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Response of Maize (*Zea mays* L.) to Seed Priming with Zinc and Boron on nutrient content and their Uptake

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Authors' contributions

Author NS did research trial and wrote the manuscript. Author JNP is major advisor and oversaw all technical and laboratory work performed by the author while conducting the field experiment and composing the literature of this research article. Additionally, he has provided all required tools and equipment's required during the investigation. Author MSA is member of the advisory committee and helped the author. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To study the effect of seed priming with zinc (Zn) and boron (B) on nutrient content and their uptake by maize crop.
Study Design: Randomized block design.
Place and Duration of Study: Field experiment at Research Farm, School of Agriculture, Abhilashi University, Chail Chowk, Mandi, (H.P.), during *kharif* for one year 2023.
Methodology: The experiment was conducted with three replications and seven treatments.

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Results: The data revealed that the highest contents of N, P and K in grains and stover of maize and their uptake by grains, stover and total uptake by maize crop was recorded under treatment T_7 (Seed priming with 0.1% borax), which was at par with treatment T_3 (Seed priming with 0.5% $ZnSO_4$).The highest zinc content in grains and stover of maize was recorded under treatment T_4 (Seed priming with 1% $ZnSO_4$), which was at par with T_3 (Seed priming with 0.5% $ZnSO_4$). While, the boron content in grains and stover of maize was highest in T_7 (Seed priming with 0.1% borax) and it was at par with T_5 (Seed priming with 0.01% borax) and T_6 (Seed priming with 0.05% borax). Whereas, total uptake of zinc by grains, stover was recorded by T_3 (Seed priming with 0.5% $ZnSO_4$), which was at par with T_4 (Seed priming with 1% $ZnSO_4$). While, total uptake of boron by grains, stover by maize crop was maximum in T_7 (Seed priming with 0.1% borax), which was significantly superior to all treatments. However, the minimum content of all these nutrients in grains, stover and their uptake by grains, stover and total uptake by maize crop was found under treatment T_1 (Absolute control).

Conclusion: This study showed that the different micronutrients and their seed priming has significantly affected the content of nutrients and their uptake by maize crop.

Keywords: Maize; seed priming; zinc; boron; nutrient content and uptake.

1. INTRODUCTION

Maize (*Zea mays* L.) is one of the most versatile emerging crops having the wider adaptability under varied agro-climatic conditions. Globally, maize is also known as ‘queen of cereals” because it has a highest genetic yield potential among the cereals. It is a C_4 plant that can effectively utilize the CO_2 even at higher intensity. Maize is the world’s leading staple cereals. Maize was domesticated more than 9,000 years ago in southern Mexico [1]. The global maize area amounts to 197 M ha, including substantial areas in sub-Saharan Africa (SSA), Asia and Latin America [2]. In India, maize crop occupies an area 10.40 million hectare with production of 35.50 million metric tons with an average yield of 3.41 metric tons ha^{-1} [3]. In many countries, maize is an important food crop of humans in many countries, especially in Latin America and a few countries in Asia, where maize crop is consumed as human food and it contributes over 20% of food calories [4]. Maize is a more adaptable and multipurpose crop than wheat and rice. Its primary usage as a feed crop for animals is distinct from its industrial use in developed nations. In terms of the global agri-food system and food nutrition security, maize has a variety of dynamic role [5]. Maize can be used as food, feed, fodder and have industrial value making, it is a farmer’s income boosting crop. It is a highly demanded crop in the world due to its high demanded as poultry feed, food processing, maize-based concentration for livestock population and rising international prices due to diversion of grain of maize towards the biofuel production.

Nutrient management in maize crop involves the managing the amount, source, placement, form and timing of the application of plant nutrients and soil amendments to increase the growth of the plant and yield while minimizing the environmental impact. The cultivation of maize is largely dependent on the proper management of nutrients, with nitrogen, phosphorus, and potassium being the three most important nutrients. Nitrogen is vital for vegetative growth of plant but its mismanagement may lead to leaching of nitrate and emission of greenhouse gases which damages environment. Various nitrogen management practices, including split application during planting and vegetative and reproductive stages, have been helpful. Nitrogen fertilizer affects dry matter production of maize by influencing leaf area development, maintenance and photosynthetic efficiency [6]. Similarly, phosphorus plays a critical role in growth of roots, flowering and grain filling and its deficiency results in poor quality of crop and reduction in the yield. Similarly, potassium is essential for the osmoregulation, enzyme activation and process of photosynthesis and biotic and abiotic stresses.

