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ORIGINAL RESEARCH ARTICLE

The influence of priming methods, planting dates, and weed interference levels on the vegetative growth, yield, and yield components of AS71 hybrid corn

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ABSTRACT

By carrying out a laboratory experiment, the influence of priming methods, including $ZnSO_4$, BSN, and hydropriming was evaluated on the seed germination of hybrid AS71 corn. Then, the main and interaction effects of the priming methods, planting dates, and weed interference levels were surveyed on the vegetative growth traits, yield, and yield components of corn in a field experiment. Based on the lab experiment, although the maximum germination percentage (100%) was observed in the treated plots by hydropriming 22 h after treatment (HAT), the greatest seedling vigor index (122.99) was recorded with treated seeds by $ZnSO_4$ (0.03 mg L^{-1}) at 8 HAT. The greatest emergence index was observed in the treated plots by hydropriming on both planting dates of June 1 and 11. The interaction of planting dates and weed interference levels revealed that the highest emergence index (14%–17%) occurred in the weed-free plots on both planting dates. BSN recorded the greatest corn 1000-grain weight that was significantly higher than the control plots by 28%. Furthermore, BSN enhanced the corn grain yield compared with the control plots by 63% and 24.9% on the planting dates of June 1 and 11, respectively. BSN, as a nutri-priming approach, by displaying the highest positive effects in boosting the corn grain yield in both weedy and weed-free plots as well as both planting dates, could be a recommendable option for growers to improve the crop yield production.

Keywords: emergence index; germination percentage; weed biomass; weed density

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1. Introduction

The world population is growing steadily to reach 8.5 billion by 2025[1]. On the other hand, cereals are one of the most important crops worldwide providing approximately 70% of human food necessities[2]. Also, weed infestation is one of the most important biotic troubles in agricultural production systems[3–7]. The reduction in crop yield production could happen depending on the species and abundance of weed populations[8]. In the absence of proper control practices, weed populations can suppress vegetative and reproductive crop growth aspects[9]. Therefore, a set of appropriate weed control approaches is one of the most important components of crop management systems[10–12]. Nowadays, the environmental consequences of herbicide utilization have led many researchers to change common weed control methods so that non-chemical control strategies have been in demand[13,14]. Grass control in the early stages of corn growth is very important to give natural superiority to corn plants in ameliorating their vegetative growth stages.

In this regard, the use of management factors to reduce the abundance of weed species plays a vital role in reducing their destructive effects[15].

Seed priming is a physiological method that improves seed efficiency for rapid and coordinated germination[16]. Accordingly, primed plants are expected to grow vigorously in competition with weed populations because of their earlier growth compared with the weed populations[17]. Hydropriming is a simple low-cost technique that improves seedling emergence[18]. However, nutri-priming as a new method positively influences the seed priming and consequently uptaking nutrients by the seeds[19]. Primed seeds can germinate earlier and more uniformly after being placed in the soil bed[19]. Delaying in sowing caused the shortening of the growing season, sensitization of the pollination period, and a severe decrease in seed yield production by 32.31% of control[20]. The basis of the increase in dry biomass at the early planting date is that weed populations have access to usable resources, but recording the reduction in late planting is the result of more weed suppression by the crop[21].

One of the most commonly used methods in the processing of seed production is broad-spectrum nutrient seed priming (BSN)[22]. The central part of this approach is to imbibe crop seed in a mixture of mineral materials, for example, phosphorus, manganese, zinc, copper, and molybdenum[22]. Priming wheat and bean seeds using $ZnSO_4$ solution improved root growth, water absorption, nutrient uptake efficiency, and ultimately total dry weight[23]. Zinc deficiency is prevalent in the early plant growth stages[24]. The deficiency of this element postpones the seedling growth and causes susceptibility to dry periods[24]. Thus, to lessen and eliminate this limitation during the priming process, this element has been used in many crops, including chickpeas, wheat, corn, and rice[24]. Priming of wheat seeds with 2% $ZnSO_4$ solution increased the percentage of seed germination by 24.6%[16]. Priming seems to have a significant capability to improve pollination substantially[25]. Priming improved the corn seed establishment, plant vegetative growth, flowering, and yield production[26]. Hydropriming and priming with $ZnSO_4$ as well as urea on three planting dates increased the germination percentage of single cross 206 corn[27]. Priming 704 silage corn using polyethylene glycol-8000 (8% by weight) increased the ratio of dry weight of cob to total biomass[28]. In addition, a considerable number of studies have been done to evaluate the influence of weed interference levels on the vegetative and reproductive traits of various crop species[29–32]. The palmer amaranth (*Amaranthus palmeri*) interference decreased dry edible bean yield production by 77% at a weed density of 2 plants m^{-2} compared with the weed-free control plot[33]. It was revealed that the weed-free treatment increased the corn 100-grain yield compared with the weedy treatment up to 18.2% in a drip irrigation system[34].

In general, this study aimed to compare the influences of different priming methods, including BSN, $ZnSO_4$, and hydropriming on the germination of hybrid AS71 corn seed in a laboratory study. Moreover, by conducting a field study, the main and interaction effects of the mentioned priming approaches, planting dates, and weed interference levels were investigated on some vegetative growth traits, yield, and yield components of hybrid AS71 corn.

2. Materials and methods

2.1. Laboratory experiment

To select the best concentration and duration of priming using two micronutrients, including $ZnSO_4$ and BSN fertilizer, and also assessing the best time for hydropriming, a three-factor factorial experiment was performed in a completely randomized design with four replications. First, the seeds were surface sterilized with 3% hypochlorite for 2 min and washed thoroughly with tap water to remove the disinfectant residue. Treatments included priming methods using $ZnSO_4$ (for 4, 8, 12, 16, and 20 h and three concentrations, including 0.01, 0.03, and 0.05 mg L^{-1}), BSN (fertilizer for 24, 36, 48, 60, and 72 h along with three concentrations, including 2, 4 and, 6 mg L^{-1}), hydropriming (for 10, 14, 18, 22, and 26 h), and additionally, control plots (without priming). Before priming, corn seeds were disinfected using a solution of sodium hypochlorite 3% for 2 min[35]. Corn seeds were placed in $ZnSO_4$ solution at the desired concentrations[36]. Since the primed seeds with BSN cannot be stored for a long time, sowing was done immediately after priming. Primed seeds (25 seeds) were planted into 10 cm diameter Petri dishes and transferred to an incubator at 25 °C[37]. Germination was considered when the emerged radicle was at least 2 mm long. The experiments were completed in each Petri dish when no further germination was observed for three consecutive days. Germinated seeds were counted twice a day. Moreover, at the end of the experiment, the root and shoot lengths were measured. Then, to measure the dry weight, the samples were placed in an oven at 75 °C for 48 h. Germination percentage (GP) was calculated using Equation (1)[38]:

$$GP = 100(N'/N) \tag{1}$$

where N' means the number of germinated seeds and N is the total number of seeds. The seedling vigor index was measured by using the formula of SVI (Seedling vigor index) = standard germination percentage × average seedling dry weight (g)/100[39].

