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Growth and yield response of tomato cv. Hisar Arun to micronutrients and plant growth regulators

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Abstract
Vegetable crops play a vital role in global nutrition and food security; however, achieving optimal productivity is often constrained by biotic and abiotic stresses. Plant growth regulators (PGRs) and micronutrients have emerged as effective tools for enhancing growth, development, and stress resilience in vegetable crops. The present study evaluated the effects of foliar applications of borax, zinc sulphate, gibberellic acid (GA_3), and naphthalene acetic acid (NAA) on the growth, flowering, and yield attributes of the tomato cultivar *Hisar Arun* during the Rabi season of 2023-2024 at the Vegetable Research Farm, CCS Haryana Agricultural University, Hisar, under semi-arid conditions. The experiment was conducted in a Randomized Block Design with three replications, comprising fifteen treatment combinations involving individual and combined applications of micronutrients and PGRs. Growth, reproductive, and yield parameters were recorded at critical growth stages. Among the treatments, GA_3 @ 50 ppm + Borax @ 0.25% (T_7) consistently outperformed all others, producing significant improvements in plant height, branching, flowering behavior, fruit set, fruit size, and overall yield. The superior performance of T_7 is attributed to the synergistic effects of GA_3-induced cell elongation and enhanced photosynthate translocation facilitated by boron. These outcomes align with earlier findings on the beneficial interaction of PGRs with micronutrients in improving tomato productivity. Based on the results, foliar application of GA_3 @ 50 ppm + Borax @ 0.25% can be recommended for farmers cultivating tomato under semi-arid and late-winter conditions similar to Hisar, as it provides a reliable and sustainable strategy to maximize growth and yield. The treatment also shows potential to partially substitute chemical fertilizers under fluctuating temperature and humidity conditions.

Keywords: Plant growth regulators (PGRs), Gibberellic acid (GA_3), and Naphthalene acetic acid (NAA), Foliar application

Introduction
Tomato (*Solanum lycopersicum* L.) is globally recognized as the leading processing vegetable and serves as a major dietary source of vitamins A and C, as well as the potent antioxidant lycopene. India ranks as the second-largest producer of tomato in the world. The characteristic red colour of tomato fruit is attributed to the pigment lycopene, which functions as a powerful antioxidant. Tomatoes are also rich in essential minerals and vitamins, and due to their high content of vitamin C, malic acid, and citric acid, they are often referred to as "the poor man's orange." Lycopene plays a significant role in neutralizing free radicals within cells, which are known to contribute to cancer development; therefore, regular tomato consumption may help reduce cellular damage (Bhowmik *et al*., 2012) [2]. About 251.69 million tons of tomato has been produced from 6.16 million hectares of land across the globe (FAOSTAT, 2022) [15] The nutritional importance of tomatoes can be largely attributed to their content of various health-promoting compounds, including vitamins, carotenoids, and phenolic compounds (Li *et al*., 2018) [17]. These bioactive constituents exhibit a wide range of physiological properties, such as anti-inflammatory, anti-allergenic, antimicrobial, vasodilatory, antithrombotic, cardioprotective, and antioxidant effects (Braga *et al*., 2016) [3]. Tomatoes are also rich in carotenoids and serve as the primary dietary source of lycopene (Viuda-Martos *et al*., 2014) [18]. In addition, they contain naturally occurring antioxidants such as vitamins C and E (Khan *et al*., 2021) [16], as well as substantial amounts of metabolites like sucrose, hexoses, citrate, malate, and ascorbic acid (Li *et*

