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Seed priming and soil application of Zinc improved yield and shoot Zn concentration of corn (*Zea mays* L.)

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A R T I C L E I N F O

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A B S T R A C T

Background: Zinc (Zn) deficiency is a serious issue which negatively affects yield and quality of different crops. Various crop species and cultivars exhibit varying responses to Zn application with diverse techniques. Improved seed germination and subsequent seedling establishment in corn has been observed by Zn application via seed priming. This improvement in early growth stages ultimately leads to higher yields of grains enriched with Zn.
Methods: The current greenhouse study evaluated the impact of $ZnSO_4$ (5 mM solution) seed priming durations (i.e., 1, 10, 30 and 60 min) on dry matter yield and shoot Zn concentration on corn (*Zea mays* L.) grown on different soil types (Zn-deficit and Zn-sufficient) (soil supplementation with Zn) soils. Unprimed seeds were taken as control for comparison. Chlorophyll index, dry matter yield and shoot Zn concentration were recorded at 20 and 25 days after emergence.
Results: Seed priming with $ZnSO_4$ for 60 min significantly improved chlorophyll index on Zn-deficit (1.44 %–5.72 %), and Zn-sufficient (2.28 %–2.97 %) soil. Similarly, dry matter yield was improved by 32.45 %–58.20 % on Zn-deficit and 0–3.79 % on Zn-sufficient soil by the seeds primed for 60 min compared to unprimed seeds. Likewise, $ZnSO_4$ seed priming for 60 min improved shoot Zn concentration by 17.21 %–32.83 %, and 0 %–11.85 % on Zn-deficit and Zn-sufficient soils, respectively. The improvements in the recorded traits were directly proportional to priming duration. A higher improvement in the recorded traits was recorded on Zn-deficit soil than Zn-sufficient soil. However, the values of the traits on Zn-deficit soil were ~50 % less than those observed from Zn-sufficient soil.
Conclusion: Growth and Zn accumulation in corn was increased with increasing priming duration. However, seed priming alone was insufficient to improve shoot Zn concentration. This might be attributed to low priming duration. Therefore, future studies with longer priming duration are needed to reach sound conclusions. Nonetheless, both seed priming and soil application of Zn are required to improve growth and shoot Zn concentration of corn on Zn-deficit soils.

1. Introduction

Zinc (Zn) deficiency is an extensive paradox in crop production (Cakmak, 2004; Hotz and Brown, 2004; Ortiz-Monasterio et al., 2007) since 50 % of global cultivated lands suffer from inadequate plant available Zn (Cakmak, 2008). Approximately 1.1 billion individuals worldwide are believed to be experiencing Zn deficiency (Kumssa et al., 2015). A significant prevalence of Zn deficiency has been observed in ~50 % of arable soils in Türkiye, and ~80 % in soils located in the Central Anatolia region (Cakmak, 2004). The Central Anatolia is the most important cereal production region of Türkiye (Cakmak, 2004) and foods prepared with low Zn contents in grains causes serious nutrition problems for the human. Furthermore, Zn-deficiency is common in the world (Gibson et al., 2006) and Türkiye (Cakmak et al., 1999) due to Zn deficiency in soils.

Different methodologies (agronomic or genetic techniques) are used to enhance the micronutrients levels in diverse agricultural crops. Biofortification, which involves the exogenous application of micronutrients (Cakmak, 2008) is a widely used agronomic method for enhancing the concentration of nutrients in grains. Micronutrient-rich fertilizers are applied in a several ways to increase nutrient concentration in grains during biofortification (Márquez-Quiroz et al., 2015; Pathak et al., 2012).

Various techniques, including soil and foliar application (Kinaci and

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Gulmezoglu, 2007), and seed priming are used to apply micronutrients (Farooq et al., 2018; Rehman et al., 2018a, 2018b, 2018c). Application of Zn fertilizer through soil or foliar methods have been reported to lower the adverse impacts of Zn deficiency on crop productivity (Cakmak, 2008; Haider et al., 2018b, 2018a; Rehman et al., 2018c, 2018a, 2018b). Soil application of Zn is an effective method to increase crop yields on Zn-deficit soils (Cakmak, 2008; Cakmak et al., 1999, 1997; Liu et al., 2020a; Mohammed and Pekşen, 2020; Ullah et al., 2020b, 2020a; Wissuwa et al., 2008); however, this method did not increase grain Zn concentration. Recent study has suggested that the application of moderate Zn levels may enhance Zn concentration in grains that have previously undergone biofortification (Yaseen and Hussain, 2020).

