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Effects of different priming applications on seed germination and some agromorphological characteristics of bread wheat (*Triticum aestivum* L.)

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Abstract: This study was conducted to determine the effects of some priming treatments on seed germination properties, grain yield, and several agromorphological characteristics of bread wheat. Two commonly grown bread wheat varieties, namely Adana-99 and Pandas, were selected for experimentation conducted during the 2007–08 and 2008–09 growing periods. The seeds of the Adana-99 and Pandas wheat varieties were primed with the following: (1) distilled water, (2) 100 ppm indole-3-acetic acid (IAA), (3) 2.5% potassium chloride (KCl), (4) 1% potassium dihydrogen phosphate (KH₂PO₄), (5) 10% polyethylene glycol (PEG-6000), or (6) gibberellic acid (GA₃, used only for field experiments). Nonprimed seeds were used as the control group. First 1000 mL of priming media was prepared for each priming treatment, and seeds of both varieties were rinsed in the solution for 12 h at room temperature. Germination percentage at two different temperatures (10 °C and 20 °C), coleoptile length, seedling emergence percentage, and seedling growth rate were evaluated under laboratory conditions. Primed seeds of both varieties were sown on two different dates under field conditions to evaluate certain agromorphological characteristics. PEG, IAA, and distilled water treatments increased seed germination percentage, seedling emergence percentage, and seedling growth rate. PEG, KCl, and hydropriming treatments increased grain yield compared to the control. Among the different priming agents used in the study, PEG, KCl, and hydropriming were the most effective treatments to attain higher germination percentage and grain yield.

Key words: Bread wheat, seed germination, grain yield, priming

1. Introduction

Turkey ranks among the top ten producers of wheat in the world with an annual production of 22 million tons (Yücel et al., 2011; FAO, 2014). In Turkey, wheat production nearly doubled from 9 million tons to approximately 17.5 million tons between 1971 and 1982 (Yediay et al., 2011). This impressive increase may be attributed to an increasing wheat production area and yield over the last four decades (Yücel et al. 2009); alternatively, it might have resulted primarily from the use of water-conserving cultural practices on the Anatolian plateau (Curtis, 1982; Dalrymple, 1986). In Turkey, wheat is typically rotated with other field crops such as sugar beet + wheat and maize + wheat. Farmers often face unsuitable seedbed conditions from plant and straw residuals, especially due

to the late harvest of precrops and conditions of heavy rain. Under these adverse seedbed conditions, some seed priming applications may provide certain advantages such as higher germination rate and stand establishment. Good germination and stand establishment are maximizing factors in crop production, and their importance is well recognized by farmers and researchers (Dell-Aquila and Tritto, 1990; Chivas et al., 1998; Farooq et al., 2008; Yari et al., 2011).

Seed priming is increasingly considered a better approach to enhancing rapid and uniform emergence and to achieving high seedling vigor and better yields in vegetables, floriculture, and some field crops (Dearman et al., 1987; Parera and Cantliffe, 1994; Bruggink et al., 1999). In addition to better establishment, farmers have reported

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that primed crops grew more vigorously, flowered earlier, and gave higher yields (Farooq et al., 2008; Lemrasky and Hosseini, 2012). Methods of seed priming have been described in detail by Bradford (1986) and Khan (1992). Common priming techniques include osmopriming (soaking seeds in osmotic solutions such as polyethylene glycol), halopriming (soaking seeds in salt solutions), hydropriming (soaking seeds in water), matripriming (placing seeds between saturated jute mat layers), and hardening (alternate soaking of seeds in tap water and drying before sowing) (McDonald, 2000; Basra et al., 2003; Ghassemi-Golezani et al., 2008b).

