



RESEARCH ARTICLE

Agronomic biofortification of garlic (*Allium sativum* L.) through strategic foliar application of zinc sulphate and borax under subtropical conditions of Jammu

Diksha Rani¹, Manoj Kumar¹, Satish Kumar¹, BR Bazaya², SP Singh³, RK Samnotra¹, Sandeep Chopra¹, Anil Bhushan¹ & Neha Kumari^{1*}

¹Division of Vegetable Science, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu 180 009, Jammu and Kashmir, India

²Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu 180 009, Jammu and Kashmir, India

³Division of Economics and Agribusiness Management, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu 180 009, Jammu and Kashmir, India

*Correspondence email - nehaarajput149@gmail.com

Received: 14 June 2025; Accepted: 21 October 2025; Available online: Version 1.0: 27 January 2026

Cite this article: Diksha R, Manoj K, Satish K, Bazaya BR, Singh SP, Samnotra RK, Sandeep C, Anil B, Neha K. Agronomic biofortification of garlic (*Allium sativum* L.) through strategic foliar application of zinc sulphate and borax under subtropical conditions of Jammu. *Plant Science Today*. 2026;13(sp1):01-13. <https://doi.org/10.14719/pst.10061>

Abstract

Despite the well-known benefits of zinc and boron biofortification in improving nutritional content and quality in garlic, there is no established optimum application approach for zinc and boron micronutrients under Jammu's subtropical climate. Therefore study was carried out to investigate the potential of zinc and boron biofortification in the garlic crop to enhance the nutrient content. The favourable effects of zinc and boron on the productivity and qualitative attributes of garlic underscore the necessity to determine a standardized optimal dosage of these micronutrients. The SJG-16-01 garlic genotype was utilised to optimize crop output. Sowing was done in the month of October with a spacing of 15 × 10 cm. The research comprised 16 treatments, each replicated thrice inside a randomised complete block design (RCBD) during the Rabi season of 2022-23. Zinc sulphate and borax were applied as foliar sprays 45 and 60 days after planting, at doses of 0.25, 0.5 and 0.75 %, both separately and in conjunction. Vegetative growth data were recorded at various time intervals to study the growth of the crop with the application of zinc sulphate and borax. The findings indicated that the application of a combination of zinc sulphate (0.5 %) and borax (0.25 %) twice, at 45 and 60 days post-planting, enhanced the growth, production and quality of garlic as represented by cell plot analysis. Vegetative growth data were recorded at various time intervals to study the growth of the crop with the application of zinc sulphate and borax. The mineral content of zinc and boron was also enhanced with the application of treatments. Nonetheless, the identical treatment concurrently improves the productivity and profitability of the crop in the subtropical circumstances of Jammu.

Keywords: *Allium sativum*; borax; cell plot; foliar application; profitability; quality; zinc sulphate

Introduction

Garlic (*Allium sativum* L.), a diploid bulb in the *Alliaceae* family (2n=16), ranks just behind onion in global allium production. It's commercial bulbs perform best under warm days, reduced relative humidity and good soil drainage. In higher-latitude regions, garlic behaves as a cool-season crop, typically planted in October and lifted by late May. The bulbs' characteristic pungent aroma and flavour arise mainly from diallyl-disulphide (1). Biofortification is a coordinated strategy to lessen crop-associated micronutrient imbalance by supplementing available soil or foliar pools of key elements. Though garlic is widely cultivated, subtropical districts such as Jammu often report suboptimal yield because soils short-change the crop on zinc and boron. Researchers have begun exploring garlic as a biomarker for edible-element fortification, given its documented ability to absorb selenium, zinc and boron after targeted foliar applications (2-4).

Throughout the last 30 years, intensive cropping has resulted in the continual and relentless deployment of high-analysis fertilisers

devoid integrating micronutrients (5). Research on the agronomic biofortification of zinc in garlic under Jammu conditions is of necessary concern, as the soil in this region is deficient in zinc and boron, also with garlic as a staple crop source (6). Soil administration necessitates higher amounts of supplementation to satisfy nutrient demand. Foliar supplementation is an efficient method of achieving what is needed while also enhancing the rate of absorption of nutrients. Agronomic biofortification entails the deliberate use of mineral fertilisers or micronutrient solutions on crops throughout their growth stages, a crucial approach to enhance the nutritional capacity of the crop. A more straightforward method is agronomic biofortification and a pragmatic approach to enhancing micro-nutrient levels in the short term compared to breeding (7). Foliar nutrient supplementation is the most rapid and straightforward method to rectify mineral deficiencies. Foliar application of fertilisers is an efficient technique, especially when a plant's soil nutrient absorption is insufficient for optimal growth (8,9).

Zinc acts as a cofactor in dozens of enzymes, influencing plant growth at several levels. It helps produce tryptophan, the amino acid from which the growth hormone auxin is made and it anchors ribosomes charged with protein assembly (10). Beyond that, zinc participates in making chlorophyll and carbohydrates, supports cytochromes that shuttle electrons and keeps DNA, RNA and nitrogen-metabolism pathways running smoothly (11). Plants take up the element mainly as Zn^{2+} and rely on it to keep activity rates of key enzymes within healthy ranges (12). Plants absorb boron primarily in the form of H_3BO_3 , a process that underpins efficient sugar transport throughout the vascular system (13). The element is additionally involved in cell division and appears to raise calcium availability while promoting starch catabolism. Although soil-borne boron is taken up quickly, the ion moves very little once inside the plant (14). A shortfall, therefore, can hinder the redistribution of carbohydrates, nitrogen and starch and restrict protein synthesis (15). As a consequence, current agronomic trials have turned to targeted biofortification, coupling boron with zinc to enhance garlics' nutritional value.

Materials and Methods

The study was carried out during the 2022-2023 Rabi season at Vegetable Research Farm-I, situated on the main Sher-E-Kashmir University of Agricultural Sciences & Technology (SKUAST)-Jammu campus. A randomised complete block design (RCBD) with three replications was set up, using garlic genotype SJG-16-01 grown in 2 m x 2 m plots spaced 15 cm between rows and 10 cm within rows. SJG-16-01 (SKUAST Jammu Garlic) genotype was collected from the Division of Vegetable Science of SKUAST-Jammu, Chatha, Jammu & Kashmir. Zinc and boron deficiencies have been documented in the soils of Jammu and Kashmir (16, 17). Soil testing before planting showed zinc at 0.53 ppm, rated medium and boron at 0.44 ppm, rated low, values that match previous regional reports on nutrient status. Based on that diagnosis, a range of zinc sulphate and borax concentrations was prepared for foliar application. Treatments were sprayed at 45 days and again at 60 days after planting, following standard timing for garlic in the valley.

The experiment utilized a total of 16 treatments: T₁- control (distilled water spray), T₂- ZnSO₄0.25 %, T₃- ZnSO₄0.5 %, T₄- ZnSO₄ 0.75 %, T₅- Borax 0.25 %, T₆- Borax 0.5 %, T₇- Borax 0.75 %, T₈- ZnSO₄ 0.25 % + Borax 0.25 %, T₉- ZnSO₄0.25 % + Borax 0.5 %, T₁₀- ZnSO₄ 0.25 % + Borax 0.75 %, T₁₁- ZnSO₄ 0.5 % + Borax 0.25 %, T₁₂- ZnSO₄ 0.5 % + Borax 0.5 %, T₁₃- ZnSO₄ 0.5 % + Borax 0.75 %, T₁₄- ZnSO₄0.75 % + Borax 0.25 %, T₁₅- ZnSO₄0.75 % + Borax 0.5 %, T₁₆- ZnSO₄ 0.75 % + Borax 0.75 %. Micronutrient application occurred at 45 and 60 days post-planting, in conjunction with farm yard manure at 20 t/ha and nitrogen: phosphorus: potassium at a ratio of 100:50:50 kg/ha.

The study examined an extensive array of growth, yield, quality and nutritional uptake metrics for garlic subjected to diverse foliar treatments of zinc sulfate and borax. The key growth parameters (plant height, leaf length, number of leaves, leaf area index at 120 days, days to 50 % maturity), yield parameters (neck thickness, bulb weight, polar and equatorial diameter, number of cloves per bulb, weight of cloves, yield per plot and per hectare) and quality parameters (sulphur content, ascorbic acid content, total soluble solids, zinc and boron content in bulbs) were studied. The quality parameters, such as total soluble solids (TSS), ascorbic acid content and sulphur content, were assessed by the method hand refractometer (18, 19). Genotypic and phenotypic correlation analyses was performed to understand trait associations in garlic, also the rank for the treatments was given, highlighting the superiority of specific zinc sulphate and borax foliar treatments represented in cell plot analysis.

Statistical analysis

An analysis was conducted for each parameter utilizing SPSS version 16.0 (SPSS Inc., Chicago, USA). The data were subjected to a two-way analysis of variance for RCBD.

