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Einkorn Wheat (*Triticum monococcum* ssp. *monococcum*) Tolerates Cold Stress Better than Bread Wheat (*Triticum aestivum* L.) During Germination

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Abstract

Twelve bread wheat (*Triticum aestivum* L.) cultivars and ten einkorn wheat (*Triticum monococcum* ssp. *monococcum* L.) populations were investigated for germination rate (GR-%), germination power (GP-%), coleoptile length (CL-cm), shoot length (SL-cm), root length (RL-cm), shoot/root length ratio (SRLR), root fresh weight (RFW-mg), root dry weight (RDW-mg), and root fresh /dry weight ratio (RFDWR) under seven different cold stress levels in a three replicate randomized complete block design with factorial restriction. Experimental materials, which were utilized in this research, showed significantly different responses under seven cold levels. From them, 20 bread wheat genotypes demonstrated higher significance for GR, RL, and RDW; significance for CL and SL; and non-significance for GP, SRLR, and RFW. Pearson linear correlation coefficients calculated were highly significant between RL-SL, RL-RFW, and RDW-RFW but not between GR-RFDWR, GP-RFDWR, CL-RFDWR, SL-RFDWR, RL-RFDWR, SRLR-RFDWR, RFW-RFDWR, and RDW-RFDWR. Similarly, Spearman correlation coefficients were highly positive between GR-GP, GR-CL, GR-SL, GR-RL, GR-RFW, GR-RDW, GP-CL, GP-SL, GP-RL, GP-RFW, GP-RDW, CL-SL, CL-RL, CL-SLRLR, CL-RFW, CL-RDW, SL-RL, SL-SLRLR, SL-FW, SL-RFDWR, RL-SRLR, RL-RFW, RL-RDW, SRLR-RFW, SRLR-RDW, and SRLR-RFDWR. On the other hand, PCs were not significant for SL (0.156), RL (0.156), and RDW (0.156) in PC 1; significant in PC2 for RFDWR (0.99); and significant in PC3 for GR (-0.342). Cumulative variance of first three PCs was 87.58% and the average dendogram for both bread and einkorn wheat entries produced two main groups. As a result, einkorn wheat populations from higher elevations seemed to provide good genetic resources for cold tolerance during germination stages. It is obvious that these characters easily can be used in any wheat breeding programs against cold stress.

Anahtar Kelimeler: Bread wheat, cold stress, einkorn, germination stages

Siyez Buğdayı (*Triticum monococcum* ssp. *monococcum*) Çimlenme Döneminde Soğuğa Ekmeklik Buğdaydan (*Triticum aestivum* L.) Daha İyi Dayanmaktadır

Öz

On iki ekmeklik buğday çeşidi ve 10 siyez buğday populasyonunun yedi soğuk düzeyindeki çimlenme hızı (ÇH), çimlenme gücü (ÇG), koleoptil uzunluğu (KU), çim boyu (ÇB), kök boyu (KB) çim kök uzunluğu oranı (ÇKUO), kök yaş ağırlığı (KYA), kök kuru ağırlığı (KKA) ve kök yaş kuru ağırlık oranı (KYKAO) üç tekerrürlü faktöriyel düzenlenmiş tesadüf blokları deneme deseninde araştırılmıştır. Bu araştırmadaki çalışma materyali; yedi soğuk düzeyinde önemli farklılıklar göstermiştir. Yirmi ekmeklik buğday genotipi ÇH, KU ve KKA bakımından çok önemli; KB ve ÇB bakımından önemli; ÇG, ÇKBO ve KKA bakımından da önemsiz farklılıklar sergilemişlerdir. Hesaplanan Pearson doğrusal korelasyon katsayıları KU-ÇU, KU-KYA ve KKA-KYA arasında çok önemli iken ÇH-KYKAO, ÇG-KYKAO, KU-KYKAO, ÇU-KYKAO, KU-KYKAO, ÇKUO-KYKAO, KYA-KYKAO ve KKA-KYKAO arasında önemsiz bulunmuşlardır. Benzer şekilde, Spearman korelasyon katsayıları, soğuk stresi altında ÇH-ÇG, ÇH-KU, ÇH-ÇU, ÇH-KU, ÇH-KYA, ÇH-KKA, ÇG-KU, ÇG-ÇU, ÇG-KU, ÇG-KYA, ÇG-KKA, KU-ÇU, KU-KB, KU-ÇKUO, KU-KYA, KU-KKA, ÇU-KB, ÇU-ÇKUO, ÇU-KYA, ÇU-KYKAO, KU-SKUR, KU-KYA, KB-KKA, ÇKUO-KYA, ÇKUO-KKA ve ÇKUO-KYKAO arasında yüksek olumlu ilişki göstermişlerdir. Öte yandan, AB1'deki ÇB (0.156), KB (0.156), KKA ((0.156)'lar önemsiz iken AB2'deki KYKAO (0.99) ile AB3'deki ÇH (-0.342)'lar önemli bulunmuştur. İlk üçte yeralan AB'lerin birikimli

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varyansı %87.58 olmuş ve ortalama temelli öbekağacı siyez ve ekmeklik buğdaylarını iki ana gruba ayırmıştır. Sonuç olarak; yüksek bölgelerden toplanan kavuzlu siyez buğday populasyonlarının çimlenme dönemi soğuklarına karşı uygun gen kaynakları olabilecekleri ve soğuk dayanımı için çalışan buğday ıslah programları tarafından kullanılabileceği düşünülmektedir.