2.2. Field experiment

A study was conducted at the Research Farm (52°35' E, 29°43' N, altitude 1810 m a.s.l) of the School of Agriculture, Shiraz University, Shiraz, Fars in 2016. Some soil characteristics and meteorological data of the Research Farm during the 2016 growing season were shown in **Tables 1** and **2**, respectively. Field operations, including plowing using a reversible plow plus two vertical discs (conventional tillage) and fertilizer application (150 kg ha^{-1} of urea + 100 kg ha^{-1} of triple superphosphate + 50 kg ha^{-1} of potash sulfate) were carried out completely. It is worth mentioning that the mentioned quantity of fertilizer was used as the pre-planting application, and 50 kg ha^{-1} of urea was used at the 8-leaf stage. Each plot measured 5 m × 4.5 m. The distance between the center of row beds was set at 55 cm and the distance between two seeds on each row bed was 15 cm. To eliminate the marginal effect, the first and last rows in each plot, as well as 0.5 m from both sides of each row were not planted. The corn density was 70,000 seeds ha^{-1}, which were planted on June 1 and 11, 2016. The experiment was directed using a split factorial based randomized complete block design with 4 replications. Before performing the priming, corn seeds were disinfected with 3% sodium hypochlorite solution for 2 min[35]. According to the results of the lab study, the most effective treatments, in terms of concentration and time duration, of all three priming techniques were applied in the field study.

The dominant weed species included redroot pigweed (*Amaranthus retroflexus* L.), barnyard grasses (*Echinochloa crus galli* L.), common lambs quarters (*Chenopodium album* L.), field bindweed (*Covulvulus*

Table 1. Some soil characteristics at the experimental site.

Soil pattern	Acidity (pH)	Electrical conductivity (dS m^{-1})	Nitrogen %	Phosphorus (mg kg^{-1} soil)	Potassium (mg kg^{-1} soil)	Organic matter %	Sand %	Silt %	Clay %
Sandy clay silt	7.75	1.3	0.01	7.2	550.7	1.7	1.5	64	34.5

Table 2. Meteorological data of the experimental site during the 2017 growing season.

	Temperatures (°C)			Relative humidity (%)			Sunny h
Month	Maximum	Minimum	Average	Maximum	Minimum	Average	
May	34.35	10.70	22.53	43.33	8.97	26.15	11.85
June	34.69	15.57	25.13	37.41	12.32	24.78	10.77
July	34.91	15.06	24.99	39.70	15.25	27.48	10.68
August	32.16	9.75	20.95	45.22	11.35	28.29	10.50
September	27.80	5.10	17.00	50.00	13.00	31.00	9.90

arvensis L.), and duckweed (*Portulaca oleracea* L.). The total weed density and total weed dry weight were calculated based on the mentioned predominant weed species in the experimental plots. The total weed density was reported as weed numbers per square meter (Plants m^{-2}). To evaluate the dry biomass, the samples were placed in an oven at 75 °C for 48 h and reported as g per square meter (g m^{-2}). To eliminate weed populations in weed-free plots, hand weeding was done weekly.

Phenological data were collected from the planting date to the physiological maturity stage by monitoring changes in plant phenology for each plot. The recording of these stages was accomplished according to the prevalent method of dividing the development of corn plants into two general vegetative and reproductive growth cycles. Moreover, according to Edalat and Naderi[40], to record each phenological stage; approximately 50% of plants in each plot must be at that given stage. It was assumed that the vegetative stage started from the emergence and continued until the emergence of the tassel, and besides, the reproductive stage started from cresting and ended until maturity. The date of the ear physiological maturity was recorded for 50% of the plants in each plot and was reported based on the growing degree days (GDD). Also, according to Maguire[41], the final emergence index was calculated by using Equation (2).

$$\text{Final Emergence Index (FEI)} = \sum(n/d) \tag{2}$$

n: Number of seeds germinated in d days

d: Number of days

To determine the trend of changes in plant height and leaf area index (LAI), 5 plants were randomly selected during the growing season based on GDD of 1481.75, 1258.9, 971.25, 816.05 and 676.1[42]. The leaf area of the samples was measured using the Delta-T Device Leaf Area Meter. At the end of the growing season, two middle lines of each plot were harvested to measure several traits, such as the number of grain rows per ear, 1000-seed weight (g), and grain yield (kg ha^{-1}).

2.3. Data analysis

One-way analysis of variance (ANOVA) was performed using SAS *v*. 9.1 software (SAS Institute 2003). Data normality was checked for normality by plotting QQ [quantile-quantile] plots in GraphPad Prism 8 (GraphPad Software, San Diego, CA, USA). Also, Barlett's test was used to verify the homogeneity of the variances. Fisher's protected least significant difference (LSD) test was used to separate means at the 5% level of probability.

3. Results and discussion

3.1. Laboratory experiment

3.1.1. Germination percentage

Hydropriming increased the germination percentage compared with the control plots so that with increasing the duration of priming and increasing water absorption to 22 h, it reached out to the maximum level (100%), which was significantly 25% higher than the control plots (**Table 3**). Also, the highest seedling vigor index by 14.15 was recorded at 22 HAT, which was statistically different compared with the recorded levels of seedling vigor index at 10 HAT (8.05), 26 HAT (7.84), and control plot (8.33) (**Table 3**). It was reported that the maximum germination percentage of 704 single cross hybrid corn was observed after hydropriming treatment by 86.67% at 26 HAT with 25% increase compared to the control plots[43].

By using $ZnSO_4$ as a priming approach, in concentration levels of 0.05 mg L^{-1}, the highest germination percentage was observed at both 4 and 8 HAT by 94.66%, recording an increase of approximately 18% to that of the control plot (**Table 4**). Besides, the germination percentage decreased after the application of $ZnSO_4$

Table 3. The influence of hydropriming on the corn germination percentage and seedling vigor index.

Treatment	Time (h)	Germination (%)	Seedling vigor index
Hydropriming	10	88.00ab*	8.05b
	14	90.66ab	11.72a
	18	96.00a	12.76a
	22	100.00a	14.15a
	26	88.00ab	7.84b
	Control	80.00b	8.33b

*Means within columns followed by the different letter are significantly different at $P \leq 0.05$ using LSD's test.

Table 4. The influence of $ZnSO_4$ on the corn germination percentage and seedling vigor index.

Treatment	Concentration (mg L^{-1})	Time (h)	Germination (%)	Seedling vigor index
$ZnSO_4$	0.01	4	92.00 ab*	117.83abc
		8	85.33ab	105.73bcde
		12	77.33abc	88.94efg
		16	77.33abc	83.21fg
		20	85.33abc	62.07h
	0.03	4	92.66ab	130.39a
		8	92.00ab	122.99ab
		12	77.33abc	93.64def
		16	77.33abc	71.04gh
		20	81.33abc	55.41hi
	0.05	4	94.66a	111.22bed
		8	94.66a	101.05cef
		12	74.66bc	56.26hi
		16	74.00bc	37.79i
		20	74.00abc	42.52i
Control			80.00abc	55.24i

*Means within columns followed by the different letter are significantly different at $P \leq 0.05$ using LSD's test.

Table 5. The influence of BSN on the *corn* germination percentage and seedling vigor index.