Seed priming is a low-cost approach for delivering fertilizer even under unfavorable circumstances (Farooq et al., 2010). It is a pre-sowing method that generates a physiological state in seeds to improve germination efficiency. Seeds are partially hydrated to avoid the radicle from emerging during germination (Farooq et al. 2006a, b, c). Seeds are immersed in aerated liquids and then dried during seed priming (Farooq et al., 2012; Rehman et al., 2015). Previous studies have shown that Zn seed priming enhanced germination facilitated establishment of chickpea plants (Ullah et al., 2019). Zn seed priming has also enhanced biomass production, yield, and grain concentration of corn (Krishnaraj et al., 2020; Martínez-Cuesta et al., 2021). Seed priming is an economically viable, pragmatic, and readily implementable technique that enhances the micronutrient composition of grains (Foti et al., 2008; Harris et al., 2007). Priming maize seeds for 16 h with 1 % $ZnSO_4$ raised their Zn content from 15 to 560 mg kg^{-1} (Harris et al., 2007). On the other hand, it was shown that plants originating from seeds treated with Zn priming exhibited higher biomass and grain production than unprimed seeds. The grain yield of primed seeds exhibited a 27 % improvement in comparison to the control treatment (Harris et al., 2007).

Corn is considered a vital agricultural commodity due to its ability to provide a substantial portion of the daily caloric requirements of a large portion of the global population (Shiferaw et al., 2011). Due to this characteristic, corn is considered a crucial agricultural crop. The Zn deficiency may be potentially addressed using biofortification techniques aimed at enhancing the Zn concentration in maize kernels (Iqbal et al., 2018; Kanwal et al., 2010). Recent research has shown that biofortified maize exhibits significantly higher levels of Zn (Liu et al., 2020b). Zinc is a crucial mineral necessary for immune system modulation, wound healing, DNA synthesis, and various other essential functions (Deshpande et al., 2013; Plum et al., 2010). Consequently, use of biofortified corn can mitigate the prevalence of childhood malnutrition via enhancing the protein intake among early children (Maqbool and Beshir, 2019; Obaid et al., 2022). The use of biofortification technologies is of utmost importance in enhancing the zinc concentration in corn seeds, with the aim of mitigating hunger and malnutrition challenges prevalent in regions where corn constitutes a significant component of the diet (Gunaratna et al., 2019).

Previous studies reported beneficial impacts of seed priming on corn growth and productivity (Kakar et al., 2023; Raza et al., 2023). Nevertheless, the specific seed priming duration and its influence on growth and shoot Zn concentration of corn plants remains uncertain. This study was conducted to investigate the impact of different $ZnSO_4$ priming durations on biomass output, chlorophyll index, and shoot Zn concentration of corn plants grown in soils with deficient and sufficient Zn levels. The variation in priming duration is predicted to have an impact on biomass production, chlorophyll index, and shoot Zn content. It was hypothesized that soil with Zn deficiency would exhibit more significant enhancements in biomass production, chlorophyll index, and shoot zinc content compared to soil with sufficient Zn availability.

2. Materials and methods

2.1. Materials

This study was carried out in a greenhouse located at Faculty of Agriculture, Cukurova University, Türkiye. The seeds of 'Yeni Doga' corn variety having good germination rate were used as plant material. Free-draining plastic pots (8.8-liter capacity) filled with 4 kg soil were used to grow corn plants. Soil with natural Zn deficiency (0.08 mg Zn kg^{-1}) collected from the experimental field of Faculty of Agriculture, Cukurova University, Türkiye was used to fill the pots. The critical deficiency limit of Zn extracted by DTPA is 0.5 mg kg^{-1}, which clearly shows the experimental soil was Zn-deficit (Lindsay and Norvell, 1978).

2.2. Methods

2.2.1. Treatments and experimental design

The experiment consisted of two factors, i.e., soil types (Zn-sufficient and Zn-deficit), and seed priming durations (, 10, 30 and 60 min). The pots were divided into two groups for creating soil type treatment. The pot soil in the Zn-sufficient group was fertilized with 5 mg Zn kg^{-1} supplemental Zn, whereas the soil in Zn-deficit pot group did not receive any supplemental Zn application. Corn seeds were soaked in aerated solution of 5 mM $ZnSO_4-7H_2O$ solution for different durations (1, 10, 30 and 60 min) and dried to their original weight. Furthermore, unprimed seeds were taken as control in the study.