Keywords: Ekmeklik buğday, soğuk stresi, siyez, çimlenme dönemleri

Introduction

Wheat (*Triticum* ssp.) was first cultivated more than ten thousand years ago and, today, it has provided staple food for more than one third of the world's population (Goutam et al. 2013; Rahaie et al. 2013; Shahzad et al. 2013). The 670.8 million tons of annual global wheat production, which are produced by 200 million farmers, end up in various foods: bread, pasta, noodles, cakes, and biscuits (Eren et al. 2015). In short, wheat directly assures human survival and improves life quality in both developed and developing countries, but mostly in developing countries (Shahzad et al. 2013) including Turkey Şehirali et al. 2000; Braun et al. 2001; Kün et al. 2005).

What we harvest, however, is what is left from biotic or abiotic stresses. Among abiotic stresses cold, drought, and salt are the most common and destructive ones. Cold stress, which widely ranges across the world, ruins wheat crop depending upon cold degree, cold duration, plant growth stage, and stress time (Gupta and Sheoran 1983). Plants, on the other hand, develop many adaptive strategies against the cold stress (Gill et al. 2003) and save themselves by different morphological, developmental, physiological, and biochemical response mechanisms (Bohnert et al. 1995).

It needs differing temperatures at different growth stages, depending on its growth type, planting season, and production region to develop well. Temperature in wheat production regions might go as low as -35°C in winter and as high as 45°C in summer. The optimum ones, however, are -10 to -17°C in winter and 30 to 35^{0}C in summer. The higher sensitivity in wheat, among other growth stages, occurs especially in the early growth and germination (Khodabandeh 2003).

Wheat germinates well in higher than 4°C and shoots just afterward. While higher temperatures restrict germination, lower temperatures of 2°C, an optimum of 8 to 10°C, and a maximum 20 to 22°C accelerate the germination (Khodabandeh 2003). Germination and growth are normally controlled by soil temperature before emergence (Hegarty 1973). Root temperature, which is induced by soil temperature affects root growth, root number, and length in barley and turnip (Macduff and Wild 1986). Roots of barley, oats, rye, and wheat stay shorter at low temperatures such as at 5^{0}C (Abbasal-Ani and Hay 1983) while develop faster at higher temperatures (15°25°C). The temperature also affects shoot and root ratio (Davidson 1969). Good seed germination is among the prerequisites for a successful stand establishment and for further crop development.

Consequently, testing, locating, and characterizing better genetic resources against cold stress (Zencirci and Karagöz 2005), as they do in other characters (Koç et al. 2000; Karagöz et al. 2010) as well, could provide cold tolerant wheat germplasm and could expectedly ensure wheat yield. This study, therefore, aimed to investigate the response of 12 bread wheat (*Triticum aestivum* L.) cultivars and 10 einkorn (*T. monococcum* ssp. *monococcum*) wheat populations for the germination rate (GR), the germinating power (GP), the coleoptile length (CL), the shoot length (SL), the root length (RL), the shoot/root length ratio (SRLR), root fresh weight (RFW), the root dry weight (RDW), the root fresh weight/root ratio (RFDWR) under seven cold stress levels.

Material and Method

Plant Material

Gerek-79, İkizce-96, Kıraç-66, Kenanbey, Flamura-85, Momtchill, Bayraktar 2000, Tosunbey, Pandas, Pehlivan, Demir-2000, and Gün-91 bread wheat (*T. aestivum* L.) cultivars and Population-1, Population-2, Population-4, Population-5, Population-6, Population-9, Population-10, Population-11, Population-14, and Population-15 einkorn (*Triticum monococcum* ssp. *monococcum*) wheat populations (Table 1) were tested against cold stress during germination stage. Bread wheat cultivars were kindly provided by the agricultural research institutes in Turkey and einkorn wheat (*Triticum monococcum* ssp. *monococcum*) populations by Quality Feed Company, Bolu.

Table 1. Numbers, experimental materials, and breeding research institutes of 12 bread wheat cultivars and collection sites of 10 einkorn populations

Çizelge 1. On iki ekmeklik buğday çeşidi ve on siyez populasyonunun sıraları, adları ve ıslah eden araştırma enstitüleri / toplama yerleri

Numbers	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	Kastamonu, İhsangazi, Çatalyazı Village
19	Population-10	Kastamonu, İhsangazi, Uzunoğlu District
20	Population-11	Kastamonu, İhsangazi, Çay District
21	Population-14	Kastamonu, İhsangazi, Center
22	Population-15	Kastamonu, İhsangazi, Center

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

[1]CRIFC (TBMAE) : Tarla Bitkileri Merkez Araştırma Enstitüsü, Ankara;
[2]ARI (ATAE) : Anadolu Tarımsal Araştırma Enstitüsü, Eskişehir;
[3]TARI (TTAE) : Trakya Tarımsal Araştırma Enstitüsü, Edirne;
[4]CARI (ÇTAE) : Çukurova Tarımsal Araştırma Enstitüsü, Adana

Cold Stress Tests

The seeds (of 3 X 30 for each entry per treatment) were surface-sterilized in 96% ethanol for 30 seconds and 10% sodium hypochlorite for 15 minute, and rinsed twice in distilled water, then, 30 (10 X 3) seeds were germinated on wet filter paper under 7 levels of cold stress: control (23±1), 2, 0, -2, -4, -6, and -8°C. PH in each petri dishes was adjusted to 5.9 ±1 and germinated 8 days at 23±1°C in a dark growth room. After 4 days GR (%) and after 8 days GP (%), CL (cm), SL (cm), RL (cm),), SRLR, FRW (mg), DRW (mg), RFDWR were measured.