Over the last 2–3 decades, several researchers have employed various presowing seed treatments in order to determine its effects on seed germination, seedling emergence, important agronomic traits, yield, and yield components in many crops (Farooq et al., 2008; Yari et al., 2011; Jafar et al., 2012). One of the major constraints to the commercial application of presowing treatments is the variability among cultivars (and even among the seed lots of the same cultivar), concentration, and duration of the presowing treatment (Brown et al., 1987; Giri and Schillinger, 2003; Iqbal et al., 2006; Kaya et al., 2006; Arif et al., 2007). Ghobadi et al. (2012) reported a significant improvement in germination and early growth of bread wheat following hormonal priming treatment and osmopriming as compared with the control. CaCl_2 and KCl applications ($\Psi_s = -1.25$ MPa) in rice positively affected germination, seedling growth, grain yield, and quality (Farooq et al., 2006). Maximum fertile tillers, grain per spike, 1000-grain weight, grain yield, harvest index, and salinity tolerance were observed in plants raised from seeds osmoprimed (with CaCl_2) followed by ascorbate priming in wheat (Jafar et al., 2012). Kinetin application (150 mg L^{-1}) to the bread wheat seeds increased plant growth potential and grain yield (Iqbal and Ashraf, 2005). Ghassemi-Golezani et al. (2008a) concluded that hydropriming is a simple, low cost, and environmentally friendly technique for improving seed germination and seedling vigor of lentils. Kaya et al. (2006) reported that hydropriming increased germination and seedling growth under salt and drought stresses. Lemrasky and Hosseini (2012) indicated that the maximum seed germination percentage was observed when seed primed by PEG 10% for 45 h and greatest stem and radicle length were obtained after seed priming with 2% KCl and 4% KCl for 45 h. Iqbal and Ashraf (2013) have also reported that GA_3 priming-induced increase in grain yield was attributed to the GA_3 priming-induced modulation of ions uptake, partitioning, and hormone homeostasis under saline conditions. The objective of the present study was to investigate and validate the effects of different priming techniques on the seed germination properties, seedling growth, and

several agromorphological plant traits in bread wheat. In addition, we also aimed to elucidate the compensatory effect of priming applications at late sowing.

2. Materials and methods

2.1. Seed materials

The seeds of two bread wheat cultivars, Adana-99 and Pandas, were used as research materials in this study. Newly harvested seeds of both wheat varieties were obtained from the East Mediterranean Agricultural Research Institute, Adana.

2.2. Seed priming treatments

For sterilization of fungal agents, the seeds of wheat cultivars were surface-sterilized with 2% sodium hypochloride for 10 min followed by washing with distilled water, and were then air dried (Basra et al., 2003). The six priming media were used as described below: distilled water, IAA (100 ppm), KCl (2.5%), KH_2PO_4 (1%), PEG-6000 (10%), and GA_3 (100 ppm; used only for field experiments). These priming media were selected due to their positive effect on germination, emergence, seedling growth, and grain yield in wheat according to previous investigations (Michel and Koufmann, 1973; Misra and Dwivedi, 1980; Dell-Aquila and Taranto, 1986; Das and Choudhury, 1996; Giri and Schillinger, 2003). Unprimed seeds were used as the control. One liter of priming media was prepared for each priming application, and 250 g of seeds of both varieties were rinsed in the solution for 12 h (Dell-Aquila and Tritto, 1990) at room temperature in dark conditions. After the priming application, seeds were washed with distilled water, dried on paper towels at room temperature, and ventilated until they regained their original moisture content (Giri and Schillinger, 2003).

2.3. Germination analysis

Germination experiments were conducted in temperature-controlled germinators at 10 °C and 20 °C according to standard protocols established by the International Seed Testing Association (ISTA). For each experiment, 25 seeds were germinated in 9 cm-diameter petri dishes with three replicates. Filter papers in each petri dish were moistened twice with 10 mL of distilled water during the experiment. Each germination experiment was arranged according to a completely randomized factorial design (Farooq et al., 2006). Radicle protrusion of 5 mm was scored as germination. Germinated seeds were recorded daily until day 8 of the experiment, and germination percentage (GP) was evaluated according to the following equation described by Ashraf and Ebu-Shakra (1978):

$$\text{GP (germination percentage)} = (\text{total germinated seeds after 8 days} / \text{total number of seeds}) \times 100$$

2.4. Seedling emergence test

The seedling emergence test was conducted in plant growth chambers under controlled light, temperature, and

humidity conditions with completely randomized factorial design with three replicates and two factors. Twenty seeds were sown in plastic pots with dimensions of 20 × 10 × 15 cm, consisting of sand sieved through 0.8 mm mesh. Growth chamber conditions were set at 60% humidity, 13-h light exposure, and 20 °C temperature. Seedling emergence was measured by counting individual seedlings at 8 and 16 days after planting, and results from 16 days were used to calculate the seedling emergence percentage (Farooq et al., 2006). Seedling growth rate was computed by recording the height of 10 seedlings in each plastic pot once a week after the start of emergence (Giri and Schillinger, 2003; Hunt, 2003)

Parameters were evaluated under laboratory conditions, including germination rate at two different temperatures (10 °C and 20 °C) and coleoptile length (cm) in an incubator, seedling emergence percentage (%), and seedling growth rate (mm day⁻¹) in a growth chamber.

