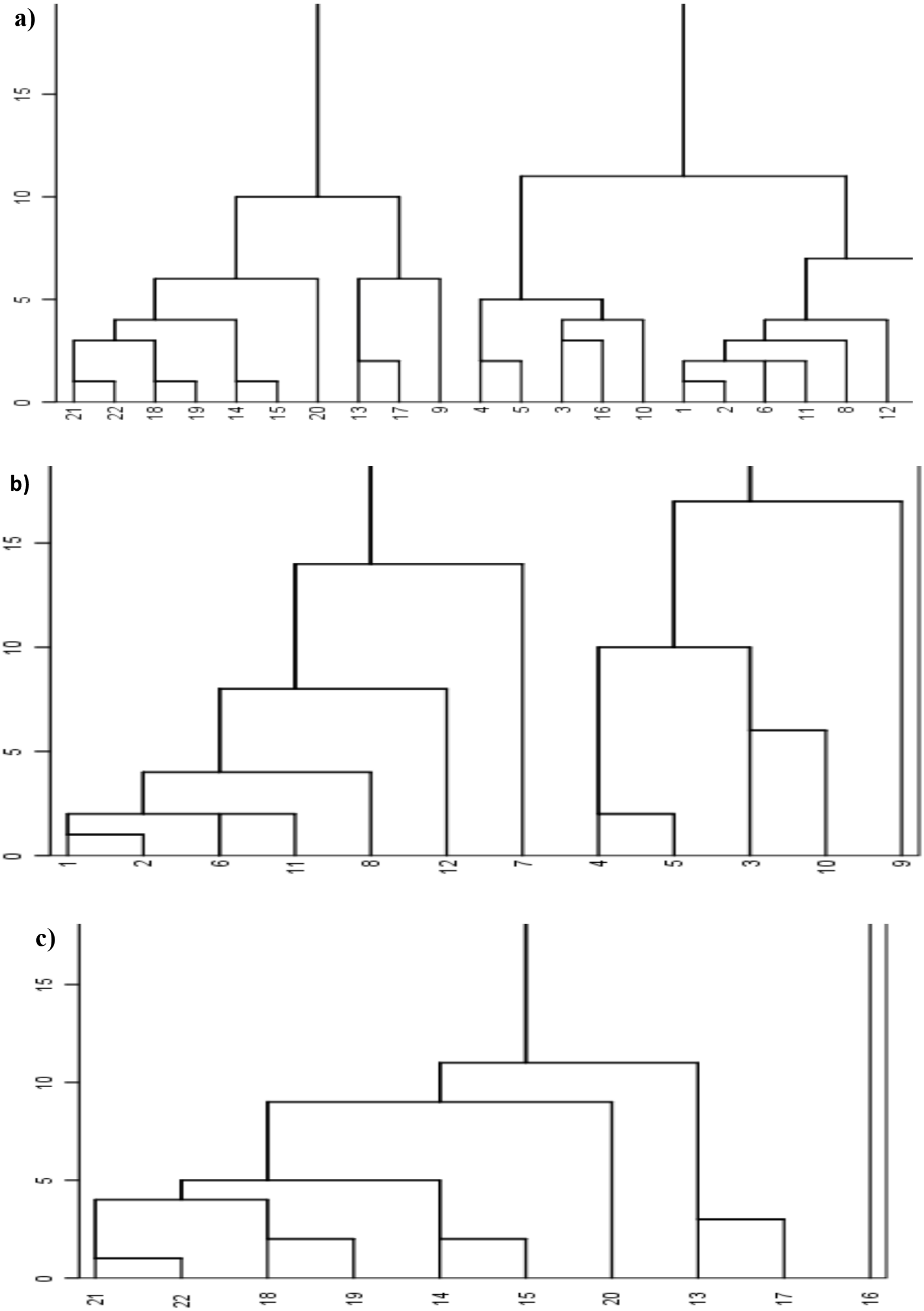

Figure 1. Dendrograms: a) for bread wheat cultivars and einkorn wheat populations together, b) twelve bread wheat cultivars, and c) ten einkorn populations (numbers below dendrograms are wheat entry code numbers from Table 1).

the salt concentration in the soil occurs the lower the plants germinate (Khan et al., 2000). The decreased water intake by osmotic limitations and Na and Cl ion toxicity around the seed under salt stress prevents germination (Shokohhifard et al., 1989; Murillo-Amador et al., 2002; Sabir and Ashraf, 2007; Rahman et al., 2008).

