Rahman MM *et al.* (2025)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 53, Issue 3, Article number 14504
DOI:10.15835/nbha53314504
Research Article

Synergistic effects of humic acid and boron on quantitative and qualitative traits of tomato

Md. Mofizur RAHMAN[1], Khairul KABIR[1*], Md. Saidur RAHMAN[2], Md. Rezwan SARKER[1], Mohammad S. RAYHAN[3], Chaity D. PUJA[1], Farzana ISLAM[1], Khaleda KHATUN[1], Mohammad Shah JAHAN[1*]

[1]*Sher-e-Bangla Agricultural University, Faculty of Agriculture, Department of Horticulture, Dhaka 1207, Bangladesh; mofizur.rahman@sau.edu.bd; kabir@sau.edu.bd (*corresponding author); rezwansf@sau.edu.bd; chaitypuja@sau.edu.bd; farzanaislamshosi@gmail.com; drkhaleda@sau.edu.bd; shahjahanhort@sau.edu.bd (*corresponding author)*
[2]*Sher-e-Bangla Agricultural University, Faculty of Agriculture, Department of Agricultural Botany, Dhaka 1207, Bangladesh; saidur34@sau.edu.bd*
[3]*Ministry of Agriculture, Department of Agricultural Extension, Administration and Finance Wing, Khamarbari, Dhaka 1215, Bangladesh; shehab500raihan@gmail.com*

Abstract

In tropical climates, environmental stresses impose significant obstacle to growing tomato plants and achieving higher fruit yield and better quality. The external treatment of humic acid and boron has the potential to address these challenges in tomato production. However, the interaction effects of humic acid and boron in tomato cultivation is largely elucidate. This research aimed to evaluate the impacts of humic acid and boron on growth parameters, yield, and quality features of tomato (*Lycopersicon esculentum* L.). The treatments were consisted of three levels humic acid (0, 50 and 100 ppm) and boron (0, 25 and 50 ppm) and they were foliar sprayed at the vegetative, flowering, and fruit setting stages. The results revealed that combined application of humic acid and boron potentially improved the quantitative and qualitative characteristics of tomato plants over control. The maximum plant height (121.10 cm), the dry weight of each plant (46.72 g), fruit diameter (6.1 cm), single fruit weight (70.4 g), yield per plant (4.45 kg) were observed in combined treatment of 100 ppm humic acid with 25 ppm boron at mature stage. Furthermore, TSS (4.90 °B), total sugar (5.06 mg), vitamin C (21.35 mg), protein (3.11%), ash (0.69 mg), lycopene (4.97 mg), and sodium (6.96 mg) content were higher in 100 ppm humic acid with 25 ppm boron as compared to control at mature stage. These findings revealed that the combined foliar application of humic acid with boron could be practical approach for increasing tomato production and improving quality traits of tomato in subtropical climatic regions.

Keywords: biomass; biostimulants; micronutrient; yield

Received: 28 Mar 2025. Received in revised form: 30 Aug 2025. Accepted: 05 Sep 2025. Published online: 17 Sep 2025.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

Introduction

Food and nutritional security need to be given the highest priority to feed the world population which is predicted to surpass 9.7 billion by 2050 (UNO, 2019). It is the prime concern for addressing the vital nexus of food availability, quality, and long-term production is imperative for Bangladeshi economy due to the rapidly expansion of population. Globally, tomato (*Lycopersicon esculentum* L.) is the 2nd most significant horticultural crop in terms of production and consumption (Aytaç *et al*., 2024). It contains niche health-promoting nutrient substances, including antioxidants, minerals, vitamin C, and total carotenoids (Chhaba *et al*., 2024). In 2023, Bangladesh produces roughly 46920.49 metric tonnes of tomatoes on 76943.14 acres lands (BBS, 2024) and the average tomato production in Bangladesh is 14.94 t ha^{-1} (FAO, 2023). However, the yield of tomatoes is not meet the national demand and substantial amount of tomato export from abroad. Though, tomatoes are a globally important horticultural crop, their productivity and quality is often constrained by inadequate nutrient availability (Suliman *et al*., 2020). Recent research findings have addressed these challenges, such as the foliar treatment of biostimulants and micronutrients on fruits and vegetables reduce the negative impacts of diverse stressors (De Hita *et al*., 2020; Cristofano *et al*., 2021).

Humic acids are powerful plant biostimulants that are commercially available as organic fertilizers. It promotes plant development by increasing cell elongation and nutrient uptake through improved water and nutrient flow into cells (Ride *et al*., 2024). Many studies have shown that humic acid mitigates plant stress, and helps in the absorption of nutrients required for normal growth of plants (Suliman *et al*., 2020). The application of humic acid increases tomato plant growth by promoting the absorption of essential nutrients, including nitrogen, phosphorus, iron, and copper (Ibrahim *et al*., 2019). Applying humic acid as a foliar spray was found to be very beneficial for enhancing the vegetative development, yield, and fruit quality of tomatoes (Kumar *et al*., 2017). In addition, humic acid increases photosynthetic efficiency in plants by improving nutrient uptake and leaf chlorophyll content (Chah-Nasir *et al*., 2023; Hussain *et al*., 2021).

Boron is a crucial micronutrient for plants, playing a vital role in cell division, flowering, fruit setting, and carbohydrate metabolism (Xu *et al*., 2021). It is also a key element for growth hormone synthesis and boron deficiency in tomato plants damages roots and shoot growth, as well as creating fruit-cracking (Chhaba *et al*., 2024). Boron is also a key microelement involved in cell division and growth hormone synthesis in plants (Ahmed *et al*., 2020). In addition, boron application regulates the reproductive development of plants by activating numerous enzymes involved in plant metabolism (Kohli *et al*., 2023). In addition to enhancing plant heath and fruit yield, foliar fertilization with boron also promotes the absorption of critical minerals to support plant growth (Ali *et al*., 2024).

Therefore, the availability of nutrients and environmental factors has a significant impact on tomato production, affecting both fruit quality and yield. While the individual functions of humic acid and boron in enhancing plant growth, nutrient uptake, and fruit development have been documented, their interactive effects on tomato remain insufficiently studied. Specifically, there is a lack of comprehensive research evaluating how the combined application of humic acid and boron influences quantitative traits as well as qualitative parameters. Based on this, the present research focused on investigating the effects of foliar application of humic acid with boron to develop sustainable cultivation practices that enhance the productivity and fruit quality of tomatoes.