al., 2018) [17]. However, the excessive use of inorganic fertilizers has resulted in soil, air, and water pollution through nutrient leaching, degradation of soil physical properties, and the accumulation of toxic chemicals in water bodies (Kakar *et al*., 2020) [20]. This overuse has also contributed to severe environmental problems and biodiversity loss (Mozumder & Berrens, 2007) [22]. Moreover, the continuous and excessive application of inorganic fertilizers causes plant tissues to absorb and accumulate heavy metals, which in turn reduces the nutritional value and grain quality of crops (Abebe *et al*., 2022; Lolamo *et al*., 2023) [19, 21]. Plant growth regulators (PGRs) are widely used in crop production to enhance plant growth and yield by improving fruit set, fruit number, and fruit weight (Batlang, 2008) [1]. Micronutrients, such as Zinc (Zn) and Boron (B), are essential for physiological activities like chlorophyll formation, photosynthesis, and meristematic development. Boron is crucial for cell division, pollen tube growth, and the mobilization of photosynthates, which directly correlates with fruit weight. Zinc is vital for the formation of Tryptophan, a precursor of Indole Acetic Acid (IAA), thus stimulating growth, maximizing flower set, and ensuring even ripening. Plant Growth Regulators (PGRs) like Gibberellic Acid (GA_3) and Naphthalene Acetic Acid (NAA) are organic substances that, even in minimal quantities, can significantly alter plant physiological functions, improving fruit set, size, and total yield. GA_3 stimulates stem and internode elongation and is known to induce parthenocarpy fruit formation, while NAA promotes cell division, elongation, and helps prevent young fruit abortion. Thus, plant hormones are the key regulators of plant growth and developmental processes as well as crucial for biotic and abiotic stress response throughout their life cycle (Hassan and Miyajima, 2019) [23]. However, the comprehensive study on the foliar applications of the micro-nutrient's borax and zinc sulphate, along with the plant growth regulators gibberellic acid (GA_3) and naphthalene acetic acid (NAA), in response to the fertilization minimization for crop cultivation are still scare. Therefore, it has been hypothesized that application of certain PGRs like auxin, gibberellic acid (GA_3) and others might ascertain excellent tomato var Hissar Arun production under semi- arid or adverse environmental conditions with low chemical fertilizer requirements. Considering these, the present research was designed to assess the responses of tomato plants to varied levels of fertilizers 150-60-80 kg NPK/ha excess than recommendation after the foliar application of micronutrients borax and zinc sulphate, along with the plant growth regulators gibberellic acid (GA_3) and naphthalene acetic acid (NAA). Growth parameters like plant height and number of primary branches per plant were significantly influenced by different micronutrients and plant growth regulators.

Materials and Methods

The field experiment was conducted during the Rabi season of 2023-24 at the Research Farm of the Department of Vegetable Science, CCS Haryana Agricultural University, Hisar, India, which experiences a semi-arid subtropical climate. Hisar Arun tomato Hisar Arun (Selection-7) variety used was in the experiment and laid out in a Randomized Block Design (RBD) with three replications. Meteorological observations were recorded at the agromet observatory located within the research farm. As, Hisar is characterized by hot, dry summers, cold winters, low rainfall, and wide temperature fluctuations. During the cropping period, mean weekly maximum temperatures ranged from 11.7 to 45.6°C, while minimum temperatures ranged from 4.8 to 28.4°C. Morning relative humidity varied between 42-100%, evening humidity between 14-84%, and daily sunshine hours ranged from 0.0 to 9.6 hours. Total rainfall during the season was 79.80 mm. Prior to transplanting, the recommended dose of farmyard manure (FYM) was incorporated, followed by repeated ploughing and cross-harrowing to achieve a fine tilth. One-third of the nitrogen and the full doses of phosphorus and potassium were applied during final land preparation. The remaining nitrogen was top-dressed at 25 and 45 days after transplanting. Healthy seedlings were transplanted on 15 December 2023 in the evening on ridges spaced 60 cm apart, with 45 cm between plants. Twenty-two parameters were recorded, covering morphological, yield, and yield attributing traits. A total of fifteen treatment combinations (T_1-T_{15}) involving different concentrations and combinations of plant growth regulators (PGRs) and micronutrients were evaluated. The treatments included: T_1 - GA_3 @ 50 ppm; T_2 - GA_3 @ 100 ppm; T_3 - NAA @ 50 ppm; T_4 - NAA @ 100 ppm; T_5 - Borax @ 0.25%; T_6 - Zinc Sulphate @ 0.25%; T_7 - GA_3 @ 50 ppm + Borax @ 0.25%; T_8 - GA_3 @ 50 ppm + Borax @ 0.50%; T_9 - GA_3 @ 50 ppm + Zinc Sulphate @ 0.25%; T_{10} - GA_3 @ 50 ppm + Zinc Sulphate @ 0.50%; T_{11} - NAA @ 50 ppm + Borax @ 0.25%; T_{12} - NAA @ 50 ppm + Borax @ 0.50%; T_{13} - NAA @ 50 ppm + Zinc Sulphate @ 0.25%; T_{14} - NAA @ 50 ppm + Zinc Sulphate @ 0.50%; and T_{15} - Control (water spray). All foliar sprays were applied at appropriate crop growth stages following standard procedures. Observations based on qualitative growth parameters and agronomic yield or yield attributing characters like days to 50% flowering, plant height (cm) at harvest, polar diameter (cm), equatorial diameter (cm), leaf area index, duration of crop (days), days to first picking Fruit, set (%),flower clusters per plant, number of fruits per plant number of primary branches, fruits per plant, and average fruit weight, fruit yield (q/ha) and duration of crop (days) were taken from five randomly selected plants and fruits per plot. The influence of fertilizers, plant growth regulators (PGRs), and micronutrients on the vegetative growth of tomato was assessed by measuring plant height (cm), number of branches and leaves per plant, and canopy spread (cm) periodically at 30, 60, and 90 days after transplanting (DAT). Fruit set (%) was determined by counting the number of fruits on each tagged stem, dividing the total number of fruits by the total number of flowers, and multiplying by 100. The polar diameter of fruits, which is often considered synonymous with fruit length, was measured using a digital Vernier caliper from the stalk end to the blossom end. Additionally, polar diameter (cm), equatorial diameter (cm), and total leaf area (cm^2) were determined at the fruiting stage. Total leaf area was measured using a leaf area meter. For large compound leaves, the leaflets were separated, measured individually using the electric leaf area meter, and the average was calculated. The total leaf area of the sample was then divided by the ground area of the sample plot. Harvests were carried out at marketable maturity, and cumulative yields were used to compute yield per hectare. The experiment used a factorial randomized block design in the field and a completely randomized design in the laboratory. Data were analysed via ANOVA, and significant differences between treatments were determined using a 5% critical difference (CD).