A total of 10 seeds were sown in each pot filled with either Zn-sufficient and or Zn-deficit soil. The plants were thinned to 3 per pot ten days after emergence (DAE). The pots were irrigated to field capacity to exclude the effects of moisture stress. The experiment was conducted according to randomized complete block design with split plot arrangements. Soil types were kept in the main plots, whereas priming durations were randomized in the sub plots. Everything was done in triplicate.

2.2.2. Harvesting, sample preparation and analysis

The plants were harvested at two different times based on Zn-deficiency symptoms. Appearance of white to yellowish-white line on both sides of the leaves is the most frequently observed Zn-deficiency symptom in corn. Therefore, the plants were harvested once these symptoms appeared in the Zn-deficit treatment. The first harvest was done at 22 DAE when plants had 5 leaves (BBCH-15), while second harvest was done at 28 DAE (BBCH-17) (Meier, 2001).

The chlorophyll index (SPAD values) was recorded before each harvest using a Soil Plant Analysis Development (SPAD) meter (Minolta SPAD 502) (Yuan et al., 2016). The top second leaf of maize plants was used to record SPAD values.

The harvested whole plant samples were collected, rinsed with deionized water, and dried in an oven at 70 °C for 48 h until the weight was stabilized. The whole-plant dry matter yield was recorded by weighing the dried samples on an electronic scale. The stems and leaves were separated from the dried samples and the stem portion was ground in a vibrating agate mill. The 0.2 g powder from freshly ground sample was subjected to wet digestion, where the powder was mixed with 2 ml of hydrogen peroxide (H_2O_2) and 5 ml of nitric acid (HNO_3). The resulting filtrate was filtered using Whatman No. 1 filter paper. The final volume of the resulting filtrate was raised to 20 ml by adding distilled water. Afterwards, Zn concentration in the filtrate was determined by using an atomic absorption spectrophotometer.

2.3. Statistical analysis

The recorded data were analyzed by two-way analysis of variance (ANOVA) to determine the significance between the applied treatments (Steel et al., 1997). The data were tested for normal distribution before performing ANOVA, and Shapiro-Wilk normality test (Shapiro and Wilk,

1965) denoted that the data had a normal distribution. Hence, original data were used in the statistical analysis. Least significant difference post-hoc test at 95 % probability was used to compare treatment means in cases ANOVA indicated significant differences among treatments. Pearson correlation was computed to examine the relationship between the recorded traits. All statistical analyses were conducted using SPSS statistical software version 20 (IBM, 2015).

3. Results

3.1. Effects of different priming durations and soil types on chlorophyll index

The chlorophyll index (SPAD values) was significantly altered by individual and interactive effects of different soil types and priming durations (non-significant at 2nd harvest) (Table 1).

Seed priming had a pronounced effect on SPAD values on Zn-deficit soil compared to Zn-sufficient soil during 1st harvest. Mean SPAD values were 45.9 and 47.8 on Zn-deficit and Zn-sufficient soils, respectively. The SPAD values of the plants grown on Zn-deficit soil conditions increased by 6 % with 60-minute priming duration as compared to control treatment. The increase in SPAD values of the plants grown on Zn-sufficient soil was 3 %. The results indicated that the effect of seed treatment was more pronounced under Zn deficiency; therefore, seed priming with Zn on Zn-sufficient soil had relatively low efficiency (Table 2).

Seed priming duration caused significant differences in SPAD values regardless of soil type. The SPAD values of the plants grown from the seeds primed for 30 and 60 min were 3 % and 6 % higher than the control, respectively. The results revealed that SPAD values were linearly increased with increasing priming duration (Table 2). The differences in the SPAD values during 2nd harvest were quite low (1 and 1 %) compared to 1st harvest. The SPAD value during 2nd harvest was increased by 1 % for the seed primed for in 60 min (Table 2).