Statistical Analysis

The experiment was set up in a 3 replication, with the factorial restriction, randomized complete block design. Analysis of variance (ANOVA), Fisher's protected test (F), least significant difference (LSD) tests for mean values separation (Gomez and Gomez 1984), Pearson linear correlations among the characters (Kalaycı 2006), cold tolerance indice (Zencirci et al. 1990; El-Hendawy et al. 2005; Mahmoodzadeh et al. 2013), stress susceptibility and tolerance index, mean productivity, and geometric mean productivity (Ali and El-Sadek 2016) were calculated by EXCEL. Principal component analysis (PCA) was performed and dendograms were drawn by SPSS (Zobel et al. 1988).

Results and Discussions

"Cold stress" seriously delay the crop establishment, worsens crop development and totally kills them particularly during the germination stage, and reduces final yield. Understanding the effect of the cold on the crops is a good way to overcome serious cold damages on wheat. Twelve bread wheat (*T. aestivum* L.) cultivars and 10 einkorn wheat (T. *monococcum* ssp. *monococcum*) populations which were, therefore, investigated for that purpose provided the following results.

Differences Among Germination Stages, Among and within Bread Wheat Cultivars and Einkorn Populations

The experiments were analyzed and F values were calculated by the ANOVA test (Table 2). They showed that, there were highly significant (P<0.01) differences between cold levels and cultivars. Blocks were highly significant for the GR, GP, RL, SRLR, RFW (P<0.01), significant for the CL, SL, and RFDWR (P<0.05, and non-significant for the RDW. That meant except for RDW the blocking was effective to differentiate cold levels and wheat cultivars / populations.

Germination characters significantly differed (P<0.01) for seven cold levels (control, 2, 0, -2, -4, -6, and -8ºC). Percent decrease among cold levels including control ranged between 30.09 to 97.85. The highest decreases (%) were in the SL (99.73%), SRLR (97.85%), RDW (95.56%), RFW (94.77%), RL (94.50%), and CL (91.95%). Differences among 12 bread wheat (*Triticum aestivum* L.) cultivars and 10 einkorn (*Triticum monococcum* ssp. *monococcum*) wheat populations were also highly significant for GR, RL, RDW, and 10.60 (P<0.01); significant for CL and SL (P<0.05); non-significant for GP, SRLR, and RFW. There was no cultivar by cold level interaction for any characters investigated.

Differences within the GR, GP, CL, SL, RL, SRLR, FW, RDW, and RFDWR under cold levels (control, 2, 0, -2, -4, -6, and -8°C), as reflected by the F values in ANOVA, arose and were, meantime, revealed by LSD to the most extent. Control always had the highest germination values (Table 3).

Bread wheat cultivars and einkorn wheat populations differed under cold levels, as were perceived by F tests in ANOVA and were discriminated by LSD (Table 4). Percent decrease among the cultivars / populations ranged between 41.09-73.85%. Population-5, Population-1, Population-6, Population-2, Population-4, Population-14, Population-10, Population-11, Population-9, Population-15, and Gerek-79 had the highest GR while İkizce 96 had the lowest (P<0.05). Population-1, Population-5, Population-6, Population-4, Population-10, Population-2, Population-14, Population-9, Population-11, Gerek 79, and Flamura 85 had the highest GP while İkizce 96 and Tosunbey had the lowest (P<0.05). Demir 2000, Population-6, Population-4, Population-1, Population-2, Population-15, Population-5, Gerek 79, Population-11, Population-10, Population-9, and Population-14 had the highest CL while Kıraç 66 had the lowest (P<0.05). Population-4, Population-6, Population-15, Population-2, Population-1, Population-11, Population-5, Population-9, Gerek 79, Population-10, and Population-14 had the highest SL while Kıraç 66 had the lowest SL (P<0.05). Population-6, Population-1, Population-4, Momthcill, Flamura 85, Population-15, Population-2, Population-11, and Population-9 had the highest RL while Kıraç 66 (P<0.05). Momthcill, Population-6, Pandas, Population-9, Population-11, Population-1, Gerek 79, and Population-15, İkizce 96, and Bayraktar 2000 had the highest SRLR while Kıraç 66 and Gün 91 had the lowest (P<0.05). Population-6, Momtchill, Flamura 85, Gerek 79, Populasyon-1, Populasyon-5, Populasyon-4, Populasyon-15, and Populasyon-2 had the highest RDW while Kıraç 66 had the lowest (P<0.05). Population-6, Population-4, Population-5, Population-1, and Population-11 had the highest RDW while Population-15 had the lowest (P<0.05). Kıraç 66 had the highest RFDWR while Demir 2000, Tosunbey, Population-4, Gün 91, Bayraktar 2000, Population-1, Kenanbey, and Population-14 had the lowest (P<0.05). As seen, mostly einkorn populations had obtained the highest values for germination characters.

Mahmoodabad et al. (2011) showed that the lowest germination values at 2°C, differences existed among the cultivars, Gaspard, Sardari, Cascogen, Bezostaja 1, and MV17. They had the highest germination rate, and there was no significant difference in stem (shoot) length. The highest shoot length was at 5°C, the lowest stem length was at 2°C, and the lowest root length was at 2°C. No significant differences for root length existed among cultivars. Sardari had the longest coleoptile while Gaspard, Bezostaya 1 and Cascogen had the lowest, and followed by MV 17.

The lowest temperature was 2°C and the optimum one ranged between 2-5°C for the characters studied by these authors. Bezostaja 1 developed all characters the best at lower temperatures and was followed by Sardari.