2.5. Field experiment

Field experiments were conducted for 2 years. However, during the first year there was severe bird damage at the seedling emergence stage. Thus, field experiments conducted in the second year were used for further evaluations. Primed seeds of both varieties were sown on two different dates at the research and experimental area of the Vocational School of Kozan, Çukurova University, Adana, Turkey. Each plot consisted of 5 rows of 1 m each. The row spacing was determined at 20 cm, and 450 seeds were planted per square meter (90 seeds per row). The first sowing was carried out on 17 November 2008 (timely sowing) under dry soil conditions, and plots were irrigated to obtain homogeneity for seedling establishment. The second sowings (late sowings) were carried out on 14 January 2009 under moisture soil conditions. Homogeneity of seedling establishment was confirmed for both sowings. In the second year, experimental plants

were protected with string bags to prevent damage from environmental factors such as birds. All cultural practices, such as fertilization and weed control, were performed according to standard local agricultural practices. All plots were protected by a string bag at the plant maturity stage to prevent bird damage. Three middle rows were harvested to measure grain yield, and 10 randomly selected plants were evaluated for agromorphological characteristics.

3. Results

3.1. Laboratory experiments

Analysis of variance (ANOVA) showed a significant effect of seed priming treatment on seedling growth rate; however, germination percentages (%) at 10 °C and 20 °C, coleoptile length (cm), and seedling emergence percentage (%) were not significantly affected by seed priming treatment (Table 1). Germination percentage (%) at 20 °C was partially higher in seeds primed with distilled water, IAA, and KCl, when compared with the 10 °C condition for both wheat varieties (Table 2). The highest germination percentage (%) was observed with the PEG treatment in both varieties at both germination temperatures of 10 °C and 20 °C. In the case of cultivar Adana-99, the highest germination percentage was obtained by the IAA treatment at 10 °C germination temperature. Coleoptile length (cm) was higher in KCl application for Pandas and PEG application for Adana-99. Average seedling emergence was higher in Adana-99 compared to the Pandas cultivar. KCl, KH₂PO₄, and PEG treatments partially increased seedling emergence (%) compared to the control in the case of Adana-99. However, it was lower than the control in the case of Pandas. The highest seedling growth rate (mm day⁻¹) was observed with the hydropriming treatment for both Pandas and Adana-99. Mean seedling growth rate was significantly higher for Adana-99 compared to Pandas.

Table 1. Analysis of variance for seed priming effects on germination properties in laboratory experiments.

Mean square						
Source	DF	Germination percentage at 10°C (%)	Germination percentage at 20°C (%)	Coleoptile length (cm)	Seedling emergence (%)	Seedling growth rate (mm day ⁻¹)
Cultivar (C)	1	34.02	34.02*	0.001	156.2*	43.78**
Priming (P)	5	10.69	2.36	0.121	29.0	20.18**
C × P	5	10.69	2.36	0.024	31.2	8.33
Error	24	9.72	5.55	0.055	27.7	4.47
CV (%)		3.20	2.38	6.39	5.54	37.62

*: statistically significant at 0.05 level, **: statistically significant at 0.01 level.

Table 2. Effect of different priming media on seed germination properties of wheat.

Priming treatment	Germination percentage at 10 °C (%)	Germination percentage at 20 °C (%)	Coleoptile length (cm)	Seedling emergence (%)	Seedling growth rate (mm day ⁻¹)
Pandas					
Control	96.7	96.7	3.65	98.3	4.57 bcd*
Distilled Water	95.0	98.3	3.72	88.3	10.23 a
IAA	95.0	98.3	3.37	98.3	3.67 cd
KCl	93.3	98.3	3.83	90.0	2.37 d
KH ₂ PO ₄	98.3	96.7	3.81	91.7	3.23 cd
PEG	100.0	100.0	3.74	91.7	3.07 cd
Mean	96.4	98.1 b**	3.69	93.1 b	4.52 b
Adana-99					
Control	98.3	100.0	3.75	96.7	7.70 ab
Distilled Water	96.7	100.0	3.65	95.0	8.03 ab
IAA	100.0	100.0	3.45	96.7	6.10 bc
KCl	98.3	100.0	3.77	98.3	7.20 ab
KH ₂ PO ₄	98.3	100.0	3.60	98.3	5.33 bcd
PEG	98.3	100.0	3.85	98.3	6.00 bc
Mean	98.3	100.0 a	3.68	97.2 a	6.73 a

*: Different letters indicate significant difference between priming treatments at 0.05 level.