Treatment	Concentration (mg L^{-1})	Time (h)	Germination (%)	Seedling vigor index
BSN	2	24	77.33abc*	43.64cd
		36	90.67a	90.88a
		48	61.33bcde	23.70ef
		60	69.33abcd	43.47cd
		72	89.33a	69.98b
	4	24	56.00cdef	19.67efg
		36	70.67abcd	31.72de
		48	52.00de	14.48fg
		60	53.33de	19.38efg
		72	80.00ab	44.30cd
	6	24	42.67e	13.19fg
		36	54.67cde	22.68ef
		48	35.00f	7.07g
		60	38.00f	14.12fg
		72	73.33abcd	31.04de
Control			80.00ab	55.98c

*Means within columns followed by the different letter are significantly different at $P \leq 0.05$ using

concentrations at 12 HAT compared with the previous time duration points (**Table 4**). In using BSN, at the concentration of 2 mg L^{-1}, the highest germination percentage was recorded by 90.67% at 36 HAT, which was not significantly higher than control plots by 16% (**Table 5**). As a remarkable finding, the germination percentage decreased by increasing the BSN concentration (**Table 5**). To vindicate this result, it seems that lesser water absorption reduces the inflammation of the seed embryonic cells and subsequently reduces the osmotic potential plus effects of female toxicity[44]. Giri and Schillinger[45] reported that wheat seed priming using the 4% potassium chloride solution lowers the germination rate compared with non-treated plants in control plots, probably due to the toxic effects of the solution on seed embryos. They showed that wheat germination could be improved by soaking the seeds in the water for 12 h[45].

3.1.2 Seedling vigor index

Interestingly, the seedling vigor index was enhanced by increasing the hydropriming time up to 22 h (**Table 3**). At 22 HAT, the highest seedling vigor index of 14.15 was recorded, which showed a raising of 69.8% compared with the control plot (**Table 3**). The recorded values of the seedling vigor index at 14, 18, and 22 HAT were significantly higher than those at 10 and 22 HAT (**Table 3**). The seedling vigor index showed a reduction by increasing the $ZnSO_4$ concentration and the time duration of the application (**Table 4**). The highest seedling vigor index was recorded up to 130.39 at 4 HAT by using $ZnSO_4$ at the concentration of 0.03 mg L^{-1}, which was significantly higher than that of the control plot by approximately 2.4 times (**Table 4**). The lowest seedling vigor index was 37.79 after using $ZnSO_4$ at the concentration of 0.05 mg L^{-1} at 16 HAT, which was not significantly different from the control plot (**Table 4**).

In performing the priming using BSN, the seedling vigor index decreased by raising the BSN concentration (**Table 5**). Treatment with the concentration of 2 mg L^{-1} and 36 h priming duration showed the highest seedling vigor index of 90.88, which was significantly higher by approximately 1.6-fold than that of the control plot (**Table 5**). Performing the priming with calcium chloride increased the seedling vigor index of 9.6% compared with the control plot[46]. The lowest seedling vigor index by 7.07 was obtained at the concentration of 6 mg L^{-1}, 48 HAT, which was significantly lower than that of the control plot (**Table 5**).

3.2. Field experiment

3.2.1. Total weed density and dry weight

Although the total weed density was significantly affected by the main factors, it was not affected by the interaction of planting date and priming method ($P \leq 0.01$) (**Table 6**). As shown in **Figure 1**, the heighst total weed densities at 1258.9 and 1481.75 GDD were approximately 1000 plants m^{-2}, on both planting dates, which were not significantly different. The lowest weed density (ca. 180 plants m^{-2}) was recorded at 676.1 GDD on the planting date of June 11 (**Figure 1(a)**). The level of lowest weed density on the planting date of June 1 was significantly higher than that of on June 11 by almost (**Figure 1(a)**). Overall, the weed density increased by increasing GDD on both planting dates (**Figure 1(a)**).

Table 6. Analysis of variance (ANOVA) of some weed flora traits.

SOV	DF	Total weed density	Total weed dry weight
Repetition	2	304603.6**	6669085**
Planting date	1	873661.7**	13389312**
Priming	3	286842.8**	5926045**
Error	2	29087.7	669
Planting date × Priming	3	89430.3^{ns}	386599**
Error		9202.5	29262
CV(%)		12.21	2.33

Ns: non-significant; *: Significant at $P \leq 0.05$; **: Significant at $P \leq 0.01$.

According to **Table 6**, the total weed dry weight was significantly affected by the main factors and their interactions at $P \leq 0.01$ (**Table 6**). The control plot, cultivated on June 1, displayed the most weed dry weight significantly by 1790.3 g m^{-2} (**Figure 1(b)**). The greatest level of suppressing weed dry biomass was recorded in hydropriming on June 11 by recording 1442.1 g m^{-2}, which was not significantly different compared with

BSN (1438 g m^{-2}) and $ZnSO_4$ (1553.8 g m^{-2}) (**Figure 1(b)**). Generally, the total weed dry weight decreased by delaying the planting date so that the falling was 19.44, 23.41, and 20.46 for primed corn seeds by hydropriming, $ZnSO_4$, and BSN, respectively, compared with those on June 1 (**Figure 1(b)**). Also, this reduction was recorded in the control plot by 26.99% (**Figure 1(b)**). Meanwhile, performing the priming using BSN, $ZnSO_4$, and hydroprime reduced the total weed dry weight by 15.7%, 7.1%, and 15.4%, respectively, compared with the control plot on June 11 (**Figure 1(b)**).

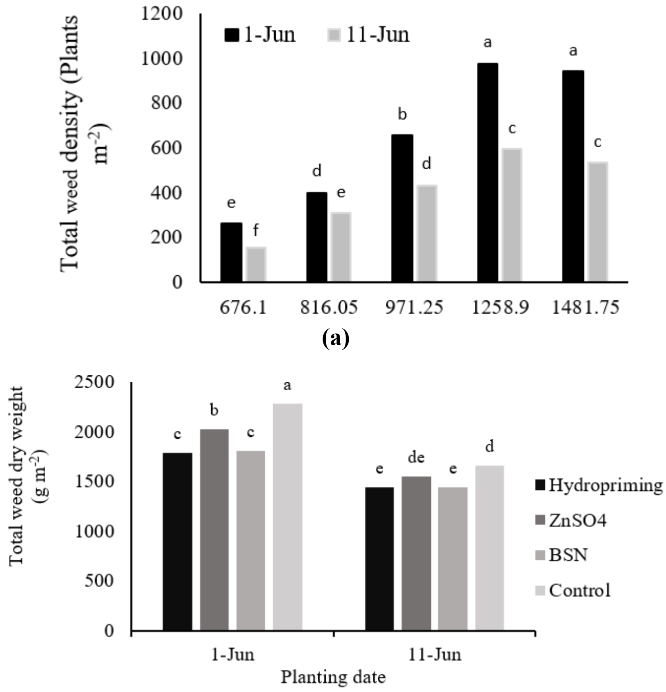


Figure 1. (a) The influence of planting date on the total weed density during the growing season (at five GDD) and **(b)** the interaction of planting date and priming method on the total weed dry weight. Bars with different letters are significantly different at $P \leq 0.05$ using LSD's test.

The reason for recording higher dry biomass of total weed populations seems to be more consumption of resources by the weed flora in the early planting date[21]. Due to the fact that weed populations are mostly annuals and reproduce by seeds, environmental conditions, especially soil temperature and humidity, may not have been available for germination and regrowth at the late planting dates; consequently, they could not produce a high dry weight[47].

3.2.2. Corn vegetative characteristics

The reason for recording higher dry biomass of total weed populations seems to be more consumption of resources by the weed flora in the early planting date[21]. Due to the fact that weed populations are mostly annuals and reproduce by seeds, environmental conditions, especially soil temperature and humidity, may not have been available for germination and regrowth at the late planting dates; consequently, they could not produce a high dry weight[47]. The lowest value of the emergence index (ca. 14.28) was observed in control plots on both planting time points of June 1 and 11, which was significantly lower than those of other treatments (**Figure 2(a)**). The interaction between planting date and priming method represented that priming enhanced the emergence index on both planting dates compared with control plots (**Figure 2(a)**). In general, accomplishing the priming using BSN, $ZnSO_4$, and hydropriming ameliorated the emergence index compared with the control plot by 2.7%, 0.9%, and 1.6% on June 1 and 4.6%, 1.8%, and 7.6% on June 11, respectively (**Figure 2(a)**). The enhanced emergence in primed seeds can be due to the activity of degrading enzymes, such as alpha-amylase[48]. The accelerated seedling emergence and the improved yield production were reported after performing the hydropriming of corn seeds[49].

