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Research Article

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Understanding the Impact of Zinc and Boron Applications on Growth and Yield Attributes in Potato

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Abstract

Research examines the impact of zinc (Zn) and boron (B) on the growth, and yield of potato plants. The screen house experiment used four treatments: T1 (Control), T2 (Zn 5g/L), T3 (B 2g/L), and T4 (Zn 5g/L + B 2g/L). Growth characteristics were evaluated, such as the emergence percentage, plant vigor, number of stem /meter^2, plant height, and stem diameter. In addition, essential yield metrics such as number of tubers, tuber weight (g), dry matter content, and specific gravity were also assessed. The findings indicated that concurrent administration of T4 had a substantial positive impact on the plant's vitality, height, stem thickness, and stem density per square meter compared to the control group. This suggests a cooperative influence of these micronutrients on the growth of plant structures. However, in terms of yield qualities, the use of Zn alone T2 led to the greatest tuber weight, dry matter content, and specific gravity. Showing that Zn plays a crucial role in maximizing tuber growth and quality. The treatment T4 enhanced yield parameters compared to the control, but it did not exceed the effects of either Zn or B individually in T2 and T3. This emphasizes the intricate interaction between these nutrients. However, when it comes to maximizing yield attributes in potato cultivation, using Zn alone may be more successful. The results indicate that customizing the management of micronutrients could optimize the growth and output of potatoes, hence enhancing agricultural productivity. Additional research is advised to investigate the most effective dosages and combinations.

Keywords: Zinc (Zn), Boron (B), Potato, Morphology, Combination of micronutrients.

Introduction

Potatoes (*Solanum tuberosum*) are grown on about 19.34 million hectares around the world, and 376 million tonnes of them are produced (Lenka, Divya, & Das, 2020). The Pakistani agricultural products are suitable for export and Pakistan grows a lot of potatoes. It has a yearly production of 4.0 million tonnes and is grown across an area of around 170,300 hectares. There are three distinct growing seasons (spring, summer, and autumn) and agroecological zones in Pakistan where this crop is grown. Okara, Sahiwal, Kasur, Sialkot, Sheikhupura, Jhang, Narowal, Pakpattan, Gujranwala, T.T. Singh, Khanewal Depal Pur, and Lahore are all part of the plains areas of Punjab Province that produce more than 86% of the world's potatoes (Faseeh, Ahmed, Farooq, & Asad, 2024). Potato holds significant agricultural value in Pakistan, serving as an important crop for ensuring food security and fostering economic growth. Nevertheless, the traditional techniques employed for seed potato production in Pakistan face numerous obstacles, such as subpar seed quality, low crop yield due to vulnerability to diseases, and excessive water consumption (Naz *et al.*, 2024). Since potato output and quality rely on the usage of micronutrients, it is crucial to include these minerals in the fertilizer schedule to maintain agricultural productivity in modern farming. According to reports, zinc (Zn) and boron (B) have been found to play a special role in increasing potato production among micronutrients (Ahmed *et al.*, 2024; Zewide & Sherefu, 2021). Zinc aids in enhancing the pace of photosynthesis and the movement of photosynthates, resulting in an augmentation in the size and quantity of tubers.