Results and Discussion

According to **Table 1**, the combined application of plant growth regulators and micronutrients showed a similar trend in plant height at 60 and 90 DAT as well as at final harvest. The maximum plant height (92.18 cm) was recorded in treatment T_{10} (GA_3 @ 50 ppm + Zinc sulphate @ 0.50%), which was statistically at par with T_9 (90.01 cm), T_7 (89.33 cm), and T_8 (83.41 cm). The lowest plant height (70.46 cm) was noted in the control (T_{15}), indicating the promotive effect of these treatments on vegetative growth. This enhancement may be attributed to GA_3-induced cell elongation and zinc-mediated auxin synthesis (Singh, 2023; Bhujel *et al*., 2024; Mondal and Ghosh, 2023) [4, 8, 11]. The number of branches per plant was significantly influenced by the different combinations of micronutrients and plant growth regulators (Table 4.2). The highest number of branches (6.72) was observed in T_7 (GA_3 @ 50 ppm + Borax @ 0.25%), which was statistically at par with T_8 (6.61). The lowest number of branches (4.03) occurred in the control (T_{15}). The maximum number of primary branches (6.72) occurred in T_7, showing a 40% increase over the control (4.03), likely due to GA_3 breaking apical dominance and boron supporting meristem activity (Haleema *et al*., 2018; Singh *et al*., 2019) [5, 12]. Leaf area index (LAI) also varied significantly, ranging from 3.37 to 5.98. The maximum LAI (5.98) was recorded in T_7, statistically at par with T_{10} (5.85), while the lowest (3.37) occurred in the control (T_{15}). Leaf area index (5.98) and crop duration (159.23 days) were also highest in T_7, due to GA_3-enhanced cell activity and boron-induced leaf expansion (Masroor *et al*., 2006) [9]. Kim *et al*. (2022) [24] and Loudari *et al*. (2022) [25] reported that adverse or fluctuating weather conditions disrupt key physiological processes, including stomatal conductance, transpiration dynamics, and hormonal regulation. Such disturbances impair nutrient uptake, limit photosynthetic efficiency, and ultimately suppress plant growth and development, consistent with the growth restrictions observed in tomato under similar environmental imbalances.