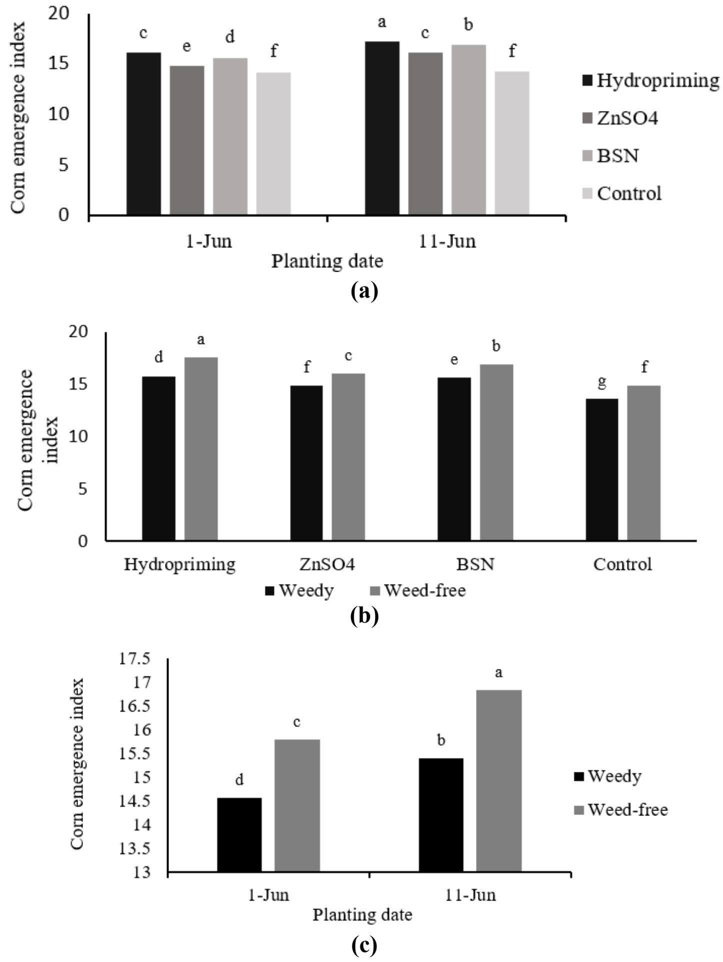


Figure 2. **(a)** The interaction effect between planting date and priming method on the corn emergence index, **(b)** the interaction effect between weed interference level and priming method on the corn emergence index and **(c)** the interaction between planting date and weed interference level on the corn emergence index. Bars within columns followed by different letters are significantly different at $P \leq 0.05$ using LSD's test.

According to **Figure 2(b)**, the greatest emergence index (17.54) was observed in weed-free plots, where corn seeds had been primed by hydropriming, that was significantly higher than those of all other treatments. Moreover, the values of emergence index in treated plants by $ZnSO_4$, BSN, and control treatments in weed-free plots were recorded up to 16.03, 16.86, and 14.83, respectively (**Figure 2(b)**). On the other hand, the emergence index level in the treated plants by $ZnSO_4$, BSN, and control in weedy plots were up to 14.89, 15.06, and 13.64, respectively, which were lower than those of weed-free plots (**Figure 2(b)**). And as a significant finding, the recorded values of emergence index in weed-free plots treated by $ZnSO_4$ and in weedy plots were not significantly different (**Figure 2(b)**). Generally, the interaction effect between priming method and weed interference level represented that performing the priming by BSN, $ZnSO_4$, and hydropriming improved the emergence index compared with the control plot up to 12.56%, 8.39%, and 13.56% in weedy plots and by 12.04%, 7.48%, and 15.45% in weed-free plots (**Figure 2(b)**). However, the values of emergence index in weed-free plots was higher than that of weedy plots (**Figure 2(b)**).

The interaction between planting date and weed interference level depicted that the highest levels of emergence index were observed in the weed-free plots on both planting dates of June 1 and 11 by 16% and 17%, respectively (**Figure 2(c)**). And equally important, the recorded emergence index values in the weed-free plots were significantly higher than in the weedy plots on both planting dates (**Figure 2(c)**). These results were consistent with the reported findings by Teal et al.[50] and Nielsen et al.[51].

The corn LAI was significantly affected by the main factors ($P \leq 0.01$) and interactions between planting date and priming method ($P \leq 0.01$) as well as planting date and weed interference level ($P \leq 0.05$) (**Table 7**). The recorded LAI values for treated plants, planted on June 1, by hydropriming, $ZnSO_4$, and BSN were 16.13, 14.77, and 15.61, respectively, which were significantly lower than those that were planted on June 11 (**Figure 3(a)**). The highest LAI (17.19) was observed in treated plants by hydropriming, which were planted on June 11, which was significantly higher than those treated by $ZnSO_4$ and BSN (**Figure 3(a)**). Noticeably, the LAI values in control plots on both planting dates were not significantly different (**Figure 3(a)**). The results revealed that delayed planting dates caused a significant drop in LAI while priming methods significantly enhanced the LAI on both planting dates compared with the control plots (Figure 3a). In general, hydropriming, BSN, and $ZnSO_4$ prevented the LAI from declining on late planting dates by 32.3%, 22.5%, and 14.2%, respectively, compared with the control plot (**Figure 3(a)**). Moradi et al.[52] highlighted that primed seeds have a higher LAI than non-primed plants due to faster emergence and earlier completion of the vegetative growth period.

Table 7. Analysis of variance of the corn traits.

SOV	DF	Emergence index	LAI	Plant height	Number of grain rows per ear	1000-grain weight	Grain yield
Repetition	2	0.12	4.23	32.14	0.008	12.56	614575
Planting date	1	62.10**	106540**	2352**	2.707**	51501.17**	13082010.23**
Error	2	0.01	0.001	3.93	0.034	8.68	602327117
Priming	3	13.62**	29777.29**	711.80**	2.181**	10575.71**	13174373.50**
Weed interference	1	21.46**	273702**	4332**	1.817**	374555.25**	74260807**
Planting date × Priming	3	1.85**	1788.28**	16.38**	0.319**	1741.10**	177022.30**
Planting date × Weed interference level	1	0.34**	1102.08*	330.75**	0.004ns	223.19ns	4695195**
Priming × Weed interference level	3	0.27**	52.16ns	67.37ns	0.102ns	295.69**	130187.86**
Planting date × Priming method × Weed interference	3	0.07**	215.95ns	40.13ns	1.73**	313.53**	179743.73**
Error		0.01	245.58	138	0.06	71.34	488369.4
CV (%)		72.0	13.5	3.00	1.97	3.66	10.74

Ns: non-significant; *: Significant at $P \leq 0.05$; **: Significant at $P \leq 0.01$.

Based on the interaction effects of planting date and weed interference level, it was observed that weed competition reduced the corn LAI (**Figure 3(b)**). The highest LAI was obtained in the weed-free plots on June 1 by 3.04, and the lowest LAI was recorded in the weedy plots on June 11 by 2.04, which were significantly different (**Figure 3(b)**). The delay in the planting date reduced the LAI values in both weedy and weed-free plots (**Figure 3(b)**).