** : Different letters indicate significant difference between mean values of wheat varieties at 0.05 level.

3.2. Field experiments

Combined analysis of variance for seed priming treatment (Table 3) showed that sowing time had significant effects on the number of stems per square meter, number of spikes per square meter, plant height (cm), heading date (day), spike length (cm), number of grains per spike, grain yield per spike (g), and grain yield per hectare. The cultivar had significant effects on the number of tillers per plant, plant height, heading date, grain yield per spike, and grain yield per hectare, while priming treatment had a significant effect on spike length and grain yield. The sowing date-cultivar interaction had a significant effect on the number of plants per square meter and the heading date (Table 3).

On the basis of the ANOVA results (data not shown), there were significant differences between the cultivars in terms of number of plants per square meter, number of tillers per plant, plant height, heading date, and grain yield for both timely and late sowing (Table 4). The mean number of stems per square meter, number of spikes per square meter, plant height, heading date, spike length, number of grains per spike, grain yield per spike, and grain yield of both varieties were significantly affected by the

different sowing times (Table 4). Although the number of plants per square meter for timely sowing and grain yield per spike for late sowing was higher in Pandas than in the other cultivar, cultivar Pandas showed a higher number of tillers per plant and heading date for both timely and late sowings (Table 4). The Adana-99 cultivar exhibited higher plant height and grain yield compared to Pandas for both timely and late sowing (Table 4). The comparison of means indicated that all the plant characteristics, except for the number of plant per square meter, number of stems per square meter, and number of tillers per plant, were higher at timely sowing than late sowing (Table 4).

The effect of different priming applications on both bread wheat cultivars for several agronomic characteristics in both timely- and late-sown cropping conditions is described in Table 5. The maximum number of plants per square meter and the higher number of stems per square meter were observed in Pandas by PEG treatment in both timely and late sowing conditions. The highest plant and stem numbers per square meter were observed with PEG treatment in late sowings in Adana-99. The lowest number of spikes per square meter was obtained

Table 3. Combined analysis of variance for seed priming treatment for some agro-morphological plant characteristics, yield-related components, and grain yield of wheat.

Source	DF	Number of plants per square meter	Number of stems per square meter	Number of spikes per square meter	Number of tillers per plant	Plant height (cm)	Heading date (days)	Spike length (cm)	Number of grains per spike	Grain yield per spike (g)	Grain yield (kg ha ⁻¹)
Replication	3	3402.65*	18,812.44*	8967.31	0.07	30.96*	7.06*	3.52**	8.08	0.146**	16,134.27**
Sowing date (SD)	1	1014.00	31,624.32*	355,275.57**	0.17	9642.29**	31,022.28**	11.97**	89.82*	1.039**	1,317,233.70**
Cultivar (C)	1	35.43	7393.75	522.89	0.69**	5022.32**	440.03**	0.20	10.50	0.265**	30,195.71**
Priming treatment (PT)	6	2335.11	8381.84	5554.51	0.13	8.28	2.22	0.44*	28.91	0.042	14,940.05**
SD × C	1	13,007.58**	141.75	5628.89	0.00	31.29	228.57**	0.38	15.08	0.341	2335.08
C × PT	6	518.62	4692.68	1497.33	0.11	7.39	1.26	0.27	22.87	0.043	4125.75
SD × PT	6	2441.36	9599.25	1568.38	0.06	2.49	1.68	0.19	14.20	0.014	2764.35
C × SD × PT	6	2272.85	3735.39	6437.99	0.02	5.06	2.75	0.09	11.23	0.010	23,534.45
Error	81	99,547.79	7273.03	4658.27	0.08	9.82	2.42	0.17	16.03	0.038	4022.15
CV (%)		9.94	14.44	13.19	17.34	3.50	1.36	4.79	11.87	13.39	13.00

*; Statistically significant at 0.05 level, **; Statistically significant at 0.01 level.

Table 4. Mean comparison of wheat varieties for several plant characters on timely and late sowing.