The Pakistani soils are poor in zinc and boron and 20.6% of children have zinc concentrations below 60 g/dL (Younas, Fatima, Ahmad, & Ayyaz, 2023). In Indian soils, zinc is the micronutrient with the highest deficiency rate at 52%, followed by boron at 33% (Lenka & Das, 2019). Boron (B) and zinc (Zn) may strengthen and permeate cell membranes, protecting against fungal infections and increasing agricultural yield (Machado, Steiner, Zuffo, & Machado, 2018). Several enzyme systems, auxins, protein synthesis, seed formation, and maturity need zinc. Several enzyme systems, auxins, protein synthesis, seed formation, and maturity need zinc. Zinc is thought to facilitate RNA synthesis, which is essential for protein synthesis. Zinc (Zn) plays a crucial part in biological systems, acting either as a metallic constituent of enzymes or as a cofactor that contributes to their function, structure, or regulation (Lenka *et al.*, 2020). Boron is necessary for the transportation of sugar, the synthesis of cell walls, the process of lignification, and the metabolism of phenols. Boron has a role in the process of breaking down carbohydrates and building proteins. Dicotyledons have a larger molar need for boron compared to all other micronutrients (Sathya, Pitchai, & Indirani, 2009). The potato crop is viewed as an essential solution to population growth and hunger owing to its capacity to be grown in a broad variety of latitudes and practically all soils and climates, save the equatorial area (Shitikova, Abiala, & Povarnitsyna, 2022; Yali, 2022). The fluctuating weather conditions pose a substantial obstacle to potato agriculture as they heighten the likelihood of crop failure, prolong the growing season, reduce yields, diminish quality, disrupt host-pathogen interactions, and negatively affect insect dispersal and ecology (Ahmed *et al.*, 2024). Therefore, it is imperative to employ adaptation tactics to promote optimal development and maximize production. This study aims to examine the combined effect of Zn and B on disease control, growth, and yield attributes. This will be achieved by applying Zn and B alone and in combination through foliar application at various time intervals under controlled conditions.

Material and Methods

This research was conducted in a screen house at the Horticulture Research Institute (HRI), NARC, during the 2023–2024 cropping season. The potato variety (HRI P2) was grown in three replications. The sowing took place on October 10, 2023. To ensure accurate results, uniform cultural practices were applied across all treatments and replications. The plants were watered as needed to maintain optimal growth condition

Table1. List of treatments with different concentrations of Zn and B and mode of application.

Treatment	Concentration	Mode of Application
T1 (Control)	No Treatment	
T2 (Zn)	Zinc sulfate: 5g/L	1st spray after 1 month of sowing,2nd spray 20 days after 1st spray
T3 (B)	Boric acid:2g/L	1st spray after 1 month of sowing,2nd spray 20 days after 1st spray
T4(Zn + B`)	Zn, 5g/L+ B, 2g/L	1st spray after 1 month of sowing,2nd spray 20 days after 1st spray

Phenotypic parameters

Emergence Percentage: First, count the number of emerging plants until no new shoots appear. Emergence percentage was determined by using the following formula: This percentage reflects the proportion of tubers that successfully produced shoots
.

$$\text{Emergence Percentage} = \frac{\text{Total Number of Tubers Planted}}{\text{Number of Emerged Plants}} \times 100$$

Plant Vigor: To calculate plant vigor, evaluate each plant and assign a vigor score from 1 to 5 based on the scale provided. Average these scores by summing them and dividing them by the total number of plants assessed. This average score indicates the overall plant vigor.

1 = Poor Plant Vigor
2 = Normal Plant Vigor
3 = Good Plant Vigor
4 = Better Growth Vigor
5 = Excellent Plant Vigor

Number of Stems Per Meter Square: To calculate the number of stems per square meter (stems/m²) in potatoes, count the total number of stems (N)) within a measured area (A) in square meters. Then, use the formula:

$$\text{Number of Stems/m2} = \frac{\text{N}}{A}$$

Where:
N = Total number of stems counted within the sampled area.
A = Length of ridge× Ridge to ridge distance

Plant Height (cm): To calculate plant height, measure the height of each plant from the soil base to the tip of the highest leaf in centimeters. Record these measurements, then average them by summing all the heights and dividing by the number of plants measured

Stem Diameter (mm): To calculate stem diameter, use a vernier caliper to measure the diameter of the stem at a specified height, typically just above the soil level. Record the measurement in millimeters (mm).