As shown in **Figure 3**, the obtained LAI at all GDD on the planting date of June 1 were significantly higher than those of June 11. Also, the highest LAI was recorded at 1258.9 GDD up to 2.7 on the planting date of June 11, which was significantly higher relative to the planting date of June 1 by 11.18% (**Figure 3(c)**). The recorded LAI values at 1258.9 and 1481.75 on June 1 were not statistically different (**Figure 3(c)**). The decline in the vegetative period was effective in reducing LAI on the planting date of June 11 compared with the planting date of June 1, which was consistent with the results of Zahedi et al.[53], Aghaalikhani and Safari[54], and Naderi[55]. At 673.1 GDD, the lowest LAI values were observed for planting date of June 1 and 11 by 1.4 and 1.2, respectively, which were significantly different (**Figure 3(c)**).

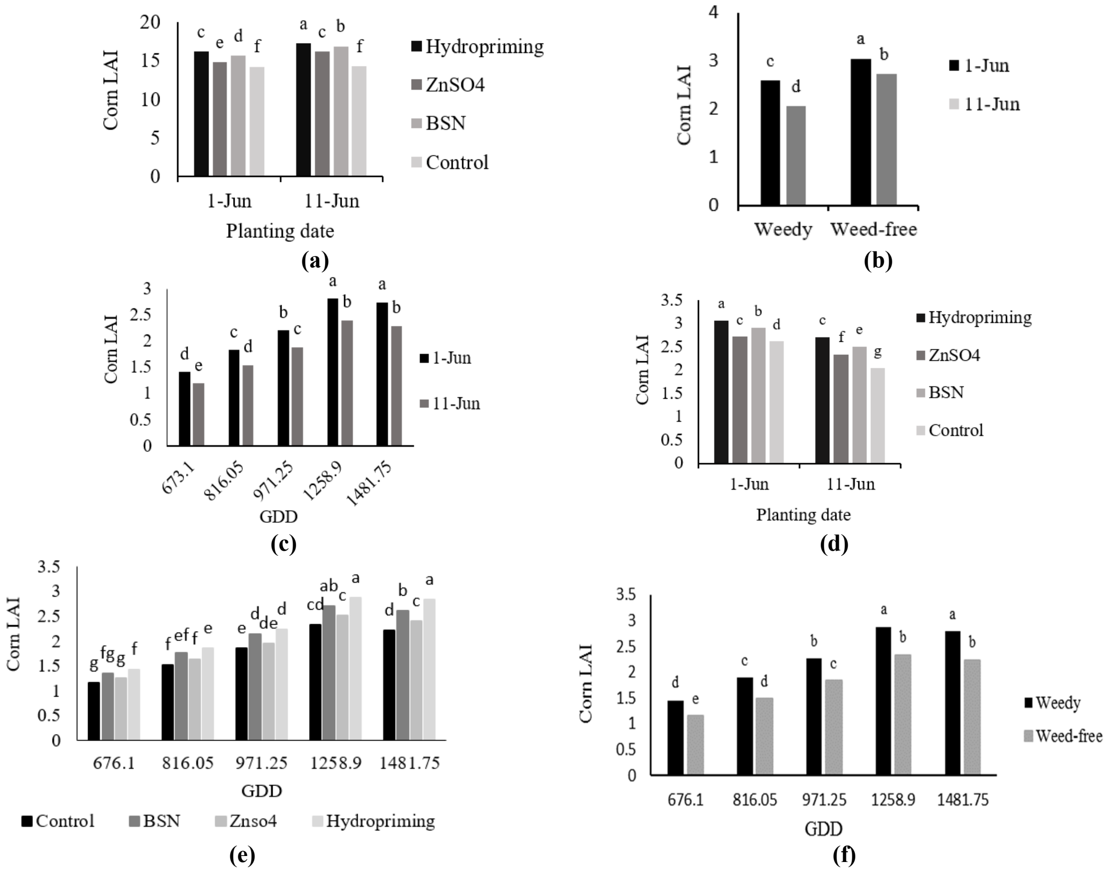


Figure 3. **(a)** The interaction effect between planting date and priming method on the corn LAI, **(b)** the interaction effect between planting date and weed interference level on the corn LAI, **(c)** the influence of planting date on the corn LAI during the growing season (at five GDD), **(d)** the interaction effect between planting date and priming method on the corn LAI, **(e)** the influence of priming method on the corn LAI during the growing season (at five GDD), and **(f)** the influence of weed interference level on the corn LAI during the growing season (at five GDD). Bars with different letters are significantly different at $P \leq 0.05$ using LSD's test.

The results of the interaction effects between planting dates and priming methods indicated that the greatest LAI (3.06) was observed with hydropriming on June 1. On the other hand, the lowest LAI (2.33) was recorded with $ZnSO_4$ on June 11 (**Figure 3(d)**). Noticeably, the recorded LAI levels in all treatments on June 1 were significantly higher than those on June 11 (**Figure 3(d)**). Surprisingly, the obtained LAI in the control plot on June 1 was significantly higher than those on June 11 by 21.83%, which explained that the delay in planting could influence the crop vegetative growth significantly (**Figure 3(d)**). Accordingly, the levels of LAI in treated plots by hydropriming, $ZnSO_4$, and BSN on the planting date of June 11 reduced by 11.76%, 14.02%, and 13.79%, respectively, compared with those on June 1 (**Figure 3(d)**). In other words, the results displayed that improving of the vegetative growth is not possible even by using the priming methods in case of delay in the planting date. According to **Figure 3(e)**, the greatest LAI was obtained with treated plants by hydropriming at 1258.9 GDD by 2.8, which was not significantly different relative to the recorded LAI values in treated plants by BSN (2.6) and hydropriming (2.7) at 1258.9 and 1481.75 GDD, respectively (**Figure 3(e)**). Hydropriming and $ZnSO_4$ represented the highest and lowest performance in increasing the corn LAI among priming methods at all GDD (**Figure 3(e)**). The lowest LAI was observed in treated plants by $ZnSO_4$ up to 1.2 at 676.1 GDD, which was significantly different compared with recorded LAI with BSN (**Figure 3(e)**). Generally, the lowest LAI values at all GDD, were obtained in control plots (**Figure 3(e)**).

At 1258.9 GDD, the highest LAI of 2.88 was observed in weed-free plots, which was not different relative to recorded LAI in weed-free plots at 1481.75 GDD (**Figure 3(f)**). The corn LAI was lower in weedy plots than weed-free plots at all GDD, so that LAI at the beginning of the vegetative stage was 1.15 in weedy plots and 1.45 in weed-free plots (**Figure 3(f)**). This result affirms the destructive effects of weed-crop competition in reducing LAI; as a crucial consequence of inhibiting the foliage growth and development. The lowest LAI was obtained in weedy plots at 676.1 by 1.2 (**Figure 3(f)**). Moreover, the lowest Decreased LAI under the impression of weed interference was reported by Williams and Lindquist[21], which showed that the presence of weed populations prevents the LAI enhancement.