Cultivars	Number of plants per square meter		Number of stems per square meter		Number of spikes per square meter		Number of tillers per plant		Plant height (cm)		Heading date (day)		Spike length (cm)		Number of grains per spike		Grain yield per spike (g)		Grain yield (kg ha ⁻¹)	
	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS
Pandas	360 a*	344 b	583	614	583	456	1.73 a	1.80 a	92.7 b	73 b	134.2 a	98.1 a	9.21	8.45	33.9	32.9	1.54	1.46 a	5750 b	3680 b
Adana-99	339 b	367 a	564	600	564	466	1.56 b	1.65 b	105.0 a	88 a	127.4 b	97.0 b	9.01	8.48	35.3	32.8	1.55	1.25 b	6170 a	3910 a
Mean	350	356	573 b	607 a	573 a	461 b	1.64	1.72	98 a	80 b	130.8 a	97.5 b	9.11 a	8.46 b	34.6 a	32.8 b	1.55 a	1.36 b	5960 a	3800 b

TS: timely sowing, LS : late sowing.

*; Different letters indicate significant difference at 0.05 level.

in control applications for timely sowing. However, it was lowest in the GA₃ application in late sowings for both cultivars. Compared to the control plants and other priming applications, PEG application partially increased the number of spikes in Pandas for timely sowings and in Adana-99 cultivar for late sowings. Number of tillers, plant height, and heading dates were not significantly affected by seed priming (Table 5). The highest spike length for timely sowings was observed with distilled water application in Pandas and with PEG application in Adana-99. The number of grains per spike and grain yield per spike were not affected by the different osmopriming applications. The highest grain yield was observed in Pandas under timely sowing conditions and in Adana-99 under late sowing conditions by using PEG application. The results also depicted that IAA and KCl application caused a partial increase in grain yield at timely sowing in Adana-99 and late sowing in Pandas, respectively.

4. Discussion

This study revealed that PEG and IAA treatments caused partial increases in the germination percentage compared to the control (with the exception of the germination percentage in Adana-99 at 20 °C). PEG application provided a slight advantage to the germination percentage in cultivar Pandas. The priming media affected the germination percentage of the wheat varieties in different ways. Germination tests showed that Adana-99 has a higher germination percentage than Pandas. The different response of the varieties to different priming media was previously reported by Giri and Schillinger (2003). Several osmotica, such as PEG, have been shown to have positive effects on germination capability (Dell-Aquila and Taranto, 1986; Lemrasky and Husseini, 2012). The positive effect of PEG application on increased germination percentage might be explained by an increase in the activity of key enzymes, such as amylase and proteases (Dell-Aquila and Tritto, 1990), which play an important role in the growth and development of the seed embryo. Indeed, these results are in agreement with Yari et al. (2010), who reported that seeds soaked in PEG-6000 had better germination performance, possibly due to low osmotic potential of the solution or to long priming duration. Lemrasky and Hosseini (2012) reported that the maximum seed germination percentage was obtained when the seed was primed with 10% PEG for 45 h, and the rate of germination was improved when the seed was soaked in water and 10% PEG. Dell-Aquila et al. (1984) indicated a relationship between the pattern of water absorption, the reactivation of mitotic activity, and the start and synchronization of germination upon the correct application of osmopriming treatment. In addition, it

has been reported that PEG application activates several compounds that promote germination (Jie et al., 2002). These results are in accordance with the findings of Yari et al. (2010), who observed maximum seedling growth rate for both wheat cultivars in seeds treated with distilled water.

When taken together, the results show that hydropriming treatment was comparatively superior in seedling growth rate among all priming applications. These findings are in agreement with previous reports (Ahmadi et al., 2007; Ghassemi-Golezaniki et al., 2008a). Several researchers reported the positive effect of hydropriming on seedling emergence rate, seedling establishment, early vigor, and the faster development of the seedling (Kibite and Harker, 1991). Priming with PEG-6000 resulted in the highest number of plants per square meter at late sowing in both wheat varieties. Thus, seed priming with PEG appears to have promoted stand establishment at late sowing under field conditions.

Spike length is an important component of grain yield and was found to be higher in Pandas seeds primed with distilled water and Adana-99 seeds primed with PEG at timely sowing. Jafar et al. (2012) concluded that maximum spike length was observed from osmopriming and hydropriming treatments in bread wheat. Thus, our results were in agreement with these previous results. There are reports that hydration of seeds that equals, but does not exceed, the lag phase of priming permits early DNA replication, increased RNA and protein synthesis, greater ATP availability, faster embryo growth, repair of deteriorated seed parts (Karssen et al., 1989; Saha et al., 1990), and reduced leakage of metabolites (Styer and Cantliffe, 1983) than checks (Giri and Schillinger, 2003).