Number of Tubers Per Meter Square:
To calculate the number of tubers per square meter, count the total number of tubers (N) in a sampled area (A) in square meters. Use the formula:

$$\text{Number of Tubers/m2} = \frac{\text{N}}{A}$$

Where:
N = Total number of tubers counted within the sampled area.
A = Length of ridge × Ridge to ridge distance
This gives the density of tubers per square meter.
Tubers Weight (kg)/m²: To calculate tuber weight per square meter, weigh the total tubers (W) from a sampled area (A) in kilograms. Use the formula:

$$\text{Tuber Weight (kg)/m2} = \frac{W}{A}$$

Where:
W = Total tubers weight (Kg) counted within the sampled area.
A = Length of ridge× Ridge to ridge distance
This provides the average weight of tubers per square meter.
Physiological Parameters
Tuber Dry Matter Content: Five tubers were chopped into one-to-two-centimeter cubes and dried 200 g subsamples from thoroughly mixed chopped tubers were in an oven at 80 °C for three days in two paper bags until a constant weight was attained. Then each sample's dry matter percentage was calculated.
Specific Gravity: First, a sample of tuber was weighed in air, and then it was re-weighed in water to determine specific gravities.

$$\text{Specific gravity} = \frac{\text{Weight in Air}}{\text{Weight in Air} - \text{Weight in Water}}$$

Data analysis: Data analysis was done using Statistix 8.1 software. R language program was also utilized for correlation and PCA analysis.

Results

Growth Parameter: The effect of boron (B) and zinc (Zn) treatments on certain growth parameters of potato plants was investigated. The emergence percentage was significantly dependent on the treatments. It ranged from 92% to 94% (Figure 1A). While a maximum emergence percentage (94%) was seen in T3, followed by T1 and T4 both had an emerging rate of 93%. The treatments affected plant vigor (Figure 1B). While the T2 (Zn 5g/L) and both the T3 (B 2g/L) and T4 (Zn, 5g/L+ B, 2g/L) treatments produced vigor values of 3.9 and 4, respectively, the control group (T1) had the lowest vigor level of 2.9. T4 (Zn, 5g/L+ B, 2g/L) produced the maximum number of stems per square meter an average of 13 stems (Figure 1C). Followed by T2 (Zn 5g/L) produced 12.6 and T 1 (Control) produced 12 stems per square meter respectively, the control (T1) and Zn-only T2 (Zn 5g/L) trailed closely. The treatment T3 (B 2g/L) produced a slightly reduced stem density (9.6 stems per square meter). The T4 (Zn, 5g/L+ B, 2g/L) likewise produced the highest stem diameter (7.2 mm), followed by the control group (T1) with 6.5 mm. The T2 (Zn 5g/L) and T3 (B 2g/L) treatments produced stem diameters of 6.2 mm and 5.8 mm, respectively (Figure 1D). The treatments T4 (Zn, 5g/L+ B, 2g/L) showed a positive impact on the plant height. The maximum height of 60.6 cm was observed in T4 (Figure 1E). The application of T2 (Zn 5g/L) and T3 (B 2g/L) led to plant heights of 59.1 cm and 57.8 cm, respectively. The control group (T1), which had the shortest plants at 54 cm.

Yield Parameter: The number of tubers per square meter differed almost among treatments (Figure 2A). The T1 (Control) and the T2 (Zn 5g/L) both produced 23 tubers per square meter. The T3 (B 2g/L) resulted in a slight increase, with 24 tubers per square meter. The treatment T4 (Zn, 5g/L+ B, 2g/L) produced the most tubers (25 per square meter), indicating that zinc and boron may have an additive influence on tuber production.

The treatments had a considerable impact on tuber weight (Figure 2B), which is a direct measure of yield. The T1 (Control), exhibited the smallest tuber weight, measuring 1.35 kg/m². The application of zinc alone T2 (Zn 5g/L) yielded the maximum tuber weight of 1.93 kg/m², with the T3 (B 2g/L), closely following at 1.88 kg/m². However, when the combined treatment T4 (Zn, 5g/L+ B, 2g/L) was used, there was a significant decrease in tuber weight of 1.77 kg/m² compared to when micronutrients were applied separately.

