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Research Article

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Effect of zinc and boron foliar application on tomato growth and yield under protected structure

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ABSTRACT
In modern agricultural practices, enhancing crop growth and yield has become a pivotal focus for ensuring food security and economic sustainability. One promising approach involves the utilization of foliar application techniques, which allow for the targeted delivery of essential nutrients directly to plant tissues. Tomato is the one of most important promising vegetables worldwide which is rich in minerals, vitamins, essential amino acids, sugars and dietary fibers. An experiment was conducted in 2023 at Kernel Agro Farm in Buddhabhumi municipality, Kapilvastu, Nepal. The aim of the study was to optimize the concentration of zinc and boron foliar application on tomato growth and yield related attributes.A randomized complete block design (RCBD) experiment with five treatments and four replications was set up to explore the "Effect of zinc and boron foliar application on tomato growth and yield under protected structures." Treatments included control (no foliar spray), zinc 0.5%, zinc 1%, boron 0.25%, and boron 0.5%. A variety of observations were made, including plant height (cm), flower and fruit numbers, yield (ton/ha), and quality indicators (Total Soluble Solid, Titratable Acidity, and pH). The results revealed a noticeable difference between the treatments in terms of contributing features. Zinc 1% showed significantly superior outcomes for plant height (177 cm), flower and fruit production (63.1), number of fruit(61.3), and yield(40.57 tons/ha). Similar outcomes were also seen for boron at 0.25 percent as compared to zinc1% for yield and yield-attributing features.Boron0.25% showed significantly outcomes for plant height (176cm),flower and fruit production(53.8), number of fruit per plant(50.7) ,and yield(31.32tons/ha). The results for quality parameters were not significant. Therefore, tomato development and production can be improved by applying a foliar spray with 1% zinc and 0.25% boron. Taken together, these results offer valuable insights for tomato growers and agricultural practitioners seeking to optimize crop production in protected structures. Further research could delve deeper into the underlying mechanisms driving these effects and explore potential variations in application rates or timings for even greater outcomes.
Keywords: *Solanum lycopersicum*, effect, yield, quality, foliage application, micronutrients

INTRODUCTION
The tomato (*Solanum lycopersicum*) is one of the world's most important vegetables, with a total production of about 186.8 million metric tons in 2020 (FAOSTAT, 2021). The tomato is one of the most widely cultivated and economically important vegetable crops worldwide (Chaudhari *et al*., 2020). It is grown in all over the world including Nepal due to the diverse soil and climatic conditions (Ahmed and Saha,1976; Agyeman *et al*.,2014).It belongs to the Solanaceae family and is consumed both raw and processed in various forms such as sauces, soups, and salads due to its high nutritional value and culinary versatility (Shukla *et al*., 2017).The tropical region of Nepal provides favorable conditions for tomato cultivation, characterized by warm temperatures and high humidity (Shrestha *et al*., 2017).Tomato is a self-crossing annual crop(Mohamed *et al*., 2010).Antioxidant is an outstanding property of tomato(Borguini and Torres, 2009).The major advantages of protected cultivation is to increase the photosynthesis efficiency rate and decreasing the rate of transpiration (Kumar *et al*., 2017).Through photosynthesis of green plants its yield contributing character, fruit set, and fruit yield of tomato are expanded with the use of foliar application (Adams, 2004).High temperature growing environment conditions cause fruit abscission in tomato (Aung, 1976). To maximize crop yield, nutrient management is essential (Menzel and Simpson, 1987) by enhancing the fruit quality and quantity (Ganeshamurthy *et al*., 2011). Tomato required both macro and micro nutrients to complete its lifecycle (Fageria, 1992; Brady and Weil, 2002).Nutrient deficiencies can significantly impact