For both varieties and sowing times, PEG, IAA, and distilled water seed priming applications increased grain yield. This may be a result of seed priming causing biochemical changes in the structure of the seeds, such as activation of enzymes related to germination and stand establishment. Jafar et al. (2012) reported that osmopriming seeds (with CaCl₂) followed by ascorbate priming treatments also enhanced protease and α-amylase activities, which in turn helped to improve carbohydrate metabolism, leading to better assimilate translocation. All these factors might explain the higher grain yield in treatment compared to control conditions. However, Giri and Schillinger (2003) reported that none of the wheat seed priming media benefited field emergence or subsequent grain yield in any of the cultivars compared to the controls.

In summation, among the different priming agents used in the study, PEG priming on bread wheat seeds was the most effective application for promoting seed germination, stand establishment, and grain yield under

Table 5. Effect of different priming media on several agronomic plant characters of wheat.

Priming media	Number of plants per square meter		Number of stems per square meter		Number of spikes per square meter		Number of tillers per plant		Plant height (cm)		Heading date (day)		Spike length (cm)		Number of grains per spike		Grain yield per spike (g)		Grain yield (kg ha ⁻¹)		
	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	TS	LS	
Control	350	359 abc*	585	675	491	442	1.66	1.88	92.0	73.3	134	99.0	9.48 abc	8.61	33.9	33.6	1.501	1.331	5890 abcd	3090 d	
Distilled Water	366	325 c	587	637	545	451	1.88	2.00	94.9	73.6	135	98.2	9.61 a	8.90	38.0	36.5	1.621	1.567	5670 cd	3560 cd	
IAA	392	349 abc	553	567	501	447	1.63	1.63	91.8	73.0	135	98.2	8.74 cd	8.15	33.4	28.7	1.468	1.405	5740 bcd	4020 abc	
GA ₃	340	338 bc	550	562	500	427	1.64	1.67	92.5	72.3	136	98.0	9.09 abcd	8.38	28.9	31.9	1.445	1.437	5780 bcd	3250 d	
KCl	342	349 abc	551	602	495	494	1.58	1.72	91.4	74.0	134	97.2	9.05 abcd	8.26	35.7	32.5	1.646	1.665	5660 cd	4200 ab	
KH ₂ PO ₄	335	329 c	621	573	496	461	1.95	1.79	93.4	74.2	134	98.0	9.26 abcd	8.40	35.7	33.0	1.578	1.462	5250 de	3830 abc	
PEG	395	363 abc	632	684	559	472	1.74	1.89	92.9	71.8	133	98.0	9.26 abcd	8.38	31.9	34.0	1.538	1.355	6290 abcd	3790 bc	
Adana-99																					
Control	327	394 ab	513	631	474	462	1.31	1.61	103.7	86.8	128	96.5	9.02 abcd	8.49	36.0	32.0	1.591	1.244	4420 e	3890 abc	
Distilled Water	360	331 c	560	602	492	470	1.70	1.84	104.5	86.9	128	97.5	8.98 abcd	8.50	36.0	32.4	1.627	1.278	6090 abcd	4100 ab	
IAA	345	379 abc	575	547	517	481	1.51	1.46	107.2	88.8	127	97.2	8.84 bcd	8.45	37.9	33.5	1.641	1.261	7090 a	3810 abc	
GA ₃	345	340 bc	532	617	480	442	1.57	1.81	103.7	87.6	128	96.7	8.68 d	8.43	32.5	32.7	1.420	1.245	5880 abcd	394 abc	
KCl	354	343 bc	627	572	559	443	1.82	1.67	106.4	88.5	127	97.5	8.73 d	8.62	34.5	33.1	1.554	1.220	6980 ab	3790 bc	
KH ₂ PO ₄	324	379 abc	598	582	552	452	1.58	1.55	106.8	87.5	127	97.7	9.25 abcd	8.43	35.1	35.2	1.464	1.257	6650 abc	3540 cd	
PEG	321	404 a	546	650	493	513	1.41	1.61	103.4	86.7	128	96.0	9.58 ab	8.39	35.0	30.4	1.590	1.265	6110 abcd	4320 a	

TS: timely sowing, LS: late sowing.
 *: Different letters indicate significant difference at 0.05 level.

unfavorable sowing conditions such as late sowing. Seedling growth rate was also enhanced by priming seeds with water. Thus, PEG and hydropriming treatments are simple, cheap, and effective methods to improve seed germination and seedling growth in field conditions. In conclusion, although some priming treatments appear to have practical value, further work is needed to ascertain

and verify the most appropriate priming method in wheat under unfavorable conditions.

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