4.1. Differences among germination stages and among and within both bread wheat cultivars and einkorn populations

The most salt affected and, therefore, decreased (%) germination characters (Table 3) were coleoptile length (95.11), shoot length (100.00), root length (100.00), root fresh weight (92.24), and root dry weight (85.94). All wheat entries and salt doses were highly significantly ($P < 0.01$) different for all the most decreased characters (Table 2). This was parallel to the fact that significant differences in bread wheat cultivars existed for many characters including shoot length and root length (Biabani et al., 2013; Mahmoodzadeh et al., 2013).

A highly significant ($P < 0.01$) blocking effect for coleoptile length, shoot length, and root length; a significant ($P < 0.05$) effect for root fresh weight; and a nonsignificant effect for root fresh weight for all cultivars were calculated. The highest coleoptile length, root fresh weight, and root dry weight development were between 0 and 0.15 M, and shoot length between 0 and 0.20 M. Coleoptile length, root fresh weight, and root dry weight started to decrease at 0.20 M (Table 3). A completely randomized block design (RCBD) with a factorial restriction, which we preferred here, was a good choice to differentiate wheat entries and salt doses. RCBD behaved the same as in the study by Biabani et al. (2013) but not as in the one by Abdelkader et al. (2015), in whose studies significant but lower varietal differences were observed. Higher significant differences between salt doses and cultivars for most characters were observed because of effective blocking, which increased the efficiency of the experiment. No cultivar by dose interaction existed in this experiment. However, Biabani et al. (2013) determined significant cultivar by salt interaction for shoot length, dry shoot weight, and germination rate.

Control treatment in the experiment here always gave the highest coleoptile length, shoot length root length, root fresh weight, and root dry weight. Coleoptile length and root fresh weight were still higher between 0 and 0.15 M and root length between 0 and 0.10 M. Decrease in coleoptile length, root fresh weight, and root dry weight clearly started at 0.15 M (Table 3). What that meant was we obtained a good curve for salt doses in the experiment. This was opposite to what Mahmoodzadeh et al. (2013) determined, whose cultivar and doses between 0 and 20 (dsm - 1 NaCl) did differ. Our findings, on the other hand, fit well with what Biabani et al. (2013), Karakullukçu and Adak (2008), and Benlioğlu and Özkan (2015) reported. Biabani et al. (2013) successfully achieved lower but significant salt doses and a good curve for shoot length, root length, shoot fresh and dry weight, root fresh weight, root dry weight, vigor index, mean germination time, and germination rate for the cultivars. Karakullukçu and Adak (2008) determined decreases in fresh and dry weight of chickpea under salt stress as well.

Bread wheat cultivars and einkorn populations differed for all most salt affected germination characters to the greatest extent ($P < 0.05$). Bread wheat cultivars and einkorn populations were in the very same 2 groups in many cases (Table 4), although some individual cultivars or populations behaved differently for some characters. The population structure of einkorn populations did most likely induce uniform germination as modern improved bread wheat cultivars did. While some bread wheat cultivars had the highest values the others had lower values for some characters. That was parallel to what Mahmoodzadeh et al. (2013), Biabani et al. (2013), and Abdelkader et al. (2015) determined under different salt doses. The highest coleoptile length of Gerek 79, Momtchill, Demir 2000, Bayraktar 2000, and Pehlivan bread wheat cultivars might be a good indicator for salt stress as it is for drought stress as well (Farhad et al., 2014).

4.2. Correlation between characters with and without salt stress

Pearson linear correlation coefficients (r; Kalaycı, 2006) reflected linear correlations at different significance levels (Table 6a). The highest correlation coefficients (0.900–1.000) were between root dry weight and root length and root dry weight and root fresh weight. Higher significant relationships of 0.700–0.890 were among coleoptile length and root fresh weight, and coleoptile length and root dry weight. The lowest linear relationships of 0.000–0.250 did not occur among any of the characters. Most germination characters were related to each other as expected. No research that studied correlations among germination characters unfortunately was found.