Results and Discussion

Growth parameters

The maximum plant heights of 35.71 cm, 40.56 cm and 59.53 cm were considerably attained with T₃ (ZnSO₄ 0.5 %), as indicated in Table 1. Zinc is crucial for nitrogen and auxin metabolism in plants

Table 1. Influence of foliar spray of zinc sulphate and borax on growth parameters of garlic

Treatment (s)	Plant height (cm)			Leaf length (cm)			Number of leaves			LAI at 120 days	Days to 50 % maturity
	70 days	90 days	120 days	70 days	90 days	120 days	70 days	90 days	120 days		
T ₁	30.93	35.52	52.05	25.25	31.76	46.82	4.87	5.33	6.67	2.27	167.37
T ₂	33.39	38.69	58.56	28.68	33.95	49.55	5.80	6.20	7.60	3.41	164.55
T ₃	35.71	40.56	59.53	30.51	36.49	51.08	6.07	6.40	7.73	3.86	164.44
T ₄	32.90	37.65	57.70	28.05	33.36	48.33	5.73	6.13	7.50	2.97	164.89
T ₅	34.02	39.31	59.30	29.30	35.26	50.39	6.00	6.33	7.70	3.71	167.26
T ₆	33.14	38.42	58.25	28.48	33.91	48.50	5.53	5.93	7.33	3.08	167.33
T ₇	31.64	36.33	55.99	26.88	32.22	47.36	5.47	5.90	7.30	2.54	167.11
T ₈	33.26	38.66	58.34	28.54	32.93	49.21	5.20	5.73	7.13	3.13	165.44
T ₉	32.95	37.99	57.98	28.37	33.47	48.37	5.33	5.80	7.20	2.89	165.55
T ₁₀	32.79	37.37	57.52	27.94	33.06	48.26	5.27	5.77	7.17	2.77	166.00
T ₁₁	33.40	38.81	58.96	28.70	34.34	49.72	5.60	6.07	7.40	3.43	165.22
T ₁₂	33.12	38.20	58.02	28.44	33.53	48.46	5.13	5.67	7.07	2.89	165.00
T ₁₃	32.51	37.30	56.66	27.79	32.88	47.97	5.07	5.60	7.03	2.63	165.33
T ₁₄	32.61	37.35	57.47	27.88	32.93	48.07	5.40	5.87	7.27	2.77	166.11
T ₁₅	32.15	37.16	56.61	27.66	32.80	47.75	4.93	5.40	6.93	2.52	166.66
T ₁₆	31.93	36.98	56.27	27.43	32.33	47.61	5.00	5.40	7.00	2.48	167.00
SEm (±)	0.54	0.53	0.82	0.65	0.50	0.63	0.21	0.15	0.15	0.14	1.24
CD (0.05)	1.56	1.53	2.37	1.87	1.44	1.83	0.61	0.43	0.44	0.42	NS

T₁-Control (Distilled water spray), T₂- ZnSO₄0.25 %, T₃- ZnSO₄0.5 %, T₄- ZnSO₄0.75 %, T₅- Borax 0.25 %, T₆- Borax 0.5 %, T₇- Borax 0.75 %, T₈- ZnSO₄0.25 % + Borax 0.25 %, T₉- ZnSO₄0.25 % + Borax 0.5 %, T₁₀- ZnSO₄ 0.25 % + Borax 0.75 %, T₁₁- ZnSO₄ 0.5 % + Borax 0.25 %, T₁₂- ZnSO₄ 0.5 % + Borax 0.5 %, T₁₃- ZnSO₄ 0.5 % + Borax 0.75 %, T₁₄- ZnSO₄0.75 % + Borax 0.25 %, T₁₅- ZnSO₄0.75 % + Borax 0.5 %, T₁₆- ZnSO₄ 0.75 % + Borax 0.75 %, CD - Critical difference, LAI - Leaf area index

and facilitates plant growth by promoting the synthesis of tryptophan, a precursor of the auxin hormone. Similarly, after 70, 90 and 120 days of planting, leaf lengths of 30.51 cm, 36.49 cm and 51.08 cm were significantly attained with T_3 ($ZnSO_4$ 0.5 %), as indicated in Table 1, due to improved cell division, chlorophyll synthesis and cellular expansion that contribute to increased leaf length of the crop. Leaf elongation causes the plant's leaves to grow longer and taller, reducing water potential levels in the cell wall and facilitating water entry to promote cell elongation (20).

The maximum leaf area index of 3.86 was significantly attained at 120 days post-planting with the identical treatment. The increase was attributed to the maximum total leaf surface area achieved with a greater number of leaves. Zinc in all forms markedly enhanced chlorophyll content, a crucial determinant of leaf area index (21). Days to 50% of maturity of garlic were not affected by the utilisation of zinc (Zn) and boron (B), where the results were found non-significant. The data acquired is reported in Table 1 and the bar graph analysis of growth parameters for each variable is depicted in Fig.1 below. The box plot analysis of growth parameters as influenced by contrasting levels of nutrients is depicted in Fig. 2.

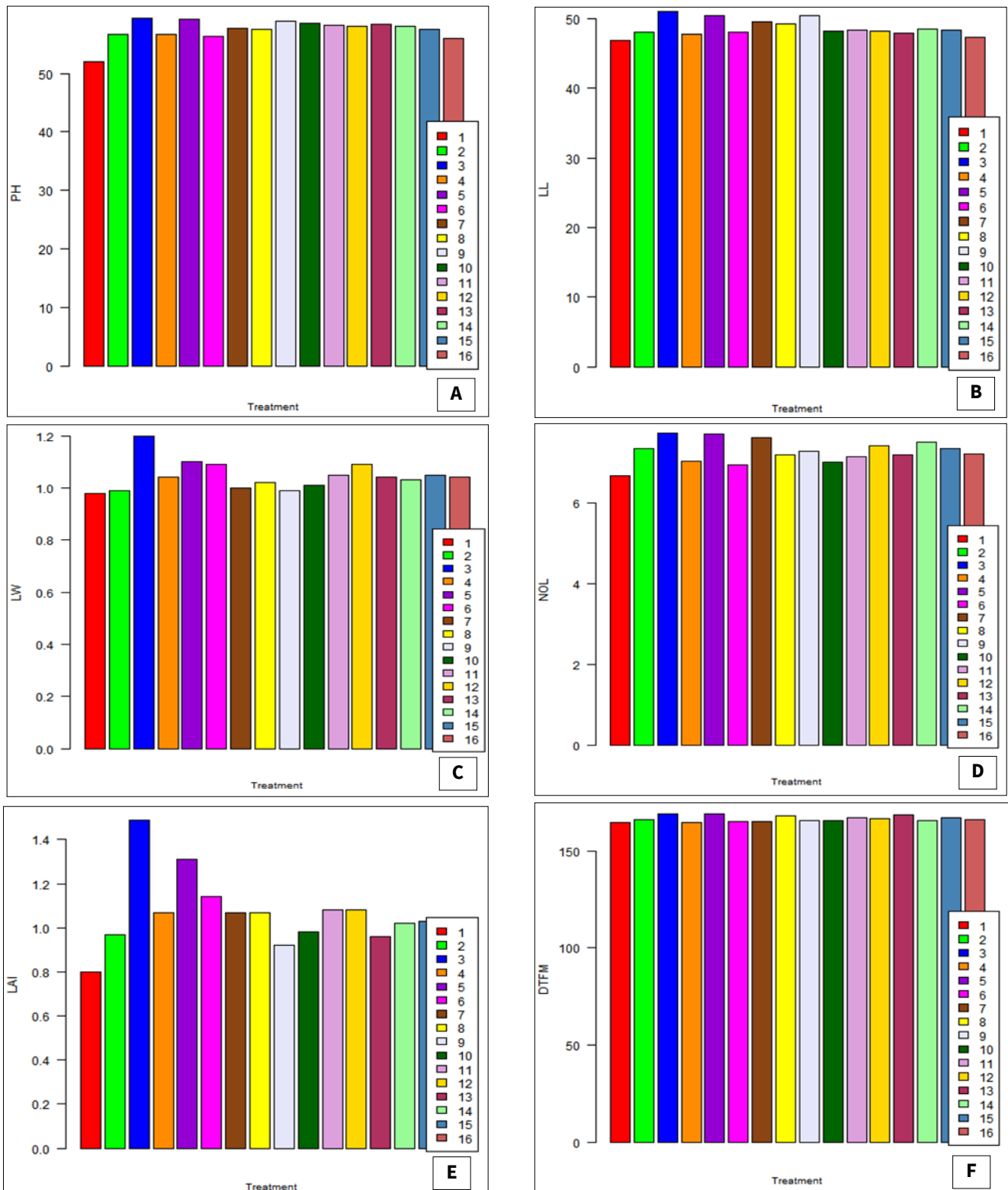


Fig. 1. Bar-graph analysis of growth parameters of garlic: **A.** Plant height, **B.** Leaf length, **C.** Leaf width, **D.** Number of leaves, **E.** Leaf area index, **F.** Days to 50 % maturity.