tomato growth and yield, leading to reduced productivity and quality. The effect of nanoparticles of zinc oxide in tomato is discovered by reseachers in the recent year (Ahmed *et al*., 2021). Among essential plant nutrients, zinc (Zn) and boron (B) play vital roles in various physiological processes and are crucial for optimal plant growth and development (Singh *et al*., 2020). Zinc is an essential micronutrient required for enzyme activation, protein synthesis, and overall plant growth (Gunes *et al*., 2007). It is involved in various metabolic processes, including chlorophyll production, photosynthesis, and carbohydrate metabolism (Gupta *et al*., 2020). Boron, another essential micronutrient, is necessary for cell division, cell wall synthesis, and pollen germination (Camacho-Cristóbal *et al*., 2008). If the optimum dose of boron is not apply then toxicity effects may appears (Gupta, 1993; Marschner, 1995).Due to deficiency of boron different kinds of disorder are occurs like Shoulder check crack and minimize by the application of boron (Huang and Snapp, 2004).For the regular growth and development of crops the supply of boron is important (Gupta, 1979).Fruit formation and flowering are also influenced by boron(Nonnecke, 1989).

Inadequate availability of zinc and boron in the soil can limit their uptake by tomato plants, resulting in nutrient deficiencies and subsequent negative impacts on growth and yield. Foliar application of zinc and boron has been widely recognized as an effective strategy to enhance nutrient uptake and address deficiencies in crops, including tomatoes (Shukla *et al*., 2017). After utilizing these micronutrients, the yield and quality of tomato is improved (Ali *et al*., 2008).Tomato ranked in third place after cauliflower and cabbage in terms of area covered and production share in Nepal. It covers 22600 hectares and shares 432616 MT of production (MoALD, 2022). To investigate the combined effect of zinc and boron on the growth, yield, and quality of tomato and helps to uplift the productivity of tomato.

MATERIALS AND METHODS

Location of the experiment

The research activities were carried out in the protected structure of Kernel Agro Farm (27.6 ºN, 83.03 ºE), lumbini province, Kapilvastu, Gorusinge,Nepal. The average annual temperature and RH of the location are 25.6 ºC and 60%, respectively (DoHM, 2022). The soil type was sandy loam (Khanal and Bhattarai, 2020).

Source of seed

The tomato cultivar "Gaurabh-555" was obtained from the local agro-vet of Buddhabhumi municipality. Local agro-vet brought the seed from reputable seed suppliers and company. Gaurabha 555 is a highly regarded tomato hybrid variety developed by renowned breeders (Lamsal *et al*., 2022).The purity percentage of those seeds was 98%, and the germination percentage was 91%. The hybrid variety Gaurabh-555 is a semi-determinant type with a tall variety tolerant to tomato yellow leaf curl virus and bacterial wilt, an oval shape, and a bright red color. The fruit weighs about 100–130g.

Seedling raising

Seedlings were grown in a plastic tray inside greenhouse with a mixture of cow dung, cocopeat and sand (1:1:2) on 15 November 2022 and transplanted into well prepared plot inside greenhouse after 30 days of sowing.

Transplanting

Field preparation was done a week before transplanting. Plowing and plots were prepared with the spade and hoe keeping row to row distance 70 cm and plant to plant distance 40cm. Transplanting of 30-day-old seedlings was done on December 15, 2022.The fertilizers were applied at the recommended dose of 100:70:60 NPK kg/ha. The full dose of P and K and 1/2 of N as basal doses are applied during transplanting. The calculated amount of fertilizer, as shown in Table 2 with 2 quintals of FYM, was applied. The remaining N was top-dressed after 45 days of transplanting.

Experimental Design

The experiment was conducted in a randomized complete block design (RCBD) with five treatments and four replications. Therefore, there were a total of twenty plots. Block distances were maintained at 1m. Each plot was separated by 75cm. The total number of plant per plot was 6.