Materials and Methods

Planting materials and growing seedlings

The experiment was conducted at the Horticulture Farm of Sher-e-Bangla Agricultural University, Dhaka-1207 which is located at 90°33' E longitude and 23°77' N latitude from October 2022 to April 2023.

BARI Tomato-14 variety was used as the planting materials. Earthenware pots measuring 30 cm in height, 25 cm in width, and 14.72 L in volume were used for growing the plants. The earthen pots were filled with a sand, soil and farmyard manure at 2:1:1 (v/v/v) ratio, as well as the necessary fertilizers. Throughout the growth period, standard cultural practices including weeding, irrigation, and pesticide application, were performed as and when needed.

Experimental design and treatments

Humic acid (at three level concentrations, 0, 50 and 100 ppm) and boron (at three level concentrations, 0, 25 and 50 ppm) were foliar applied three times at the vegetative, flowering, and fruit setting stages and the experiment was layout in a completely randomized design with five replications. A total of 9 treatment combinations, and a total of 45 experimental pots. Healthy seedlings of tomato were raised in nursery trays and transplanted into pots at the 4-5 leaf stage (approximately 25 days after sowing). Five seedlings were selected for each treatment for data collection.

Measurement of growth characteristics

Data on plant height (cm) and branches per plant were counted at 30, 60 and 90 days after transplanting (DAT).

Measurement of physiological attributes

The total dry weight of plant was determined by summing the dry weights of the leaves, branches, roots, and other growing portions. Leaf chlorophyll content was measured at three growth stages (vegetative, flowering and fruiting) using a SPAD-502 meter (Minolta, Tokyo, Japan) The first flowering and fruiting days were noted and counted by evaluating how many days were required from transplanting to flowering and fruiting at 50% flowering and fruit setting.

Measurement of yield components

Fruit yield plant^{-1} (kg) was determined by multiplying single fruit weight (g) and number of fruits plant^{-1} for each treatment. It was recorded by averaging the harvested of all plants in each treatment. Besides, fruit length (cm) and diameter (cm) were calculated using Digital Caliper -515 (DC-515).

Determination of total soluble solids (TSS)

The total soluble solid (TSS) content of tomatoes was estimated through a digital hand refractormeter and expressed in ^{0}Brix, according to method suggested by Beckles (2012).

Sugar content analysis

To estimate total sugar content, a 5-mL aliquot was taken from a 100-mL sample, and three drops of hydrochloric acid (HCl) was added, and the solution was stored overnight. The following day, two to three drops of phenolphthalein indicator were added, and then the solution was neutralized using a 30% of sodium hydroxide (NaOH). The neutralize solution was then titrated using methylene blue as an indicator against 1.0% glucose standard in a boiling solution. According to Lane and Eynon (1923), the endpoint was designated by the appearance of brick red color as, and the results were expressed as a percentage of total sugar.

To determine the reducing sugars, 10 g of pulp was ground with distilled water and the homogenate was filtered by muslin cloth. Next, 5 mL each of Fehling solution "A" and "B" were combined in a 100 mL conical flask and the mixture was titrated against a 1% glucose solution in a boiling water bath. The endpoint was marked by the appearance of a brick-red color with methylene blue as an indicator.

Non-reducing sugar content was calculated by subtracting the quantity of reducing sugars from total invested sugars and multiplying by a factor of 0.95.

Non-reducing sugar (%) = Total sugar (%) - Reducing sugar (%) × 0.95.

Sugar content was expressed in mg/100 g fresh weight (FW).

Estimation of protein percentage

The protein percentage was measured using the method described by Kjeldahl Method (AOAC, 2005).

Vitamin-C content determination

The vitamin-C content of tomato fruits was assessed following the procedure of oxidation reduction titration method (Tee *et al*., 1988). Individual fruits were homogenized, and resulting fruit pulp was filtered by Whatman No. 1 filter paper. The filtrate was then diluted to a 100 mL volume using a 5% oxalic acid solution. For titration, the dye solution 2, 6-dichlorophenol indophenol was used. Prior to analyzing the fruit samples, the dye was standardized using a known concentration of L-ascorbic acid. For each titration 5 mL solution of the extract was used, and the pink color indicated the end point of the titration, which lasted for 10 seconds. Subsequently, the burette reading was recorded and used to calculate the vitamin C concentration

Analysis of ash content

The method narrated by John *et al.* (2020) was used to measure ash content in tomato fruits. Shortly, containing 1 g of crushed tomato samples was placed in a porcelain crucible and heated to 600 °C for approximately 6 h in a muffle furnace. After cooling in dryers, the samples were weighed on an electric balance the ash content was calculated and expressed as mg/100 g FW.

Lycopene content analysis

Lycopene content was analyzed based on Fish *et al.* (2002). A 250 cm^3 beaker was filled with 100 g of pulp that had been ground using an electric tissue blender. A solvent mixture of hexane, acetone, and ethanol were then added in a volume ratio of 2:1:1, and the mixer was shaken on an electric shaker for 10 minutes or more. Next, 1 mL of distilled water was added, and the sample was agitated for an additional 10 minutes. For phase separation, the solution was transferred into a 250 mL funnel and left to stand for at least 5 minutes. After that, the top layer (hexane) was taken out and put in an amber screw vial. An aliquot of the hexane extract was placed in a 1 mL cuvette, and its absorbance was measured at 503 nm against a solvent blank using a spectrophotometer.

Estimation of sodium content

The sodium content of tomato fruit was determined using Atomic Absorption Spectroscopy (AOAC, 2005). The sample was prepared in a 100 mL volumetric flask. A blank was measured first, followed by a series of standard solutions of known sodium concentration to calibrate the instrument. Finally, the prepared sample was analyzed. The absorbance was recorded, and the Na concentration in the sample was determined based on the calibration curve.

Statistical analysis

Data were analyzed using IBM SPSS Statistics 21 (IBM Corp., Armonk, NY, USA) software. Mean differences among the treatments were compared using at least significant difference (LSD) at $p < 0.05$. Graphs were prepared with Microsoft XL's.

Results

Growth characteristics

The interaction effect of humic acid and boron had a significant effect on plant height and number of branches of tomato plant (Table 1). The results suggested that the application of 100 ppm humic acid combined with 25 ppm boron led to an increment of plant height (36.37 cm, 91.22 cm and 121.13 cm) at 30, 60, and 90 days after transplanting (DAT), respectively, while the control treatment plants had the least height (18.63 cm, 45.87 cm and 73.37 cm) at 30, 60, and 90 DAT, respectively (Table 1). Similarly, the maximum number of branches per plant (7.7, 16.5, and 26.7) at 30, 60, and 90 DAT, respectively, was observed with the 100 ppm humic acid and 25 ppm boron treatment (Table 1).

