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Effect of Foliar Application of Humic Acid on Vegetative Growth Attributes of Jamun (*Syzygium cumini* (L.) Skeels.) cv. Goma Priyanka

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was carried out at Instructional Farm, Department of Fruit Science, College of Horticulture and Forestry in Jhalarapatan, Jhalawar during 2021-22 and 2022-23 with the object of assessing the response of foliar application of humic acid on growth attributes of Jamun (*Syzygium cumini* (L.) Skeels) cv. Goma Priyanka. The experiment comprised of 4 treatment combinations in randomized block design with three replications consisted of HA_0: [Control], HA_1: [1000ppm humic acid], HA_2: [2000 ppm humic acid], and HA_3: [3000 ppm humic acid]. On the basis of the results emanated from present investigation, it could be concluded that foliar application of humic acid HA_3 (3000 ppm) was significantly superior plant growth parameters viz. rootstock girth, scion girth, plant height, canopy volume, canopy spread E-W, N-S, of Jamun cv. Goma Priyanka plants.

Keywords: Humic acid; jamun; growth attributes.

1. INTRODUCTION

Jamun, scientifically known as *Syzygium cumini* Skeels, is unique in that it is an indigenous minor fruit crop in India. It also goes by the names Eugenia cumini and Syzygium jambolanum, both of which belong to the Myrtaceae family. Jambul, Black Plum, Java Plum, Indian Blackberry, Jambulang, and Jamun are some of its many names. This tree can be found in Madagascar, South America, Eastern Africa, and the Asian subcontinent. Additionally, it has adapted to the climates of Florida and Hawaii in the United States of America [1]. Although jamun has historical roots in India, it is now grown in Thailand, the Philippines, and Madagascar, among other places. It is impressive that the tree has established itself successfully in places as diverse as California, Algeria, Israel, and the West Indies.

Jamun is primarily found in tropical and subtropical regions of India. Up to 1300 meters in the lower Himalayan regions and up to 1600 meters in the Kumaon highlands are where its existence is noted. Jamun is grown in a broad geographic range, from Tamil Nadu in the south to the Indo-Gangetic plains in the north [2]. While approximately 75 native species reside within the Syzygium genus, only a handful possess notable commercial value. Jamun, recognized for its substantial evergreen form, bears fruits resembling dates but distinguished by their darker hue and prominent elongated seeds.

Its extensive cultivation is a hallmark of India, with production zones stretching from the Indo-Gangetic plains in the north to Tamil Nadu in the south. Maharashtra assumes a leading role in jamun production, followed by Uttar Pradesh, Tamil Nadu, Gujarat, and other contributing states.

Jamun fruits are rich repositories of nutrients, notably boasting a high iron content.

Goma Priyanka stands as a highly promising jamun cultivar, officially released by CHES Godhra (CIAH-ICAR) Gujarat in 2009. Its potential is particularly recognized for the semi-arid regions within our country. This cultivar is characterized by its dense foliage, expansive growth habit, semi-dwarf stature, and elegantly drooping branches. A notable trait is its early flowering, commencing from the fourth year onwards, making it an early-bearing variety that holds significant value.

Humic acid, often referred to as the "black gold" of agriculture, is a pivotal element of humic materials and plays a significant role in the fundamental components of peat, lignite, and soil. Due to its high solubility in water and its abundant water-soluble active regions, it is readily assimilated by plants as a fertilizer. The utilization of humic acid as an organic fertilizer or soil enhancer has been gaining substantial interest. Hilta et al. [3] examined that applying humic constituents through foliar application enhances plant growth and mineral content. Perminova et al. [4] reported that Humic acid had the ability to protect plants against abiotic and biotic stresses, as well as stimulate their growth and development, promoting increases in yields and agricultural production. The application of humic substances to leaves offers substantial benefits to plant growth by orchestrating the assimilation of both major and minor elements. These substances function as activators and inhibitors for a range of enzymes, induce changes in membrane permeability, and play a vital role in protein synthesis and the augmentation of biomass. In soils, humic substances, encompassing humic and fulvic acids, constitute a substantial portion, accounting for 65–70% of organic matter. The diverse roles these substances fulfill confer significant advantages, rendering them a valuable asset for fostering plant growth [5,6]. The positive effects of humic substances on plant growth may be attributable to their indirect effects on fertilizer efficacy or their direct effects on plant biomass. The beneficial properties of HS, which enhance the availability of micronutrients such as Fe and Zn from sparingly soluble hydroxides, have been primarily credited for their effects [7].