Table 2. F values for studied characters of GR, GP, CL, SL, RL, SRLR, RFW, RDW, and RFDWR under the cold stress: control, 2, 0, -2, -4, -6, -8 ^{0}C

Çizelge 2. Çalışılan ÇH, ÇG, KU, ÇU, RU, ÇKUO, KYA, KKA ve KYKAO karakterlerinin kontrol, 2, 0, -2, -4, -6 ve -8 ^{0}C 'lerdeki soğuk stresi altındaki F değerleri

Sources of variation	DF	GR†	GP	CL	SL	RL	SRLR	RFW	RDW	RFDWR
Blocks	2	3.14**	1.18**	12.88*	12.88*	4.19**	0.30**	427.10**	3.02^{ns}	18.51*
Treatments	153	21.85**	17.42**	92.16**	92.16**	24.69**	3.01**	2086.59**	17.34**	40.37**
Cultivars	21	14.99**	6.82^{ns}	28.89*	28.89*	7.16**	2.13^{ns}	507.25^{ns}	5.47**	10.60**
Cold levels	6	104.26**	107.35**	602.09*	602.09*	159.68**	9.22**	13863.95**	219.16**	26.63**
Cultivar *Cold levels	126	1.45^{ns}	1.02^{ns}	3.76^{ns}	3.76^{ns}	1.20^{ns}	0.38^{ns}	107.69^{ns}	1.91^{ns}	13.30^{ns}
Error	306	0.75	0.35	1.52	1.52	0.65	0.26	59.26	0.47	22.82*

† GR: Germination rate, GP: Germination Power, CL: Coleoptile Length, SL: Shoot Length, RL: Root Length, SRLR: Shoot-Root Length Ratio, RFW: Root Fresh Weight, RDW: Root Dry Weight, RFDWR: Root Fresh-Dry Weight Ratio

† GR (ÇH): çimlenme hızı, GP (ÇG): çimlenme gücü, CL (KU): koleoptil uzunluğu, SL (ÇB): çim boyu, RL (KB): kök boyu, SRLR (ÇKBO): çim kök boy oranı, RFW (KYA): kök yaş ağırlığı, RDW (KKA): kök kuru ağırlığı ve RFDWR (KYKAO): kök yaş kuru ağırlık oranı

**, Significant at the 0.01, **; 0.05 significant at 0.05 probability level, ns no significant;*

***, P<0.01 düzeyinde önemli, * P<0.05 düzeyinde önemli, ns önemli değil*

Jones (1986), Cook (1997), and Foolad and Lin (1999) reported that significant differences occurred among cultivars during germination and early seedling. Chilling temperatures in the cultivated plants ranged between 0-12°C during germination, which significantly delayed the onset, reduced the rate, and increased the dispersion of seed germination events (Jones 1986; Foolad and Lin 1997; Foolad and Lin 1998).

Poor seed germination resulted in uneven stand establishment and poor crop performance (Foolad and Lin 1997). The presence of environmental stresses, such as cold, restricted the establishment of direct-seeded crops. Most commercial cultivars of some crops were highly sensitive to cold stress during seed germination while genetic variation, however, existed within the cultivated plants and their related wild species (Jones 1986; Maas 1986; Foolad and Lin 1997; Foolad and Lin 1998).

Wheat, a wide range grown crop, is considered to have the broadest adaptation among all cereal crop species (Briggle and Curtis 1987). Cold tolerance (Braun et al. 1998) in wheat, in a general sense, refers to the performance at the temperatures lower than the ones optimum for growth (about 20ºC). Of course, there are definitely differences in the growth rate of cultivars at low temperatures and, consequently, in their adaptations to cool climate. However, the term "cold tolerance" is most frequently used to describe a plant's response to freezing temperatures, lower than -4ºC, which have more dramatic effects on the crop.

Cold Tolerance Indices

Cold tolerance indice, is an indice which is based on the ranks of cultivars / populations together with other (El-Hendawy et al. 2005; Mahmoodzadeh et al. 2013; Ali and El-Sadek 2016). Indices, therefor, were calculated to group wheat entries. Cold tolerance indice, as reported by Zencirci et al. (1990), Askari et al. (2016) and Oyiga et al. (2016) grouped the entries as tolerant, moderate, and susceptible. (Table 5). As seen from the Table 5, Population-6, Population-1, Population-4, Population-2, Population-5, and İkizce 96 were tolerant; Bayraktar 2000, Tosunbey, Kıraç 66, İkizce 96, Pehlivan, and Demir 2000 were susceptible. Stress susceptibility index, stress tolerance index, mean productivity and geometric mean productivity, which were compared by Ali and El-Sadak (2016) did not went along with drought tolerance indice.

Correlation Among Germination Characters under Salt Stress

Pearson linear correlation coefficients (r; Kalaycı 2006) between GR, GP, CL, SL, RL, SRLR, FW, RDW, and RFDWR under cold stress levels of control, 2, 0, -2, -4, -6 and -8°C were significant at different significance levels (Table 5). Those highly significant linear relationships, of which their r ranged between 0.900-1.000, existed among RL-SL, RL-RFW, and RDW-RFW.