3.2. Effects of different priming durations and soil types on dry matter yield

The individual and interactive effects of seed priming durations and soil types exerted significant impacts on dry matter yield at both harvests (Table 1, Fig. 1). Dry matter yield was more affected by priming durations at both harvests. Nonetheless, the differences were more pronounced on Zn-deficit soil compared to Zn-sufficient soil (Table 3).

Dry matter yield of control treatment at 1st harvest was 1.14 g plant^{-1} under Zn-deficit soil, while mean yield for seed priming was 1.31 g plant^{-1}. Dry matter was increased by 15 % with Zn seed priming

Table 1
Analysis of variance for different growth and nutrient uptake traits of corn plants grown with seed primed with Zn for different durations on Zn-sufficient and Zn-deficit.

Traits		1st harvest		2nd harvest	
		F value	P value	F value	P value
Chlorophyll index	Soil types (T)	11.30	0.003*	20.95	0.000*
	Priming durations (D)	4.96	0.006*	2.14	0.114 NS
	T × D	0.97	0.446NS	0.95	0.005*
Dry matter yield	Soil types (T)	148.4	0.000*	281.21	0.000*
	Priming durations (D)	8.07	0.000*	4.23	0.012*
	T × D	4.52	0.009*	3.36	0.030*
Shoot Zn concentration	Soil types (T)	418.9	0.000*	1351.64	0.000*
	Priming durations (D)	6.66	0.001*	6.40	0.002*
	T × D	3.15	0.037*	6.06	0.002*

*=significant at 0.05 %, NS = non-significant.

Table 2
The impact of different Zn seed priming durations on SPAD values of corn plants grown on Zn-deficit and Zn-sufficient soils.

Treatments	22 days after emergence		28 days after emergence	
	Zn-deficit	Zn-sufficient	Zn-deficit	Zn-sufficient
Dry seeds (control)	45.4 ± 1.24 a	47.0 ± 0.51 a	41.6 ± 0.72 ab	43.7 ± 0.32 a
1 min	46.4 ± 0.91 a	48.2 ± 1.72 a	43.5 ± 0.92 a	44.5 ± 1.21 a
10 min	42.7 ± 2.11 b	46.6 ± 2.36 a	39.6 ± 0.76 b	43.9 ± 1.56 a
30 min	46.8 ± 0.21 a	48.8 ± 2.11 a	42.2 ± 3.23 ab	44.7 ± 0.87 a
60 min	48.0 ± 1.62 a	48.4 ± 1.18 a	42.2 ± 1.79 ab	44.7 ± 1.42 a
Means (soil types)	45.9 B	47.8 A	41.8 B	44.3 A

Means sharing the same letters within a column are statistically non-significant ($p > 0.05$).

(Table 3). In contrast, dry matter yield under Zn-sufficient soil was lower than control treatment.

Like 1st harvest, seed priming increased dry matter yield by 37 % on Zn-deficit soil compared to the control at 2nd harvest. The difference between control, and 30- and 60-minute priming duration were significant. However, dry matter yield on Zn-deficit and Zn-sufficient soils was non-significant (Table 3).

Different priming durations had significant effect on dry matter yield. Dry matter yields of the plants grown from seeds primed for 1, 10, 30 and 60 min were 1.19, 1.23, 1.30 and 1.51 g plant^{-1}, respectively on Zn-deficit soil. The yields were significantly increased compared to the control treatment. However, this increase was not observed on Zn-sufficient soil as 60-minute priming duration (1.61 g plant^{-1}) had lower dry biomass yield than control (1.65 g plant^{-1}).

3.3. Effects different priming durations and soil types on shoot Zn concentration

The individual and interactive effects of seed priming durations and soil types exerted significant impacts on shoot Zn concentration at both harvests (Table 1). The increasing priming duration linearly improved shoot Zn concentration (Table 4). The Zn concentration of control plants at 1st harvest was 12.2 mg kg^{-1} on Zn-deficit soil, it increased to 12.2, 12.4, 14.0 and 14.3 mg kg^{-1} for seeds primed for 1, 10, 30 and 60 min, respectively (Table 4).

Like the dry matter yield, seed priming resulted in higher increase in shoot Zn concentration on Zn-deficit soil at 1st harvest compared to 2nd harvest. Mean Zn concentration under for seed priming at 1st harvest was 13.1 mg kg^{-1}, while decreased to 6.9 mg kg^{-1} at 2nd harvest. Similar results were obtained on Zn-sufficient soil (Table 4). The results indicated that the seed priming increases Zn concentration; however, this may not be sufficient unless additional Zn is supplied to soil. Therefore, seed priming along with soil application will be effective in increasing the shoot Zn concentration of plants.