2. MATERIALS AND METHODS

The conducted experiment transpired within the confines of the Instructional Farm, which finds its location intricately linked to the Department of Fruit Science at the esteemed College of Horticulture and Forestry in Jhalarapatan, a prominent site within the Jhalawar region. Jhalawar district is positioned in the South-Eastern part of Rajasthan, India, spanning from 23°4' to 24°52' N latitude and 75°29' to 76°56' E longitude. In terms of agro-climatic classification, this district falls within Zone V and is classified as the Humid South Eastern Plain. This scientific study embarked upon an exploration of considerable significance, spanning a biennial period from 2021 to 2023. The focal point of this temporal trajectory was an established orchard, poised at a pivotal juncture commonly referred to as the "gestation phase." During this period, characterized by burgeoning potential and transformative growth, the orchard became a nurturing habitat for a collection of Jamun trees, uniquely classified under the Goma Priyanka cultivar. These trees, thoughtfully placed upon raised beds, stand as a testament to the intricacies of adaptation and vigour. The experiment is laid out in randomized block design concept containing 4 treatment combinations (HA_0, HA_1, HA_2, HA_3,) in which HA_0: Control (Water Spray) with three replications (10 plants per replication). HA_1: 1000 ppm, HA_2: 2000 ppm, HA_3: 3000ppm. Application of treatment was given in first week of August.

List 1. Treatments Details

S. No.	Treatment notation	Treatment content
1.	HA_0	Control (Water Spray)
2.	HA_1	Humic acid 1000 ppm
3.	HA_2	Humic acid 2000 ppm
4.	HA_3	Humic Acid 3000 ppm

Observations recorded: The initial growth characteristics of Jamun cv. Goma Priyanka plants were meticulously documented during August 2021 and August 2022, Following, this, a consistent schedule of recording growth parameters was upheld, with measurements taken at bi-monthly intervals until the research concluded. These intervals encompassed observations in October 2021, December 2021, and March 2022. Furthermore, the second year of the investigation entailed the collection of data concerning both growth and physiological attributes. This data was gathered during specific intervals, specifically in October 2022, December 2022, leading up to the culmination of the experiment in March 2023.

Data collected throughout the research duration:

1. Rootstock girth (mm)
2. Scion girth (mm)
3. Height of the plant(m)
4. Canopy volume (m^3)
5. Canopy spread (m)

   a) East-West
   b) North-South

3. RESULTS

Individual Effect of Humic Acid: The outcome detailing the isolated impact of humic acid on the percentage increase in rootstock girth for Jamun cv. Goma Priyanka plants across consecutive experimental seasons (2021-22 and 2022-23) is presented in Table 1. The outcome indicated that during the initial year of experimentation, the maximum percentage increase in rootstock girth (1.83%) in March 2022 was observed with the HA_3 treatment at a concentration of 3000ppm.

The data indicated a lack of statistically significant differences among all the treatments concerning the foliar effects of humic acid. Similarly, the minimum percentage increase in rootstock girth (1.79%) was recorded in the control treatment (HA_0).