Table 1. Interaction effects of humic acid and boron on growth characteristics of tomato

Humic acid (ppm)	Boron (ppm)	Plant height (cm) at			Number of branches plant^{-1} at		
		30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Control	Control	18.63±1.5 g	45.87±2.9 f	73.37±4.2 e	3.2±0.17 f	8.0±0.29 e	16.2±1.0 e
	25	22.63±1.6 efg	59.62±3.2 de	92.59±3.9 cd	4.8±0.17 de	10.5±0.58 d	19.0±0.76 cde
	50	20.77±0.4 fg	53.53±2.3 ef	83.73±5.1 de	4.0±0.17 e	9.5±0.58d e	17.7±1.6 e
50	Control	26.30±0.7 cde	68.23±4.9 cd	98.23±4.6 bcd	4.5±0.23 de	11.3±0.17 cd	21.5±1.3 bcd
	25	31.47±1.7 b	81.53±3.5 bc	110.36±5.8 bcd	6.0±0.38 b	13.7±0.88 b	23.6±0.72 bc
	50	29.47±0.7 bc	77.57±3.9 bc	107.83±6.2 bc	5.8±0.33 bc	14.2±0.17 b	22.5±1.2 bc
100	Control	24.70±1.7 def	67.29±3.5 cd	95.29±3.5 bcd	4.0±0.29 e	9.5±0.29d e	18.2±0.93 de
	25	36.37±0.8 a	91.22±4.2 a	121.13±6.9 a	7.7±0.17 a	16.5±1.1 a	26.7±0.73 a
	50	26.93±1.8 cd	72.83±3.3 bc	102.83±6.2 bc	5.2±0.33 cd	12.7±0.88 bc	21.5±1.7 bcd
P-value		0.001	0.001	0.001	0.002	0.001	0.001
$LSD_{0.05}$		1.08	2.80	3.07	0.26	0.53	0.71
CV (%)		8.31	9.04	9.23	8.86	7.81	9.51

Note: Means ±SEs of five biological replicates were used to present the data. Different letters in the same column indicate significant differences between treatments ($p < 0.05$). DAT=days after transplanting

Physiological attributes

The combined application of humic acid and boron had a substantial effect on total dry weight of plant, leaf chlorophyll content at different stages (Table 2), days to first flowering (Figure 1A) and days to first fruiting (Figure. 1B). According to the results, the highest total dry weight of the plant was observed in 100 ppm humic acid with 25 ppm boron treatment plants (46.72 g), which was 64.3% higher than that of the control plants (28.43 g) (Table 2). The relative chlorophyll content (SPAD index) was also higher in 100 ppm humic acid with 25 ppm boron treatment, showing 45.1%, 49.3%, and 54.5% over the control plants at the vegetative, flowering, and fruiting stages, respectively (Table 2). Humic acid and boron had also promoted effects on reproduction processes and the. early flowering (34.11 days) was observed in the 100 ppm humic acid and 25 ppm boron treatment, whereas the control treatments showed delayed (46.67 days) flowering (Figure 1A). Similarly, plants treated with 100 ppm humic acid and 25 ppm boron required the fewest days to first fruiting, showing 18.6 days earlier than control plants (Figure 1B).

Table 2. Interaction effects of humic acid and boron on physiological attributes of tomato

Humic acid (ppm)	Boron (ppm)	Total dry weight of plant (g)	SPAD index		
			Vegetative stage	Flowering stage	Fruiting stage
Control	Control	28.43±1.0 d	37.47±2.0 d	34.77±1.0 f	31.70±1.2 e
	25	39.19±1.3 bc	40.30±2.3 cd	37.57±2.1 e	34.50±2.1 de
	50	37.91±1.5 bc	41.93±2.2 bcd	39.43±1.1 cd	36.20±1.0 cde
50	Control	36.90±3.1 c	45.90±2.9 bc	43.47±1.3 bc	40.70±1.3 bc
	25	42.10±1.9 abc	49.47±2.3 ab	46.83±2.2 ab	43.90±1.0 ab
	50	40.85±2.6 abc	47.97±2.0 abc	45.23±0.9 b	42.57±1.5 b
100	Control	43.77±2.8 ab	41.60±1.8 cd	38.80±1.0 cd	35.80±1.9 cde
	25	46.72±1.9 a	54.37±3.5 a	51.73±3.4 a	48.97±3.5 a
	50	40.27±1.3 abc	46.07±1.5 bc	43.60±1.5 bc	40.30±1.6 bcd
P-value		0.001	0.002	0.001	0.001
$LSD_{0.05}$		1.11	1.17	1.09	1.12
CV (%)		8.92	8.79	6.52	7.35

Note: Means ±SEs of five biological replicates were used to present the data. Different letters in the same column indicate significant differences between treatments ($p < 0.05$)

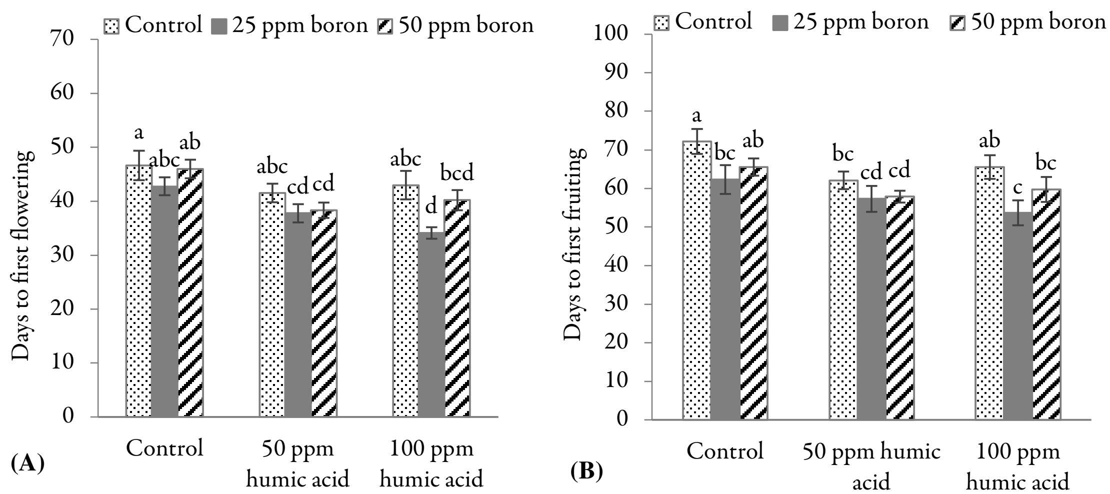

Figure 1. Synergistic functions of humic acid and boron on (A) days to first flowering (B) days to first fruiting of tomato