3.4. Correlations between growth and nutrient acquisition traits

There was a substantial correlation between recorded growth and nutrient absorption traits (Table 5). A significant positive connection was recorded between dry matter yield and shoot Zn concentrations (r = 0.684, p 0.01) at 1st harvest; however, a significant negative correlation was noted (r = −0.569, p 0.05) during 2nd harvest. No significant correlation was recorded between chlorophyll index and the other traits during both harvests (Table 5).

There was a substantial positive correlation (r = 0.718, p 0.01) between the dry matter yields of the 1st and 2nd harvest. However, a

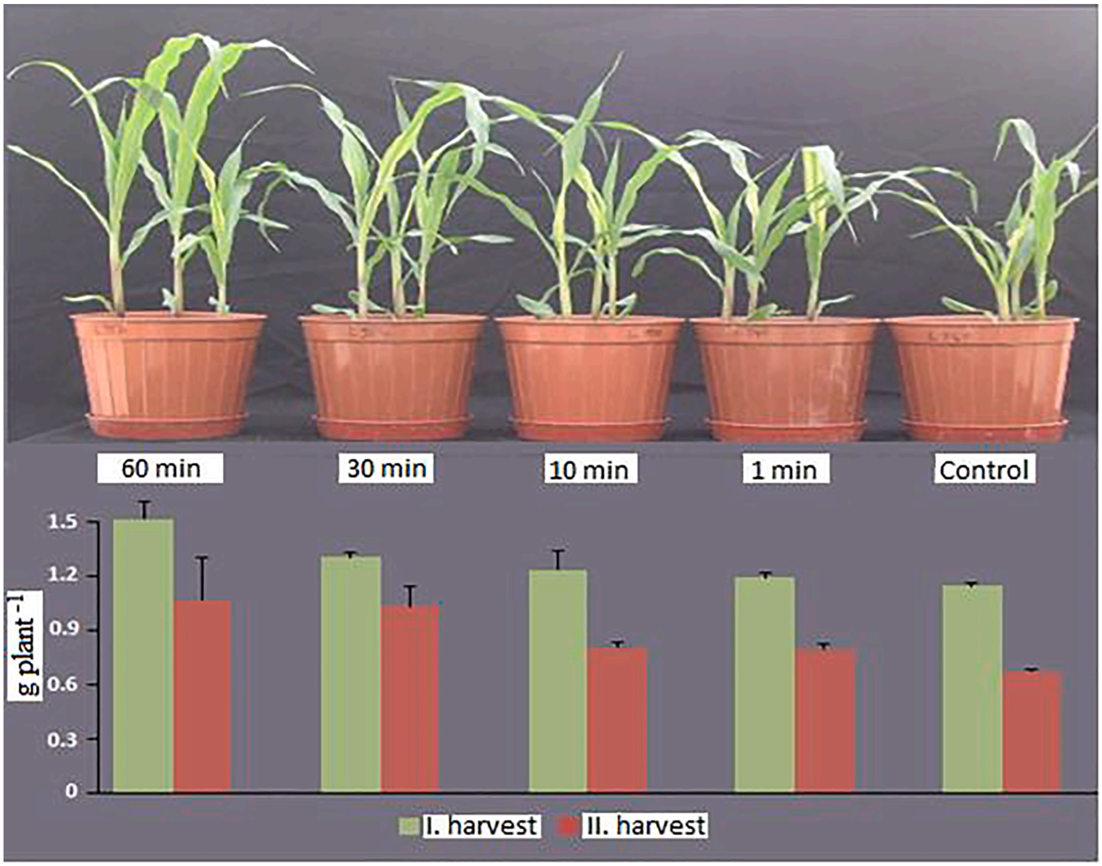

Fig. 1. The influence of different $ZnSO_4$ (5 mM) priming durations on growth and dry matter yield of corn (the plant pictures were taken before 2nd harvest).

Table 3
The impact of different $ZnSO_4$ seed priming durations on dry biomass yield of corn plants grown on Zn-deficit and Zn-sufficient soils.

