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Effect of Foliar Spray of Different Plant Growth Regulators (PGRs), Micronutrients and Seaweed Extract on Vegetative Growth, Flowering, Fruit Yield and Quality of Pomegranate (*Punica granatum* L.)

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Abstract

An experiment was conducted during 2025–2026 at the Central Orchard (Horticulture Research Farm), Department of Horticulture, Naini Agricultural Institute, Faculty of Agriculture, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj, Uttar Pradesh, India, to evaluate foliar applications of plant growth regulators, micronutrients, and seaweed extract in pomegranate (*Punica granatum* L.) cv. Kandhari. Eight-year-old, uniform trees of pomegranate cv. *Kandhari* were used for the study. The experiment was laid out in a randomised block design (RBD) with eleven treatments and three replications. The treatments comprised foliar applications of plant growth regulators (GA_3 and NAA), micronutrients ($ZnSO_4$ and borax), and seaweed extract, applied individually and in different combinations. The first foliar spray was applied in September 2025. The results revealed that treatment T_{10} (GA_3 at 100 ppm + NAA at 40 ppm + seaweed extract at 5 ml L^{-1} + $ZnSO_4$ at 0.5% + borax at 0.2%) produced the maximum vegetative growth and was the most effective treatment. However, T_6 (NAA at 40 ppm + $ZnSO_4$ at 0.5% + borax at 0.2%) was found to be the most economically viable treatment. The study indicates that integrated foliar application of plant growth regulators, micronutrients, and seaweed extract can significantly improve vegetative growth, total number of flowers, number of fruits per plant, and fruit weight (g) in pomegranate under Prayagraj agro-climatic conditions.

Keywords: Pomegranate; Punica granatum L.; plant growth regulators; GA_3; NAA; $ZnSO_4$; borax; seaweed extract; vegetative growth; flowering; fruit yield.

1. Introduction

Pomegranate (*Punica granatum* L.) is one of the most important fruit crops cultivated in tropical and subtropical regions owing to its adaptability to arid and semi-arid climates, high nutritional value, medicinal importance, and excellent export potential (J. Sharma et al., 2014). The fruits are rich in antioxidants, anthocyanins, polyphenols, vitamins, and minerals, making pomegranate a valuable functional food with increasing commercial importance (ICAR–National Research Centre on Pomegranate [ICAR-NRCP], 2024; Marathe et al., 2025). India is the largest producer of pomegranate in the world, with the crop occupying approximately 2.32 lakh hectares and producing about 28.96 lakh metric tonnes. Despite its leading position, considerable variation in productivity exists across different growing regions, suggesting ample scope for improving crop performance through scientific orchard management practices (ICAR-NRCP, 2024; Madrewar et al., 2026). Among the various factors influencing productivity, vegetative growth plays a fundamental role in determining the growth and yield potential of pomegranate. Adequate shoot elongation and leaf development contribute to better canopy establishment, enhanced photosynthetic activity, and efficient translocation of assimilates, which ultimately support flowering, fruit set, and fruit development. However, nutrient deficiencies, hormonal imbalance, and environmental stresses often restrict vegetative growth, resulting in shorter shoots, fewer leaves, and reduced productivity (Kumar et al., 2018). Foliar application of plant growth regulators, micronutrients, and biostimulants has emerged as an effective approach for improving vegetative growth in fruit crops. Gibberellic acid (GA_3) promotes cell division and elongation, leading to increased shoot growth, while naphthalene acetic acid (NAA) enhances vegetative vigour and plant development (Thakur & Sharma, 2020). Similarly, zinc and boron are essential for enzyme activity, chlorophyll synthesis, auxin metabolism, and carbohydrate translocation, thereby supporting healthy shoot and leaf growth. Seaweed extracts, owing to their natural growth-promoting substances and bioactive compounds, further enhance nutrient uptake, photosynthetic efficiency, and overall plant vigour (Davarpanah et al., 2016; Maity et al., 2021; Marathe et al., 2025).

Recent pomegranate research has reported that foliar zinc and boron applications can influence growth and yield traits in cv. Kandhari, while foliar zinc has also been evaluated for physiological responses of pomegranate under water-deficit conditions (Guleria et al., 2025; Zahedi et al., 2024). Recent work has also examined NAA and other plant growth regulators in relation to pomegranate flowering and fruit set, and broader horticultural evidence continues to support seaweed extracts as biostimulants for growth-related responses (Raigond et al., 2024; Mughunth et al., 2024). In pomegranate, integrated nutrient-management treatments incorporating foliar seaweed extract and micronutrients have likewise been evaluated for vegetative growth and flowering (Ranjith & Rajeswari, 2026).