The corn plant height was significantly affected by the main factors ($P \leq 0.01$) and interactions between planting date and priming method ($P \leq 0.01$) as well as planting date and weed interference level ($P \leq 0.01$), while the interactions between priming method and weed interference level, and also planting dates, priming methods and weed interference levels did not significantly affect the plant height (**Table 7**). Overall, the delay in planting date reduced the plant height not only in treated crops with the priming methods, but also in control plots (**Figure 4(a)**). The highest plant height (222.33 cm) was recorded in treated plants by hydropriming, planted on June 1. Also, the lowest plant height (197.5 cm) was observed in treated plots by $ZnSO_4$ cultivated on June 11 (**Figure 4(a)**). The primed corn plants by hydropriming, BSN, and $ZnSO_4$ on June 11 represented a drop in their heights up to 8.2%, 6.34%, and 3.3%, respectively, compared with those on June 1 (**Figure 4(a)**).

As shown in Figure 4b, the highest (220.58 cm) and lowest (187.58 cm) plant heights were related to the interaction between weed-free treatment and the planting date of June 11, and on the other hand, weed interference level and the planting date of June 11, respectively, which were significantly different (**Figure 4(b)**). The findings showed that in both weedy and weed-free plots, the height of corn plants cultivated on June 1 was significantly higher than cultivated plants on June 11 (**Figure 4(b)**).

The highest plant height (ca. 220 cm) was recorded at 1481.75 GDD on planting date of June 1, which was not significantly different compared with the recorded plant height on both of planting dates at 1481.75 and 1258.9 GDD (**Figure 4(c)**). The recorded height of plants cultivated on June 1 was significantly higher

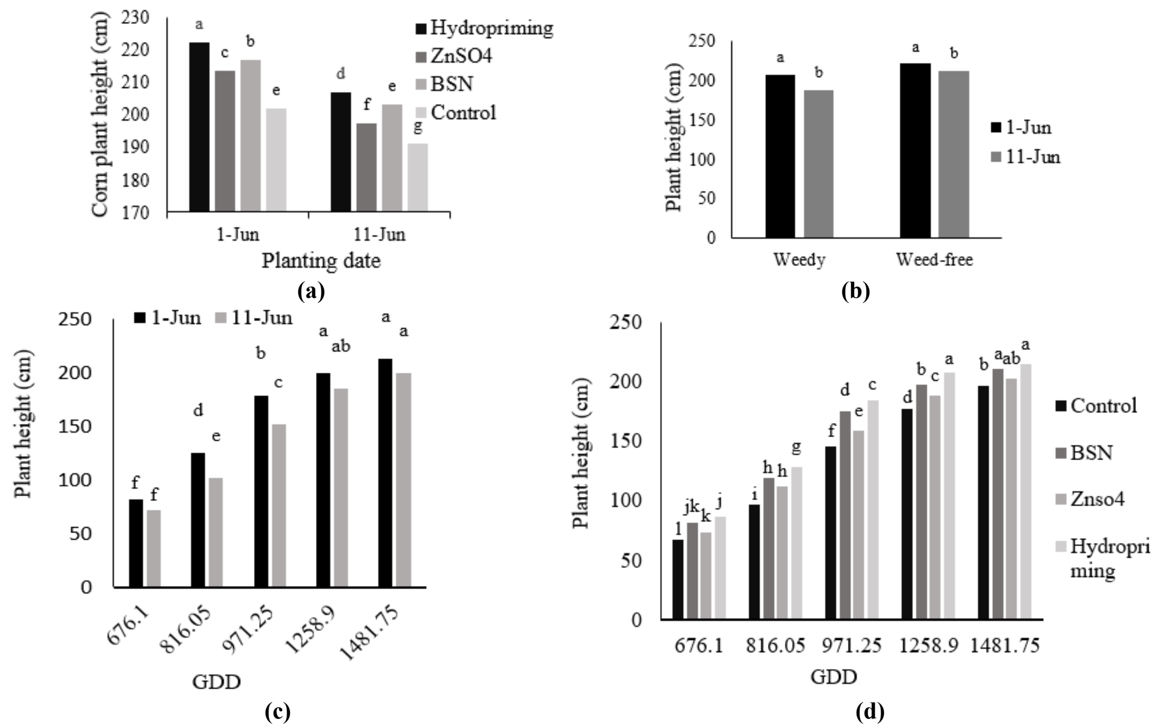


Figure 4. (a) The interaction effect between planting date and priming method on the corn plant height, **(b)** the interaction effect between planting date and weed interference level on the corn plant height, **(c)** the effect of planting date on the corn plant height during the growing season (at five GDD), and **(d)** the effect of priming method on the corn plant height during the growing season (at five GDD). Bars with different letters are significantly different at $P \leq 0.05$ using LSD's test.

than those on June 11 up to 17% and 23% at 971.25 and 816.05, respectively (Figure 4c). Noticeably, it was found that by increasing GDD, the plant height increased on both planting dates (**Figure 4(c)**). Studying the effects of priming approaches at various GDD displayed that by increasing GDD, the plant height increased not only in treated plants by priming methods but also in the control plots (**Figure 4(d)**). As a remarkable finding, at all GDD, the height of treated plants by hydropriming was significantly the greatest. Moreover, the plant height recorded in control plots was the lowest (**Figure 4(d)**). Among the priming methods, $ZnSO_4$ showed the lowest performance in enhancing the plant height at all GDD (**Figure 4(d)**). It was suggested that the decrease in the plant height could be mainly owing to the shortening of the internode distances because of changes in the day length[56]. Moreover, delay in the planting date could reduce the plant height and decline the growing period[57]. The height of the sunflower plants was higher on the planting date of June 31 than cultivated plants on July 29. In other words, the plant height decreased by delaying in planting date[58]. It was presumably because of an increase in temperature during the growing season, a reduction of the vegetative growth period, and an acceleration of the flowering process[58]. It was proven that primed plants are taller than non-primed plants[25].

3.2.3. Corn yield production

The number of grain rows per ear was significantly affected by main factors ($P \leq 0.01$) and also interactions between planting date and priming method ($P \leq 0.01$), planting date and weed interference level ($P \leq 0.01$), and priming method and weed interference level ($P \leq 0.01$) (**Table 7**). As shown in Figure 5a, although the delay in the planting date caused a significant decrease in the number of grain rows per ear, priming treatments increased the number of grain rows per ear on both planting dates compared with the control plot (**Figure 5(a)**). On both planting dates, the highest number of grain rows per ear was observed with BSN treatment by 14.8 and 14.25 on June 1 and 11, respectively, which showed an increase of 7.7% and 10.52% compared with the control plots planted on June 1 and 11, respectively (**Figure 5(a)**). The treated plots by $ZnSO_4$, planted on June 11, displayed the lowest number of grain rows per ear (13.26) compared with treated plots by other priming approaches (**Figure 5(a)**). It is worth mentioning that the recorded number of grain rows per year in all priming treatments was significantly higher than control plots on both planting dates (**Figure 5(a)**). The number of grain rows in weed-free and weedy plots were 14 and 13.8, respectively, which were significantly different (**Figure 5(b)**). According to Figure 5b, the number of grain rows per ear was higher in weed-free plots by 2.7% compared with the weedy plots, which shows that weed-crop competition reduces the crop yield productivity (**Figure 5(b)**).