Treatments	22 days after emergence		28 days after emergence	
	Zn-deficit	Zn-sufficient	Zn-deficit	Zn-sufficient
	(g plant^{-1})			
Dry seeds (control)	0.67 ± 0.01 b	1.58 ± 0.19 a	1.14 ± 0.02 c	1.65 ± 0.12 a
1 min	0.79 ± 0.03 b	1.65 ± 0.08 a	1.19 ± 0.02 c	1.53 ± 0.12 a
10 min	0.80 ± 0.03 b	1.46 ± 0.10 a	1.23 ± 0.11 bc	1.57 ± 0.08 a
30 min	1.03 ± 0.11 a	1.54 ± 0.06 a	1.30 ± 0.03 b	1.69 ± 0.07 a
60 min	1.06 ± 0.24 a	1.64 ± 0.05 a	1.51 ± 0.10 a	1.65 ± 0.10 a
Means (soil types)	0.92 B	1.57 A	1.31 B	1.61 A

Means sharing the same letters within a column are statistically non-significant ($p > 0.05$).

Table 4
The impact of different Zn seed priming durations on shoot Zn concentrations (mg kg^{-1}) of corn plants grown on Zn-deficit and Zn-sufficient soils.

Treatments	22 days after emergence		28 days after emergence	
	Zn-deficit	Zn-sufficient	Zn-deficit	Zn-sufficient
Dry seeds (control)	12.20 ± 1.1 b	31.20 ± 2.8 bc	6.70 ± 0.5 b	20.00 ± 2.0 a
1 min	12.20 ± 0.9 b	30.30 ± 1.6 bc	7.40 ± 1.4 b	20.80 ± 3.0 b
10 min	12.40 ± 0.8 b	26.30 ± 3.9 c	6.90 ± 0.6 b	17.50 ± 1.4 a
30 min	14.00 ± 0.1 a	38.10 ± 3.2 a	6.80 ± 0.5 b	22.10 ± 3.2 a
60 min	14.30 ± 2.4 a	34.90 ± 5.1 ab	8.90 ± 0.9 a	20.00 ± 1.2 a
Means (soil types)	13.10 B	32.40 A	6.90 B	20.10 A

Means sharing the same letters within a column are statistically non-significant ($p > 0.05$).

negative correlation was noted between the dry matter yield of 1st harvest and the Zn concentrations of the 2nd harvest ($r = -0.551$, p 0.05). There was a significant positive association between the dry matter yield at the 2nd harvest and the Zn content during 1st harvest ($r = 0.811$, p0.01).

4. Discussion

The use of Zn-based fertilizers has been shown to enhance the quality and nutritional composition of corn grains. One potential solution to address the Zn deficiency in corn is to enhance the Zn concentrations in the grain without compromising crop yields. Research has shown that the use of Zn-enriched fertilizers during agronomic biofortification lead to an augmentation in the Zn content maize grains, especially when combined with other strategies aimed at improving soil fertility (Gunaratna et al., 2019).

Seed priming is an inexpensive method of providing fertilizers to crop plants, even under adverse conditions (Farooq et al., 2010). Seeds undergo partial hydration during seed priming, which triggers the germination process; however, radicle does not emerge (Farooq et al., 2006a,b,c). Seeds are submerged in aerated liquids and then dried

Table 5
Correlations among chlorophyll index, dry matter yield and Zn concentrations of corn plants grown with different Zn seed priming durations on Zn-deficit and Zn-sufficient soil.

	CI1	DM1	Conc1	CI2	DM2
DM1	0.498				
Conc1	0.418	0.684**			
CI2	0.345	0.110	0.144		
DM2	0.512	0.718**	0.811**	0.135	
Conc2	−0.145	−0.551*	−0.496	−0.056	−0.569*

** = correlation is significant at the 0.01 level (2-tailed), * = correlation is significant at the 0.05 level (2-tailed), DM1 = dry matter yield at 1st harvest, DM2 = dry matter yield at 2nd harvest, CI1 = chlorophyll index at 1st harvest, CI2 = chlorophyll index at 2nd harvest, Conc1 = shoot Zn concentration at 1st harvest, Conc2 = shoot Zn concentration at 2nd harvest.