Vertical bars indicate ±SE. Different letters within a trait indicate significant differences ($p < 0.05$)

Yield components

Foliar spraying with humic acid and boron had a significant influence on number of flowers plant^{-1}, number of fruits plant^{-1}, fruit length, fruit diameter, single fruit weight and yield plant^{-1} (Table 3). The results showed that the treatment with 100 ppm humic acid combined with 25 ppm boron had the highest number of flowers plant^{-1} (78.2), whereas the control had the lowest (36.3) (Table 3). The results suggested that plants sprayed with the combination of 100 ppm humic acid and 25 ppm boron exhibited the largest number of fruits plant^{-1} (63.3), while the fewest fruits number (26.0) were observed in the control (Table 3). It was observed that the longest fruit (6.3 cm) was achieved in the treatment of 100 ppm humic acid along with 25 ppm boron treatment, while the control treatment produced the smaller fruit (3.7 cm) (Table 3). The statistical analysis showed that the widest fruit (6.1 cm) was found in 100 ppm humic acid and 25 ppm boron treatment group, whereas, control group produced the smallest (3.1 cm) fruit (Table 3). The most notable increase in fruit weight was observed in the plants treated with 100 ppm humic acid and 25 ppm boron, which increased fruit weight by 44.3% compared to the control (Table 3). The maximum fruit production (4.45 kg) was observed in 100 ppm humic acid with 25 ppm boron treatment plants, whereas the minimum fruit production (1.27 kg) was found in the control plant (Table 3).

Table 3. Interaction effects of humic acid and boron on yield components and yield of tomato

Humic acid (ppm)	Boron (ppm)	Number of flowers plant^{-1}	Number of fruits plant^{-1}	Fruit length (cm)	Fruit diameter (cm)	Single fruit weight (g)	Yield plant^{-1} (kg)
Control	Control	36.3±2.0 e	26.0±1.8 f	3.7±0.09 e	3.1±0.14 f	48.8±4.1 d	1.27±0.15 e
	25	47.3±2.5 cd	35.5±2.0 de	4.2±0.15 e	4.0±0.28 de	59.0±1.3 bcd	2.09±0.13 cd
	50	40.8±1.7 de	30.2±2.2 ef	4.0±0.17 e	3.8±0.26 ef	55.4±2.5 cd	1.68±0.19 de
50	Control	54.0±2.6 c	42.5±1.3 c	4.8±0.12 d	4.6±0.16 cd	57.1±4.2 cd	2.43±0.24 c
	25	69.2±3.0 b	53.7±3.9 b	5.6±0.22 b	5.1±0.38 b	69.0±2.1 ab	3.72±0.36 b
	50	62.2±3.1 b	49.5±1.9 b	5.4±0.23 bc	5.2±0.35 bc	62.9±2.1 abc	3.12±0.21 b
100	Control	45.8±1.8 cd	33.7±1.2 e	4.2±0.18 e	4.0±0.24 de	60.8±6.1 abc	2.05±0.23 cd
	25	78.2±4.2 a	63.3±2.0 a	6.3±0.15 a	6.1±0.05 a	70.4±3.0 a	4.45±0.16 a
	50	51.9±2.2 c	40.6±2.2 cd	5.1±0.23 cd	4.9±0.20 bc	57.5±2.3 cd	2.33±0.15 cd
P-value		0.001	0.002	0.001	0.003	0.007	0.002
$LSD_{0.05}$		2.63	2.30	0.16	0.19	1.56	0.20
CV (%)		8.23	8.85	6.16	8.98	9.07	7.26

Note: Means ±SEs of five biological replicates were used to present the data. Different letters in the same column indicate significant differences between treatments ($p < 0.05$)

Quality traits

The application of humic acid and boron had a considerable impact on quality parameters of tomato fruits including, total soluble solids (Figure 2A), total sugar (Figure 2B), reducing sugar (Figure 2C), non-reducing sugar (Figure 2D), protein percentage, vitamin-C content, ash content, lycopene content and sodium content (Table 4). The results illustrated that the TSS was maximal (4.9 °Brix) in the treatment where 100 ppm humic acid and 25 ppm boron was applied, and the minimal (3.1 °Brix) was recorded in control (Figure 2A). Compared to the control, the total sugar, reducing sugar and non-reducing sugar contents were enhanced by 52.8%, 52.3% and 53.7%, respectively, in the treatment with 100 ppm humic acid and 25 ppm boron, respectively (Figure 2B-D). The treatment with 100 ppm humic acid and 25 ppm boron had the highest fruit protein content (3.11%), whereas the lowest (2.37%) was observed in control group (Table 4). The treatment with 100 ppm humic acid and 25 ppm boron displayed a noticeable increase of vitamin-C content and that was 63.8% higher over the control (Table 4). The current study showed that, the highest ash content (0.68 mg/100 g) was observed in 100 ppm humic acid with 25 ppm boron, while the control produced the lowest ash content (0.32 mg/100 g) (Table 4). I addition, the more lycopene content (4.97 mg/100 g) of fruits was observed in in 100 ppm humic acid with 25 ppm boron treatment, where less lycopene content (4.09 mg/100 g) was found in control, showing 21.5% higher than control (Table 4). Data also revealed that 100 ppm humic acid and 25 ppm boron treated plant showed 41.5% higher the sodium content as compared to control group (Table 4).