All main factors and their interactions significantly influenced the corn 1000-grain weight ($P \leq 0.01$), except the interaction of planting date and weed interference level (**Table 7**). According to **Figure 6(a)**, the levels of 1000-grain weight in treated plants by priming approaches were significantly higher than those of control plots on both planting dates (**Figure 6(a)**). The highest level of 1000-grain weight (317.5 g) was recorded in treated plants by BSN, planted on June 1 (**Figure 6(a)**). Also, the lowest level of 1000-grain weight was observed in treated plants by $ZnSO_4$, planted on June 11 (**Figure 6(a)**). The delay in the planting date reduced the 1000-grain weight (**Figure 6(a)**). The 1000-grain weight values of treated plants, cultivated on June 1; by hydropriming, $ZnSO_4$, and BSN were higher by 24.76%, 18.3%, and 31.18%, respectively, compared with those planted on June 11 (**Figure 6(a)**). The same trend was realized in control plots so that the planted crops on June 1 showed a higher 1000-grain weight by 23.3% than those cultivated on June 11 (**Figure 6(a)**). Furthermore, BSN displayed the best performance in enhancing the corn 1000-grain weight, which significantly improved the corn 1000-grain weight compared with control plots by 29.9% and 21.87% on June 1 and 11, respectively (**Figure 6(a)**).

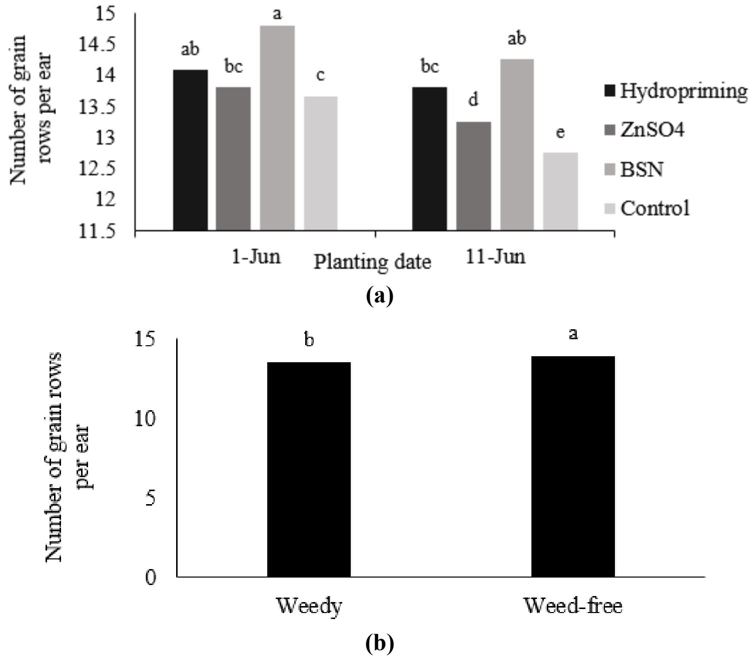


Figure 5. (a) The interaction effect between planting date and priming method on the number of grain rows in corn ear and **(b)** the influence of weed interference level on the number of corn grain rows per ear. Bars with different letters are significantly different at $P \leq 0.05$ using LSD's test.

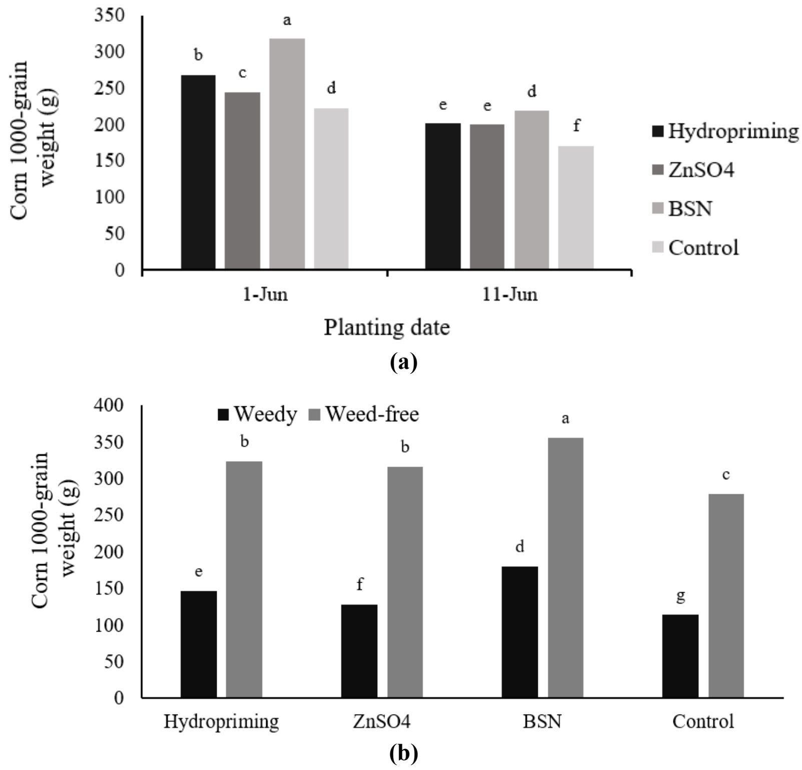
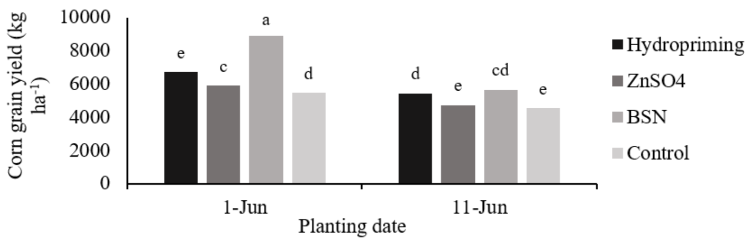


Figure 6. (a) The interaction effect between planting date and priming method on the corn 1000-grain weight and **(b)** the interaction between priming method and weed interference level on the corn 1000- grain weight. Bars with different letters are significantly different at $P \leq 0.05$ using LSD's test.

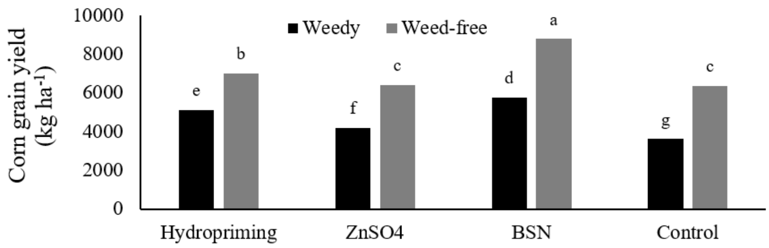
The 1000-grain weight of corn plants treated by hydropriming, $ZnSO_4$, and BSN in weed-free plots was higher than weedy plots by 54.81%, 59.73%, and 49.24%, respectively (**Figure 6(b)**). According to **Figure 6(b)**, the highest and lowest corn 1000-grain weight was obtained in treated plots by BSN up to 355.53 g and $ZnSO_4$ up to 127.53 g in the weed-free and weedy plots, respectively (**Figure 6(b)**).

The corn grain yield was significantly affected by the main factors and their interactions ($P \leq 0.01$) (**Table 7**). As expected, the delay in planting date decreased the grain yield generally (**Figure 7(a)**). The recorded grain yield of corn plants treated by hydropriming, $ZnSO_4$, and BSN, planted on June 1, was higher than cultivated plants on June 11 by 19.36%, 20.09%

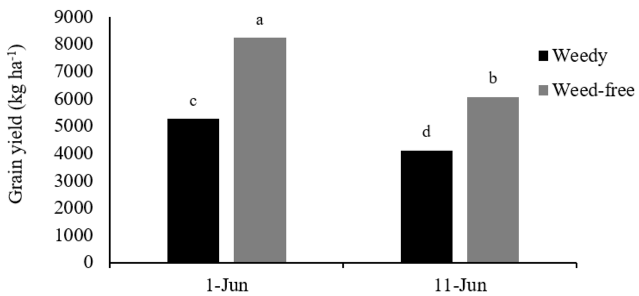
, and 36.34%, respectively (**Figure 7(a)**).