1.1 Research Gap

However, the literature considered in this study provides limited information on the simultaneous foliar application of GA_3, NAA, $ZnSO_4$, borax, and seaweed extract in pomegranate cv. Kandhari, particularly under the agro-climatic conditions of Prayagraj. A comparative evaluation of these inputs, applied individually and in combinations within a single experiment, is therefore needed to clarify their relative effects on the growth, flowering, and fruit attributes assessed in this manuscript.

1.2 Objective

Accordingly, the objective of the present investigation was to evaluate the effects of foliar application of GA_3, NAA, $ZnSO_4$, borax, and seaweed extract, applied alone and in selected combinations, on shoot length, number of leaves, total number of flowers, number of fruits per plant, and fruit weight of pomegranate cv. Kandhari under Prayagraj agro-climatic conditions.

2. Materials and Methods

The present investigation was carried out during 2025 at the Research Field, Central Orchard (Horticulture Research Farm-HRF), Department of Horticulture, Naini Agricultural Institute (NAI), Faculty of Agriculture (FoA), Sam Higginbottom University of

Agriculture, Technology and Sciences (SHUATS), district Prayagraj (U.P.), India. Prayagraj District lies within the subtropical belt of south-eastern U.P., which experiences extremely hot summers and fairly cold winters. Treatment details were denoted as T_0 – Control; T_1 – GA_3 at 100 ppm; T_2 – GA_3 at 100 ppm + NAA at 40 ppm; T_3 – GA_3 at 100 ppm + $ZnSO_4$ at 0.5% + Borax at 0.2%; T_4 – GA_3 at 100 ppm + Seaweed extract at 5 ml/L; T_5 – NAA at 40 ppm; T_6 – NAA at 40 ppm + $ZnSO_4$ at 0.5% + Borax at 0.2%; T_7 – NAA at 40 ppm + Seaweed extract at 5 ml/L; T_8 – $ZnSO_4$ at 0.5% + Borax at 0.2%; T_9 – Seaweed extract at 5 ml/L; and T_{10} – GA_3 at 100 ppm + NAA at 40 ppm + Seaweed extract at 5 ml/L + $ZnSO_4$ at 0.5% + Borax at 0.2%. Observations were recorded on vegetative growth, viz., shoot height (cm) and number of leaves. The data recorded during the investigation were subjected to statistical analysis using the analysis of variance technique (Fisher, 1950).