One of the most important minerals for both people and plants is zinc. It is one of the key players in the metabolism of carbohydrates. It is required for the synthesis of vital plant enzymes and activates the majority of enzymes. Moreover, it starts a range of enzymatic processes [7]. Because zinc is necessary for the synthesis of both proteins and carbohydrates, low zinc levels lead to the buildup of amino acids and a decrease in the amount of sugar in plant tissues. A zinc deficit causes an accumulation of carbohydrates in plant leaves because of several enzymes where zinc is deficient [8]. Furthermore, zinc aids pollination by playing a part in formation of the pollen tube [9]. The deficiency of zinc in plants resulted in many abnormalities that can be noticed as visible symptoms like stunted growth, reduced size of leaves, and chlorosis of leaves and sterility of spikelets.

The micronutrient poverty such as Zn affects the quality of mature and harvested crop products, infection resulting from fungal or disease attack is increased [10]. Zinc is so vital to human health that even a small deficit can have severe effects. Zinc deficiency in human's results in anorexia, appetite loss, loss of taste and smell, and other symptoms that might weaken the immune system or lead to anemia. Deficits in zinc have been connected to problems during pregnancy and labor as well as birth abnormalities in the fetus [11]. The risk is deficiency of zinc dominant in children (under the age of 5 years) because they have higher demands of zinc to complete their growth and for the process of their development [12].

A vital micronutrient for the growth and health of all crops is boron. It is a component of plant cell walls and reproductive organs. In the soil, it is mobile even though it is not in plants. The synthesis of cell walls is one of boron's numerous vital functions in plants. Reduced pollen vitality, unfilled pollen grains, and fewer blooms per plant are often symptoms of boron deficiency. Low boron levels might also prevent roots from growing. Because boron is involved in several metabolic processes, crop output is severely reduced when boron is toxic or deficient. Ahmad et al., [13] reported that the sexual reproduction in plants is more sensitive to boron deficiency as compared to vegetative growth of crops.

Seed priming is a process of regulating the germination process by managing the temperature and seed moisture content. The seed priming is a cost-effective process of supplementation of the micronutrients or we can say that priming is the process of controlled hydration of seeds to a level that permits pre-germinated the metabolic activity of seed. There are several benefits of seed priming and such as: Faster emergence of seed, enables the seed to germinate and emerge even under adverse agro-climatic conditions. The Seed priming also helps in increasing the yield of the crops. According to Koirala [14], seed priming helps in the faster emergence, better and uniform stands, less need for re-sow of seed, provides more vigorous plant, earlier flowering, prior to harvesting and higher staple grain yield in maize. Seed priming is a useful practice, applied prior to planting, which partially hydrates the seeds to a point of germination process initiation, followed by drying which prevents the radicle emergence. The primed seeds show increased germination rate and seedling establishment at suboptimal conditions [15]. The objective of this study was to evaluate the effect of various seed priming with micronutrients Zn and B on maize crop.