TTable 3. Differences among GR. GP. CL. SL. RL. SRLR. FW. RDW and RFDWR under cold stress: control, 2, 0, -2, -4, -6, and -8 °C

Çizelge 3. Kontrol, 2, 0, -2, -4, -6 ve -8 °C soğuk stresleri altında ÇH, ÇG, KU, ÇU, RU, ÇKUO, KYA, KKA ve KYKAO arasındaki farklılıklar

Cold levels	GR†	GP	CL	SL	RL	SRLR	RFW	RDW	RFDWR
Control	99.20a	100.00a	3.73a	14.94a	8.36a	1.86a	77.46a	9.23a	12.03a
2	83.20ab	89.70ab	3.19ab	9.72b	5.55ab	1.82ab	52.72ab	6.95ab	11.13ab
0	72.10a-c	94.80a-c	2.61a-c	8.04bc	4.86a-c	1.74a-c	45.31a-c	4.49a-c	10.64a-c
-2	71.80a-d	83.00a-d	2.14a-d	6.59cd	4.45a-d	1.72a-d	40.67a-d	3.88a-d	10.60a-d
-4	63.50a-e	74.11a-e	1.62b-e	3.03e	2.38b-e	1.56a-e	22.03b-e	2.11b-e	10.40a-e
-6	52.90b-f	61.70a-f	1.32b-f	1.31ef	1.53b-f	1.23a-f	13.68b-f	1.34c-e	10.11a-f
-8	31.20e-g	36.50e-g	0.31c-g	0.04fg	0.46c-g	0.04g	4.05c-g	0.41c-g	8.41f-g
% Decrease	68.55	63.50	91.95	99.73	94.50	97.85	94.77	95.56	30.09

Table 4. Differences among 12 wheat (Triticum aestivum L.) cultivars and 10 einkorn wheat populations under cold stress: control, 2, 0, -2, -4, -6, and -8 °C

Çizelge 4. On iki ekmeklik buğday çeşidi ve 10 siyez buğday populasyonunun soğuk stresi (Kontrol, 2, 0, -2, -4, -6 ve -8 °C) altındaki farklılıkları

Cultivars/ Populations	GR†	GP	CL	SL	RL	SRLR	RFW	RDW	RFDWR
Gerek 79	68.10a-i	79.00a-j	2.32a-i	6.69a-k	4.78a-g	1.76a-e	46.56a-d	4.18b-l	10.64b-e
İkizce 96	46.70i-t	60.70j-v	1.35j-s	4.02g-s	2.71j-t	1.38c-g	26.97i-t	2.70m-u	10.64b-f
Kıraç 66	54.30f-o	71.40e-p	1.22l-u	2.96h-v	2.25l-u	0.66g-s	23.48k-v	2.41m-v	15.28a
Kenanbey	58.10e-n	76.20d-m	1.66h-n	5.14d-n	3.23g-p	0.89f-n	32.78e-m	3.37e-n	10.07c-p
Flamura 85	63.80d-j	77.90a-k	1.86e-m	5.35d-m	4.99a-e	0.85f-p	48.33a-c	4.58a-f	10.72b-e
Momtchill	61.40d-l	74.30d-o	1.96e-l	7.22a-i	5.00a-d	2.52a	49.40ab	4.35b-i	12.03b
Bayraktar 2000	48.60h-r	63.80g-t	1.37i-r	3.48g-u	2.72j-t	1.09e-k	25.98j-u	3.11g-t	9.88c-r
Tosunbey	49.50g-q	62.60j-u	1.29l-u	4.01g-t	3.10i-q	0.84f-q	28.55h-q	3.20g-r	9.26c-u
Pandas	62.40d-k	75.20d-n	1.60h-o	5.08d-o	3.40f-m	2.19a-b	31.95f-o	3.26f-p	10.55b-g
Pehlivan	48.60h-s	64.80g-s	1.57h-q	4.25g-r	2.90j-r	1,21c-j	27.07i-s	3.35e-o	10.46b-h
Demir 2000	53.30f-p	65.50g-r	3.07a	4.26g-q	2.84j-s	1.01e-m	27.41i-r	3.23f-q	9.00c-v
Gün 91	59.50d-m	70.50f-q	1.58h-p	4.46f-p	3.54d-l	0.67g-r	33.17e-l	3.66c-m	9.77c-s
Population-1	88.10ab	92.90a	2.91a-d	8.20a-e	5.28a-b	1.66b-f	45.03a-e	4.88a-d	9.99c-q
Population-2	87.10a-c	83.80a-f	2.80a-e	8.25a-d	4.50a-i	1.37c-h	39.17a-i	4.30b-j	10.87bc
Population-4	82.40a-c	88.60a-d	2.94a-c	9.47a	5.17a-c	1.48c-f	44.18a-h	5.07ab	9.67c-t
Population-5	90.50a	92.90ab	2.65a-g	7.67a-g	4.94a-f	1,20c-j	44.66a-f	4.94a-c	10.15b-n
Population-6	87.60ab	91.40a-c	2.98ab	9.33a-b	5.62a	2.49ab	50.77a	5.79a	10.28b-k
Population-9	71.40a-g	80.20a-h	2.26a-k	7.42a-h	4.08a-k	1.96a-c	36.35b-k	4.30b-k	10.30b-j
Population-10	80.00a-e	86.20a-e	2.28a-j	6.50a-k	3.40f-n	1,32c-i	31.38g-p	4.36b-h	10.19b-m
Population-11	75.70a-g	79.50a-i	2.31a-l	8.08a-f	4.14a-j	1.95a-d	37.69a-j	4.70a-e	10.32b-j
Population-14	81.40a-d	82.90a-g	2.24a-k	6.35a-l	3.38g-p	1.08e-l	32.18e-n	4.38b-g	10.10c-o
Population-15	71.00a-h	76.40c-l	2.66a-f	9.07a-c	4.73a-h	1.76a-f	41.27a-h	0.64y	10.26b-l
Decrease % B. Wheat	31.42	20.75	60.26	51.80	55.00	73.41	47.40	47.37	41.09
Decrease % Population	21.54	17.76	24.83	32.95	39.50	56,62	38.19	88.94	11.03
Decrease %	48.40	34.66	57.98	63.25	59.96	73.85	48.83	88.95	41.09