The results during the second experimental season (2022-23) showcased an enhancement in rootstock girth resulting from the application of varying concentrations of humic acid across the months of October 2022, December 2022, and March 2023. The findings indicated that the most substantial percentage increase in rootstock girth (1.84%) occurred due to the application of HA_3 at a concentration of 3000ppm. This increase was in comparison to the initial value (228.43 mm) and was notably and significantly greater than the effects observed in all other treatments. Similarly, the lowest percentage increase in rootstock girth (1.72%) for Jamun cv. Goma Priyanka plants was observed in the HA_0 (control) treatment. This HA_0 treatment exhibited a statistically significant lower impact on the percentage increase of rootstock girth compared to the other treatments.

Pooled Effect of Humic Acid: The data portraying the aggregated analysis regarding the impact of humic acid on the cumulative percentage increase in rootstock girth for Jamun cv. Goma Priyanka plants during two experimental trials (2021-22 and 2022-23) is provided in Table 2. The pooled outcomes demonstrated that the maximum percentage increase (1.69%) in rootstock girth during March (2022-23) was attained with the application of HA_3 (3000ppm) humic acid treatment. Interestingly, the HA_3 (3000ppm) treatment was on par with the HA_2 (2000ppm) treatment, and both were significantly superior to the HA_1 (1000ppm) and HA_0 (control) treatments in terms of enhancing rootstock girth. Similarly, the minimum percentage increase (1.60%) in rootstock girth for Jamun cv. Goma Priyanka plants was observed in the control group, displaying a statistically significant decrease when compared to the other treatments.

3.1 Scion Girth

Individual Effect of Humic Acid: The outcome delineating the isolated impact of humic acid on the percentage increase in scion girth for Jamun cv. Goma Priyanka plants across consecutive experimental seasons (2021-22 and 2022-23) is presented in Table 3. Analysing the growth enhancement attribute, particularly the scion girth, during the initial year of experimentation (2021-22), it was observed that the maximum percentage increase in scion girth (2.48%) for Jamun cv. Goma Priyanka plants in March 2022 was achieved through the HA_3 (3000ppm) treatment. Significantly, the HA_3 treatment outperformed all other treatments in promoting the augmentation of scion girth. Conversely, the minimum percentage increase (2.33%) in scion girth for Jamun cv. Goma Priyanka plants was documented under the HA_0 (Control) treatment.

The outcomes indicated that in the second year of experimentation, the maximum percentage increase in scion girth (2.44%) during March 2022 was observed in the treatment with HA_3 level (3000ppm). The data clearly demonstrated that the HA_3 (3000ppm) treatment showed a significantly pronounced effect in enhancing the scion girth of Jamun cv. Goma Priyanka plants compared to all other treatments. Similarly, the minimum percentage increase in scion girth (2.31%) during March 2023 was documented in the control treatment (HA_0).

Pooled Effect of Humic Acid: The data regarding the combined analysis of the impact of humic acid on the cumulative percentage increase in scion girth for Jamun cv. Goma Priyanka plants across two separate experimental trials (2021-22 and 2022-23) are displayed in Table 4 and Fig. 1. The results from the pooled analysis revealed that the maximum per cent increase (2.46%) in scion girth during March (2022-23) was observed in the treatment with the application of HA_3 (3000ppm) of humic acid. This HA_3 treatment demonstrated a significant and remarkable superiority in promoting scion girth growth when compared to all other treatments. Similarly, the minimum per cent increase (2.32%) in scion girth for Jamun cv. Goma Priyanka plants was registered in the control group. This control group exhibited a statistically significant lower value compared to the other treatment groups.

3.2 Plant Height

Individual Effect of Humic Acid: The data elucidated in Table 5 reveals the progression in per cent increase of plant height of Jamun cv. Goma Priyanka with advancement of growth period on all the days of observation from October to March (2021-2023) in response to foliar application of humic acid at different levels. During first year of experimentation (2021-22) and further during March 2022, the data revealed that maximum per cent increase in plant height (3.30%) of Jamun cv. Goma Priyanka plants was recorded by application of humic acid level in HA_3 (3000ppm) treatment and it was observed significantly higher over remaining treatments and further during March 2022, the minimum per cent increase in plant height (3.18%) of Jamun was estimated in control and it was observed at par with HA_1 (1000ppm) treatment.