3. Results and Discussion

3.1 Vegetative Growth (Shoot Length and Number of Leaves)

The data on vegetative growth of pomegranate (*Punica granatum* L.) as influenced by the foliar application of different plant growth regulators (PGRs), micronutrients, and seaweed extract are presented in Table 1. Shoot length of pomegranate cv. Kandhari, recorded at 30, 60, 90, and 120 days after spray (DAS), differed significantly among the treatments. Plants receiving a foliar spray of GA_3 at 100 ppm + NAA at 40 ppm + seaweed extract at 5 ml/lit + 0.5% $ZnSO_4$ + borax at 0.2% (T_{10}) recorded the maximum shoot length values (27.82, 44.40, 47.50, and 50.00) at 30, 60, 90, and 120 DAS, respectively. This treatment was reported to be at par with NAA at 40 ppm + seaweed extract at 5 ml and 0.5% $ZnSO_4$ + borax at 0.2% at 30 DAS; GA_3 at 100 ppm + 0.5% $ZnSO_4$ + borax at 0.2% at 60 DAS; GA_3 at 100 ppm + NAA at 40 ppm, 0.5% $ZnSO_4$ + borax at 0.2%, and NAA at 40 ppm + seaweed extract at 5 ml at 90 DAS; and 0.5% $ZnSO_4$ + borax at 0.2% and NAA at 40 ppm + seaweed extract at 5 ml at 120 DAS. The minimum shoot length (cm) values were observed in T_0 (14.77, 21.90, 27.28, and 29.83) at 30, 60, 90, and 120 DAS, respectively. Gibberellic acid (GA_3) is recognised as one of the most effective growth-promoting hormones responsible for stem elongation through the stimulation of cell division and cell enlargement. Application of GA_3 increases the plasticity of cell walls and enhances metabolic activities associated with shoot growth. The observed increase in shoot length under the present treatment may therefore be attributed to enhanced internodal elongation and greater mobilisation of carbohydrates towards growing shoot apices. Similar findings were reported by Masoud et al. (2019), who observed improved vegetative growth in pomegranate following GA_3 application. Comparable results have also been reported in several fruit crops where GA_3 significantly enhanced shoot elongation and vegetative vigour (Taiz et al., 2015; Masoud et al., 2019). The beneficial effect of NAA at 40 ppm on shoot growth may be associated with its role in promoting cell enlargement, vascular differentiation, and translocation of photosynthates. Auxins stimulate meristematic activity and facilitate the development of new vegetative tissues, leading to increased shoot extension. When applied in combination with GA_3, NAA may exhibit a synergistic effect by enhancing hormonal balance and promoting continuous shoot growth. Earlier investigations in pomegranate and other fruit crops have also demonstrated that foliar application of NAA significantly improved vegetative growth parameters, including shoot length and branching (Ghosh et al., 2009; Bisht et al., 2018). Seaweed extract applied at 5 ml L^{-1} may have further contributed to increased shoot length due to the presence of naturally occurring growth-promoting substances such as cytokinins, auxins, gibberellins, amino acids, vitamins, and essential minerals. These compounds stimulate chlorophyll synthesis, photosynthetic activity, nutrient uptake, and enzyme activation, thereby enhancing plant growth and development. Seaweed-based biostimulants have been widely reported to improve vegetative growth and stress tolerance in horticultural crops. The increased shoot elongation observed in the present study may therefore be attributed to improved physiological and biochemical processes induced by seaweed extract application (Khan et al., 2009; H. S. S. Sharma et al., 2014). Zinc supplied through foliar application of $ZnSO_4$ at 0.5% also played an important role in enhancing shoot growth. Zinc is an essential micronutrient involved in auxin biosynthesis, protein synthesis, enzyme activation, and chlorophyll formation. It participates in the synthesis of tryptophan, which serves as a precursor for indole-3-acetic acid (IAA), thereby promoting cell elongation and vegetative growth. Improved zinc nutrition enhances photosynthetic efficiency and metabolic activity, resulting in increased shoot development. Similar observations were reported by Davarpanah et al. (2016) and Maity et al. (2021), who recorded enhanced growth characteristics in pomegranate following zinc application. The positive response of shoot length to borax at 0.2% may be attributed to the physiological functions of boron in cell division, cell wall synthesis, carbohydrate metabolism, and translocation of sugars from source to sink tissues. Boron is particularly important for the growth of meristematic tissues and the development of young shoots. Adequate boron availability enhances nutrient transport and metabolic activity, leading to improved vegetative growth. Previous studies in pomegranate have demonstrated that foliar application of boron, either alone or in combination with zinc, significantly improved plant growth and vigour by supporting various physiological processes (Davarpanah et al., 2016; Dhurve et al., 2018). The superior performance of the combined treatment indicates a synergistic interaction among GA_3, NAA, seaweed extract, zinc, and boron. While GA_3 and NAA directly stimulated cell division and elongation, seaweed extract enhanced physiological efficiency and nutrient uptake. Simultaneously, zinc promoted auxin synthesis and enzymatic activity, whereas boron improved carbohydrate translocation and meristematic growth. The cumulative effect of these growth-promoting substances and nutrients likely resulted in enhanced photosynthetic activity, greater assimilate production, and efficient partitioning of metabolites towards actively growing shoots, ultimately leading to maximum shoot length in pomegranate. Similar synergistic effects of plant growth regulators and micronutrients on vegetative growth have been reported by several researchers in pomegranate and other fruit crops (Marschner, 2012; Davarpanah et al., 2016; Maity et al., 2021).

The data pertaining to the number of leaves per plant of pomegranate cv. Kandhari, recorded at 30, 60, 90, and 120 days after spray (DAS), differed significantly among the treatments following foliar application of plant growth regulators, micronutrients, and seaweed extract. Plants receiving a foliar spray of GA_3 at 100 ppm + NAA at 40 ppm + seaweed extract at 5 ml/lit + 0.5% $ZnSO_4$ + borax at 0.2% (T_{10}) recorded the maximum number of leaves per plant (29.83, 41.33, 41.50, and 53.17) at 30, 60, 90, and 120 DAS, respectively. This treatment was reported to be at par with NAA at 40 ppm + seaweed extract at 5 ml at 30 DAS, GA_3 at 100 ppm + NAA at 40 ppm at 60 DAS, NAA at 40 ppm + seaweed extract at 5 ml at 90 DAS, and GA_3 at 100 ppm + NAA at 40 ppm at 120 DAS. The minimum number of leaves per plant (cm) values were observed in T_0 (15.33, 21.17, 26.17, and 28.33) at 30, 60, 90, and