The tubers' dry matter content exhibited variation in response to the treatments (Figure 2C). T1 (Control) had the lowest dry matter content, measuring at 23.83%. The application of T2 (Zn 5g/L), resulted in a substantial rise in the dry matter content, reaching 29.06%, which was the highest among all the treatments. The use of boron treatment T3 (B 2g/L) led to a significant rise in the dry matter content, reaching 27.9%. Nevertheless, treatment T4 (Zn, 5g/L+ B, 2g/L), exhibited a decrease in dry matter content of 25.3%, which, while more than the control, was still lower than the separate treatments of zinc and boron.
The administration of micronutrients resulted in small increases in specific gravity (Figure 2D), which is a crucial predictor of tuber quality. The specific gravity of T1 (Control) was the lowest, measuring 1.03. The application of zinc T2 (Zn 5g/L), led to the greatest specific gravity of 1.09, with the boron treatment T3 (B 2g/L), closely following at 1.08. The T4 (Zn, 5g/L+ B, 2g/L) resulted in a specific gravity of 1.07, which was lower than the specific gravity of the separate treatments but greater than the control

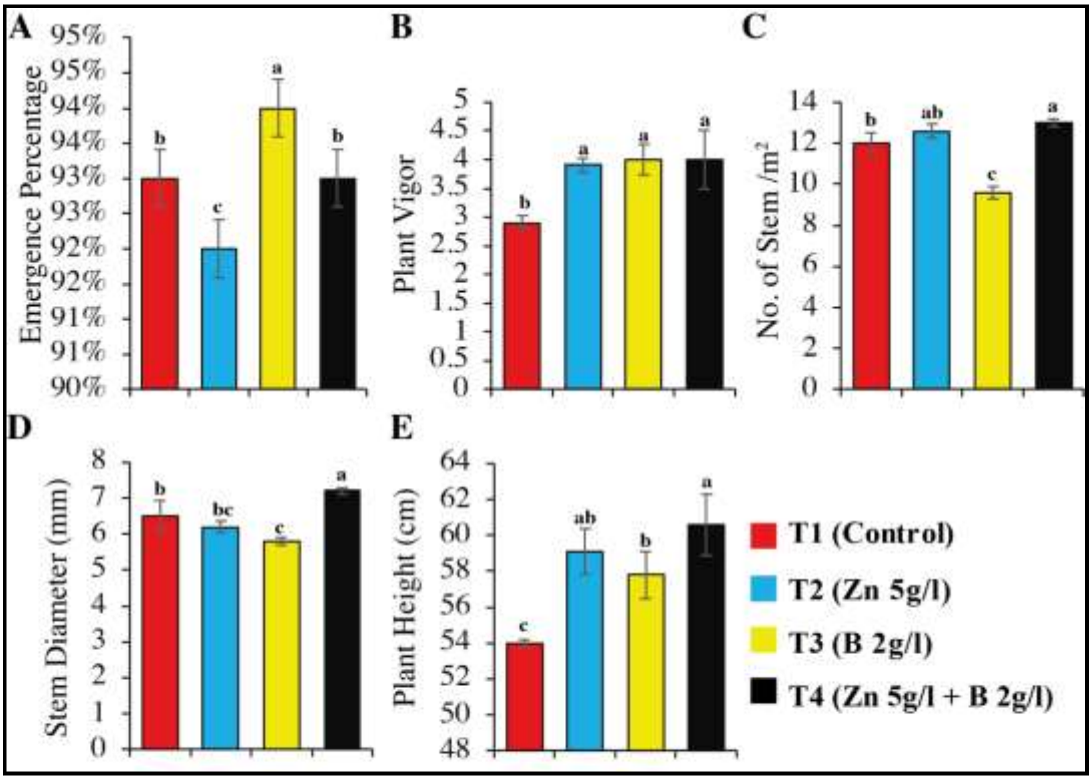

Figure 1. Growth parameters of potato tubers under different treatments of Zinc (Zn) and Boron (B). The least significance differences (LSD) test was used and different small letters above the bars were different from each other ($p > 0.05$).