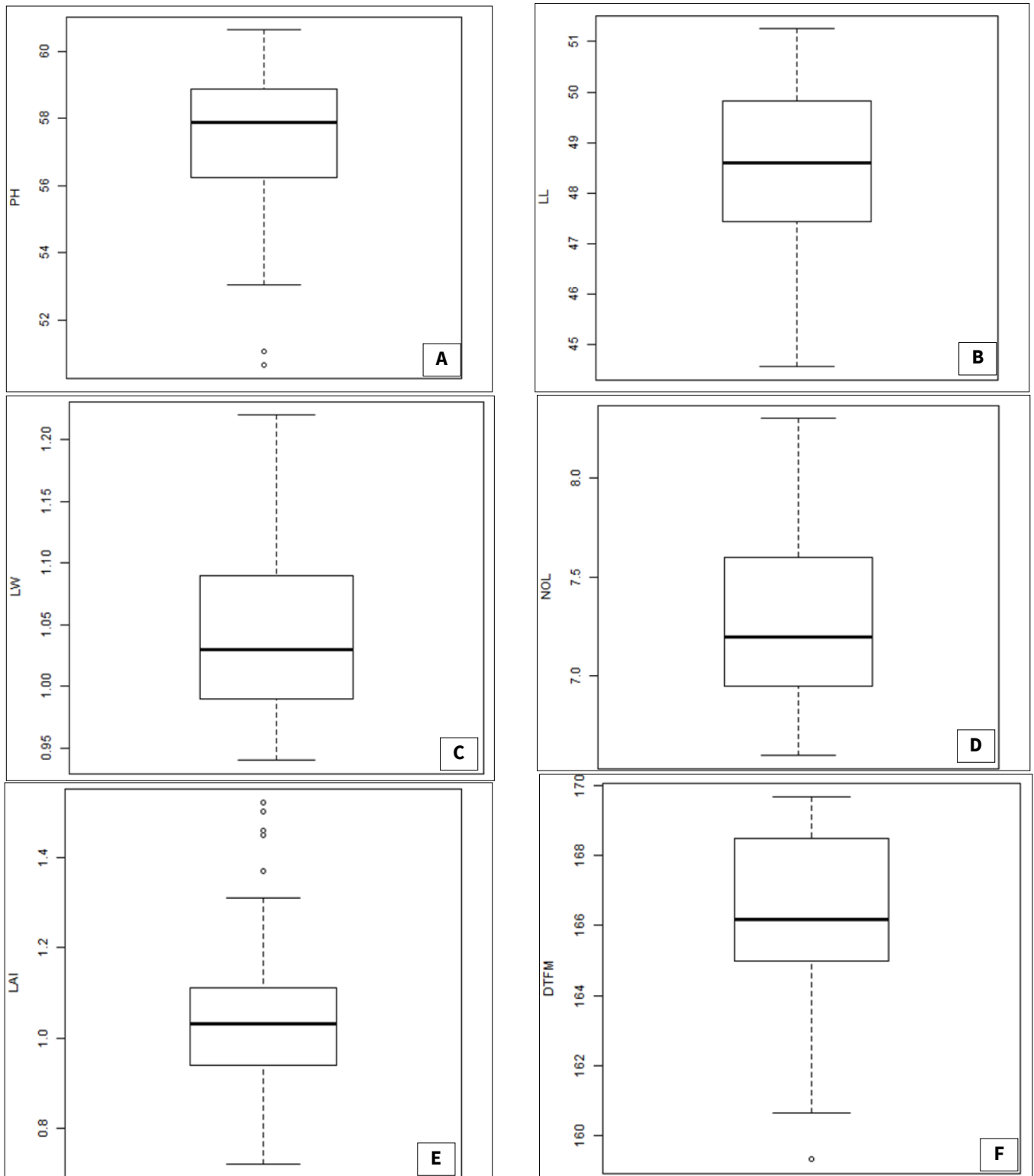


Fig. 2. Box-plot analysis of growth parameters of garlic: **A.** Plant height, **B.** Leaf length, **C.** Leaf width, **D.** Number of leaves, **E.** Leaf area index, **F.** Days to 50 % maturity.

The enhanced accumulation of photosynthates in the bulbs, attributable to a greater number of leaves per plant, caused the thickness of the neck to grow, as seen in Table 1. Consequently, it suggests improved translocation of carbs from the source to the sink. The growth parameter outcomes were consistent with the findings of various research (22, 23).

Yield metrics

The largest neck thickness reported was 1.04 cm with T₁₂ (ZnSO₄ 0.5 % + Borax 0.25 %). This may pertain to enhanced cellular proliferation and nitrogen metabolism. Enhanced fertilisation is

associated with sustained leaf growth, as nitrogen facilitates cell division, hence maintaining a broad neck (24). The optimal bulb weight (31.00 g) was attained with T₁₂ (ZnSO₄ 0.5 % + Borax 0.25 %), attributable to the function of zinc in enhancing photosynthate production in the leaves through augmented photosynthesis, while boron facilitates the translocation of photosynthates to the bulb (Table 2). Likewise, the same treatment yielded the largest number of cloves per bulb (26.30) as well as a 10-clove weight of 11.29 g, as indicated in Table 2. This may be ascribed to the augmented absorption of micronutrients by the growing cloves, resulting from higher photosynthesis and sugar metabolism.

Table 2. Influence of foliar spray of zinc sulphate and borax on yield metrics of garlic

Treatment(s)	Neck thickness (cm)	Bulb weight (g)	Polar diameter (cm)	Equatorial diameter (cm)	No. of cloves per bulb	10 clove weight (g)	Yield (kg)	Yield per hectare (q)
T ₁	0.88	23.46	3.48	3.62	23.35	9.89	2.83	56.30
T ₂	0.96	27.12	3.73	4.17	25.00	10.67	3.27	64.84
T ₃	0.98	27.61	3.96	4.24	25.90	11.04	3.30	66.25
T ₄	0.90	24.77	3.59	3.78	24.00	9.96	3.00	59.44
T ₅	1.00	28.86	4.10	4.28	26.21	11.18	3.47	69.26
T ₆	0.99	28.50	4.03	4.26	26.03	11.13	3.40	68.39
T ₇	0.95	26.99	3.63	4.15	25.77	10.62	3.23	64.77
T ₈	1.02	30.05	3.88	4.30	25.50	10.89	3.60	72.12
T ₉	1.01	29.72	3.85	4.29	25.18	10.73	3.57	71.33
T ₁₀	0.94	26.44	3.59	3.96	24.57	10.47	3.20	63.46
T ₁₁	1.04	31.00	4.20	4.40	26.30	11.29	3.73	74.40
T ₁₂	1.03	30.83	3.92	4.38	26.25	10.93	3.70	74.00
T ₁₃	0.93	26.32	3.60	3.90	24.75	10.55	3.17	63.43
T ₁₄	0.91	24.99	3.57	3.81	24.33	10.33	3.03	59.97
T ₁₅	0.92	25.74	3.56	3.89	23.70	10.22	3.10	61.78
T ₁₆	0.89	24.19	3.53	3.69	23.37	10.16	2.90	58.05
SEm (±)	0.02	0.28	0.09	0.07	0.60	0.29	0.04	0.69
CD (0.05)	0.05	0.81	0.26	0.19	1.75	0.84	0.12	2.00

T₁-Control (Distilled water spray), T₂- ZnSO₄0.25 %, T₃- ZnSO₄0.5 %, T₄- ZnSO₄0.75 %, T₅- Borax 0.25 %, T₆- Borax 0.5 %, T₇- Borax 0.75 %, T₈- ZnSO₄0.25 % + Borax 0.25 %, T₉- ZnSO₄0.25 % + Borax 0.5 %, T₁₀- ZnSO₄0.25 % + Borax 0.75 %, T₁₁- ZnSO₄0.5 % + Borax 0.25 %, T₁₂- ZnSO₄0.5 % + Borax 0.5 %, T₁₃- ZnSO₄0.5 % + Borax 0.75 %, T₁₄- ZnSO₄0.75 % + Borax 0.25 %, T₁₅- ZnSO₄0.75 % + Borax 0.5 %, T₁₆- ZnSO₄0.75 % + Borax 0.75 %, **CD**- Critical difference

The maximal diameter, comprising a polar diameter of 4.20 cm and an equatorial diameter of 4.40 cm, was attained using the same technique as indicated in Table 2. The augmentation of stored carbohydrates resulting from heightened photosynthetic activity caused the bulbs' diameter to grow. The maximum yield of 3.73 kg per plot and 74.40 quintals per hectare was achieved with T₁₂ (ZnSO₄ 0.5 % + Borax 0.25 %). The boxplot of the dataset is presented below as Graph 1. The use of Zn and B enhanced vegetative development and yield-related traits, resulting in increased crop output. Zinc is crucial for the metabolism of plant starch (25). Boron improved the yield by making the transfer easier and concentration of photosynthates produced in the leaves to the developing bulb. The data acquired from various treatments are presented in Table 2. The outcomes were consistent with the findings of various research (13, 22, 26, 27). Fig. 3 illustrates the bar graph analysis for collection of yield metrics for each parameter and the box plot analysis of various yield metrics dataset are illustrated below in Fig. 4.