† GR:Germination rate, GP:Germination Power, CL:Coleoptile Length, SL:Shoot Length, RL:Root Length, SRLR:Shoot-Root Length Ratio, RFW: Root Fresh Weight, RDW: Root Dry Weight, RFDWR: Root Fresh-Dry Weight Ratio *, Significant at the 0.01, **; 0.05 significant at 0.05 probability level, ns no

*† GR (ÇH): çimlenme hızı, GP (ÇG); çimlenme gücü, CL (KU):koleoptil uzunluğu, SL (ÇB): çim boyu, RL (KB): kök boyu, SRLR (ÇKBO): çim kök boy oranı, RFW (KYA): kök yaş ağırlığı, RDW (KKA): kök kuru ağırlığı ve RFDWR (KYKAO): kök yaş kuru ağırlık oranı significant; **, P<0.01 düzeyinde önemli, * P<0.05 düzeyinde önemli ns önemli değil*

Table 5. Indices for overall cold evaluation of wheat entries from different germination characters which grouped entries into tolerant, moderate, and susceptible

Çizelge 5. Tolerant, orta ve duyarlı olarak gruplandırılan buğdaylarda değişik çimlenme özelliklerinden elde edilen değerlerin genel soğuk değerlendirme indisleri

Cultivar / Populations	Drought tolerance indice	Stress Susceptibility Index	Stress Tolerance Index	Mean productivity	Geometric mean productivity
TOLERANT					
Population-6	2.89	0.12	0.97	17.14	9.83
Population-1	5.44	0.12	0.97	16.33	9.83
Population-4	6.11	0.13	0.97	14.64	9.50
Population-2	6.56	0.24	0.93	14.49	9.66
Population-5	6.56	0.12	0.97	17.60	9.83
Momtchill	7.56	0.73	0.80	19.93	8.94
MODERATE					
Population-11	7.78	-0.02	0.83	14.75	9.13
Gerek-79	8.22	0.85	0.77	17.75	8.76
Population-9	9.33	0.73	0.80	14.44	8.94
Population-15	9.56	0.49	0.87	14.89	9.31
Flamura-85	9.78	1.83	0.50	18.70	7.07
Population-10	10.78	0.73	0.80	14.14	8.94
Population-14	11.44	0.88	0.76	15.93	8.42
Pandas	12.44	0.98	0.73	13.71	8.56
Kenanbey	15.33	1.59	0.57	15.73	7.53
Gün-91	15.56	0.85	0.77	16.14	8.76
SUSCEPTIPLE					
Demir	16.33	0.76	0.79	14.59	8.61
Pehlivan	16.78	2.40	0.34	17.76	5.68
İkizce	17.78	2.32	0.37	17.24	6.06
Kıraç-66	18.44	2.07	0.43	14.33	6.58
Tosunbey	19.11	1.46	0.60	17.30	7.75
Bayraktar 2000	19.22	2.02	0.45	15.32	6.47

Under cold stress, Spearman correlation coefficients were highly positive among the GR-GP, GR-CL, GR-SL, GR-RL, GR-RFW, GR-RDW, GP-CL, GP-SL, GP-RL, GP-RFW, GP-RDW, CL-SL, CL-RL, CL-SLRLR, CL-RFW, CL-RDW, SL-RL, SL-SLRLR, SL-FW, SL-RFDWR, RL-SRLR, RL-RFW, RL-RDW, SRLR-RFW, SRLR-RDW, and SRLR-RFDWR. Without cold stress, Spearman correlation coefficients were mostly not correlated among characters except the CL-SL (0.77), Cl-SRLR (0.62), SL-RL (0.80), RL-RFW (0.94), and SL-RDW (0.87), ($P<0.01$), and RFW-RDW (0.45), RFW-RFDWR (0.45), and RL-RFDWR (0.52), ($P<0.05$).

Those higher Pearson and Spearman relationships consisting of root characters might indicate the importance of these root characters against cold stress during germination. Those linear significant relationships, of which their r ranged between 0.700-0.890, occurred among GR-SL and GP-RL. Those lower linear relationships, of which their r happened to be between 0.260-0.490 existed among GR-CL, GP-CL, and CL-SRLR. No linear relationships, of which their r was between 0.000-0.250, did exist among the GR-RFDWR, GP-RFDWR, CL-RFDWR, SL-RFDWR, RL-RFDWR, SRLR-RFDWR, RFW-RFDWR, and RDW-RFDWR. That higher number of no relationship among many characters may reflect the difficulties in cold tolerance studies germination characters.

Saeidi et al. (2012) determined that the correlation coefficients between grain yield under normal and post-anthesis water stress for crown viability under freezing stress (temperatures below zero) were to be negative. Coefficients between grain yield in post-anthesis water stress with crown viability under freezing stress at -3 and -5°C, were higher, r = 0.86 and r = 0.64, respectively. Lower yielding cultivars, particularly at post-anthesis water stress were more resistant to prevailing of freezing stress at early growing season after winter, which suggested that higher yielding cultivars for post-anthesis water stress also had to be more resistant to freezing stress at early growing season.