Coleoptile length, shoot length, root length, root fresh weight, and root dry weight were highly correlated (Table 6b) under salt (0.15 M) conditions but not under control (0 NaCl) conditions. The highest correlation coefficients under salt (0.15 M) stress indicated that the most affected and decreased characters (coleoptile length, shoot length, root length, root fresh weight, and root dry weight) between character pairs under salt stress (Table 6b) were significant ($P > 0.01$). Not all the characters, however, under stress correlated significantly. Only coleoptile length and shoot length (0.70) and root length and root fresh weight (0.66) were significantly correlated ($P < 0.05$. Coleoptile length and root dry weight (–0.36) and shoot length and root fresh weight (–0.35) were negatively but not significantly correlated. Similar results were reported by Askari et al. (2016) and Oyiga et al. (2016).

4.3. Principal component analysis (PCA)

A significant coefficient, which was ≥ 0.3 PC (Hair et al. 1987), was 0.356 for root dry weight, 0.335 for root length, 0.310 for shoot/root length ratio, and 0.309 for root fresh weight, of which these 4 formed PC 1. Root, as seen, was the most important germination character. Shoot length and root fresh dry weight ratio had 0.613 in PC2. Germination rate had 0.779 and germination power had 0.633 PC3. The first three PCs had a total of 90.525%. The highest was PC1 (71.946%), with PC2 the second (11.098%) and PC3 the least (7.481%) (Table 7). PCA successfully revealed the variation and its ratios in the characters as the first three PCs, which were reported to be higher for spike characters of bread, durum, emmer, and einkorn wheat populations (Karagöz and Zencirci, 2005).

4.4. Dendrograms

4.4.1. Overall dendrogram for both bread wheat (*T. aestivum* L.) cultivars and einkorn *Triticum monococcum* L. subsp. *monococcum*) populations

An overall dendrogram based on the averages of 22 wheat genotypes clearly grouped wheat entries separately (Figure 1). In other words, bread wheat cultivars differed from einkorn populations for germination characters, as indicated by salt total tolerance and salt tolerance indices (Zencirci et al., 1990; Askari et al., 2016; Oyiga et al., 2016). Salt susceptible einkorn populations, Population-14, Population-10, Population-9, Population-4, and Population-11, were in one group. The other group had salt tolerant Bayraktar 2000, Gerek 79, İkizce 96, Gün 91, Demir 2000, and Momtchil bread wheat cultivars. This was also parallel with Karagöz and Zencirci (2005), who grouped 8 einkorn populations and 2 durum wheat cultivars, i.e. Kızıltan 91 and Kunduru 1149, in two different groups for spike characters.

4.4.1.1. Bread wheat (*T. aestivum* L.) cultivars

Two subdendrograms for bread wheat cultivars were formed. The first one had 7 cultivars: Kenanbey, Momtchill, İkizce 96, Pandas, Gün 91, Flamura 85, and Gerek 79. The second subgroup consisted of five cultivars: Kiraç 66, Bayraktar 2000, Tosunbey, Demir 2000, and Pehlivan (Figure 1b). Bread wheat cultivars reflected a clear-cut grouping for germination characters under salt stress.

4.4.1.2. Einkorn (*T. monococcum* L. subsp. *monococcum*) populations

Average based dendrograms grouped einkorn populations into two groups except Population-5, which stayed alone. Other populations: Population-14, Population-15, Population-9, Population-10, Population-2, Population-4, and Population-11 were in subsubgroup one and Population-1 and Population-6 in the other subsubgroup. Karagöz and Zencirci (2005) also obtained two separate dendrograms for improved durum wheat cultivars and einkorn spike characteristics.

The salt tolerance mechanisms in modern, hulled, and wild wheats are not well known yet. The wild and cultured relatives of wheat are promising and expected to provide novel genetic resources for salt tolerance. Therefore, their genetic and physiological basis against salt should be investigated. Among those wheats, the hulled wheats are known to be essential resources for either biotic or abiotic factors on these days. These stress factors especially at the beginning of crop development, i.e. germination, shooting etc., create problems, worsen development, and decrease yield in the final stage. Although the salt stress of einkorn seemed low the detailed study here we carried out against salt at the germination stage was considered to be a good choice as it successfully differentiated bread wheat cultivars as tolerant and einkorn populations as susceptible, clarified the characteristics of germination stages, and reflected the commonality in bread wheat cultivars and einkorn populations against salt.

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