The data during second year of experimentation (2022-23) revealed that during March 2023, the critical evaluation of data revealed that there was significant effect of varying humic acid levels on per cent increase of plant height attribute in Jamun cv. Goma Priyanka plants, further the maximum per cent increase in plant height (3.29%) was estimated under foliar application level of humic acid level in HA_3 (3000ppm) treatment and it was observed significantly higher over remaining treatments. Likewise, during March 2023, the minimum per cent increase in plant height (3.13%) of Jamun cv. Goma Priyanka leaves was recorded in HA_0(control).

Table 1. Effect of Humic acid on per cent increase of Rootstock girth (mm) in Jamun cv. Goma Priyanka plants

Treatments	Initial Value (mm)	I Experimental Year			Initial Value (mm)	II Experimental Year		
		Oct. 2021	Dec. 2021	March 2022		Oct. 2022	Dec. 2022	Mar. 2023
HA_0 (Control)	217.41	218.93 (1.09%)	220.96 (1.45%)	223.33 (1.79%)	230.61	232.27 (1.10%)	234.33 (1.45%)	236.37 (1.72%)
HA_1 (1000ppm)	216.16	217.79 (1.11%)	219.86 (1.48%)	222.12 (1.80%)	228.97	230.58 (1.10%)	232.78 (1.46%)	234.98 (1.76%)
HA_2 (2000ppm)	215.33	216.96 (1.11%)	219.07 (1.49%)	221.41 (1.82%)	228.79	230.64 (1.13%)	232.91 (1.51%)	235.14 (1.80%)
HA_3 (3000ppm)	215.07	216.78 (1.14%)	218.94 (1.51%)	221.19 (1.83%)	228.43	230.54 (1.18%)	232.88 (1.55%)	235.11 (1.84%)
SEm (±)	1.31	0.01	0.01	0.01	1.28	0.01	0.01	0.01
CD (5%)	NS	0.03	0.03	NS	NS	0.05	0.03	0.03

Values in parenthesis indicate square root transformed values

Table 2. Pooled analysis exhibiting effect of Humic acid on per cent increase of Rootstock girth (mm) in Jamun cv. Goma Priyanka plants

Treatments	Pooled Analysis (I and II experimental year)			
	Initial Value (mm)	Oct. (2021-22)	Dec. (2021-22)	Mar. (2022-23)
HA_0 (Control)	224.01	225.60 (1.09%)	227.65 (1.45%)	228.67 (1.60%)
HA_1 (1000ppm)	222.57	224.23 (1.11%)	226.33 (1.47%)	227.42 (1.63%)
HA_2 (2000ppm)	222.06	223.80 (1.13%)	226.00 (1.50%)	227.11 (1.66%)
HA_3 (3000ppm)	221.73	223.67 (1.16%)	225.91 (1.53%)	227.03 (1.69%)
SEm(±)	1.25	0.009	0.009	0.008
CD (5%)	NS	0.026	0.028	0.024

Values in parenthesis indicate square root transformed values

Table 3. Effect of Humic Acid on per cent increase of Scion girth (mm) in Jamun cv. Goma Priyanka plants

Treatments	Initial Value (mm)	I Experimental Year			Initial Value (mm)	II Experimental Year		
		Oct. 2021	Dec. 2021	March 2022		Oct. 2022	Dec. 2022	Mar. 2023
HA_0 (Control)	202.02	205.39 (1.46%)	208.51 (1.92%)	212.11 (2.33%)	219.31	222.95 (1.46%)	226.31 (1.91%)	230.05 (2.31%)
HA_1 (1000ppm)	199.01	202.50 (1.50%)	205.81 (1.97%)	209.25 (2.37%)	216.87	220.66 (1.49%)	224.10 (1.95%)	227.82 (2.34%)
HA_2 (2000ppm)	201.63	205.43 (1.54%)	208.81 (2.01%)	212.43 (2.41%)	219.83	223.88 (1.52%)	227.55 (1.99%)	231.42 (2.39%)
HA_3 (3000ppm)	195.13	199.12 (1.58%)	202.69 (2.08%)	206.24 (2.48%)	216.32	220.64 (1.56%)	224.22 (2.02%)	228.34 (2.44%)
SEm(±)	2.71	0.008	0.010	0.008	2.74	0.013	0.010	0.008
CD (5%)	7.83	0.023	0.030	0.025	7.92	0.039	0.029	0.024