during priming (Farooq et al., 2012; Rehman et al., 2015). Sed priming with Zn has been reported to improve germination and establishment of chickpea plants (Ullah et al. in 2019). Corn plants subjected to different priming durations exhibited differences in chlorophyll index, dry matter yield, and shoot Zn concentration grown on different soils. The hypothesis that variations in soil types and priming durations would result in different chlorophyll index, dry matter yield, and shoot Zn content was confirmed by the collected data. While the chlorophyll index and dry matter production exhibited significant enhancement in Zn-deficient soil as compared to Zn-sufficient soil, the shoot Zn content was higher in the Zn-sufficient soil. This indicated that although Zn seed priming improved growth, soil application of Zn was necessary to improve shoot Zn concentration. Foliar application and seed priming are used to supply micronutrients to plants, including Zn (Farooq et al., 2018; Rehman et al., 2018a, 2018b, 2018c). Soil application of Zn has been reported to improve grain Zn concentration of different arable crops (Cakmak, 2008; Haider et al., 2018b, 2018a; Rehman et al., 2018c, 2018a, 2018b). Nonetheless, soil-applied Zn is common and successful method to overcome Zn deficiency in soils (Cakmak, 2008; Cakmak et al., 1999, 1997; Liu et al., 2020a; Mohammed and Pekşen, 2020; Ullah et al., 2020b, 2020a; Wissuwa et al., 2008). The results of the current study support prior research indicating that seed priming alone is inadequate for enhancing plant Zn content, necessitating the additional soil application of Zn. Based on current study findings, the application of Zn to soil has been seen to result in an augmentation of Zn levels in grains that have undergone prior biofortification (Yaseen and Hussain, 2020).

The chlorophyll index, dry matter yield and shoot Zn concentrations of corn plants emerging from Zn primed seeds were significantly altered by different priming durations. The Zn deficiency symptoms were primarily associated with a decrease in plant height and leaf elongation and the appearance of light gray necrotic areas on middle-aged leaves (Fig. 1). The Zn deficiency symptoms observed in this study were consistent with those reported in many earlier studies (Aktaş et al., 2006; Harris et al., 2007). The accuracy of various deformations such as stunted growth and interveinal chlorosis were also confirmed by chlorophyll index, shoot dry matter yield and Zn concentration. No significant differences were observed in the severity of Zn deficiency symptoms in plants. It has been reported earlier that Zn deficiency symptoms are associated with Zn content rather than Zn concentration (Daneshbakhsh et al., 2013).

The application of Zn at a rate of 2.75 kg ha^{-1} is used to enhance the development of corn and raise the production of grain in soils that are poor in Zn. The empirical evidence suggests that the introduction of Zn into the soil has a substantial impact on enhancing the Zn absorption in maize grains (Harris et al., 2007). In the same way, seed priming with Zn containing for different time had pronounced effects on dry matter yield (Table 3). Harris et al. (2007) reported that seed priming with Zn is a practical method for better seed germination. Dry matter yield was increased by 4 %, 8 %, 14 % and 32 % with the increase in priming duration compared to the control under Zn-deficit soil. Seed priming along with soil Zn application improved the growth and shoot Zn concentration. Continuous Zn availability around the seeds in soil activated enzymes activation expressed protein synthesis genes, which helped the crop plants to acquire higher Zn concentration (Ullah et al., 2020b). The continuous Zn supply resulted in higher protein synthesis since it is involved in protein synthesis mechanism (Broadley et al., 2007; Rehman et al., 2018b, 2018a). Grain protein and grain Zn are positively associated with each other (Cakmak et al., 2010). The protein synthesis is negatively affected under Zn-deficiency; thus, negatively affecting the growth of plants (Marschner, 2011). Exogenous Zn application, particularly via soil application improves grain protein concentration, which ultimately improves grain mineral contents, fiber and carbohydrates (Ullah et al., 2020b).

5. Conclusion

The results indicated that Zn-priming for 60 min increased chlorophyll index, dry matter yield, and shoot Zn concentration of corn plants. Growth and Zn accumulation in corn was increased with increasing priming duration. However, seed priming alone was inadequate to improve shoot Zn concentration. This might be attributed to the low duration of seed priming. Therefore, future studies with longer priming duration are needed to reach sound conclusions. Nonetheless, the result of the current study suggests that both seed priming and soil application of Zn are required to improve growth and shoot Zn concentration of corn on Zn-deficit soils.

CRediT authorship contribution statement

Inci Tolay: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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