2. MATERIALS AND METHODS

A field experiment was carried out at the Research Farm of the School of Agriculture, Abhilashi University, Chail Chowk, Mandi (H.P.) during *Kharif* 2023, situated at 30^0 32' N latitude and 74^0 53' E longitudes, with an elevation of 1391 m above mean sea level. The climate of Himachal Pradesh's Mandi district is moderate in the summer (March to June) and cool in the winter. During the crop growing season the maximum temperature of 36º C and minimum temperature of 15º c was observed. The soil of the experimental field was slightly acidic in reaction, medium in organic carbon, low in available nitrogen and medium in available phosphorus and potassium. The pH of the experimental soil was slightly acidic in reaction, which is 6.30 with an electrical conductivity of 0.08 dS m^{-1}), medium in organic carbon (0.63%), low in available nitrogen (198.61 kg ha^{-1}), medium in available phosphorus (10.37 kg ha^{-1}) and potassium (288.15 kg ha^{-1}), deficient in Zinc (0.86 mg kg^{-1}) and B (0.74 mg kg^{-1}). The spacing for the tested variety (Hybrid corn-9220) was 60 × 20 cm row to row and plant to plant. The experiment was laid out in a randomized block design (RBD) with seven treatments and three replications. The treatments, *viz*, T_1 (Absolute control) T_2 (Seed priming with water), T_3 (Seed priming with 0.5% $ZnSO_4$), T_4 (Seed priming with 1% $ZnSO_4$), T_5 (Seed priming with 0.01% borax), T_6 (Seed priming with 0.05% borax) and T_7 (Seed priming with 0.1% borax). For seed priming the solution of micronutrients (zinc and boron) were mixed in 50 liters of water in which the seed of maize will be soaked for 24 hours before sowing. Plant samples were collected from each treatment after harvest of the crop and they were cleaned and shade dried. Later, the shade dried samples were oven dried at 60 ± 50º C for 24 hours till their weight were constant and the samples then finely powdered using a mixer grinder. The finely grind plant samples were used for the analysis of N, P, K, Zn and B content and their uptake by maize crop. The estimation of the nitrogen content in the plant samples was done by the modified Kjeldahl's digestion and distillation method as described by Jackson [16].The phosphorus content in the plant was determined by the vanadomolybdate phosphoric yellow color method and the phosphorus content in the plant samples was estimated using a spectrophotometer as described by Jackson [16]. Potassium content in plant samples of maize was determined by using a flame photometer [16]. The zinc content in plant samples was determined by di acid method with estimation by AAS [17]. The boron content in samples of maize is determined by using the Azomethine-H method by Gupta [18]. The N, P, K (kg ha^{-1}), Zn, B (mg ha^{-1}) uptake by grains and stover of maize in each treatment was calculated by multiplying the N,P,K (%) and Zn, B (mg kg^{-1}) with yields of grains and stover (q ha^{-1}). The total uptake of different nutrients was calculated after sum of their uptake by grain and stover of maize crop.

3. RESULTS AND DISCUSSION

3.1 Nitrogen (N) Content (%) and Uptake (kg ha^{-1})

The nitrogen content in grains and stover of maize crop were significantly increased by the seed priming treatments in this Table 1 and Fig. 1. However, the mean value of data showed that the maximum N content in grains and stover of maize crop were recorded in treatment T_7 (Seed priming with 0.1% borax), which was statistically at par with T_3 (Seed priming with 0.5% $ZnSO_4$). While, minimum nitrogen content in grains and stover noted under the T_1 (Absolute control). Like T_7 (Seed priming with 0.1% borax) which was significantly on par with treatment T_3 (Seed priming with 0.5% $ZnSO_4$). Whereas, the minimum nitrogen uptake by grains and stover of maize crop was recorded under the treatment T_1 (Absolute control).

The nitrogen content and uptake is increased with Zn and B seed priming which might be associated with the enhanced enzymatic activities. The aim of nutrient seed priming is to increase the nitrogen content along with the priming effect to improve the seed quality and better crop establishment [19]. This is particularly important since seedling growth is maintained by seed mineral nutrient reserves until root uptakes commences supplying the nutrients for grains and stover of crop [20]. The total nitrogen uptake was high in seed priming with boron. B influences nitrogen metabolism and uptake through its effects on enzymes, membrane function, and nutrient interactions. The results are correlated by Asokon [21].

3.2 Phosphorus (P) Content (%) and Uptake (kg ha^{-1})

The phosphorus content and their uptake by maize are shown in Table 2 and illustrated in Fig. 2. The study states that there were significant differences in the P content and their uptake by the grains, stover and total uptake by maize through seed priming with zinc and boron. The highest P content in grains and stover of maize crop was noted under the treatment T_7 (Seed priming with 0.1% borax), which was statistically at par with T_3 (Seed priming with 0.5% $ZnSO_4$). However, the lowest P content in grains and stover of maize was recorded under the treatment T_1 (Absolute control). During the study, the highest P uptake by grains, stover and total uptake by maize crop was recorded under treatment T_7 (Seed priming with 0.1% borax), which was statistically on par with treatment T_3 (Seed priming with 0.5% $ZnSO_4$). Whereas, the minimum P uptake by maize grains, stover and total uptake was observed in treatment T_1 (Absolute control) during field study.