Duration and Method of application of zinc and boron

The calculated amount of zinc 0.5%, zinc 1%, Boron 0.5%and Boron 0.25% were 23.9gm/l, 47.61gm/l, 47.61gm/l and 23.8gm/l respectively and resulted in two liters of water, which was sprayed with hand spray and knapsack spray in the morning. The first spray was done at 40 DAT, i.e., on the 23rd of January, and three more were done at 20-day intervals. The sources of zinc and boron were zinc sulfate (21%), and borax (10.5%), respectively.

Intercultural operation

Pruning was done periodically at a 10-day interval from 40 DAT. Weeding was done before spraying zinc and boron. Similarly, irrigation was frequently done at 3-day intervals. The yellow sticky trap was attached in two different places at the middle of the plant's height for flying insects.

Observation recorded

Data were recorded from randomly selected four plants of each plots at different interval.

Plant Height (cm)

The height of the plant was measure form the bottom to the top of its tallest tiller at 40 DAT, 60DAT, 80DAT and 100 DAT.

Reproductive parameter

Number of flowers were counted at 40DAT, 60DAT, 80DAT and 100DAT. Fruit were counted at 80DAT, 100DAT from the same sample plant, and the mean was calculated. Harvested fruits were weighted in kg and product yield of tomato of each were recorded.

Quality parameters

Quality parameters (Total Soluble Solid, Titratable Acidity, and pH) were observed three times. The first quality parameters were major on the first harvest and two more quality parameters were measured at 10-day intervals. The titratable acidity of tomato juice was estimated by titrating 5 mL of the tomato juice against 0.1N NaOH solution using phenolphthalein indicator until the end point is reached (Tilahun A.Teka., 2013).While TSS was measured by hand with a refractometer and pH was measured using a digital pH meter(Tigchelaar E.C., 1986). The titratable acidity was calculated using the following equation:

$$Percentage\ of\ acid = \frac{mL\ NaOH \times (NaOH)\ 0.0064 \times 100}{(mL\ juice\ or\ g\ Juice)}$$

Where 1ml 0.1M NaOH is equivalent to 0.0064g citric acid. (Tilahun, 2013).

Statistical analysis

All recorded data was entered in Microsoft Excel (2013) and then analyzed according to the technique of analysis of variance(ANOVA)using R Studio (4.2.2) for both descriptive and inferential statistics(Gomez and Gomez., 1984).The means were compared using LSD when F test was found significant (Jan *et al*., 2009).

RESULTS AND DISCUSSION

The study indicate a comprehensive analysis of the effects of zinc and boron applications on various parameters of tomato plants, including plant height, reproductive parameters, and quality parameters. These findings provide valuable insights into how these micronutrients impact the growth, reproduction, and quality of tomato plants.

Plant height (cm)

Zinc and boron applied topically had a substantial impact on the tomato plants' height. At harvest, zinc at 1% (177 cm) and boron at 0.25% (176 cm) showed the highest plant heights while zinc 0.5% and boron 0.5% showed 156 cm and 174cm respectively. In addition, plants' height grew steadily as Zn concentrations in foliar sprays increased (Haleema *et al.*, 2017).

The study demonstrates that the topical application of zinc and boron has a significant influence on the height of tomato plants. Specifically, the plants treated with zinc at 1% and boron at 0.25% exhibited the tallest heights at harvest. This suggests that these concentrations of zinc and boron positively affect the elongation and overall growth of tomato plants. Moreover, a noteworthy observation is that plant height exhibited a gradual increase as the concentration of zinc in foliar sprays increased. This trend suggests a potential dose-response relationship between zinc application and plant height.

Reproductive parameters

Number of flowers/clusters

The maximum mean number of flowers/clusters was found at 80 DAT(52.6) where zinc 1% showed highest number of flowers/clusters 26.9 and 63.1 at 60DAT and 80DAT respectively followed by boron 0.25% showed 14.7 and 53.8 number of flower/cluster at 60 DAT and 80 DAT respectively.Boron0.5% showed 11.8 and 53.4 number of flower/cluster at 60 DAT and 80 DAT respectively.Zinc0.5% showed 21.6 and 50.1 number of flower/cluster at 60 DAT and 80 DAT respectively .Boron nutrition regulates water absorption and carbohydrates metabolism(Haque *et al*., 2011).