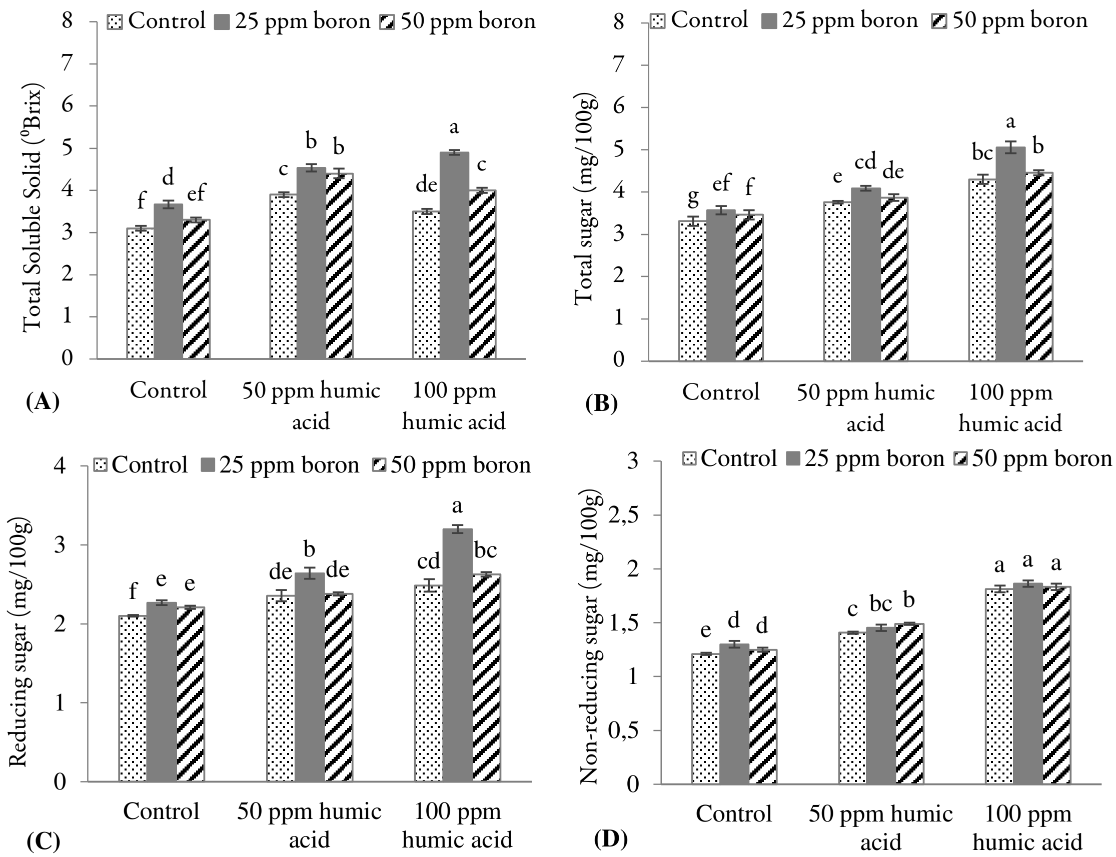

Figure 2. Interactive effect of humic acid and boron on fruit quality of tomato (A) total soluble solid (B) total sugar (C) reducing sugar (D) non-reducing sugar

Means ± SEs of five biological replicates were used to present the data. Different letters within a trait indicate significant differences ($p < 0.05$)

Table 4. Interaction effects of humic acid and boron on nutritional quality of tomato

Humic acid (ppm)	Boron (ppm)	Protein (%)	Ascorbic acid (mg/100g)	Ash (mg/100g FW)	Lycopene (mg/100g)	Sodium (mg/100g)
Control	Control	2.37±0.04 e	13.03±0.14 e	0.32±0.02 d	4.09±0.08 e	4.92±0.04 e
	25	2.62±0.01 c	16.02±0.22 c	0.36±0.02 d	4.39±0.01 cd	5.36±0.14 d
	50	2.50±0.06 cd	13.88±0.79 de	0.35±0.01 d	4.35±0.07 de	5.32±0.13 d
50	Control	2.46±0.05 de	17.78±0.06 b	0.55±0.01 c	4.11±0.03 e	5.18±0.07 de
	25	2.84±0.04 b	19.10±0.40 b	0.62±0.02 bc	4.68±0.11 b	6.25±0.21 b
	50	2.79±0.03 b	18.49±0.51 b	0.58±0.02 bc	4.55±0.10 bcd	6.05±0.07 bc
100	Control	2.48±0.03 de	15.03±0.25 cd	0.60±0.03 bc	4.61±0.11 bcd	5.88±0.07 c
	25	3.11±0.03 a	21.35±0.62 a	0.69±0.01 a	4.97±0.01 a	6.96±0.03 a
	50	2.79±0.06 b	16.29±0.45 c	0.61±0.02 b	4.65±0.12 bc	6.12±0.13 bc
P-value		0.003	0.001	0.002	0.001	0.002
$LSD_{0.05}$		0.05	0.51	0.03	0.06	0.12
CV (%)		2.47	3.97	5.70	2.75	2.98

Note: Means ± SEs of five biological replicates were used to present the data. Different letters in the same column indicate significant differences between treatments ($p < 0.05$)

Discussion

The foliar spraying of humic acid and boron notably elevated the height of tomato seedlings. According to our findings, the combined effect of these compounds was superior to that of the control treatment (Table 1). This effect may occur because humic acid enhances the roots membrane permeability, thereby boosting the uptake of vital nutrients essential for plant development. The current results are consistent with the findings that humic acid facilitates the uptake of nutrients required for plant growth and development (Suliman *et al*., 2020). Similarly, humic acid application significantly increased the plant height, emphasizing its performance in promoting plant growth (Abdelkader *et al*., 2019). Besides, boron application also enhanced plant development by increasing the absorption and utilization of crucial nutrients (Ali *et al*., 2024). Boron plays a fundamental role in sustaining cell wall structure and function, both of which are vital for plant height (Shireen *et al*., 2018). This is consistent with Rahman *et al*. (2023) reported that an optimal boron concentration significantly increased the height of summer tomato plants. Regarding plant branching, the foliar sprayed of humic acid and boron also had a significant effect (Table 1). Humic acid likely accelerates plant growth by facilitating nutrient absorption. These findings support the statement by Ride *et al*. (2024) that humic acid facilitates the easy absorption of macro and micronutrients by lowering plant stress, which ultimately helps to promoting branching. Furthermore, the application of boron had a positive effect on increasing the number of branches in tomato plants by stimulating growth hormones in plants. This is in line with the findings of Ahmed *et al*. (2020), who concluded that boron, as a key micronutrient, is integral to cell division and synthesis of growth hormones.