The content and uptake of phosphorus were found higher with seed priming with zinc and boron, which enhance the various enzymatic activity and nitrogen in crop plants which might improve the efficacy of phosphorus absorbing mechanisms and encourages the root growth, which helps in the phosphorus uptake by the crop. Comparable outcomes was also obtained by Farooq et al. [22].

3.3 Potassium (K) Content (%) and Uptake (kg ha^{-1})

The potassium content and their uptake by the maize crop are shown in Table 3 and presented in Fig. 3. The data were significant for applying Zn and B seed priming treatments, according to the analysis of the data. The maximum K content in grains and stover of the maize crop was recorded under the treatment T_7 (Seed priming with 0.1% borax), which was significantly at par with the treatment T_3 (Seed priming with 0.5% $ZnSO_4$). However, the lowest K content in grains and stover of maize was noted under the treatment T_1 (Absolute control).

Table 1. Effect of seed priming with zinc and boron on nitrogen content (%) and uptake ($kg\ ha^{-1}$) by maize crop

S.N.	Treatments	Nitrogen content (%)		Nitrogen uptake ($kg\ ha^{-1}$)		
		Grains	**Stover**	**Grains**	**Stover**	**Total**
T_1	Absolute control	1.06	0.33	29.33	13.00	42.33
T_2	Seed priming with water	1.08	0.39	50.22	22.79	73.01
T_3	Seed priming with 0.5% $ZnSO_4$	1.22	0.47	63.84	32.08	95.92
T_4	Seed priming with 1% $ZnSO_4$	1.10	0.40	51.94	24.26	76.20
T_5	Seed priming with 0.01% Borax	1.12	0.42	54.89	27.04	81.93
T_6	Seed priming with 0.05% Borax	1.11	0.41	53.77	25.24	79.01
T_7	Seed priming with 0.1% Borax	1.24	0.48	66.22	33.80	100.02
SE(m)±		**0.03**	**0.01**	**0.78**	**0.78**	**2.40**
CD (P=0.05)		**0.04**	**0.04**	**5.41**	**2.48**	**7.48**

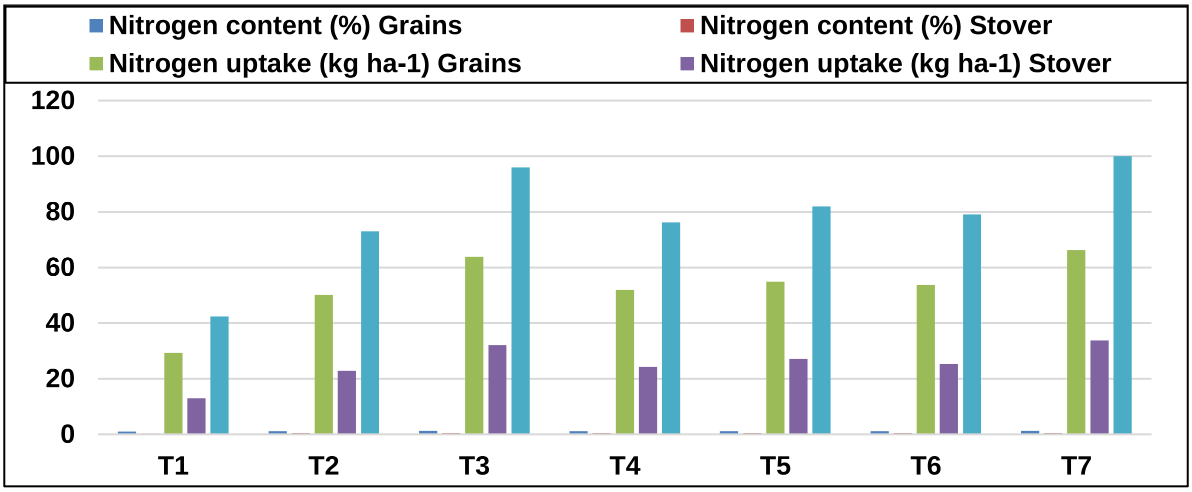

Fig. 1. Effect of seed priming with zinc and boron on nitrogen content and their uptake by maize crop

Table 2. Effect of seed priming with zinc and boron on phosphorus content (%) and uptake ($kg\ ha^{-1}$) by maize crop