Table 6. A. Pearson correlation coefficients among the GR, GP, CL, SL, RL, SRLR, FW, RDW, and RFDWR under cold stress B. Spearman correlation coefficients among the GR, GP, CL, SL, RL, SRLR, FW, RDW, and RFDWR under cold and control (no-cold)

Çizelge 6. A.Soğuk stresi (Kontrol, 2, 0, -2, -4, -6 ve -8 °C) altında ÇH, ÇG, KU, ÇU, RU, ÇKUO, KYA, KKA ve KYKAO arasındaki Pearson korelasyon katsayıları; B. Soğuk stresi ve soğuk stressiz koşullarda (ÇH, ÇG, KU, ÇU, RU, ÇKUO, KYA, KKA ve KYKAO arasındaki Pearson korelasyon katsayıları

Characters	GR†	GP	CL	SL	RL	SRLR	RFW	RDW
RFDWR	0.08	0.09	0.02	0.05	0.08	0.03	0.07	0.03
RDW	0.78	0.79	0.56	0.98	0.98	0.68	0.99	-
RFW	0.77	0.77	0.55	0.99	0.99	0.67	-	
SRLR	0.54	0.58	0.39	0.67	0.67	-		
RL	0.78	0.78	0.60	1.00	-			
SL	0.78	0.78	0.60	-				
CL	0.49	0.49	-					
GP	0.91							

B. Spearman correlation coefficients

Characters	GR†	GP	CL	SL	RL	SRLR	RFW	RDW
UNDER COLD								
RFDWR	0,05††	-0,05	0,05	0,98	0,38	0,47	0,40	0,31
RDW	0,73	0,74	0,88	0,05	0,98	0,54	0,40	
RFW	0,72	0,71	0,85	0,88	0,98	0,58		
SRLR	0,42	0,38	0,55	0,85	0,56	-		
RL	0,76	0,75	0,88	0,05				
SL	0,83	0,81	1,00					
CL	0,83	0,81						
GP	0,90	-						
Characters CONTROL (NO COLD)	GR†	GP	CL	SL	RL	SRLR	RFW	RDW
RFDWR	0,35††	0,03	0,09	0,94	0,52	0,31	0,45	0,19
RDW	0,00	0,20	0,14	0,39	0,87	0,00	0,45	
RFW	0,11	0,18	0,16	0,13	0,94	0,09	-	
SRLR	0,13	-0,17	0,62	0,23	0,19	-		
RL	0,03	0,18	0,32	0,80	-			
SL	0,16	-0,11	0,77	-				
CL	-0,19	-0,19	-					
GP	-0,12	-						

† † GR: Germination rate, GP: Germination Power, CL: Coleoptile Length, SL: Shoot Length; RL: Root Length, SRLR: Shoot-Root Length Ratio, RFW: Root Fresh Weight, RDW: Root Dry Weight, RFDWR: Root Fresh-Dry Weight Ratio.

† † Significance at 0.01 is 0.549 and at 0.05 is 4.33.

† GR (ÇH): çimlenme hızı, GP (ÇG); çimlenme gücü, CL (KU):koleoptil uzunluğu, SL (ÇB): çim boyu, RL (KB): kök boyu, SRLR (ÇKBO): çim kök boy oranı, RFW (KYA): kök yaş ağırlığı, RDW (KKA): kök kuru ağırlığı ve RFDWR (KYKAO): kök yaş kuru ağırlık oranı

*, Significant at the 0.01, **; 0.05 significant at 0.05 probability level, ns no significant;

***, P<0.01 düzeyinde önemli, * P<0.05 düzeyinde önemli, ns önemli değil*

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

Çizelge 7. Çimlenme karakterleri için ik üç AB katsayıları, her bir karakterdeki varyasyonlar ve açıklanan toplam varyasyon değeri

Characters	Principal component			Sums of squared	
	1	2	3	% of variance	Cumulative (%)
SL	0.156	-0.028	-0.100	69.24	69.24
SRLR	0.118	-0.049	-0.342	11.15	80.39
CL	0.101	-0.053	10.174	7.18	87.58
GP	0.140	0.065	-0.062		
GR	0.139	0.060	-0.046		
RL	0.156	-0.028	-0.100		
RDW	0.156	-0.044	-0.100		
RFW	0.155	-0.009	-0.112		
RFDWR	0.011	0.990	0.042		

† GR: Germination rate, GP:Germination Power, CL:Coleoptile Length, SL:Shoot Length; RL:Root Length; SRLR: Shoot Root Length Ratio, RFW: Root Fresh Weight, RDW: Root Dry Weight, RFDWR: Root Fresh-Dry Weight Ratio.

† † GR (ÇH): çimlenme hızı, GP (ÇG); çimlenme gücü, CL (KU):koleoptil uzunluğu, SL (ÇB): çim boyu, RL (KB): kök boyu, SRLR (ÇKBO): çim kök boy oranı, RFW (KYA): kök yaş ağırlığı, RDW (KKA): kök kuru ağırlığı ve RFDWR (KYKAO):kök yaş kuru ağırlık oranı

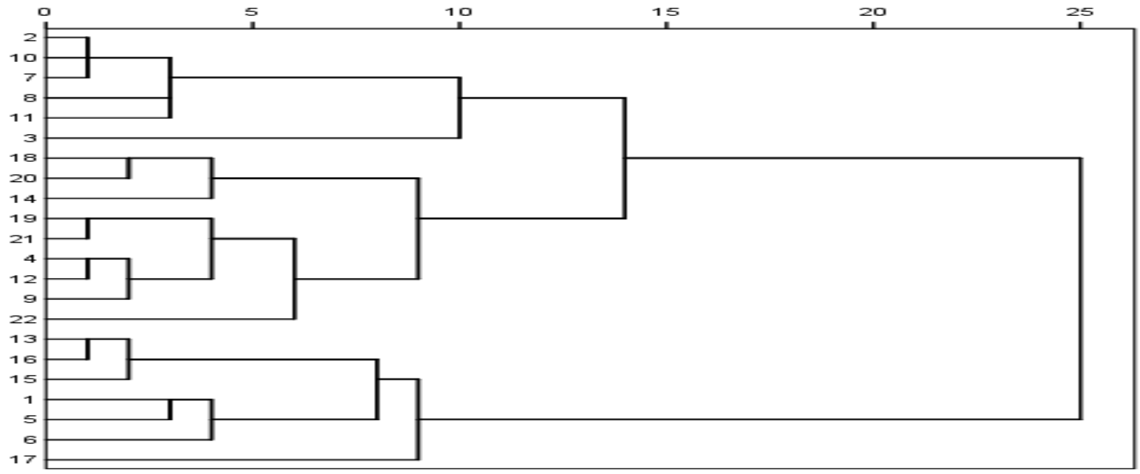

Figure 1. Dendogram for both 12 bread wheat cultivars and 10 einkorn wheat populations
Şekil 1. On iki ekmeklik buğday çeşidi ve on siyez populasyonunun öbekağacı