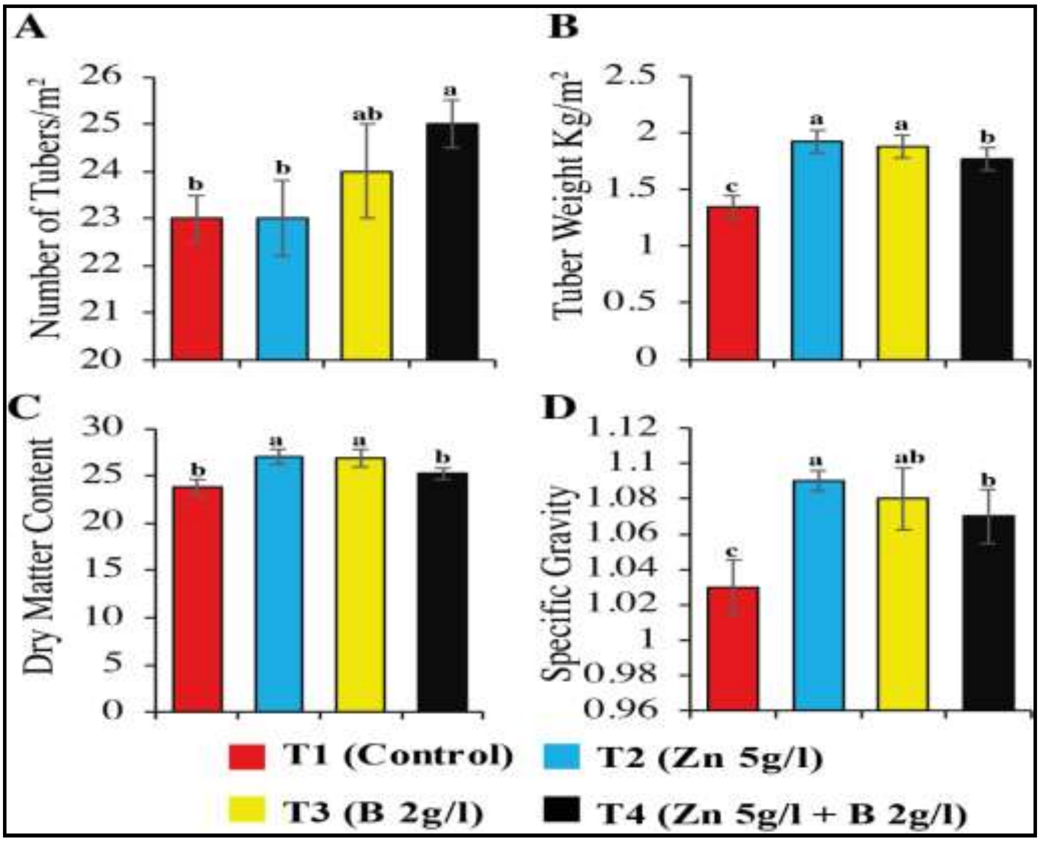

Figure 2. Yield-related parameters of potato under different treatments of Zinc (Zn) and Boron (B).

Association between growth and yield parameters: Correlation and principal component analysis are widely used to study the association between different parameters. So, we also applied these techniques to assess the association between growth and yield parameters under zinc and boron stress. All the study parameters showed association (Figures 3 and 4). DMC shows maximum association (r = 0.96) with SG (Figure 3). Similarly, SD and NOS/m2 were the major contributing factors in the PC1 and the T1 was the best treatment for these traits. For T4, PH, PV, and TW were the best characteristics.