Fruit size parameters were also influenced by the treatments. The polar diameter ranged from 3.00 to 3.90 cm, with the highest (3.90 cm) in T_7, statistically at par with T_8 (3.77 cm), and the lowest (3.00 cm) in the control. Fruit size was maximized in T_7, with polar diameter 3.90 cm and equatorial diameter 4.87 cm, improvements of 23.1% and 19.7% over control (Singh, 2023) [11]. The equatorial diameter varied from 3.91 to 4.87 cm, with T_7 recording the maximum (4.87 cm), followed by T_8 (4.71 cm), while the minimum (3.91 cm) was noted in the control (Table-1). The higher fresh biomass and improved canopy architecture enhanced the photosynthetic rate and facilitated efficient accumulation and translocation of photosynthates to sink tissues, resulting in a greater number of fruits with superior quality during the late winter season. Modulation of photosynthesis and source-sink dynamics by plant growth regulators has also been reported by earlier studies (Katel *et al*., 2022; Shah *et al*.) [26, 27]. Consequently, the application of PGRs may compensate for reduced fertilizer efficiency under adverse conditions, a trend further supported by the present correlation and PCA analyses. Among the evaluated PGRs, GA_3 and SA were particularly effective, enabling a reduction in fertilizer use by up to 20% while improving key morphological and reproductive attributes of tomato.

Earliness in flowering, an important trait for early marketability, also varied significantly among treatments. Days to 50% flowering ranged from 57.90 to 73.80 days. The earliest flowering (57.90 days) was recorded in T_7, followed by T_8 (59.35 days). The maximum number of days to 50% flowering (73.80 days) was observed in the control (T_{15}). Early reproductive development was also influenced by treatments, with T_7 recording the earliest 50% flowering (57.90 days) and first fruit picking (80.90 days), representing reductions of 27.4% and 19.7% from the control. GA_3 promotes floral initiation and fruit development, while boron improves pollen viability and hormonal regulation (Ujjwal *et al*., 2018; Lakshmi *et al*., 2022; Verma *et al*., 2015) [7, 13, 14]. The number of flower clusters per plant ranged between 13.26 and 15.96. The highest value (15.96) was recorded in T_7, which was statistically at par with T_8 (15.21), T_{10} (15.11), and T_9 (14.96). The minimum value (13.26) was noted in the control (T_{15}). Similarly, the number of flowers per cluster varied from 3.97 to 4.96. The maximum (4.96) was found in T_7, followed by T_8 (4.82), T_{10} (4.77), T_9 (4.71), and T_{11} (4.67), whereas the control (T_{15}) produced the minimum (3.97). Fruit set percentage also differed significantly, ranging from 49.33% to 55.61%. The highest fruit set (55.61%) was observed in T_{11} (NAA @ 50 ppm + Borax @ 0.25%), which was statistically at par with T_{12} (54.73%), T_{14} (54.34%), T_{13} (53.90%), and T_7 (53.56%). The lowest fruit set (49.33%) was recorded in the control (T_{15}). The number of days to first picking ranged from 80.90 to 96.81 days. The earliest picking was achieved in T_7 (80.90 days), closely followed by T_8 (82.69 days), while the control (T_{15}) took the longest time (96.81 days). Crop duration ranged from 134.99 to 159.23 days, with the longest duration in T_7 (159.23 days), statistically similar to T_8 (156.44 days) and T_{10} (152.93 days). The shortest duration (134.99 days) was observed in the control in Table-2. The number of fruits per plant ranged from 27.06 to 41.99. The maximum number (41.99) was recorded in T_7, statistically at par with T_8 (38.59) and T_{11} (38.25). The control produced the minimum number (27.06). Average fruit weight varied between 40.91 g and 48.32 g. The highest fruit weight (48.32 g) was recorded in T_7, followed by T_8 (47.24 g). The lowest weight (40.91 g) was observed in the control (T_{15}). The highest number of fruits per plant (41.99) and average fruit weight (48.32 g) also occurred in T_7, showing increases of 55.1% and 18.1% over the control, due to improved nutrient uptake and photosynthate translocation (Rahman *et al*., 2015; Kumar *et al*., 2023) [6, 10]. Fruit yield per plant ranged from 1.21 to 1.54 kg. The maximum yield (1.54 kg) was obtained in T_7, statistically similar to T_8 (1.46 kg). The minimum yield (1.21 kg) was recorded in the control. Fruit yield per plot followed the same trend, ranging from 21.85 to 30.27 kg, with the highest yield in T_7 (30.27 kg), statistically comparable to T_8 (28.66 kg). The lowest yield was again in the control (21.85 kg). Similarly, fruit yield per hectare varied between 245.50 and 297.70 q/ha. The highest yield (297.70 q/ha) was recorded in T_7, followed by T_8 (282.48 q/ha), while the lowest yield (245.50 q/ha) was recorded in the untreated control (T_{15}). The highest number of fruits per plant (41.99) and average fruit weight (48.32 g) also occurred in T_7, showing increases of 55.1% and 18.1% over the control, due to improved nutrient uptake and photosynthate translocation (Rahman *et al*., 2015; Kumar *et al*., 2023) [6, 10]. Consequently, T_7 achieved the maximum yields: 1.54 kg per plant, 30.27 kg per plot, and 297.70 q/ha, which were 27.3%, 39.6%, and 17.5% higher than the respective control values, reflecting enhanced photosynthetic efficiency (Singh, 2023) [11].