**Values in parenthesis indicate square root transformed values*

Table 4. Pooled analysis exhibiting effect of Humic acid on per cent increase of Scion girth (mm) in Jamun cv. Goma Priyanka plants

Treatments	Pooled Analysis (I and II experimental year)			
	Initial Value (mm)	Oct. (2021-22)	Dec. (2021-22)	Mar. (2022-23)
HA_0 (Control)	210.66	214.17 (1.46%)	217.41 (1.91%)	221.08 (2.32%)
HA_1 (1000ppm)	207.95	211.58 (1.49%)	214.96 (1.96%)	218.54 (2.36%)
HA_2 (2000ppm)	210.73	214.66 (1.53%)	218.18 (2.00%)	221.93 (2.40%)
HA_3 (3000ppm)	205.73	210.13 (1.57%)	213.46 (2.05%)	217.29 (2.46%)
SEm(±)	5.34	0.01	0.01	0.01
CD (5%)	15.45	0.04	0.03	0.03

**Values in parenthesis indicate square root transformed values*

Table 5. Effect of Humic Acid on per cent increase of Plant height (m)in Jamun cv. Goma Priyanka plants

Treatments	Initial Value (m)	I Experimental Year			Initial Value (m)	II Experimental Year		
		Oct. 2021	Dec. 2021	March 2022		Oct. 2022	Dec. 2022	Mar. 2023
HA_0 (Control)	2.98	3.08 (1.97%)	3.17 (2.62%)	3.27 (3.18%)	3.43	3.56 (2.02%)	3.65 (2.63%)	3.79 (3.13%)
HA_1 (1000ppm)	3.01	3.12 (2.03%)	3.21 (2.66%)	3.31 (3.20%)	3.48	3.61 (2.08%)	3.72 (2.69%)	3.85 (3.16%)
HA_2 (2000ppm)	3.03	3.15 (2.06%)	3.24 (2.69%)	3.34 (3.24%)	3.50	3.65 (2.12%)	3.75 (2.74%)	3.90 (3.22%)
HA3 (3000ppm)	3.06	3.18 (2.10%)	3.27 (2.72%)	3.38 (3.30%)	3.54	3.69 (2.16%)	3.81 (2.80%)	3.96 (3.29%)
SEm(±)	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.00
CD (5%)	0.03	0.03	0.03	0.02	0.03	0.02	0.03	0.02

Values in parenthesis indicate square root transformed values

Table 6. Effect of Humic Acid on per cent increase of Canopy volume (m^3) in Jamun cv. Goma Priyanka plants

Treatments	Initial Value (m^3)	I Experimental Year			Initial Value (m^3)	II Experimental Year		
		Oct. 2021	Dec. 2021	March 2022		Oct. 2022	Dec. 2022	Mar. 2023
HA_0 (Control)	33.09	36.30 (3.15%)	39.41 (4.40%)	43.47 (5.63%)	49.01	53.80 (3.13%)	57.84 (4.24%)	63.56 (5.42%)
HA_1 (1000ppm)	33.71	37.13 (3.24%)	40.40 (4.49%)	44.58 (5.70%)	50.12	54.85 (3.24%)	59.64 (4.37%)	66.40 (5.50%)
HA_2 (2000ppm)	34.21	37.87 (3.32%)	41.14 (4.53%)	45.51 (5.77%)	51.07	56.15 (3.29%)	61.14 (4.45%)	67.14 (5.60%)
HA_3 (3000ppm)	34.08	38.65 (3.36%)	42.05 (4.59%)	47.02 (5.93%)	52.79	58.33 (3.36%)	63.84 (4.56%)	70.47 (5.76%)
SEm(±)	0.38	0.02	0.02	0.03	0.52	0.01	0.02	0.02
CD (5%)	1.11	0.06	0.06	0.11	1.51	0.05	0.07	0.07