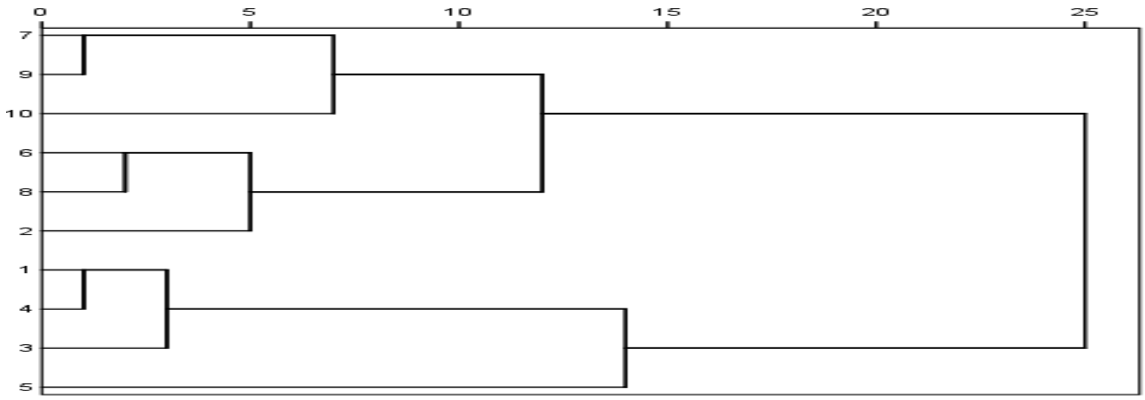

Figure 2. Dendogram for 12 wheat cultivars
Şekil 2. On iki buğday çeşidinin öbekağacı

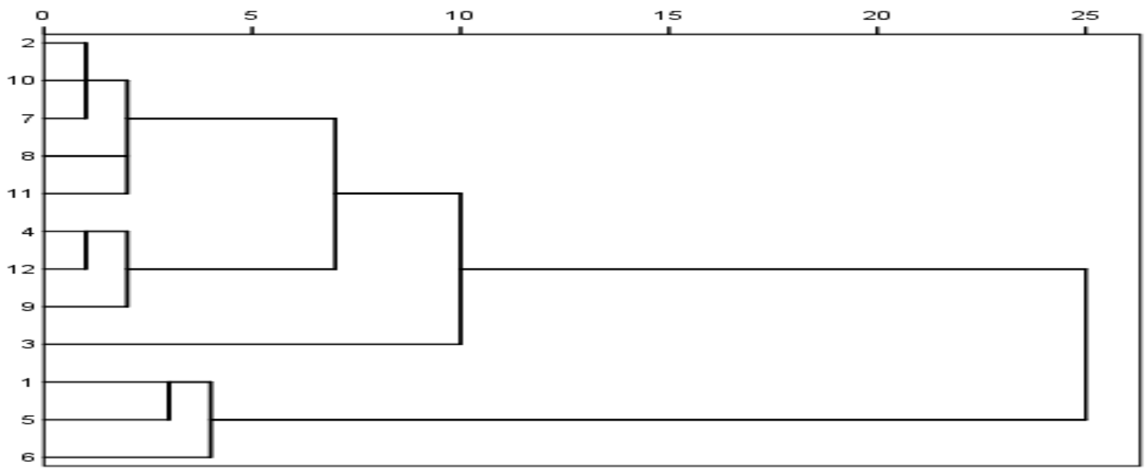

Figure 3. Dendogram for 10 einkorn wheat populations
Şekil 3. On siyez populasyonunun öbekağacı

Dendograms

Overall dendogram for bread wheat cultivars and einkorn populations

An overall dendogram based on averages of 22 entries resulted in two main groups (Figure 1). The first main group had 3 sub-groups while the second main group contained two subgroups. The first sub group in the first main group confined to only bread wheat cultivars of İkizce 96, Pehlivan, Bayraktar 2000, Momtchil, and Demir 2000. The second subgroup in the first group contained only hulled einkorns of Population-9, Population-11, and Population-2 while the third sub group consisted of Population-10, Population-14, Kenanbey, Gün 91, Pandas, and Population-15. The second main group also had two subgroups. The first sub group in the second main group contained Population-1, Population-6, and Population-4 while the second sub group consisted of Gerek 79, Flamura 85, and Momtchil. Population-9 stayed alone under the main group 2. No dendogram of the germination characters in wheat has been drawn in previous studies, therefore, we, unfortunately, failed to compare our results with any previous studies.

Conclusion

Wheat, which is a well known stable crop around the World, faces serious cold damages since it is grown in various regions of the many countries. Pre-discovered genetic resources enlargened the acreage of wheat in upper latitudes and under severe cold stress conditions. Newer genetic resources, although some might have existed in wheat landraces, need to be explored in cultured wild wheats as well as in wild relatives, too. Hulled Einkorn wheat seems a possible germination stage cold hardiness source, where wheat, like other crops, is so sensitive to cold stress. These newly determined einkorn wheat populations in this study are expected to provide new cold stress genetic resources during germination stage damages.

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