S.N.	Treatments	Phosphorus content (%)		Phosphorus uptake ($kg\ ha^{-1}$)		
		Grains	**Stover**	**Grains**	**Stover**	**Total**
T_1	Absolute control	0.11	0.121	3.04	4.77	7.81
T_2	Seed priming with water	0.15	0.123	6.98	7.21	14.19
T_3	Seed priming with 0.5% $ZnSO_4$	0.25	0.145	13.08	9.87	22.95
T_4	Seed priming with 1% $ZnSO_4$	0.17	0.125	8.03	7.58	15.61
T_5	Seed priming with 0.01% Borax	0.20	0.100	9.80	6.39	16.19
T_6	Seed priming with 0.05% Borax	0.19	0.128	9.20	7.88	17.08
T_7	Seed priming with 0.1% Borax	0.26	0.149	13.88	10.51	24.39
SE(m)±		**0.01**	**0.04**	**0.77**	**0.47**	**0.89**
CD (P=0.05)		**0.02**	**0.01**	**2.40**	**1.48**	**2.77**

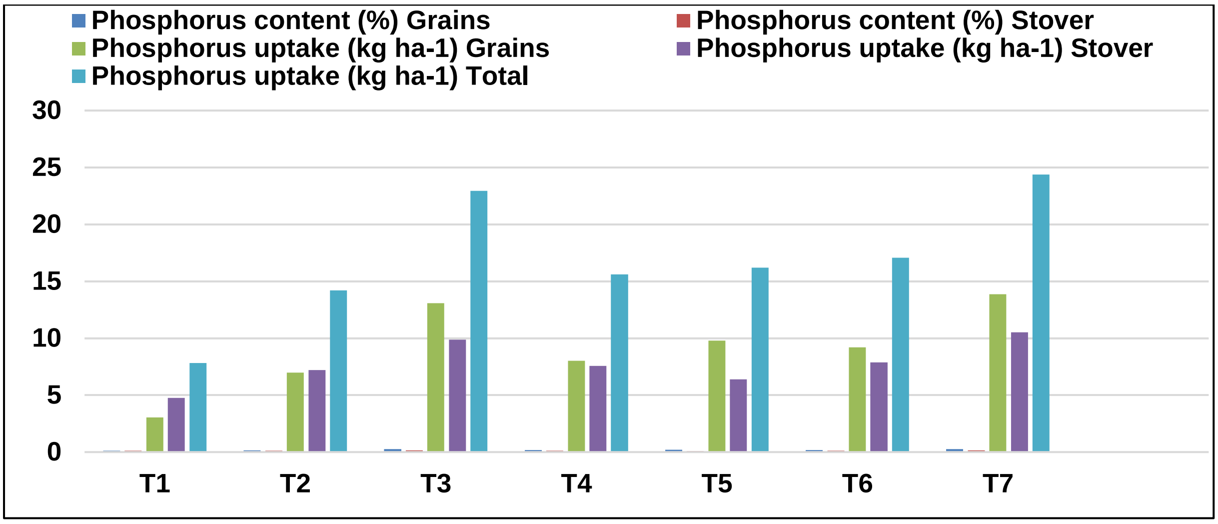

Fig. 2. Effect of seed priming with zinc and boron on phosphorus content and their uptake by maize crop

Table 3. Effect of seed priming with zinc and boron on potassium content (%) and uptake (kg ha^{-1}) by maize crop

S.N.	Treatments	Potassium content (%)		Potassium uptake (kg ha^{-1})		
		Grains	Stover	Grains	Stover	Total
T_1	Absolute control	0.20	1.01	5.53	39.79	45.33
T_2	Seed priming with water	0.25	1.03	11.63	60.18	71.81
T_3	Seed priming with 0.5% $ZnSO_4$	0.36	1.17	18.84	79.63	98.46
T_4	Seed priming with 1% $ZnSO_4$	0.28	1.05	13.22	63.47	76.79
T_5	Seed priming with 0.01% Borax	0.32	1.07	15.68	68.56	84.25
T_6	Seed priming with 0.05% Borax	0.30	1.06	14.53	65.25	79.79
T_7	Seed priming with 0.1% Borax	0.37	1.19	19.76	84.02	103.78
SE(m)±		**0.01**	**0.03**	**1.05**	**1.90**	**2.39**
CD (P=0.05)		**0.03**	**0.09**	**3.27**	**5.92**	**7.46**