The study provides insights into the impact of zinc and boron treatments on the number of flowers and clusters in tomato plants. Zinc at 1% concentration resulted in the highest number of flowers/clusters at specific time points, indicating a potential role of zinc in promoting flowering and cluster formation. Boron at 0.25% also showed positive effects on flower and cluster numbers. This suggests that both zinc and boron play a role in regulating floral development and potentially influencing fruit production

Number of Fruits

The maximum mean number of fruits(49.46) was noted at 100 DAT while a maximum number of fruits(15.8) and (61.3) was noted in zinc 1% followed by zinc 0.5%(14.2) and (39.8) at 80DAT and 100DAT. Boron0.5% showed 10.8 and 48.1 number of fruits at 80 DAT and 100 DAT respectively. Boron0.25% showed 5.94 and 50.7 number of fruits at 80 DAT and 100 DAT respectively. While control treatment showed 11.5 and 47.5 number of fruits at 80 DAT and 100 DAT respectively. The application of boron and zinc enhance the fruit set by delaying the abscisson of flower (Desouky *et al*., 2009). Due to the toxicity of boron, the rates of photosynthesis, cell division and lignin levels are declined (Nable *et al*., 1997; Reid, 2007).

The findings reveal that the application of zinc and boron affects the number of fruits produced by tomato plants. The highest mean number of fruits was observed at a particular growth stage, and zinc at 1% concentration exhibited the maximum number of fruits. This suggests that zinc application might enhance fruit set and development. However, it's noteworthy that both zinc and boron treatments seem to have varying effects on fruit production depending on the concentration and growth stage, indicating complex interactions between these nutrients and the plant's reproductive processes.

Fruit yield

In zinc 0.5% showed 30.54 ton/ha fruit yield while in the boron 0.5% showed the fruit yield (25.90 ton/ha).The maximum yield was recorded in zinc 1%(43.86ton/ha) followed by boron 0.25%(34.83ton/ha) in control plants. The final yield depends on continued supply of food materials. Effect of different doses of B has significant impact on plant height of tomato (Table 3).

The study highlights the impact of different concentrations of zinc and boron on fruit yield. Zinc at 1% concentration resulted in the highest fruit yield, followed by boron at 0.25%. This suggests that zinc and boron application can significantly influence overall fruit production in tomato plants. The findings also emphasize the importance of continued nutrient supply for achieving optimal fruit yield.

Quality parameters

Total Soluble Solids (TSS)

During the development, maturation, and ripening stages, the total soluble solids (TSS) in tomatoes increased. The first TSS was measured on April 23rd, and two more TSS were measured at 10-day intervals. In this study, the TSS content of tomatoes changed from 4.6 Brix° to 5 Brix° in zinc 1% at the 3rd harvest, as shown in Table 4.Similarly, in the control treatment the Brix° value were 3.5,4 and 4 during first ,second and third harvest stage respectively. In boron 0.25% and boron 0.5% treatments the Brixº value was 4 in all harvest stages. In zinc 0.5%, the Brixº values were 3.7,4.3 and 4.5 in the first ,second and third harvest stages respectively .The faster rate at which TSS increases is due to faster metabolic activity through respiration and transpiration (Parmar and Chundawat, 1989) .The activity of the hydrolyzing enzyme was increased by the foliar application of boron (Ben and Gaweda, 1985) and the simple sugars from starch increased(Rani and Brahmachari, 2004).

The study provides valuable insights into the effects of zinc and boron on the total soluble solids (TSS) content of tomatoes during different growth stages. Zinc at 1% concentration led to an increase in TSS content, indicating a potential role in enhancing the maturation and ripening processes. The findings also suggest that boron treatments did not have a pronounced effect on TSS content. The observed changes in TSS content could be attributed to alterations in metabolic activities influenced by these micronutrients.