Quality parameters

In Table 3, as data depicted that T₁₂ (ZnSO₄ 0.5 % + Borax 0.25 %) produced the greatest ascorbic acid level of 11.60 mg/100 g. Micronutrient delivery, participation in enzymatic activities and increased organic acid accumulation in the bulbs all contribute to a rise in ascorbic acid content, which in turn causes the ascorbic acid oxidase enzyme to work more efficiently. The maximum result for TSS with the same treatment was 33.00 °Brix. Zinc is involved in carbohydrate metabolism, boron helps with hydrolysis, metabolite synthesis and photosynthate translocation to the bulb and complex polysaccharides are broken down into simple sugars (28). There were no discernible changes in the sulphur content of the bulbs when different quantities of zinc and boron were applied. Zinc and boron function in tandem; for example, zinc enhances auxin synthesis while boron stabilises cell membranes (13, 26, 29). To maintain fertiliser availability during crucial growth periods, two foliar sprays are applied at 45 and 60 days after planting (DAP). The data obtained for various quality parameters in garlic are represented below in Table 3. Fig. 5 below illustrates the bar graph analysis for the collection of quality parameters for each parameter

and the box plot analysis of various quality parameters dataset are illustrated below in Fig. 6.

Nutrient uptake by the crop

The results suggest that the maximum zinc content is found in treatment T₃ (21.08 kg/ha), in contrast to the control T₁ (12.23 kg/ha), which exhibited the lowest zinc content. These treatments yield enhanced plant growth, disease resistance and bulb development relative to treatments with reduced zinc content, attributable to superior absorption. Similar results were obtained from previous research trials (30). The maximum boron concentration was recorded in T₅ (32.02 kg/ha), while the minimum was observed in the control T₁ (12.27 kg/ha). The data acquired from different treatments are depicted in Table 3 and Fig. 5; also, the box plot analysis is given under Fig. 6. The nutrient uptake outcomes were consistent with the findings of various research (13, 31).

Correlation analysis

The comprehension of the interrelation of diverse characteristics is also substantial as the deciphering of the variation present in the research material. The preponderance of providentially significant features in agricultural plants depends on one or more characters and the extent of a traits' expression varies based on the articulation of other characters and vice versa. Yield is a complex trait that depends on multiple characters because, when selection pressure is imposed to increase other traits, instantaneous changes occur to the economic trait that is not being selected. Therefore, to improve only one character, a breeder must take into account other characters. Similar results were also found in common with (32). Knowing the relationship between the yield and its constituent units is vital since it would reveal essential data regarding the correlation of response to selection. Joint correlation matrix across all traits under study including, plant height, leaf length, leaf width, leaf area index, number of leaves; days to 50 % maturity, neck thickness, bulb weight, number of cloves, weight of cloves, polar diameter, equatorial diameter, yield per plot kg, yield per plot quintal per hectare, total soluble solids, ascorbic acid, sulphur content, zinc content and boron content given in Table 4.

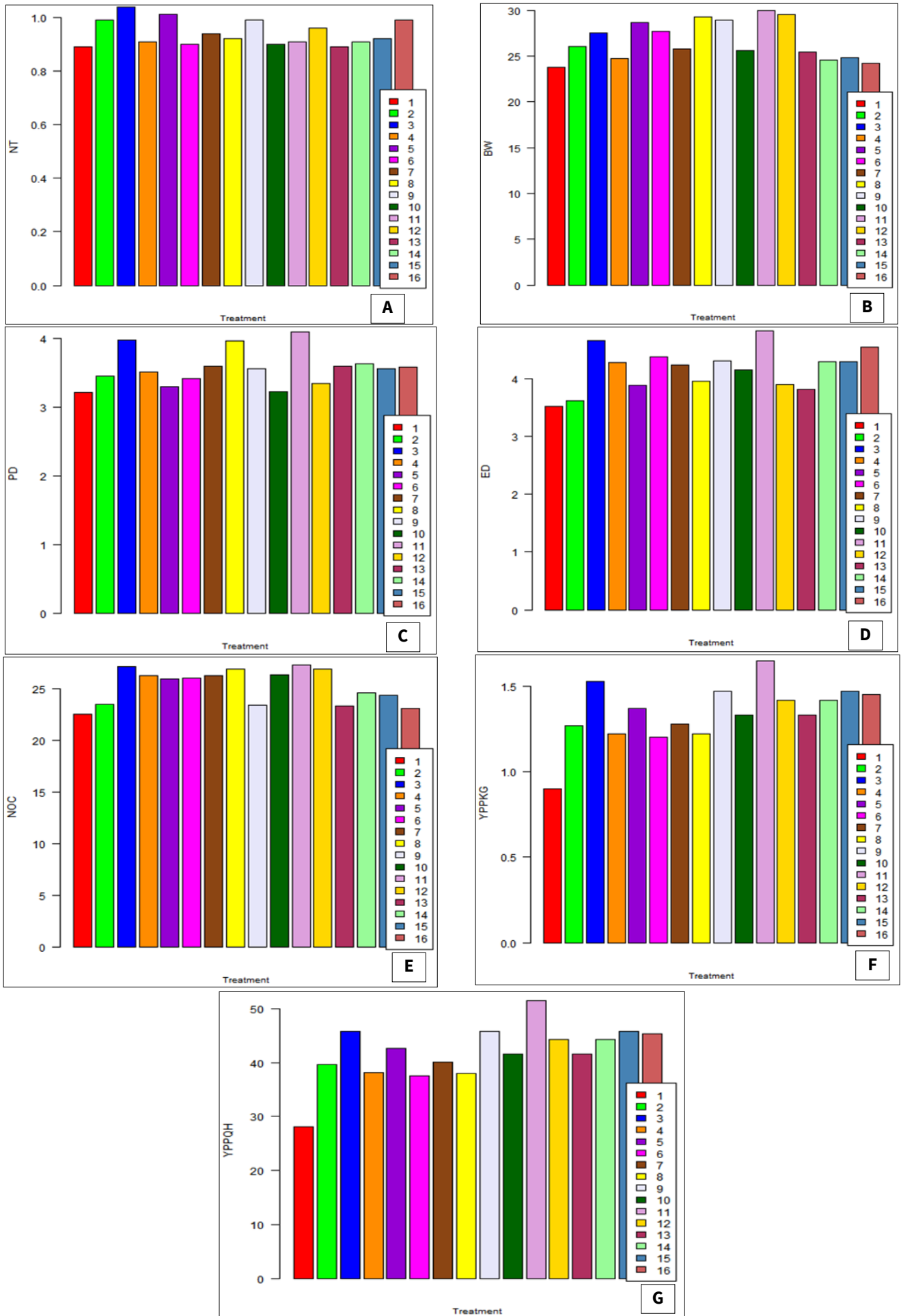


Fig. 3. Bar-graph analysis of yield metrics of garlic: **A.** Neck thickness, **B.** Bulb weight, **C.** Polar diameter, **D.** Equatorial diameter, **E.** Number of cloves, **F.** Yield per plot kg, **G.** Yield per plot quintal per hectare.