The significantly higher yield recorded in treatment GA_3 @ 50 ppm + Borax @ 0.25% (T_7) can be attributed to the synergistic physiological functions of GA_3 and boron. Boron is essential for sugar translocation, membrane integrity, and pollen tube elongation, thereby improving the movement of photosynthates to developing fruits and enhancing fruit size and weight. Concurrently, GA_3 stimulates cell elongation, accelerates growth processes, and may induce parthenocarpic fruit development, resulting in improved fruit set and enlarged fruit dimensions. The combined foliar application of GA_3 and boron thus enhanced vegetative vigor through growth promotion while simultaneously improving reproductive efficiency via better nutrient mobilization and floral functionality. These results corroborate earlier findings that the integration of GA_3 with boron produces a synergistic effect, leading to substantial improvements in tomato growth, fruit set, and overall yield performance.

Table 1: Physiological Responses of Plants to Micronutrient Application and Plant Growth Regulators its impacts on Quantitative Growth Parameters

Treatment	Days to 50% flowering	Primary branches /plant	Plant height (cm) at harvest	Polar diameter (cm)	Equatorial diameter (cm)	Leaf area index
T_1	69.35	4.69	71.60	3.22	4.21	4.69
T_2	69.89	4.78	70.93	3.22	4.10	3.51
T_3	72.04	4.38	73.62	3.03	4.01	3.48
T_4	71.44	4.82	78.17	3.10	4.04	3.74
T_5	65.44	5.13	80.92	3.43	4.33	5.41
T_6	68.96	4.92	79.17	3.23	4.26	5.18
T_7	57.90	6.72	89.33	3.90	4.87	5.98
T_8	59.35	6.61	83.41	3.77	4.71	5.66
T_9	63.21	5.92	90.01	3.45	4.49	5.62
T_{10}	62.83	6.21	92.18	3.51	4.51	5.85
T_{11}	64.56	5.48	80.47	3.47	4.46	5.51
T_{12}	65.24	5.39	79.40	3.43	4.34	5.35
T_{13}	68.42	5.05	80.96	3.29	4.29	4.86
T_{14}	66.25	5.23	81.43	3.40	4.34	5.03
T_{15}	73.80	4.03	70.46	3.00	3.91	3.37
CD at 5%	4.73	0.51	8.60	0.31	0.33	0.31
SE (m)	1.42	0.18	2.95	0.11	0.11	0.11
CV (%)	6.22	5.73	6.39	5.58	6.54	6.20

T_1 - GA_3 @ 50 ppm; T_2 - GA_3 @ 100 ppm; T_3 - NAA @ 50 ppm; T_4 - NAA @ 100 ppm; T_5 - Borax @ 0.25%; T_6 - Zinc Sulphate @ 0.25%; T_7 - GA_3 @ 50 ppm + Borax @ 0.25%; T_8 - GA_3 @ 50 ppm + Borax @ 0.50%; T_9 - GA_3 @ 50 ppm + Zinc Sulphate @ 0.25%; T_{10} - GA_3 @ 50 ppm + Zinc Sulphate @ 0.50%; T_{11} - NAA @ 50 ppm + Borax @ 0.25%; T_{12} - NAA @ 50 ppm + Borax @ 0.50%; T_{13} - NAA @ 50 ppm + Zinc Sulphate @ 0.25%; T_{14} - NAA @ 50 ppm + Zinc Sulphate @ 0.50%; and T_{15} - Control (water spray).