120 DAS, respectively. Therefore, the maximum number of leaves per plant recorded under foliar application of GA_3 at 100 ppm + NAA at 40 ppm + seaweed extract at 5 ml L^{-1} + $ZnSO_4$ at 0.5% + borax at 0.2% may be attributed to improved hormonal regulation, enhanced nutrient uptake, increased photosynthetic efficiency, and better assimilate partitioning towards actively growing tissues. The findings of the present study are in agreement with earlier reports indicating that integrated application of plant growth regulators, seaweed extracts, and micronutrients significantly promotes vegetative growth and canopy development in pomegranate and other fruit crops (Masoud et al., 2019; Davarpanah et al., 2016; Dhurve et al., 2018).

3.2 Total Number of Flowers

The total number of flowers differed significantly among the treatments (Table 2). The highest total number of flowers (148.61) was recorded in T_{10} (GA_3 at 100 ppm + NAA at 40 ppm + seaweed extract at 5 ml L^{-1} + 0.5% $ZnSO_4$ + 0.2% borax), followed by NAA at 40 ppm + 0.5% $ZnSO_4$ + 0.2% borax, GA_3 at 100 ppm + 0.5% $ZnSO_4$ + 0.2% borax, and GA_3 at 100 ppm + NAA at 40 ppm. The lowest total number of flowers (87.47) was recorded in the control (T_0). The superior performance of T_{10} may be attributed to the synergistic effect of plant growth regulators, seaweed extract, and micronutrients, which enhanced physiological activity, hormonal balance, nutrient uptake, and assimilate translocation, thereby promoting floral bud initiation and increasing flowering intensity. Similar findings have been reported in pomegranate and other fruit crops (Ghosh et al., 2009; Davarpanah et al., 2016; Masoud et al., 2019; Maity et al., 2021).

3.3 Number of Fruits Per Plant

The number of fruits per plant differed significantly among the treatments (Table 2). The highest number of fruits per plant (64.27) was recorded in T_{10} (GA_3 at 100 ppm + NAA at 40 ppm + seaweed extract at 5 ml L^{-1} + 0.5% $ZnSO_4$ + 0.2% borax), followed by NAA at 40 ppm + 0.5% $ZnSO_4$ + 0.2% borax, GA_3 at 100 ppm + 0.5% $ZnSO_4$ + 0.2% borax, and GA_3 at 100 ppm + NAA at 40 ppm. The lowest number of fruits per plant (31.37) was recorded in the control (T_0). The superior performance of T_{10} may be attributed to the synergistic effect of plant growth regulators, seaweed extract, and micronutrients, which enhanced flowering, fruit set, and nutrient translocation, resulting in a higher number of fruits per plant. Similar findings have been reported in pomegranate and other fruit crops (Masoud et al., 2019; Davarpanah et al., 2016; Maity et al., 2021).

Table 1. Effect of treatment on shoot length (cm) and Number of leaves of Pomegranate (*Punica granatum* L.)

Treatment Notation	Treatment details	Shoot length (cm)				Number of leaves			
		30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS
T_0	Control	14.77	21.90	27.28	29.83	15.33	21.17	26.17	28.33
T_1	GA_3at 100ppm	17.75	29.05	32.90	38.42	17.33	25.33	30.50	36.17
T_2	GA_3at 100ppm + NAAat 40ppm	22.25	33.54	38.32	45.43	24.83	31.33	35.67	45.17
T_3	GA_3at 100ppm + 0.5%$ZnSO_4$ + Boraxat 0.2%	23.32	36.74	41.30	46.42	25.17	33.67	38.17	47.67
T_4	GA_3at 100ppm + Seaweed extract at 5ml/lit	19.45	31.61	35.37	39.12	18.67	27.83	31.83	38.17
T_5	NAAat 40ppm	17.88	30.12	34.70	38.85	17.33	27.33	31.50	37.67
T_6	NAAat 40ppm + 0.5%$ZnSO_4$ + 0.2% Borax	24.87	39.08	42.23	48.3	25.33	35.33	39.50	48.83
T_7	NAAat 40ppm + Seaweed extractat 5ml	21.92	32.13	37.50	40.85	21.35	27.83	32.50	38.33
T_8	0.5% $ZnSO_4$ +Boraxat 0.2%	21.98	32.70	38.02	40.85	22.50	30.00	34.50	41.33
T_9	Seaweed extract at 5ml/lit	17.03	26.21	32.90	36.57	17.17	24.00	29.00	33.33
T_{10}	GA_3at 100ppm + NAAat 40ppm + Seaweed extract at 5ml/lit + 0.5%$ZnSO_4$ + Boraxat 0.2%	27.82	44.40	47.50	50.00	29.83	41.33	41.50	53.17
	F-Test	S	S	S	S	S	S	S	S
	C.D.	6.289	7.984	8.512	8.963	6.879	9.007	8.129	6.752
	SE(m)	2.117	2.688	2.865	3.017	2.316	3.032	2.736	2.273
	SE(d)	2.994	3.801	4.052	4.267	3.275	4.288	3.870	3.214
	C.V.	17.611	14.324	13.374	12.654	18.786	18.042	14.058	9.662