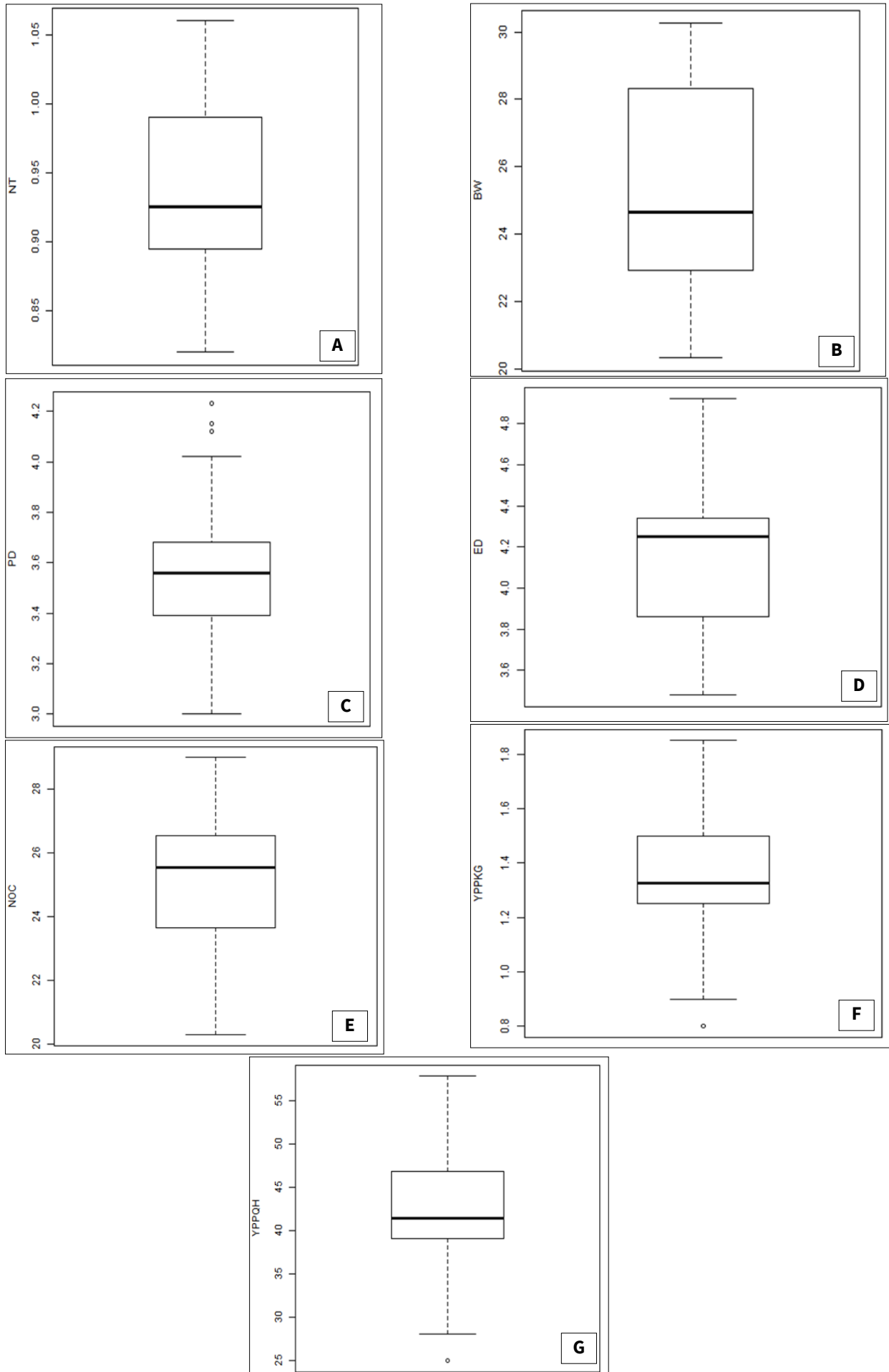


Fig. 4. Box-plot analysis of yield metrics of garlic: **A.** Neck thickness, **B.** Bulb weight, **C.** Polar diameter, **D.** Equatorial diameter, **E.** Number of cloves, **F.** Yield per plot kg, **G.** Yield per plot quintal per hectare.

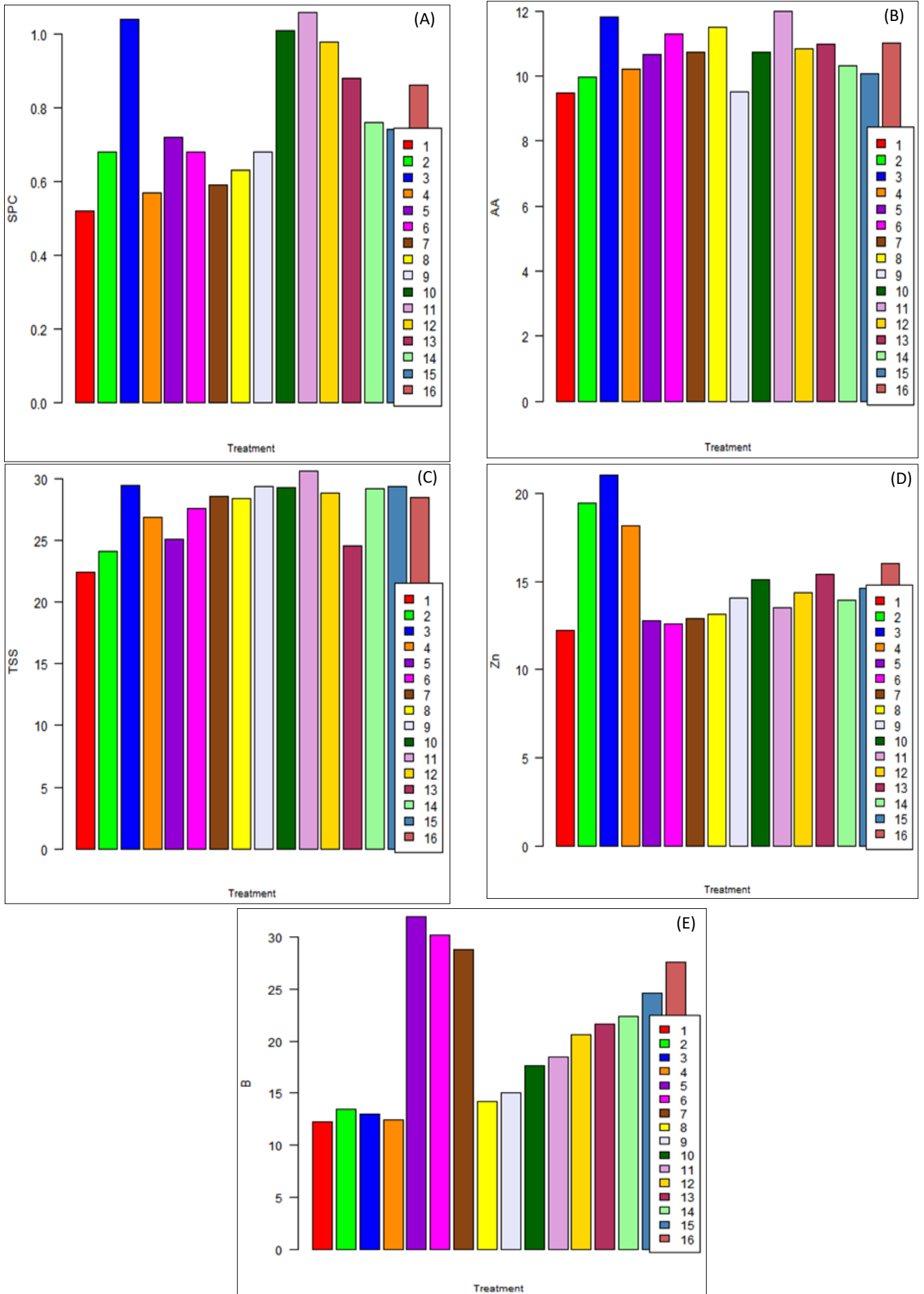


Fig. 5. Bar-graph analysis of quality parameters of garlic. **A.** Sulphur content, **B.** Ascorbic acid content, **C.** Total soluble solids, **D.** Zinc content and **E.** Boron content.

Table 3. Influence of foliar spray of zinc sulphate and borax on quality parameters of garlic and nutrient uptake by the crop after harvest

Treatment (s)	Sulphur content (mg/100g)	Ascorbic acid content (mg/100g)	TSS (°B)	Zinc content (kg/ha)	Boron content (kg/ha)
T ₁	4.67	10.00	29.00	12.23	12.27
T ₂	5.20	10.32	30.73	19.44	13.47
T ₃	5.33	10.75	31.00	21.08	13.00
T ₄	5.27	10.17	29.40	18.20	12.40
T ₅	4.83	11.01	32.00	12.77	32.02
T ₆	4.77	11.01	31.97	12.57	30.20
T ₇	4.67	10.83	31.70	12.93	28.83
T ₈	4.97	11.29	32.51	13.13	14.23
T ₉	5.03	11.16	32.33	14.07	15.00
T ₁₀	5.13	10.32	31.07	15.10	17.67
T ₁₁	5.10	11.60	33.00	13.50	18.50
T ₁₂	5.13	11.51	32.74	14.37	20.63
T ₁₃	5.20	10.98	30.66	15.43	21.63
T ₁₄	5.00	10.23	30.73	13.93	22.37
T ₁₅	4.93	10.23	29.48	14.63	24.60
T ₁₆	4.87	10.08	29.23	16.00	27.60
S.Em (±)	0.16	0.26	0.37	0.20	0.62
CD (0.05)	NS	0.74	1.06	0.58	1.78

T₁-Control (Distilled water spray), T₂- ZnSO₄0.25 %, T₃- ZnSO₄0.5 %, T₄- ZnSO₄0.75 %, T₅- Borax 0.25 %, T₆- Borax 0.5 %, T₇- Borax 0.75 %, T₈- ZnSO₄0.25 % + Borax 0.25 %, T₉- ZnSO₄0.25 % + Borax 0.5 %, T₁₀- ZnSO₄0.25 % + Borax 0.75 %, T₁₁- ZnSO₄0.5 % + Borax 0.25 %, T₁₂- ZnSO₄0.5 % + Borax 0.5 %, T₁₃- ZnSO₄0.5 % + Borax 0.75 %, T₁₄- ZnSO₄0.75 % + Borax 0.25 %, T₁₅- ZnSO₄0.75 % + Borax 0.5 %, T₁₆- ZnSO₄0.75 % + Borax 0.75 %, TSS - Total soluble solids, CD - Critical difference, NS - Non significant