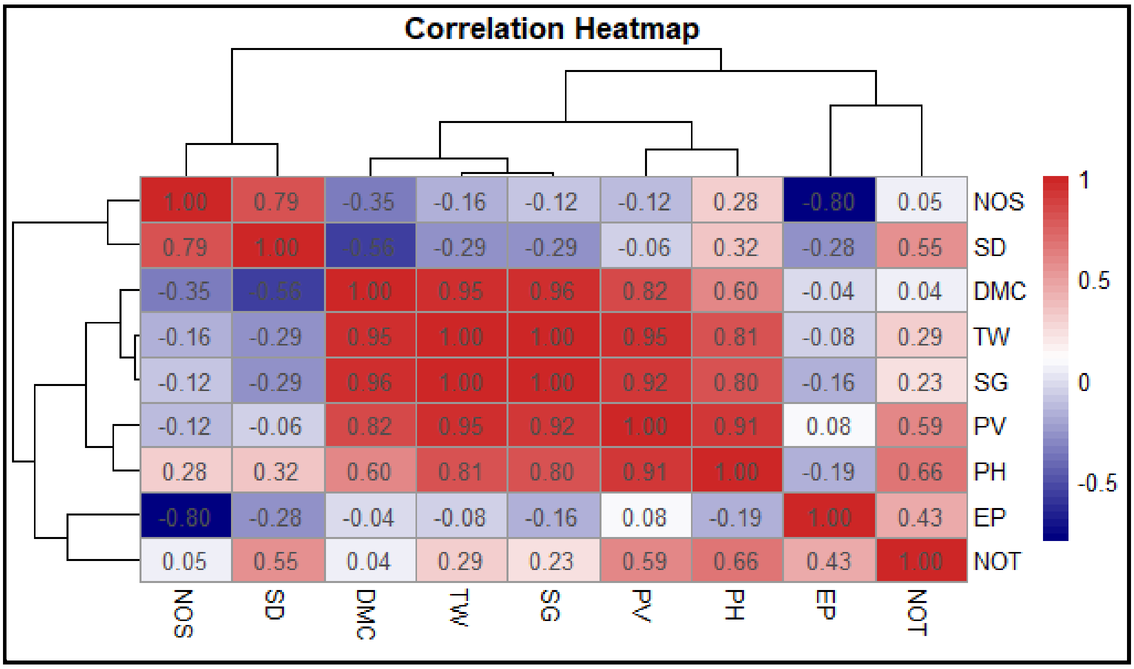

Figure 3. Correlation between potato traits. NOS = Number of stems, EP = Emergence percentage, PH = Plant height, PV = Plant vigor, SG = Specific gravity, TW = Tuber Weight, DMC = Dry matter content, SD = Stem diameter, NOS = Number of stems.