Table 2. Effect of treatment on Total number of flowers, Number of fruit per plant and Fruit weight (g) of Pomegranate (*Punica granatum* L.)

Treatment Notation	Treatment details	Total number of flowers	Number of fruit per plant	Fruit weight (g)
T_0	Control	87.47	31.37	168.31
T_1	GA_3at 100ppm	108.20	40.79	218.84
T_2	GA_3at 100ppm + NAAat 40ppm	130.33	52.82	247.50
T_3	GA_3at 100ppm + 0.5%$ZnSO_4$ + Boraxat 0.2%	133.96	54.96	251.17
T_4	GA_3at 100ppm + Seaweed extract at 5ml/lit	117.08	44.31	226.62
T_5	NAAat 40ppm	112.06	41.78	220.44
T_6	NAAat 40ppm + 0.5%$ZnSO_4$ + 0.2% Borax	138.18	61.45	254.95
T_7	NAAat 40ppm + Seaweed extractat 5ml	119.79	46.63	232.38
T_8	0.5% $ZnSO_4$ +Boraxat 0.2%	126.62	47.77	237.03
T_9	Seaweed extract at 5ml/lit	102.71	39.34	207.32
T_{10}	GA_3at 100ppm + NAAat 40ppm + Seaweed extract at 5ml/lit + 0.5%$ZnSO_4$ + Boraxat 0.2%	148.61	64.27	258.06
	F-Test	S	S	S
	C.D.	2.280	1.509	2.069
	SE(m)	0.768	0.508	0.697
	SE(d)	1.085	0.718	0.985
	C.V.	1.104	1.841	0.526

3.4 Fruit Weight (g)

Fruit weight differed significantly among the treatments (Table 2). The highest fruit weight (258.06 g) was recorded in T_{10} (GA_3 at 100 ppm + NAA at 40 ppm + seaweed extract at 5 ml L^{-1} + 0.5% $ZnSO_4$ + 0.2% borax), followed by NAA at 40 ppm + 0.5% $ZnSO_4$ + 0.2% borax, GA_3 at 100 ppm + 0.5% $ZnSO_4$ + 0.2% borax, and GA_3 at 100 ppm + NAA at 40 ppm. The lowest fruit weight (168.31 g) was recorded in the control (T_0). The superior performance of T_{10} may be attributed to the synergistic effect of plant growth regulators, seaweed extract, and micronutrients, which enhanced assimilate accumulation and translocation, resulting in increased fruit weight. Similar findings have been reported in pomegranate and other fruit crops (Davarpanah et al., 2016; H. S. S. Sharma et al., 2014; Maity et al., 2021).

4. Conclusion

The study indicated that foliar application of GA_3 at 100 ppm + NAA at 40 ppm + seaweed extract at 5 ml L^{-1} + $ZnSO_4$ at 0.5% + borax at 0.2% was the most effective treatment for improving vegetative growth, flowering, number of fruits, and fruit weight of pomegranate cv. Kandhari under Prayagraj agro-climatic conditions. This treatment recorded the highest shoot length, number of leaves, total number of flowers, number of fruits per plant, and fruit weight among the evaluated treatments. The findings suggest that the combined use of plant growth regulators, micronutrients, and seaweed extract may support better crop performance in pomegranate when applied as a foliar spray.

5. Limitations

The study was conducted at a single location under the agro-climatic conditions of Prayagraj using eight-year-old pomegranate cv. Kandhari trees, with eleven treatments and three replications. Therefore, the findings may not be directly generalisable to other cultivars, locations, or growing conditions. The evaluation was limited to shoot length, number of leaves, total flowers, fruits per plant, and fruit weight, while broader fruit-quality attributes were not reported. Further multi-location and multi-season studies involving additional cultivars, larger replication, comprehensive fruit-quality measurements, and detailed economic evaluation are required to validate the observed treatment responses.

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Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, and reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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