Titratable Acidity (TA) and pH

The application of Zn and B not affected the TA of tomatoes. It was noticed that zinc 1% (0.61) richer in organic acid while zinc 0.5% (0.41) is poor in comparison to other examined treatment (Table 5). In boron 0.25% and boron 0.5% were 0.49 and 0.47 TA respectively in the third harvest. In zinc0.5%, zinc 1%, boron 0.5% and boron 0.25% treatments the pH value were 4.5, 4.5, 4.5 and 4.5 respectively in all the harvesting stages. So, all the treatment groups and at all tomato harvest stages, the pH value did not vary significantly. Because it prevents the growth of microorganisms and shortens the time required to sterilize the raw material, a range of tomatoes deemed acidic when the pH value is below 4 is crucial (Gratao *et al*., 2008). To ensure the food safety the target pH should be in the range of 4.25 (Anthon *et al*., 2011).Due to the loss in citrus acid, the increasing value of pH was paralleled with decreasing the value of titratable acidity (Tilahun A. Teka, 2013).

Table 1. Plant height (cm) of tomato influenced by foliar application of zinc and boron.

S.N.	Treatment	PH at 40 DAT	PH at 60 DAT	PH at 80 DAT	PH at 100 DAT
1	Control	46.2±2.66	93.8± 5.09^{a}	138± 2.72 ^{c}	159 ±8.15
2	Zinc 0.5%	41.9±3.14	90.7±6.10^{a}	140± 4.18 ^{bc}	156±8.81
3	Zinc 1%	46.6± 2.66	102.3±2.98^{a}	155±2.58 ^{a}	177±5.58
4	Boron 0.5%	46.9± 1.31	97.1±4.85^{a}	149±1.39 ^{ab}	174±2.22
5	Boron 0.25%	45.7± 3.01	97.9±7.33^{a}	143±3.29^{bc}	176±9.85
6	Grand mean	45.45	96.23	145.11	168.31
7	CV	12.09	7.74	3.93	7.99
8	MS error	30.23	55.5	32.65	180.9
9	LSD	8.47	11.47	8.80	20.72
10	F-value	0.55^{ns}	1.287**	5.720**	2.20^{ns}

ns=Non – Significant ,PH= Plant Height ,CV = Coefficient of Variance, DAT = Days after transplanting , Differet letters within columns indicate statistical significance ($p < 0.005$) ,** and * indicate 1% and 5% level of significant respectively.

Table 2. Flowers number of tomato influenced by foliar application of zinc and boron

S.N.	Treatment	Flower at 60 DAT	Flower at 80 DAT	Flower at 100 DAT
1	Control	16.9±2.77^{bc}	42.8±10.3^{b}	2.60±0.53^{ab}
2	Zinc 0.5%	21.6±3.43^{ab}	50.1±8.81^{ab}	1.78±0.22^{bc}
3	Zinc 1%	26.9±3.59^{a}	63.1±16.1^{a}	1.61±0.33^{c}
4	Boron 0.5%	11.8±2.61^{c}	53.4±14^{b}	2.23±0.3^{bc}
5	Boron 0.25%	14.7±3.40^{bc}	53.8±12.9^{ab}	3.33±0.336^{a}
6	Grand mean	18.36	52.6	2.311
7	CV	32.05	30.87	24.06
8	Ms error	34.64	263.9	0.30
9	LSD	9.06	25.027	0.85
10	F-value	4.08*	0.81**	6.15**

CV = Coefficient of Variance, DAT = Days after transplanting , Differet letters within columns indicate statistical significance ($p < 0.005$) ,** and * indicate 1% and 5% level of significant respectively.

Table 3. Fruits number and fruit yield of tomato influenced by foliar application of zinc and boron.