The total dry weight of the tomato plants varied in response to different combinations of humic acid and boron. (Table 2). The increase in dry weight of the plant might be attributed to the enhancement of photosynthetic activity which promotes food production and rapid growth (Hussain *et al*., 2021). The results confirmed that humic acid accelerates the absorption of more photo-assimilates, thereby increasing plant dry weight (Ibrahim *et al*., 2019). Meanwhile, boron application promoted the absorption of the essential nutrients such as calcium, leading to greater biomass accumulation in tomato plants. These results are aligned with the previous findings of Xu *et al*. (2024), which highlighted the positive impact of boron on photosynthetic activity and dry matter production. In our study, the combined effect of humic acid and boron also positively affected the leaf chlorophyll content at the vegetative, flowering, and fruiting stages (Table 2). Humic acid may increase the activity of enzymes involved in photosynthesis by improving nutrient availability, thereby encouraging higher chlorophyll production. These results are supported by Chah-Nasir *et al*. (2023), who found that humic acid boosts photosynthetic efficiency and increases leaf chlorophyll content by advancing nutrient uptake. Similarly, foliar fertilization with boron may stimulate photosynthetic activity in plants. According to Xu *et al*. (2024), boron application can promote the synthesis of photosynthetic pigments, which directly influences the photosynthetic capacity of tomato plants. The number of days to first flowering and fruiting were significantly influenced by the combined effect of humic acid and boron (Figure. 1A and Figure. 1B, respectively). Humic acid may may reduce the flowering period by enhancing nutrient uptake and photosynthetic efficiency of tomato plants, as validated by the findings of Chah-Nasir *et al*. (2023). Moreover, humic acid hastened early fruiting by advancing metabolic processes in plants, consistent with the findings of Al-Karawi *et al*. (2021) in strawberry plants. Likewise, the application of boron shortened both the flowering and fruiting periods. Xu *et al*. (2024) revealed that boron plays a vital role in cell division, flowering, fruit set, and carbohydrate metabolism.

The experiment showed that the number of flowers and fruits varied significantly with the foliar treatments of humic acid and boron (Table 3). This effect is likely due to the humic acid, in promoting plant growth and development by enhancing the absorption of essential nutrients, thereby increasing flower and fruit production. Our results in line with the findings of Suliman *et al*. (2020), who reported that humic acid helps in the absorption of nutrients required for plant development. Similar results were also reported by Ride *et al*.

(2024). Besides, boron was effective in increasing the number of fruits in tomato plants by decreasing the proportion of abnormal fruits. Chhaba *et al*. (2024) showed that boron deficiency leads to root and foliage damage in tomato plants, resulting in fruit-cracking. A significant interaction effect of humic acid and boron was observed on fruit length and fruit diameter (Table 3). It might be happened due to the positive effect of humic acid on cell division that enhances fruit size. As noted by Chah-Nasir *et al*. (2023), humic acid positively influences auxin production, which drives cell division and differentiation, resulting in larger fruit production. Concurrently, boron application also increased both fruit length and diameter. Moreover, boron improves the absorption and utilization of key nutrients such as nitrogen, phosphorus, and potassium, which are important for plant productivity (Vera-Maldonado *et al*., 2024). The combined humic acid with boron treatments varied considerably in terms of the single fruit weight of tomato (Table 3). The increased fruit weight is likely due to the application of humic acid, which improved the tomato plant growth by absorbing essential nutrients i.e. nitrogen, phosphorus, iron, and copper and potassium (Monda *et al*., 2021). These results are in accordance with the statement of Ibrahim *et al*. (2019), who found that humic acid facilitates nutrients uptake and increases photo-assimilates allocation, leading to greater fruit weight. Foliar application of boron may further be involved in promoting translocation and assimilation of photosynthates from leaves to fruit, thus increasing fruit weight. Similar findings were also reported by Ali et al. (2024). Overall, humic acid and boron treatments significantly influenced the fruit yield of tomato plants (Table 3).

The application of humic acid and boron not only boosted vegetative growth but also positively influenced reproductive parameters such as fruit weight, fruit number and fruit size, leading to increased yield (Monda *et al*., 2021; Mbi *et al*., 2022). Foliar application of humic acid has been reported to improve respiration, total protein content, and photosynthesis efficiency in plants, thereby improving yield (Chah-Nasir *et al*., 2023). Similar findings were also observed by Ride *et al*. (2024) in tomato, who confirmed that spraying of humic acid resulted in an 88% increase in total yield per hectare. Conversely, boron advanced tomato yield by increasing fruit number and fruit weight as it activates numerous enzymes for plant metabolism. A similar result was also noted by Kohli *et al*. (2023). The total soluble solids (^{0}B) were significantly influenced by the combined treatments of humic acid and boron (Figure 2A). TSS is an essential fruit quality parameter which influences the palatability and acceptability by preserving their flavors and volatile compounds. For example, Sun *et al*. (2022) found that humic acid application resulted in the best flavor profiles for greenhouse-grown cherry tomatoes, as assessed by total soluble solids, titratable acid, and sugar-acid ratio. Besides, boron plays a vital role in response to the increased TSS content of tomatoes, which is similar to the findings of Ali *et al*. (2024), who found the maximum TSS content in brinjal fruits was observed by applying 0.25% boron. Sugar contents varied significantly with the foliar applications of humic acid and boron (Figure 2B, 2C and 2D). The increase in total sugars might be due to enhanced carbohydrates production in leaves, which are later converted to various reducing and non-reducing sugars. Similar results were observed by Bijanzadeh *et al*. (2019) and Nargesi *et al*. (2022), who reported that the external application of humic acid improved nutrient absorption, leading to increased sugar content in fruits. Humic acid and boron treatments significantly influenced on protein content of tomato fruits (Table 4). It may be due to the enhancement of various amino acid synthesis, as humic acid provides more nutrients required for this process. These results are consisted with the findings of Ride *et al*. (2024). Meanwhile, Mal *et al*. (2025) demonstrated that applying boron to the soil or as foliar sprays during the reproductive stages of crops can greatly improve the quality of the fruit by increasing the contents of protein, lycopene, carotene, and total soluble solids. In this study, ascorbic acid and lycopene contents were substantially influenced by the interaction effect of humic acid and boron (Table 4). The foliar application of humic acid enhanced ascorbic acid content in fruits by increasing the uptake and efficiency of valuable nutrients such as potassium, nitrogen, magnesium, calcium, and phosphorus. This is in line with the statement of Sindha *et al*. (2018). On the other hand, Xu *et al*. (2021) reported that foliar spraying of boron impacts the biochemical processes of plants, accelerating photosynthesis and respiration, which are required for increased Vit-C and lycopene synthesis. The current experiment showed that the ash percentage of fruits varied significantly with the foliar application of humic acid and boron (Table 4). The combined effect of humic acid and boron significantly affected biomass accumulation by producing more assimilates and transporting them to different parts of the plants which led to enhanced photosynthetic efficiency. The combination of humic acid and boron increases photosynthetic efficiency by enhancing nutrient uptake and transport, leading to better assimilate distribution (Monda *et al*., 2021). The findings of the current research aligned with the previous results of El-Kinany *et al*. (2020) in roselle plant fruit. The data in Table 4 indicate that foliar application of humic acid and boron treatments played a significant role in Na content enhancement in tomato fruits. The application of humic acid improved the absorption of vital nutrients including sodium, by increasing root permeability of plants. This is in line with the findings of Suliman *et al*. (2020), who found that humic acid aids in the absorption of nutrients required for plant development. Likewise, boron application also improved plant growth by enhancing the uptake and utilization of essential nutrients, including sodium (Ali *et al*., 2024).