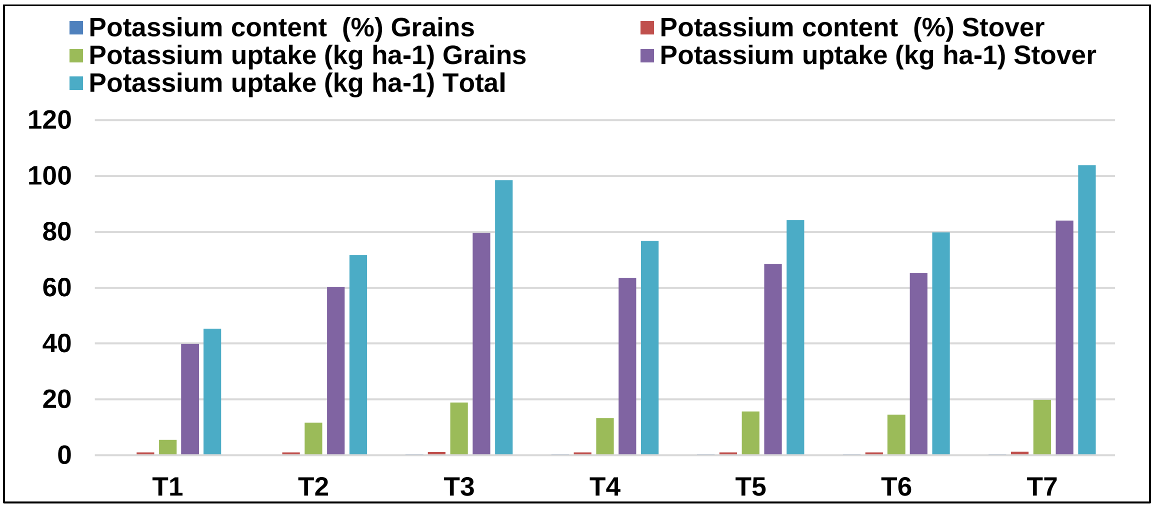

Fig. 3. Effect of seed priming with zinc and boron on potassium content and their uptake by maize crop

The maximum K uptake by grains, stover and total uptake by maize crop recorded under the treatment T_7 (Seed priming with 0.1% borax), which was statistically on par with treatment T_3 (Seed priming with 0.5% $ZnSO_4$) during the period of study. However, the minimum uptake of K in grains, stover and total uptake by maize crop were recorded under the treatment T_1 (Absolute control) during the field experiment.

The potassium content and uptake by maize crop was increased with seed priming of zinc and boron which might be due to the zinc and boron priming stimulated the activity of the different seed enzymes which enhances the content of potassium in maize crop. The similar results were given by Johnson et al. [23].

3.4 Zinc (Zn) Content (mg kg^{-1}) and Zinc (Zn) Uptake (mg ha^{-1})

The zinc content and their uptake by maize crop are presented in Table 4 and illustrated in Fig. 4. According to the data analysis, the application of Zn and B seed priming was significantly impacted by the Zn content of the maize crop's stover and grains.

However, the maximum Zn content in grains and stover of maize crop was recorded under the treatment T_4 (Seed priming with 1% $ZnSO_4$) was statistically at par with the treatment T_3 (Seed priming with 0.5% $ZnSO_4$). While, the minimum Zn content in grains and stover of maize crop were noted under the treatment T_1 (Absolute control) during field study.

The uptake of Zn by grains and stover as well as total uptake was recorded significantly under treatment T_3 (Seed priming with 0.5% $ZnSO_4$), which was on par with treatment T_4 (Seed priming with 1% $ZnSO_4$) during the experiment. However, the minimum Zn uptake by grains, stover and total uptake by maize crop was found in treatment T_1 (Absolute control).

Application of seed priming with Zinc might enhance the root development and enzyme activity, facilitating the absorption of Zn by the crop of maize which might be the reason for higher content and uptake of zinc by maize crop. The results are similar to Shreshta [24].

3.5 Boron (B) Content (mg kg^{-1}) and Uptake (mg ha^{-1})

The use of seed priming with Zn and B treatments during the course of this study had a considerable impact on the amount of B in the grains and stover of the maize crop.