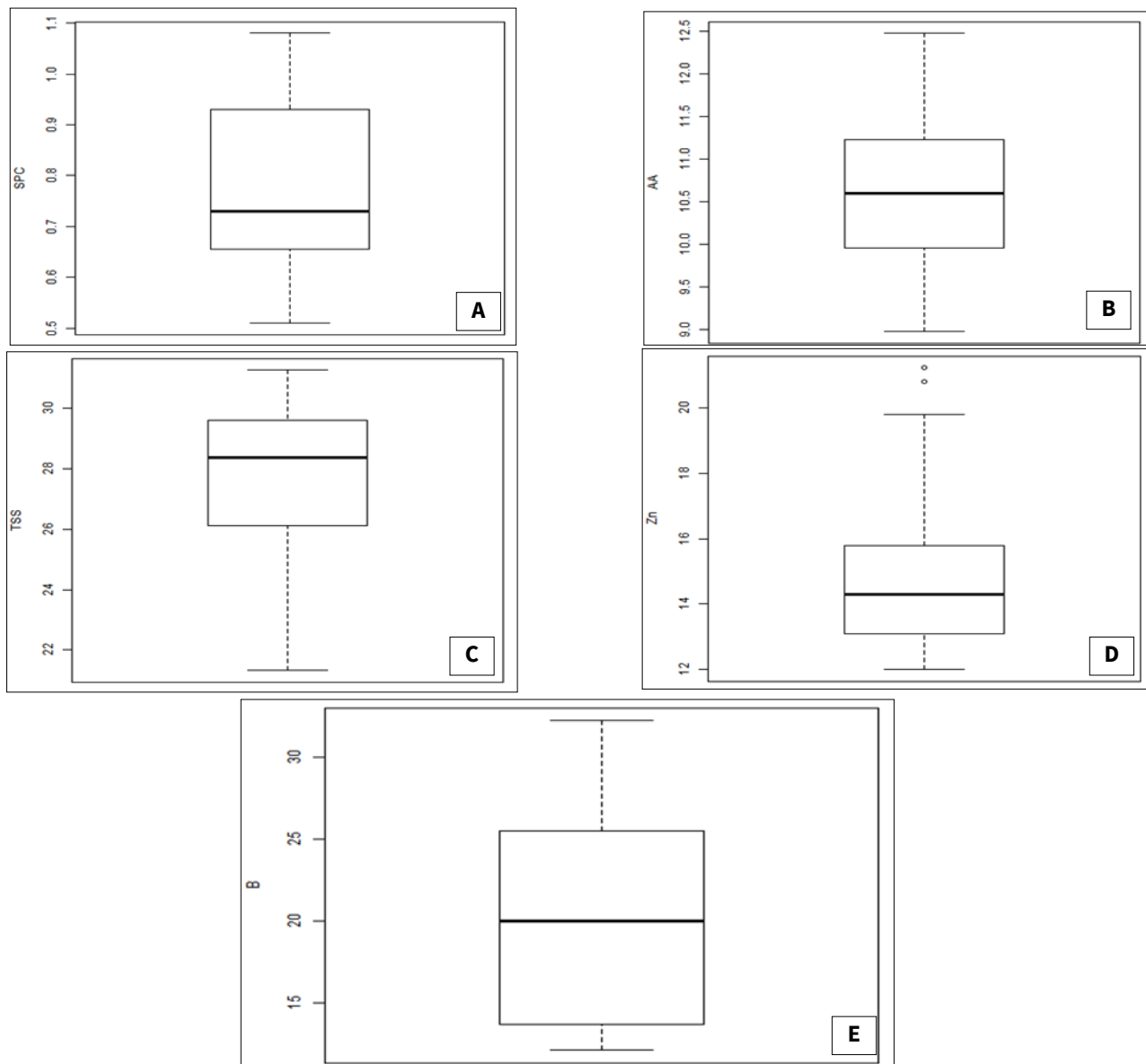
**Fig. 6.** Box-plot analysis of quality parameters of garlic: **A.** Sulphur content, **B.** Ascorbic acid content, **C.** Total soluble solids, **D.** Zinc content, **E.** Boron content.

Table 4. Phenotypic (P) and genotypic (G) correlation coefficients among different characters in garlic

Trait	PH	LL	LW	LAI	NOL	DTFM	NT	BW	NOC	WOC	PD	ED	YPPKG	YPPQH	TSS	AA	SPC	Zn	B
PH	P	1**																	
	G	1**																	
LL	P	0.661**	1**																
	G	0.661**	1**																
LW	P	0.318*	0.253NS	1**															
	G	0.614*	0.732**	0.842**	1**														
LAI	P	0.464**	0.440**	0.979**	0.516**	1**													
	G	0.670**	0.917**	0.459**	0.810**	0.994**	1**												
NOL	P	0.500**	0.436**	0.563*	0.410**	0.344*	0.194NS	1**											
	G	0.909**	1.092**	0.306*	1.03**	0.974**	0.861**	0.194NS	1**										
DTFM	P	0.399**	0.294*	0.306*	0.410**	0.344*	0.194NS	0.194NS	1**										
	G	0.963**	1.086**	1.230**	1.03**	0.974**	0.861**	0.194NS	0.194NS	1**									
NT	P	0.236NS	0.396**	0.386**	0.434**	0.396**	0.861**	0.194NS	0.194NS	1**									
	G	0.577*	0.947**	0.533*	0.717**	0.994**	0.861**	0.194NS	0.194NS	0.194NS	1**								
BW	P	0.405**	0.341*	0.175NS	0.232NS	0.154NS	0.169NS	1**											
	G	0.466NS	0.522*	0.294NS	0.309NS	0.173NS	0.513*	0.239NS	1**										
NOC	P	0.428**	0.242NS	0.3031*	0.450**	0.148NS	0.303*	0.446**	1**										
	G	0.564*	0.593*	0.792**	0.831**	0.455NS	0.238NS	0.612*	0.446**	1**									
WOC	P	0.279NS	0.273NS	0.122NS	0.195NS	-0.125NS	0.075NS	0.141NS	0.155NS	1**									
	G	0.621*	0.527*	0.149NS	0.363NS	0.066NS	0.507*	0.199NS	0.715**	0.155NS	1**								
PD	P	0.315*	0.315*	0.259NS	0.3145*	0.196NS	0.346*	0.102NS	0.264NS	0.4108**	1**								
	G	0.410NS	0.403NS	0.372NS	0.432NS	0.356NS	0.784**	0.179NS	0.350NS	0.631**	1**								
ED	P	0.323*	0.196 NS	0.358*	0.379**	0.188NS	0.032NS	0.150NS	0.167NS	0.520**	0.524**	1**							
	G	0.463NS	0.367NS	0.471NS	0.500*	0.231NS	0.108NS	0.180NS	0.170NS	0.720**	0.666**	1**							
YPPKG	P	0.459**	0.131NS	0.230NS	0.202NS	0.428**	0.091NS	0.306*	0.165NS	0.408**	0.291*	0.553**	1**						
	G	1.101**	0.843**	0.702**	0.703**	0.731**	1.223**	0.585*	0.421NS	0.528*	0.810**	0.871**	1**						
YPPQH	P	0.437**	0.095NS	0.175NS	0.148 NS	0.393**	0.064NS	0.304*	0.987**	0.371**	0.725**	0.521**	0.991**	1**					
	G	1.134**	0.821**	0.651**	0.659**	0.723**	1.213**	0.554*	0.458**	0.521*	0.810**	0.889**	1.002**	1**					
TSS	P	0.404**	0.290*	0.163NS	0.172NS	0.168NS	0.027NS	0.322*	0.402**	0.399**	0.443**	0.744**	0.542**	1**					
	G	0.688**	0.436NS	0.376NS	0.409 NS	0.418NS	0.140NS	0.124NS	0.37 NS	0.596*	0.580*	0.853**	0.939**	1**					
AA	P	0.286*	0.106NS	0.511**	0.513**	0.237NS	0.318*	0.045NS	0.358*	0.197NS	0.439**	0.491**	0.293*	0.277NS	0.336*	1**			
	G	0.514*	0.367 NS	0.736**	0.734**	0.206NS	1.004**	0.093NS	0.480NS	0.772**	0.500*	0.808**	0.585*	0.623**	0.599*	0.527*	1**		
SPC	P	0.457**	0.117NS	0.434**	0.321*	0.196NS	0.301*	0.167NS	0.270NS	0.304*	0.285*	0.454**	0.55**	0.524**	0.479**	0.537**	1**		
	G	0.615*	0.185NS	0.627**	0.432NS	0.282NS	0.786**	0.220NS	0.285NS	0.438NS	0.333NS	0.464 NS	0.9022**	0.9156**	0.5281*	0.658**	1**		
Zn	P	0.177NS	0.103NS	0.299*	0.310*	0.218NS	0.1259 NS	0.285*	0.011NS	0.3527*	0.2018 NS	0.143NS	0.194NS	0.144NS	0.006NS	0.081NS	0.288*	1**	
	G	0.25NS	0.175NS	0.421NS	0.415NS	0.329NS	0.399NS	0.537*	-0.302NS	0.024NS	0.438NS	0.228NS	0.148NS	0.313NS	0.254NS	0.011NS	0.099NS	0.290NS	
B	P	0.13NS	0.034NS	0.137NS	0.182NS	0.256NS	0.048NS	0.036NS	0.045NS	-0.296*	-0.186NS	0.163NS	0.139NS	0.158NS	0.097NS	0.149NS	0.006NS	0.463**	1**
	G	0.208NS	0.09NS	0.226NS	0.265NS	0.363NS	0.101NS	0.061NS	0.058NS	0.063NS	0.39NS	0.218NS	0.177NS	0.266NS	0.108NS	0.213NS	0.006NS	0.47NS	1**

* Significant at 5% level of significance, ** Significant at 1% level of significance, PH- Plant height, LL- Leaf length, LW- Leaf width, LAI- Leaf area index, NOL- Number of leaves, DTBM- Days to 50% maturity, NT- Neck thickness, BW- Bulb weight, NOC- Number of cloves, WOC- Weight of cloves, PD- Polar diameter, ED- Equatorial diameter, YPPKG- Yield per plot kg, YPPQH- Yield per plot quintal per hectare, TSS- Total soluble solids, AA- Ascorbic acid, SPC- Sulphur content, Zn- Zinc content, B-Boron content

Phenotypic correlation of yield per hectare with other traits

The yield per hectare demonstrated a highly substantial and favourable phenotypic correlation, as shown in Table 4, with number of cloves (0.987), equatorial diameter (0.521), polar diameter (0.725), weight of cloves (0.371), bulb weight (0.304), number of leaves (0.393) and plant height (0.437). Additionally, yield per hectare was positively and insignificantly correlated with 0.236 for neck thickness, 0.064 for days to 50 % maturity, 0.148 for leaf area index, 0.175 for leaf width and 0.095 for leaf length. The yield parameter outcomes were consistent with the findings of various research (33).