S.N.	Treatment	Fruit No at 80 DAT	Fruit No at 100 DAT	Fruit yield (tons/ha)
1	Control	11.5±1.24^{ab}	47.5 ±6.36^{ab}	24.93±2.65^{b}
2	Zinc 0.5%	14.2±4.21^{a}	39.8±3.52^{b}	30.54±1.92^{b}
3	Zinc 1%	15.8±2.24^{a}	61.3±6.08^{a}	40.57±0.89^{a}
4	Boron 0.5%	10.8±1.28^{ab}	48.1±3.24^{ab}	25.90±1.62^{b}
5	Boron 0.25%	5.94±1.59^{b}	50.7±3.45^{ab}	31.32±1.56^{b}
6	Grand mean	11.63	49.46	30.65
7	CV	29.13	18.28	18.39
8	Ms error	11.50	81.81	31.81
9	LSD	5.22	13.93	8.68
10	F-value	4.92*	2.95*	4.84*

CV = Coefficient of Variance, DAT = Days after transplanting , Different letters within columns indicate statistical significance ($p < 0.005$) ,* indicate 5% level of significant .

Table 4. TSS content of tomato under different micronutrient applications.

S.N.	Treatment	TSS1(ºBrix)	TSS2(ºBrix)	TSS3(ºBrix)
1	Control	3.5	4	4
2	Zinc 0.5%	3.7	4.3	4.5
3	Zinc 1%	4.3	4.6	5
4	Boron 0.5%	4	4	4
5	Boron 0.25%	4	4	4

TSS1= TSS at 1st harvest , TSS2 = TSS at 2nd harvest , TSS3 = TSS at 3rd harvest ,DAT = Days after transplanting.

Table 5. TA content of tomato under different micronutrient applications

S.N.	Treatment	TA1(%)	TA2(%)	TA3(%)
1	Control	0.36 ±0.03^{b}	0.35±0.01^{c}	0.52^{b}
2	Zinc 0.5%	0.44±0.01^{ab}	0.40^{b}	0.41^{e}
3	Zinc 1%	0.46±0.02^{a}	0.48^{a}	0.61^{a}
4	Boron 0.5%	0.41±0.03^{ab}	0.47^{a}	0.47^{d}
5	Boron 0.25%	0.38±0.02^{b}	0.48^{a}	0.49^{c}

TA1=TA at 1st harvest , TA2 = TA at 2nd harvest , TA3 = TA at 3rd harvest ,DAT = Days after transplanting.

Table 6. pH value of tomato juice under different micronutrient applications

S.N.	Treatment	pH 1	pH2	pH3
1	Control	4.1	4.1	4.1
2	Zinc 0.5%	4.1	4.1	4.1
3	Zinc 1 %	4.1	4.1	4.1
4	Boron 0.5%	4.1	4.1	4.1
5	Boron 0.25%	4.1	4.1	4.1

pH1= PH at 1st harvest , pH2 = pH at 2nd harvest , pH3 = pH at 3rd harvest ,DAT = Days after transplanting

The study evaluates the impact of zinc and boron treatments on the titratable acidity (TA) and pH of tomatoes. Zinc at different concentrations exhibited variations in organic acid content, with zinc at 1% being richer in organic acids. The pH values of the treated tomatoes remained relatively consistent across the different treatment groups and harvest stages. This suggests that the application of zinc and boron did not significantly affect the pH of the tomatoes. The maintenance of pH within a specific range is important for food safety and preservation.

CONCLUSIONS

This study demonstrates that zinc and boron applied topically have a substantial impact on plant height, flower and fruit number, and yield. It was discovered that adding 1% zinc and 0.25 percent boron to boost tomato plant growth and yield overall compared to the control. The tomato juice was discovered to have an acidic pH of 4.1, and the greatest TSS capital consists of tomato and TA, which were observed in 1% zinc. Therefore, tomato plants might be sprayed with 1% zinc and 0.25% boron to improve their vegetative and reproductive properties. However, zinc 0.5% produces the large number of fruits than the boron 0.25%.Since, our research finding helps to increase the tomato fruit yield and quality by providing the balance dose of micronutrients.

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CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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