Conclusions

The current study showed that combined foliar spraying of humic acid and boron significantly improved the growth, yield, and quality characteristics of BARI Tomato-14 under subtropical climatic condition. The most effective treatment was the combination of 100 ppm humic acid and 25 ppm boron, which enhanced the key nutritional characteristics such as total soluble solids, sugars, vitamin C, ash, protein, lycopene, and sodium content, as well as plant height, biomass, fruit size, and yield. These results imply that in areas experiencing environmental stress, the combined application of humic acid and boron is a viable and sustainable agronomic approach to increase tomato yield and fruit quality. Further research involving other cultivars and climatic zones is encouraged in to validate and refine this approach for wider adoption.

Authors' Contributions

Conceptualization, Investigation and Writing - original draft: MMR, KK; Data curation: MSR; Formal analysis: MRS, MSR; Funding acquisition: MMR, MSJ; Methodology: CDP, FI; Resources: KK; Supervision: KK; Validation: MMR, KK; Writing - original draft and Writing - review & editing: MSJ.

All authors read and approved the final manuscript.

Acknowledgements

This research was funded by the R and D (Agriculture and Environment Group) of the Ministry of Science and Technology, Government of the People's Republic of Bangladesh. The authors gratefully acknowledge this financial support.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Abdelkader MM, Puchkov MY, Lysakov MA, Loktionova EG, Suliman AA (2019). Effect of crezacin and humic acid on growth and physiological aspects of tomato plants (*Lycopersicon esculentum*). Journal of Applied Horticulture 21:61-66. *https://doi.org/10.37855/JAH.2019.V21I01.11*

Ahmed M, Hasanuzzaman M, Raza MA, Malik A, Ahmad S (2020). Plant nutrients for crop growth, development and stress tolerance. In: Roychowdhury R, Choudhury S, Hasanuzzaman M, Srivastava S (Eds). Sustainable Agriculture in the Era of Climate Change. Springer, Cham. *https://doi.org/10.1007/978-3-030-45669-6_3*

Ali S, Ahmed W, Abbas MH, Hajizadeh HS, Qayyum A, Abdel-Hamed EMW, Ramadan MF (2024). Impact of nitrogen and boron foliar applications on the growth, phytochemicals, and quality attributes of eggplant (*Solanum melongena*). Rendiconti Lincei Scienze Fisiche e Naturali 35(3):411-424. *http://dx.doi.org/10.1007/s12210-024-01226-z*

Al-Karawi HNR, Salman FA, Al-Deheimawi AJM (2021). The effect of foliar application of organic matter and salicylic acid on the growth and yield in strawberry (*Fragaria ananassa*). IOP Conference Series: Earth and Environmental Science 910:012081. *https://doi.org/10.1088/1755-1315/910/1/012081*

AOAC (2005). Association of Official Analytical Chemistry. Official methods of analysis. Van Nostrand's encyclopedia of chemistry. GD Considine (Ed.). John Wiley & Sons (5th ed), Washington, D.C.

Aytaç E, Ünlü HO, Turan T, Erkan İE, Akçay UC (2024). Humic acid mitigates drought stress in tomato. Bilge International Journal of Science and Technology Research 8(1):27-37. *https://dergipark.org.tr/en/pub/bilgesci/issue/83964/1421304*

BBS (2024). Yearbook of Agricultural Statistics-2023. Bangladesh Bureau of Statistics, Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka pp. 320-321. Retrieved 2025 January 20 from *https://bbs.portal.gov.bd/*

Beckles DM (2012). Factors affecting the postharvest soluble solids and sugar content of tomato (*Solanum lycopersicum* L.) fruit. Postharvest Biology and Technology 63(1):129-140. *https://doi.org/10.1016/j.postharvbio.2011.05.016*

Bijanzadeh E, Naderi R, Egan TP (2019). Exogenous application of humic acid and salicylic acid to alleviate seedling drought stress in two corn (*Zea mays* L.) hybrids. Journal of Plant Nutrition 42(13):1483-1495. *https://doi.org/10.1080/01904167.2019.1617312*

Chah-Nasir AS, Jahromi AA, Behrooznam B, Khankahdani HH, Ejraei A (2023). Effect of humic acid and amino acid foliar applications on the growth characteristics, yield, and fruit quality of tomato (*Solanum lycopersicom* L.). International Journal of Horticultural Science and Technology 10(3):309-318. *https://doi.org/10.22059/ijhst.2022.325793.477*

Chhaba H, Maurya RP, Jat MK, Choudhary RS, Choudhary RK (2024). Effect of boron and zinc on growth, yield and quality of tomato (*Solanum lycopersicum* l.) cv. 'Abhilash'. Plant Archives 24(2):2325-2332. *https://doi.org/10.51470/PLANTARCHIVES.2024.v24.no.2.332*

Cristofano F, El-Nakhel C, Rouphael Y (2021). Biostimulant substances for sustainable agriculture: origin, operating mechanisms and effects on cucurbits, leafy greens, and nightshade vegetables species. Biomolecules 11(8):1103. *https://doi.org/10.3390/biom11081103*

De Hita D, Fuentes M, Fernández V, Zamarreno AM, Olaetxea M, Garcia-Mina JM (2020). Discriminating the short-term action of root and foliar application of humic acids on plant growth: Emerging role of jasmonic acid. Frontiers in Plant Science 11:493. *https://doi.org/10.3389/fpls.2020.00493*