Association between the other traits

The zinc concentration has a highly substantial and favourable phenotypic association with sulphur content (0.288), weight of cloves (0.3527), bulb weight (0.285), neck thickness (0.393), leaf area index (0.310) and leaf width (0.299). The positive also insignificant parallelism of zinc content with ascorbic acid (0.081) and total soluble solids (0.006). The boron concentration exhibited a positive though non-significant association with all the characters under study except for the weight of cloves (-0.296), for which it shows a negative and significant correlation. Sulphur content shows high significant and positive phenotypic correlation with ascorbic acid (0.537), total soluble solids (0.479), yield per hectare (0.524), equatorial diameter (0.454), polar diameter (0.285), weight of cloves (0.285), number of cloves (0.304), days to 50 % maturity (0.301), leaf area index (0.321), leaf width (0.434) and plant height (0.457). It showed positive and insignificant correlation with bulb weight (0.270), neck thickness (0.167), number of leaves (0.196) and leaf length (0.117).

Ascorbic acid shows high significant and positive phenotypic parallelism with total soluble solids (0.336), yield per hectare (0.293), equatorial diameter (0.491), polar diameter (0.439), number of cloves (0.605), bulb weight (0.358), days to 50 % maturity (0.318), leaf area index (0.513), leaf width (0.511) and plant height (0.286). Total soluble solids shows highly significant and positive phenotypic correlation with yield per hectare (0.521), equatorial diameter (0.744), polar

diameter (0.443), weight of cloves (0.399), number of cloves (0.402), bulb weight (0.322), leaf length (0.290) and plant height (0.404). It showed positive and non-significant correlation with neck thickness (0.110), days to 50 % maturity (0.027), number of leaves (0.168), leaf area index (0.172) and leaf width (0.163). Plant height shows a highly significant and positive phenotypic correlation with leaf length (0.661), leaf width (0.318), leaf area index (0.464) and number of leaves (0.500). Research indicates that similar results were noticed from the research trial (33).

Genetic correlation of yield per hectare with other traits

The genotypic correlation coefficient quantifies the genetic link between characters, assisting in the identification of both the more critical and less critical traits to be taken into account in plant-breeding efforts (34). Research indicates that similar results were noticed from the research trial (33). Table 4 indicates that the genotypic correlation coefficients were predominantly greater in magnitude than the corresponding phenotypic coefficients, inferring that the various traits under study had inheritable associations and that the phenotypic expression of correlation was diminished by the effect of external factors and treatments. The characteristics exhibiting high phenotypic associations also demonstrate significant genotypic correlations with yield per hectare.

Cell plot analysis

In the cell plot analysis, the treatments were ranked based on comparative weightage to the traits recorded (Fig. 7). Treatment T₁₂ (ZnSO₄ 0.5 % + Borax 0.25 %), which is the most effective in terms of number of cloves (NOC), maximum neck thickness (NT), bulb weight (BW), yield per plot kg (YPPKG) and yield per plot quintal per hectare (YPPQH) was ranked higher in cell plot analysis which can be decipher from red cell color of plot. Colours ranging from dark green to pale green also reveal moderate levels for each treatment. The cell plot shows that treatment T₃ (ZnSO₄ 0.5 %) had the lowest value for days to 50 % maturity (DTFM), but there was no significance for bulb weight (BW) and boron content (B). The ranking of treatments in

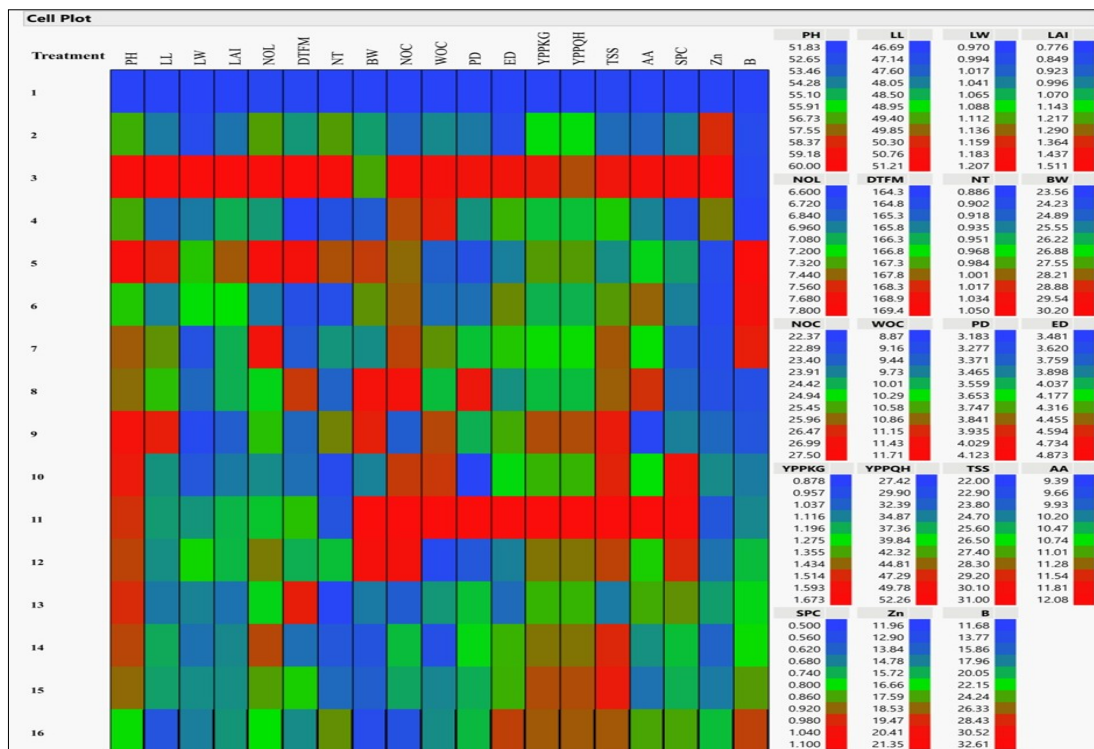


Fig. 7. Cell plot analysis of different treatments given to garlic for various traits under study.

relation to other features might be seen in this way as also represented (35).

Conclusion

This experiment indicates that a medium dosage of zinc sulphate and a low quantity of borax applied as a foliar spray significantly enhanced the growth, production and quality of garlic when administered at 45 and 60 days post-planting. A notable enhancement during the vegetative phase of garlic was associated with 0.5% zinc sulphate. The production and quality metrics of garlic were greatly improved with the combined treatment of zinc sulphate at 0.5% and borax at 0.25%, with the exception of maturity and sulphur content in garlic. It may be extrapolated that when concentration increases, yield decreases; hence, suboptimal concentrations should be utilised to enhance production. The outcomes are consequently more advantageous for farmers, enhancing quality and maximising potential while alleviating nutritional deficits. The foliar spraying strategy utilised improved the nutritional status of the crop by biofortification.

Acknowledgements

The authors would like to thank the Division of Vegetable Science, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu and Kashmir, India for providing the opportunity to conduct research experiment.