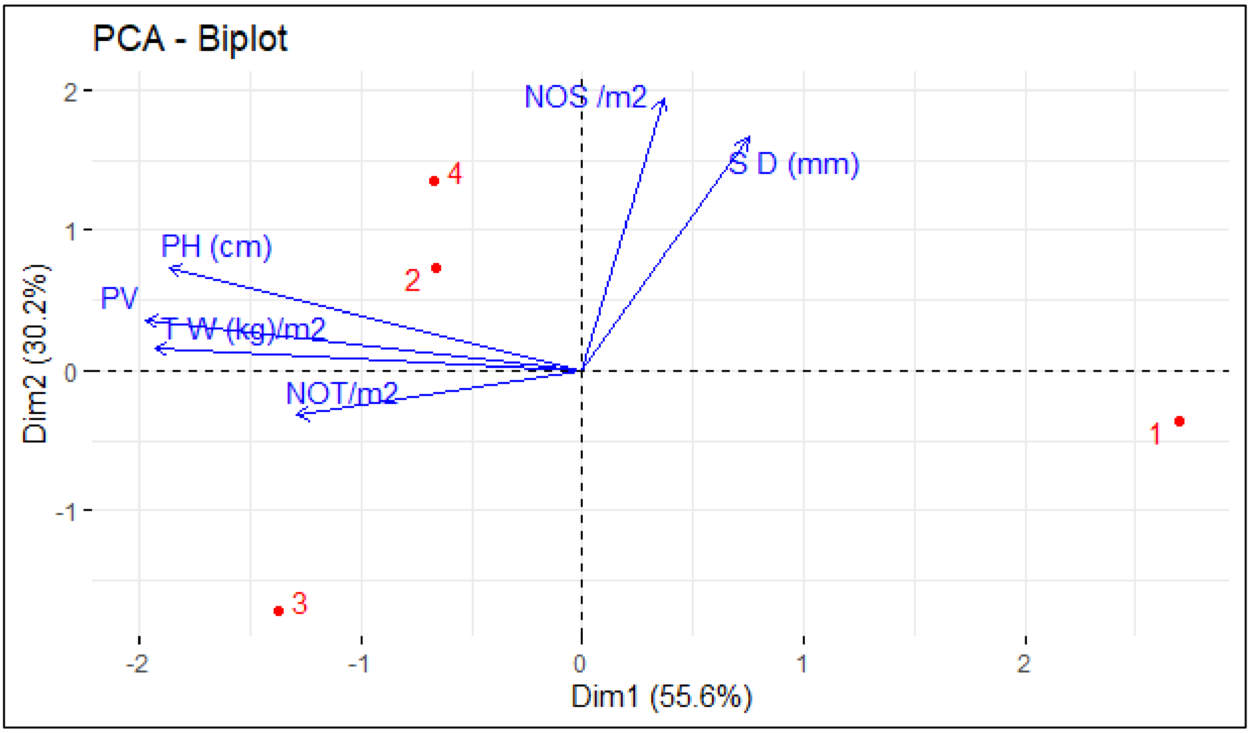

Figure 4. PCA biplot between potato traits under four treatments T 1 (Control), T2 (Zn 5g/L), T3 (B 2g/L), T4 (Zn, 5g/L+ B, 2g/L). NOS = Number of stems, EP = Emergence percentage, PH = Plant height, PV = Plant vigor, SG = Specific gravity, TW = Tuber Weight, DMC = Dry matter content, SD = Stem diameter, NOS = Number of stems.

Discussion

The use of zinc and boron, both alone and in combination, had notable impacts on the growth characteristics of potato plants. The T4 (Zn, 5g/L+ B, 2g/L) was determined to be the most efficacious, resulting in the greatest plant vitality, highest stem density per square meter, highest plant height, and widest stem diameter. This indicates a cooperative impact when both micronutrients are used in combination, most likely because of them. Zinc plays a vital role in enzyme activity, protein synthesis, and growth control. This might be the reason why we observed enhanced plant vigor and stem development in the groups treated with zinc. In a study, it is reported that consistent findings indicate that the application of a combination treatment of Zn+S+B+Mg by spraying resulted in a considerable increase in the number of primary stems per potato plant (Bari, Rabbani, Rahman, Islam, & Hoque, 2001). Zinc treatment increases potato tuber size and quantity per plant, which increases yield (Sati, Raghav, Singh, Singh, & Shukla, 2017). Our research is in accordance with these findings.

However, boron is essential for maintaining the construction of cell walls, the integrity of membranes, and the development of reproductive organs. These factors likely contribute to the increased emergence rate and height of plants treated with boron. complementing functions in plant physiological systems. Boron enhances the rate of photosynthesis by influencing the photophosphorylation process inside chloroplasts. It also alters the hormonal balance in leaves and tubers, particularly the levels of IAA, which is crucial for tuber development after the initiation of tuberization (Puzina, 2004). (Bari *et al.*, 2001) stated that using boron (in the form of borax) improved the total output, the number of tubers per plant, the fresh haulm weight per plant, and the dry matter of the tubers. When boric acid was used to fertilize potatoes, the tubers got bigger and heavier because the cell width in the tubers per medullary zone got bigger.

Boron is essential for sprouting, plant development, and tuber expansion. Soil pH greatly affects B availability. Most B compounds are soluble at low pH, however sandy soil with low pH leaches B down the profile if rainfall is significant. Due to poor B availability in subsoils, drought causes B insufficiency (Prasad, Kumar, Shivay, & Rana, 2014). Notably, although applying T3 (B 2g/L) led to a slightly higher percentage of emergence than the other treatments, it did not increase plant vigor or stem density. This suggests that while B is necessary, it may be more beneficial when used with Zn. The T1 (Control) exhibited worse performance across all assessed metrics, highlighting the significance of these micronutrients in maximizing potato growth and development. The use of zinc and boron has a notable impact on the yield characteristics of potatoes, specifically with tuber weight, dry matter content, and specific gravity.