El-Kinany RG, Salama YE, Rozan MA, Bayomy HM, Nassar AMK (2020). Impacts of humic acid, indole butyric acid (IBA) and arbuscular mycorrhizal fungi (*Glomus mosseae*) as growth promoters on yield and phytochemical characteristics of *Hibiscus sabdariffa* (Roselle). Alexandria Science Exchange Journal 41(1):29-41. *https://doi.org/10.21608/asejaiqjsae.2020.73036*

FAO (2023). Food and Agricultural Organization of the United Nations. Retrieved 2025 February 05 from *https://www.fao.org/faostat/en/#data/QCL*

Fish WW, Perkins-Veazie P, Collins JK (2002). A quantitative assay for lycopene that utilizes reduced volumes of organic solvents. Journal of Food Composition and Analysis 15(3):309-317. *https://doi.org/10.1006/jfca.2002.1069*

Hussain S, Ulhassan Z, Brestic M, Zivcak M, Zhou W, Allakhverdiev SI, Yang X, Safdar ME, Yang W, Liu W (2021). Photosynthesis research under climate change. Photosynthesis Research 150(1):5-19. *https://doi.org/10.1007/S11120-021-00861-Z*

Ibrahim A, Abdel-Razzak H, Wahb-Allah M, Alenazi M, Alsadon A, Dewir YH (2019). Improvement in growth, yield, and fruit quality of three red sweet pepper cultivars by foliar application of humic and salicylic acids. HortTechnology 29(2):170-178. *https://doi.org/10.21273/HORTTECH04263-18*

John FM, Patrick OA, Moses SA (2020). Effect of maturity stage on quality and shelf life of tomato (*Lycopersicon esculentum* Mill) using refrigerator storage system. Eurasian Journal of Agricultural Research 4(1):23-44. *https://dergipark.org.tr/en/download/article-file/1194215*

Kohli SK, Kaur H, Khanna K, Handa N, Bhardwaj R, Rinklebe J, Ahmad P (2023). Boron in plants: uptake, deficiency and biological potential. Plant Growth Regulation 100(2): 267-282. *https://doi.org/10.1007/s10725-022-00844-7*

Kumar H, Kaushik RA, Ameta KD, Regar AL, Singh K, Rajawat KS, Kumari P (2017). Effect of humic acid and nutrients mixture on quality parameter of tomato (*Lycopersicon esculentum* Mill.) under polyhouse condition. Journal of Applied and Natural Science 9(3):1369-1372. *https://doi.org/10.31018/jans.v9i3.1369*

Lane JH, Eynon L (1923). Methods for Determination of Reducing and Non-Reducing Sugars. Journal of Sciences 42:32-37.

Mal S, Sarkar D, Mandal B, Basak P, Debnath S, Chattopadhyay A, Batabyal K, Pramanik, K (2025). Improving quality of tomato (*Solanum lycopersicum* L.) fruits for fresh consumption and processing with optimized boron application. Journal of Food Composition and Analysis 140:107255. *https://doi.org/10.1016/j.jfca.2025.107255*

Mbi TK, Sighansenyuy EM, Godswill NN, Lendzemo TE, Brice TL, Acha AN (2022). Foliar supplement of Boron limits yield gaps linked to reproductive growth and development hitches in tomato (*Lycopersicon esculentum*). Horticulture International Journal 6(2):70-75. *https://doi.org/10.15406/hij.2022.06.00244*

Monda H, McKenna AM, Fountain R, Lamar RT (2021). Bioactivity of humic acids extracted from Shale Ore: Molecular characterization and structure-activity relationship with tomato plant yield under nutritional stress. Frontiers in Plant Science 12:660224. *https://doi.org/10.3389/FPLS.2021.660224*

Nargesi MM, Sedaghathoor S, Hashemabadi D (2022). Effect of foliar application of amino acid, humic acid and fulvic acid on the oil content and quality of olive. Saudi Journal of Biological Sciences 29(5):3473-3481. *https://doi.org/10.1016/j.sjbs.2022.02.034*

Rahman MS, Hossain MR, Hossain A, Khan MI (2023). Impact of foliar boron application on the growth and yield of summer tomato. Journal of Agroforestry and Environment 16(1):58-63. *https://doi.org/10.55706/jae1608*

Ride RS, Ahmed S, Monami SA, Sarkar MD (2024). Improvement in growth, yield, and fruit quality of tomato by foliar application of humic and salicylic acids. Notulae Scientia Biologicae 16(4):12189. *https://doi.org/10.55779/nsb16412189*

Shireen F, Nawaz MA, Chen C, Zhang Q, Zheng Z, Sohail H, Sun J, Cao H, Huang M, Bie Z (2018). Boron: Functions and approaches to enhance its availability in plants for sustainable agriculture. International Journal of Molecular Sciences 19(7):1856. *https://doi.org/10.3390/IJMS19071856*

Sindha DJ, Satodiya BN, Sutariya NK (2018). Effect of foliar application of different chemicals and humic acid on fruit yield and quality of custard apple (*Annona squamosa* L.) cv. local. International Journal of Chemical Studies 6(5):75-77. *https://www.chemijournal.com/archives/2018/vol6issue5/PartB/6-4-514.pdf*

Suliman AA, Abramov AG, Shalamova AA, Badran AM (2020). Effect of humic acid and naphthaleneacetic acid on vegetative growth and fruit quality of tomato plants. RUDN Journal of Agronomy and Animal Industries 15(1):30-39. *https://doi.org/10.22363/2312-797X-2020-15-1-30-39*

Sun C, Bei K, Liu Y, Pan Z (2022). Humic acid improves greenhouse tomato quality and bacterial richness in Rhizosphere Soil. ACS Omega. 7(34):29823-29831. *https://doi.org/10.1021/acsomega.2c02663*

Tee ES, Young SI, Ho SK, Mizura SS (1988). Determination of vitamin C in fresh fruits and vegetables using the dye-titration and microfluorometric methods. Pertanika 11(1):39-44.

UNO (2019). World population prospects 2019 highlights. Department of Economic and Social Affairs, Population Division. *https://population.un.org/wpp/*

Vera-Maldonado P, Aquea F, Reyes-Díaz M, Cárcamo-Fincheira P, Soto-Cerda B, Nunes-Nesi A, Inostroza-Blancheteau C (2024). Role of boron and its interaction with other elements in plants. Frontiers in Plant Science 15:1332459. *https://doi.org/10.3389/fpls.2024.1332459*

Xu W, Wang P, Yuan L, Chen X, Hu X (2021). Effects of application methods of boron on tomato growth, fruit quality and flavor. Horticulturae 7(8):223. *https://doi.org/10.3390/horticulturae7080223*