(a)



(b)



(c)

Figure 7. (a) The interaction effect between planting date and priming method on the corn grain yield, **(b)** the interaction effect between priming method and weed interference level on the corn grain yield, and **(c)** the interaction effect between planting date and weed interference level on the corn grain yield. Bars with different letters are significantly different at $P \leq 0.05$ using LSD's test.

BSN enhanced the grain yield compared with the control plots by 63% and 24.9% on the planting dates of June 1 and 11, respectively, which significantly indicated the highest performance among priming methods (**Figure 7(a)**). Moreover, the lowest grain yield (4706.04 kg ha^{-1}) was recorded in the treated plots by $ZnSO_4$ cultivated on June 11, which was significantly lower than in treated plots by hydropriming, $ZnSO_4$, and BSN, planted on June 11 (**Figure 7(a)**). In the treated plots by $ZnSO_4$, planted on June 11, the recorded corn grain yield was significantly no different compared with the control plot, planted on June 11, while it was significantly lower than the control plot cultivated on June 1 (**Figure 7(a)**). Hydropriming of safflower (*Carthamus tinctorius*) seeds and changing the planting date improved the number of heads per plant, number of seeds per head, 1000-grain weight, and safflower seed yield production[59].

In both weedy and weed-free plots, using the priming methods enhanced the grain yield compared with the control plots (**Figure 7(b)**). In the weedy plots, the recorded grain yield in control plots was lower than treated plots by hydropriming, $ZnSO_4$, and BSN up to 29.17%, 13.59%, and 32.27%, respectively (**Figure 7(b)**). In the weed-free plots, the observed grain yield in control plots was lower than treated plots by hydropriming, $ZnSO_4$, and BSN by 9.2%, 0.57%, and 27.5%, respectively (**Figure 7(b)**). The highest grain yield was recorded in the treated crops by BSN in weed-free plots up to 8782.59 kg ha^{-1}, which was significantly higher than all treatments in both weedy and weed-free plots (**Figure 7(b)**). Among priming methods, $ZnSO_4$ significantly represented the lowest performance compared with other priming approaches (**Figure 7(b)**). Furthermore, its performance in weed-free and weedy plots was equal and higher, respectively, compared with the control plots (**Figure 7(b)**).

The highest grain yield production (8221.91 kg ha^{-1}) was obtained with the corn plants cultivated on June 1 in the weed-free plots (**Figure 7(c)**). The lowest grain yield (4092.78 kg ha^{-1}) was recorded in planted corns on June 11 (**Figure 7(c)**). Generally, the postponed planting date and weedy treatment significantly decreased the values of corn grain yield (**Figure 7(c)**).

As a significant fact, weed infestations could be occurring in case of late and non-uniform seed emergence and weak seedling establishment[60–62]. In following that, a considerable competition for a wide range of growth requirements is realizable between weed populations and crops[63,64]. Based on our findings, which is in line with other studies, in the first step, priming approaches contribute to improve seed emergence and seedling development. The effect of various seed priming osmotic approaches, including copper sulphate 0.1%, zinc sulphate 0.1%, and sodium sulphate 0.1% were investigated on corn seed germination[65]. The highest seed germination was recorded in treated plots by copper sulphate up to 43% compared with the control plots (unprimed crop seeds)[65]. Moaaz et al.[66] reported that by using KNO_3, as a seed priming method, at the concentration of 0.75%, the final emergence percent and mean emergence time of tomato seeds significantly increased.

Simply, soaking crop seeds in water or a solution of nutrient elements, specially microelements, to absorb an adequate water quantity to start biochemical metabolic pathways in having a vigorous emergence and subsequently potent seedling establishment could be considered as the priming approach, which are not complicated and expensive[67–69]. The nutria-priming technique has been investigated in several crops worldwide, including corn[70], common bean[71], wheat[69], stevia[72], and mung bean[73]. Priming methods give a relative superiority to crop seeds in using restricted soil resources in competition with weed populations, which resulted in crop predominance over the growth season[74–76]. This initial domination improves the agronomic characteristics of crop species over the time[77,78]. Esper Neto et al.[79] suggested that ZnO nanoparticles (at the concentrations of approximately 70 and 100 mg L^{-1}) as a priming tool can significantly increase corn seed germination and consequently root length as well as both total fresh and dry biomass production. It was proved that the combination of bio-microbial priming, using *Trichoderma viride* and *Frateuria aurentia*, and application of 75% recommended dose of NPK fertilizer (N-P-K @ 120-60-60 kg ha^{-1}) improves the vegetative growth parameters, including leaf area (> 4200 cm^2 $plant^{-1}$), root length (> 1050 cm $plant^{-1}$), chlorophyll content (> 46 mg g^{-1}), fresh biomass (> 215 g $plant^{-1}$), dry biomass (> 21 g $plant^{-1}$) and grain yield production (> 24 g $plant^{-1}$) of baby corn[80]. Also, Damalas et al.[81] represented that hydro-priming treatments, regardless of the treatment durations, ameliorated the faba bean seed germination speed and seedling vigor index by 16.2% and13.4%, respectively, in a greenhouse experiment. In the field experiment, the highest fresh biomass was recorded with primed seed for 8 h at anthesis stage in the first and second year of the study, up to > 0.35 kg $plant^{-1}$ (22.3% higher than the control plot) and ≤ 0.4 kg $plant^{-1}$ (8.6% higher than the control plot), respectively[81]. Also, it was shown that this hydropriming treatment significantly recorded higher the faba bean seed yield production than the control plots by 12.0% and 5.9% in the first and second year, respectively[81]. In fact, the early dominance and agronomic growth aspects have a two-way relationship so that both could promote each other or vice versa. Therefore, it seems that priming and particularly nutria-priming are approaches to strengthen crop vegetative and reproductive growth aspects compared with weed species while there are no any series reports regarding their application in terms of environmental concerns[33].

4. Conclusion

Based on the results, the use of priming approaches ameliorated the corn vegetative growth as well as yield production despite the destructive effects of the delayed planting date and the presence of weed populations. In fact, improving some vegetative characteristics, like corn LAI, can suppress weed populations incrementally. Consequently, by diminishing the weed infestations during the growing season, crops would be able to catch the niches and growth resources readily, which in turn results in increasing crop yield production. However, the destructive effect of the delayed planting date is unneglectable. Generally, all three priming methods more effectively increased the crop yield production and weed control level compared with the control treatments on both planting dates. Moreover, hydropriming and BSN displayed the highest efficiency not only in improving the crop vegetative growth aspects and yield production but also in lessening the invasion of weed populations concomitantly. Therefore, although using these priming methods can be recommendable to farmers, it is notable that carrying out more field experiments under various climate conditions is required to evaluate these treatments more precisely.

Author contributions

Conceptualization, SA, SAK and RZ; methodology, SAK and RZ; software, SA, SAK and RZ; validation, SAK and RZ; formal analysis, SA and SAK; investigation, SA, SAK and RZ; resources, SAK and RZ; data curation, SA and SAK; writing—original draft preparation, SA; writing—review and editing, SAK and RZ; visualization, SA, SAK and RZ; supervision, SAK; project administration, SA, SAK and RZ; funding acquisition, SAK. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

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