Although the micronutrient application only led to minor increases in the number of tubers per square meter, the tuber weight significantly increased with the zinc and boron treatments. The results indicate that zinc alone T2 (Zn 5g/L) resulted in the greatest tuber weight, indicating that zinc plays a vital role in promoting tuber growth, maybe via boosting enzyme activity and glucose metabolism. Our findings are supported by (BAJAPAI & Chauhan, 2001) that zinc, boron, and manganese treatments increased okra yield, fresh and dried fruit weight, seed per fruit, and seed weight. Zinc and boron increased litchi plant fruit set, normal fruit, broken fruit, and fruit maturity above control, according to (Gupta, Tripathi, & Shukla, 2022). T3 (B 2g/L) also had a favorable impact on tuber weight, but somewhat less than zinc. The decreased weight of tubers in the combined treatment T4 (Zn, 5g/L+ B, 2g/L). compared to the separate administrations suggests an intricate interplay between zinc and boron, where the combined impact does not result in a straightforward cumulative advantage. Boron fertilization increased tuber number, according to (Sarkar *et al.*, 2018). Zn treatment increased the quality of tuber output for bigger potatoes (A grade) but not for smaller potatoes (D, C, and B), according to (Banerjee *et al.*, 2016). Greater food absorption in reproductive organs raises RNA and DNA contents, therefore stimulating metabolic activity (Sathya *et al.*, 2009). This indicates the need to do more research on the ideal proportions of these micronutrients to get the highest possible crop output. Zn, Mn, Fe, and Cu improved potato yield, dry matter percentage, and yield components (Rashid, 2022). Zinc and boron affect potato production, particularly tuber weight, dry matter content, and specific gravity. Starch, total solids, and mealiness affect potato tuber-specific gravity (Teich & Menzies, 1964). They also found that fertilizer application reduced specific gravity and crop quality. More specific gravity means more dry matter and more produce.

Conclusion

The findings indicated that the applications of micronutrients improved the strength and vitality of the plants, with the most favorable evaluations obtained in treatments T2, T3, and T4. The concurrent application of zinc and boron (T4) resulted in a substantial increase in stem density, plant height, and stem diameter in comparison to the control group. This indicates a synergistic impact of zinc and boron on the development of plant structures. The tuber density, tuber mass, dry matter concentration, and specific gravity were also evaluated. The use of zinc (T2) led to an increase in tuber weight, dry matter content, and specific gravity, demonstrating its crucial function in improving both the production and quality of the tubers. The use of boron treatment (T3) also enhanced these characteristics but to a lower degree. Remarkably, the application of the combination treatment (T4) resulted in a large number of tubers, however, it did not provide the maximum tuber weight or dry matter content. This indicates an intricate interplay between zinc and boron when they are combined. The combination of both zinc and boron had a good effect on the development and yield characteristics of potatoes. However, the combined application of these two elements did not consistently provide better results compared to using them individually. Correlation and Principal component analysis showed that there is an association among the studied parameters. These data indicate that zinc has a significant impact on improving both growth and production, Additional study is required to enhance the synergistic utilization of these micronutrients to maximize both the quantity and quality of potato harvest. This study will provide the basics for future potato breeding programs and the selection of nutrients and their dosages for future research.

Author's contributions

Conceived idea/funding: Raja Mohib Muazzam Naz, Aish Muhammad, Writeup: Haider Ali, Qandeela Nigar, Muhammad Umar analysis /tools: Muhammad Hanif, Waqas Ahmed Dogar, Mushtaq Ahmed, and Khalid Farooq.

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Compliance with Ethical Standards

This manuscript does not contain any studies with humans/animals performed by any authors.

Data Availability Statement

All the relevant data are within the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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