Table 2: Impact of Micronutrient Dynamics and Plant Growth Regulator Application on Agronomic Yield and Yield Attributes

Treatment	Days to first picking	Fruit set (%)	Flower clusters per plant	Number of fruits per plant	Average fruit weight (gm)	Fruit yield per plant	Fruit yield per plot	Fruit yield (q/ha)	Duration of crop (days)
T_1	92.35	50.53	14.14	30.09	44.07	1.28	23.98	253.55	139.21
T_2	93.55	50.40	14.03	29.56	43.96	1.26	22.24	246.80	137.96
T_3	95.04	49.56	13.91	27.82	43.76	1.24	22.38	248.36	135.43
T_4	94.77	50.43	13.98	28.77	42.89	1.26	22.83	250.40	136.76
T_5	88.44	50.94	14.73	34.08	44.87	1.37	24.57	265.67	143.84
T_6	90.36	51.23	14.39	31.53	44.02	1.30	23.70	256.10	142.20
T_7	80.90	53.56	15.96	41.99	48.32	1.54	30.27	297.70	159.23
T_8	82.69	52.53	15.21	38.59	47.24	1.46	28.66	282.48	156.44
T_9	87.24	51.60	14.96	36.33	45.22	1.42	27.55	271.26	150.45
T_{10}	85.49	52.33	15.11	37.68	46.50	1.44	28.16	277.37	152.93
T_{11}	87.56	55.61	14.73	38.25	45.06	1.40	27.39	269.00	147.88
T_{12}	88.24	54.73	14.69	37.07	44.99	1.39	27.18	268.53	146.73
T_{13}	90.08	53.90	14.42	34.04	44.49	1.31	26.31	258.75	143.13
T_{14}	89.25	54.34	14.48	35.15	40.65	1.35	25.36	267.88	143.99
T_{15}	96.81	49.33	13.26	27.06	40.91	1.21	21.85	245.50	134.99
CD at 5%	6.39	2.12	1.12	3.97	3.07	0.09	1.86	18.75	8.60
SE (m)	2.10	0.73	0.36	1.36	1.05	0.03	0.61	6.12	2.95
CV (%)	7.24	5.43	5.58	6.97	6.08	5.74	7.33	8.08	6.31

T_1 - GA_3 @ 50 ppm; T_2 - GA_3 @ 100 ppm; T_3 - NAA @ 50 ppm; T_4 - NAA @ 100 ppm; T_5 - Borax @ 0.25%; T_6 - Zinc Sulphate @ 0.25%; T_7 - GA_3 @ 50 ppm + Borax @ 0.25%; T_8 - GA_3 @ 50 ppm + Borax @ 0.50%; T_9 - GA_3 @ 50 ppm + Zinc Sulphate @ 0.25%; T_{10} - GA_3 @ 50 ppm + Zinc Sulphate @ 0.50%; T_{11} - NAA @ 50 ppm + Borax @ 0.25%; T_{12} - NAA @ 50 ppm + Borax @ 0.50%; T_{13} - NAA @ 50 ppm + Zinc Sulphate @ 0.25%; T_{14} - NAA @ 50 ppm + Zinc Sulphate @ 0.50%; and T_{15} - Control (water spray).

Conclusion

The results of the present investigation demonstrate that the foliar application of plant growth regulators in conjunction with micronutrients is an effective approach for improving tomato growth and yield. Among the treatments evaluated, GA_3 @ 50 ppm + Borax @ 0.25% (T_7) consistently produced superior performance, resulting in notable enhancements in key growth attributes and yield components. Based on these findings, the T_7 treatment can be recommended for farmers cultivating the tomato variety *Hisar Arun* under conditions similar to those of the study area, as it offers a reliable strategy for maximizing productivity and overall crop performance. Therefore, it can be suggested that application of GA_3 @ 50 ppm + Borax @ 0.25% would be used as substitute of chemical fertilizer for enhancing the growth and yield of tomato even under mid temperature and humidity differentiation in late winter in Hisar Haryana. Since this is an initial investigation on the use of PGRs as substitution of chemical fertilizer, further studies would be carried out with a wider range of PGRs concentrations focusing on the other abiotic stress conditions for comprehensive understanding of the interactive mode of action of the respective PGR in response to the specific growing stages of tomato.

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