Authors' contributions

DR conceptualized the study and design, drafted the initial manuscript and contributed to its review and editing. MK, SK, BRB, SPS, RKS, SC and AB contributed to conceptualizing the study and its design. NK drafted the initial manuscript and participated in reviewing and editing it. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Yang P, Song H, Wang L, Jing H. Characterization of key aroma-active compounds in black garlic by sensory-directed flavor analysis. *J Agric Food Chem.* 2019;67(28):7926-34. <https://doi.org/10.1021/acs.jafc.9b02024>
2. Shafiq M, Qadir A, Ahmad SR. Biofortification: a sustainable agronomic strategy to increase selenium content and antioxidant activity in garlic. *Appl Ecol Environ Res.* 2019;17(2):1685-704. https://doi.org/10.15666/aer/1702_16851704
3. National Horticultural Board. First advance estimates of area and production of horticulture crops [Internet]. New Delhi: Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India; 2023 [cited 2026 Jan 5]. Available from: <https://nhb.gov.in/Statistics.aspx>
4. Directorate of Agriculture. Annual area and production data of vegetable crops, Jammu and Kashmir [Internet]. Jammu: Directorate of Horticulture, Government of Jammu and Kashmir; 2022 [cited 2026 Jan 5]. Available from: <https://hortijmu.jk.gov.in/croparea.html>
5. Kaur G, Sharma N, Singh AP, Sharma R, Sharma P, Slathia PS, et al. Effect of different modes of zinc fertilization on growth, yield and economics of quality protein maize under rainfed conditions of Jammu. *Plant Sci Today.* 2025. <https://www.plantsciencetoday.online>
6. Bagal A, Sharma N, Bakshi P, Jamwal M, Jasrotia A, Kotwal N, et al. Improving growth and leaf nutrient content of guava (*Psidium guajava* L.) with micronutrient management. *Int J Adv Biochem Res.* 2025;SP-9(1):1033-6. <https://www.ijabr.in>
7. Ramzan Y, Hafeez MB, Khan S, Nadeem M, Batool S, Ahmad J. Biofortification with zinc and iron improves the grain quality and yield of wheat crop. *Int J Plant Prod.* 2020;14(3):501-10. <https://doi.org/10.1007/s42106-020-00098-1>
8. Kinaci E, Gulmezoglu N. Grain yield and yield components of triticale upon application of different foliar fertilizers. *Interciencia.* 2007;32(9):624-8. <https://www.interciencia.net>
9. Babaeian M, Tavassoli A, Ghanbari A, Esmaeilian Y, Fahimifard M. Effects of foliar micronutrient application on osmotic adjustments, grain yield and yield components in sunflower (Alstar cultivar) under water stress at three stages. *Afr J Agric Res.* 2011;6(5):1204-8. <https://doi.org/10.5897/AJAR10.1033>
10. Tisdale SL, Nelson WL. Soil fertility and fertilizers. 2nd ed. New York: Macmillan Publishing Company; 1966.
11. Kobraee S, Shamsi K, Rasekhi B. Effect of micronutrients application on yield and yield components of soybean. *Ann Biol Res.* 2011;2(2):476-82. <https://www.scholarsresearchlibrary.com>
12. Islam MR, Uddin MK, Sheikh MH, Mian MA, Islam MZ. Yield of garlic (*Allium sativum* L.) under different levels of zinc and boron. *SAARC J Agric.* 10(1):55-62. <https://doi.org/10.3329/sja.v10i1.18321>
13. Prusty M, Mishra N, Samal S, Kar DS. Effect of zinc and boron on growth, yield, bulb quality and nutrient uptake of onion (*Allium cepa* L.) cv Bhima Super under mid-central table land zone of Odisha, India. *Int J Curr Microbiol Appl Sci.* 2020;9(6):1403-12. <https://doi.org/10.20546/ijcmas.2020.906.175>
14. Bhat TA, Chattoo MA, Mushtaq F, Akhter F, Mir SA, Zargar MY, et al. Effect of zinc and boron on growth and yield of onion under temperate conditions. *Int J Curr Microbiol App Sci.* 2018;7(4):3776-83. <https://doi.org/10.20546/ijcmas.2018.704.426>
15. Stanley DW, Bourne MC, Stone AP, Wismer WV. Low temperature blanching effects on chemistry, firmness and structure of canned green beans and carrots. *J Food Sci.* 1995;60(2):327-33. <https://doi.org/10.1111/j.1365-2621.1995.tb05661.x>
16. Mondal AK. Boron in relation to quality and production of apple at Bhandarwah (J & K). *Environ Ecol Res.* 2002;20(3):611-3. <https://www.enviroecojournal.com>
17. Wani MA, Wani JA, Bhat MA, Kirmani NA, Wani ZM, Bhat SN. Mapping of soil micronutrients in Kashmir agricultural landscape using ordinary kriging and indicator approach. *J Ind Soc Remote Sens.* 2013;41:319-29. <https://doi.org/10.1007/s12524-012-0220-2>
18. Rangana. Manual of analysis of fruits and vegetables products, Tata McGraw Hill Co. Pvt. Ltd. New Delhi; 1976. p. 77.
19. Bhargava BS, Raghupathi HP. Analysis of plant materials for macro and micronutrients. In: Tandon HLS, editor. Methods of analysis of soils, plants, waters and fertilisers. Fertilizer development and consultation organisation: New Delhi. 1993. p. 49-82.
20. Parmar VK, Vekariya PD, Der YA, Thummar VM. Effect of plant growth regulators on growth and yield of coriander (*Coriandrum sativum* L.). *Intl J Agri Crop Sci.* 2018;6(6):2869-70. <https://ijagcs.com>
21. Yatsenko V, Ulianych O, Yanowskii Y. Effect of iron, zinc and boron on the growth, physiological state, productivity and storability of

- Allium Sativum* L. Ukr J Ecol. 2020;10(4):33-42. https://doi.org/10.15421/2020_168
22. Tsewang T, Kapila S, Kumar K, Verma V, Norbu T, Chaurasia OP, et al. Foliar application of zinc and boron improved physiological traits, productivity and shelf life of onion. *J Plant Nutr.* 2023;47(3):351–62. <https://doi.org/10.1080/01904167.2022.2134635>
 23. Kulthe SD, Pawar GS, Thombre PR, Pawar VS. Effects of micronutrients on growth, yield and storage of garlic (*Allium sativum* L.). *J Pharm Innov.* 2022;11(12):2045-8. <https://www.theopharmajournal.com>
 24. Desalegne L, Aklilu S. Research experiences in onion production. Research Report Number, 55, EARO, Addis Ababa, Ethiopia; 2003.
 25. Alloway TP, Gathercole SE, Kirkwood H, Elliott J. Evaluating the validity of the automated working memory assessment. *Educ Psychol.* 2008;28(7):725-34. <https://doi.org/10.1080/01443410802243828>
 26. Zhimomi KL, Deepanshu. Effect of micronutrients on growth, yield and quality of garlic (*Allium sativum* L.). *J Pharm Innov.* 2022;11(1):249-51. <https://www.theopharmajournal.com>
 27. Yadav LM, Singh YP, Kumar J, Prasad SS, Mishra AK. Response of zinc and boron application on yield, yield parameters and storage quality of garlic (*Allium sativum* L.) var. G-282. *J Pharmacogn Phytochem.* 2018;7(1):1768-70. <https://www.phytojournal.com>
 28. Srivastava R, Aggarwal A, Tiwari RS, Kumar S. Effect of micronutrients, zinc and boron on yield, quality and storability of garlic. *Indian J Agr Sci.* 2005;75(3):157-9. <https://epubs.icar.org.in>
 29. Chandan S. Effect of micronutrient management zinc and boron on crop growth, yield and quality of onion (*Allium cepa* L.). *Int J Curr Microbiol Appl Sci.* 2021;10:2190-5. <https://doi.org/10.20546/ijcmas.2021.1003.277>
 30. Almendros P, González D, Fernández MD, García-Gomez C, Obrador A. Both Zn biofortification and nutrient distribution pattern in cherry tomato plants are influenced by the application of ZnO nanofertilizer. *Heliyon.* 2022;8(3):e09130. <https://doi.org/10.1016/j.heliyon.2022.e09130>
 31. Tiwari VK, Verma V, Avantika A, Mishra A, Prasher D, Chaurasia OP, et al. Effect of foliar micronutrient application on phytoconstituents and mineral composition of carrot grown in trans-Himalayan region. *Def Life Sci J.* 2025;1(1):8-14. <https://publications.drdo.gov.in>
 32. Verma RK, Singh S, Verma RB, Singh MP, Kumar V. Effect of boron (B) and zinc (Zn) on the yield and attributing characters of cauliflower. *Natl Acad Sci Lett.* 2021;44(4):369–71. <https://doi.org/10.1007/s40009-021-01017-3>
 33. Kim SH, Iwar K, Han J, Choi I, Lee J, Ochar K. Variability of bulb morpho-geometrical properties in onion (*Allium cepa* L.) germplasm collections, using digital imaging tools. *PeerJ.* 2025;13:e19583. <https://doi.org/10.7717/peerj.19583>
 34. Tiwari JK, Upadhyay D. Correlation and path-coefficient studies in tomato (*Lycopersicon esculentum* Mill.). *Res J Agric Sciences.* 2011;2(1):63-8. <https://www.rjas.org>
 35. Sönmez İ, Erol ÜH, Sarpkaya K. Comprehensive morphological and biochemical characterization of garlic (*Allium sativum* L.) genotypes using multivariate analysis. *BMC Plant Biol.* 2025;25:856. <https://doi.org/10.1186/s12870-025-04856-9>

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonpublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonpublishing.com/journals/index.php/PST/indexing_abstracting

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (<https://creativecommons.org/licenses/by/4.0/>)

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.