The maximum B content in grains and stover of the maize crop was recorded under the treatment T_7 (Seed priming with 0.1% borax) which was at par with treatment T_5 (Seed priming with 0.01% borax) and T_6 (Seed priming with 0.05 borax).However, the minimum boron content in grains and stover of maize crop were recorded under the treatment T_1 (Absolute control). The uptake of boron by grains and stover of maize crop was recorded significantly higher under the treatment T_7 (Seed priming with 0.1% borax). Whereas, the total uptake of boron was maximum under the treatment T_7 (Seed priming with 0.1% borax). Minimum boron uptake by grains, stover and total uptake of maize crop was noted under treatment T_1 (Absolute control).

Table 4. Effect of seed priming with zinc and boron on zinc content (mg kg^{-1}) and uptake (mg ha^{-1}) by maize crop

S.N.	Treatments	Zinc content (mg kg^{-1})		Zinc uptake (mg ha^{-1})		
		Grains	**Stover**	**Grains**	**Stover**	**Total**
T_1	Absolute control	32.23	35.98	891.79	1417.73	2309.52
T_2	Seed priming with water	37.97	41.86	1765.45	2445.88	4211.33
T_3	Seed priming with 0.5% $ZnSO_4$	47.03	55.36	2463.17	3778.55	6241.72
T_4	Seed priming with 1% $ZnSO_4$	49.14	59.16	2320.55	3587.55	5907.81
T_5	Seed priming with 0.01% Borax	39.48	45.23	1934.91	2889.29	4824.20
T_6	Seed priming with 0.05% Borax	39.56	45.69	1916.29	2812.68	4728.97
T_7	Seed priming with 0.1% Borax	39.61	45.71	2115.17	3218.44	5333.61
SE(m)±		**1.18**	**1.42**	**57.77**	**83.57**	**152.86**
CD (P=0.05)		**3.68**	**4.45**	**179.97**	**260.38**	**476.24**

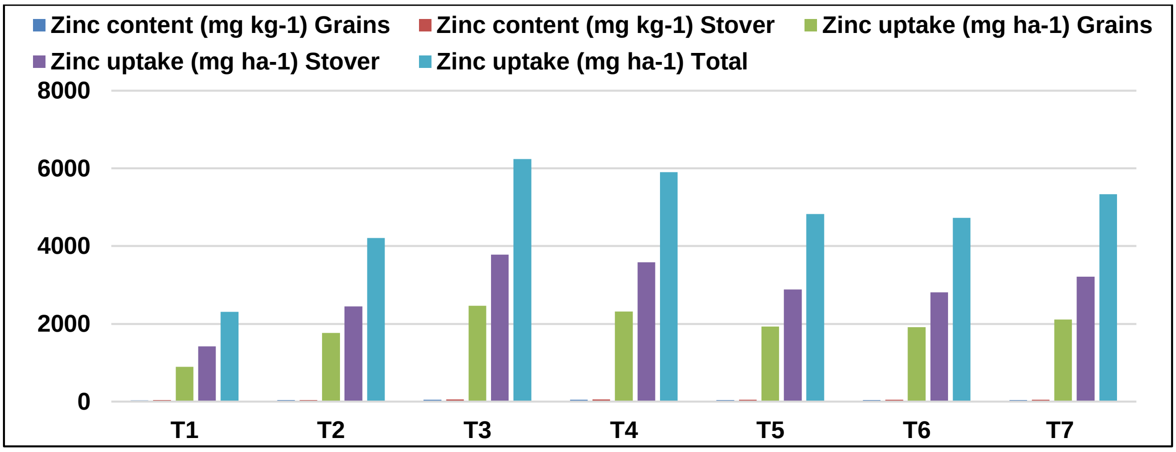

Fig. 4. Effect of seed priming with zinc and boron on zinc content and their uptake by maize crop

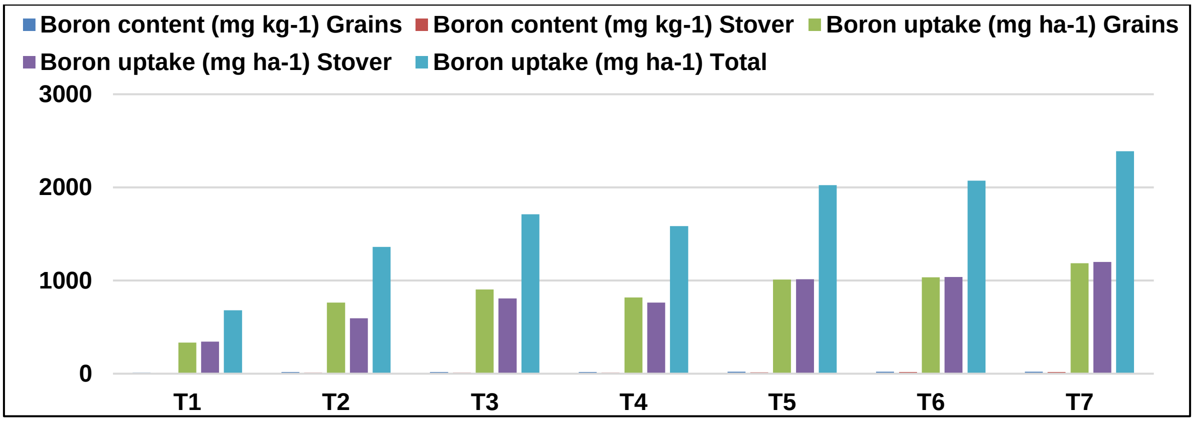

Fig. 5. Effect of seed priming with zinc and boron on boron content and their uptake by maize crop

Table 5. Effect of seed priming with zinc and boron on boron content (mg kg^{-1}) and uptake (mg ha^{-1}) by maize crop

S.N.	Treatments	Boron content (mg kg^{-1})		Boron uptake (mg ha^{-1})		
		Grains	Stover	Grains	Stover	Total
T_1	Absolute control	12.08	8.76	334.25	345.28	679.53
T_2	Seed priming with water	16.45	10.18	764.93	594.82	1359.75
T_3	Seed priming with 0.5% $ZnSO_4$	17.30	11.82	905.48	806.49	1711.97
T_4	Seed priming with 1% $ZnSO_4$	17.34	12.60	818.79	764.06	1582.85
T_5	Seed priming with 0.01% Borax	20.60	15.87	1009.61	1013.78	2023.39
T_6	Seed priming with 0.05% Borax	21.33	16.89	1033.23	1039.75	2072.98
T_7	Seed priming with 0.1% Borax	22.23	17.04	1187.08	1199.86	2386.94
SE(m)±		**0.54**	**0.43**	**27.59**	**26.22**	**53.78**
CD @ 5%		**1.68**	**1.35**	**85.96**	**81.68**	**167.55**

Application of boron with seed priming might enhance the content and uptake of the maize grain and stover, which might due to the boron plays a vital role in hormone metabolism in plants, it plays a role in synthesis and distribution of auxins, affecting the overall growth and yield which might facilitated the higher boron content and uptake. Boron is also essential for cell wall formation and strength. It contributes to the structural integrity of the plant cells, including in the maize. The boron application through seed priming has the content and uptake is higher than the application of Zn seed priming on crop of maize. The similar finding is given by Brown and Shelp [25] [26-29].

4. CONCLUSION

This study concluded that the application of zinc and boron through seed priming at different concentrations showed the significant effects on the content of various nutrients *viz:*- nitrogen, phosphorus, potassium, zinc and boron as well as their uptake by maize crop. The seed priming with 0.1% borax recorded the best values of nitrogen, phosphorus and potassium content in grains and stover of maize crop and this treatment also recorded the highest uptake of these nutrients by grains, stover as well as their total uptake by maize crop and it was statistically at par with the seed priming with 0.5% $ZnSO_4$. The zinc application by seed priming with 1% $ZnSO_4$ noted the higher content of zinc in grains and stover of maize which was on par with the application of seed priming with 0.5% $ZnSO_4$. However, uptake of zinc by grains, stover and total uptake by maize crop found maximum with 0.5% $ZnSO_4$ seed priming and was at par with 1% $ZnSO_4$ seed priming. The highest content of boron in grains and stover of maize crop were observed by 0.1% borax seed priming which was statistically comparable with seed priming of maize with 0.01% and 0.05% borax, however, significantly maximum uptake of boron by grains, stover and total uptake was recorded with 0.1% borax seed priming. Whereas, the minimum content of the nitrogen, phosphorus, potassium, zinc and boron in grains and stover of maize and their uptake by grains, stover as well as total uptake by maize crop were recorded with absolute control treatment during the field experiment.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author (s) hereby declare that No generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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