Values in parenthesis indicate square root transformed values

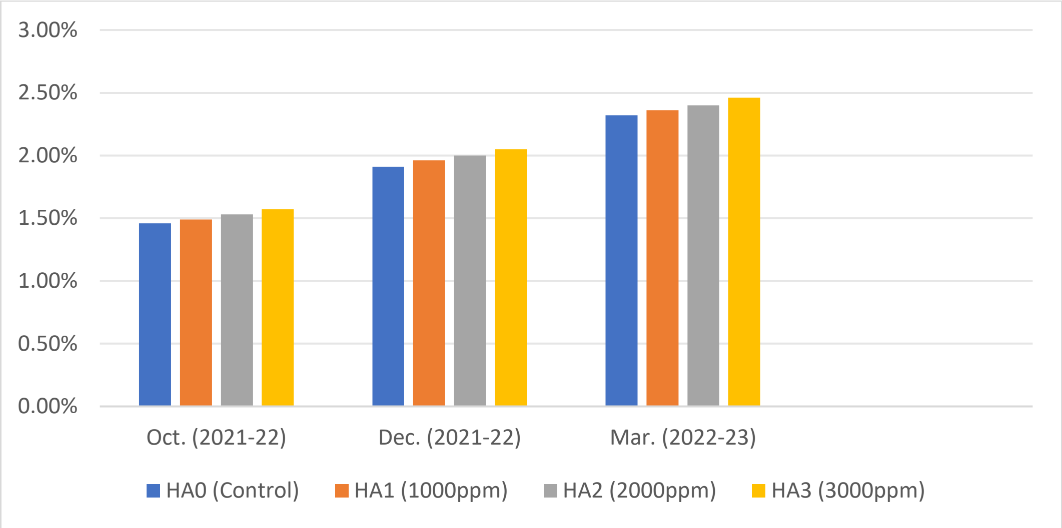

Fig. 1. Effect of Humic acid on per cent increase of Scion

3.3 Canopy Volume

Individual Effect of Humic Acid: The results concerning enhancement in canopy volume of Jamun cv. Goma Priyanka plants in response to foliar effect of humic acid during first experimental duration (Oct.2021 to March 2022) are exhibited in Table 6. The results enumerated that during first experimental duration, maximum per cent increase in canopy volume (5.93%) of Jamun cv. Goma Priyanka plants was obtained in HA_3 (3000ppm) treatment and it was observed highly significant and superior as compared with rest of the treatments. However, minimum per cent increase in canopy volume (5.63%) of Jamun cv. Goma Priyanka plants was measured in HA_0 (Control) treatment and it was found at par with HA_1 (1000ppm) treatment and it was found significantly lower as compared with HA_2 (2000ppm) and HA_3 (3000ppm) treatments.

The experimental results during second season (Oct.2022 to March 2023) revealed that maximum per cent increase in canopy volume (5.76%) of Jamun cv. Goma Priyanka plants was measured in KS_3 (3000ppm) and it was observed statistically distinct as compared with rest of the treatments. However, minimum per cent increase in canopy volume (5.42%) of Jamun cv. Goma Priyanka plants was recorded in KS_0 (Control) treatment and it was observed significantly lower as compared with rest of the treatments.

Pooled Effect of Humic Acid: The findings displayed in Table 7. and Fig. 2 depict a comprehensive analysis spanning two experimental periods (2021-23) concerning the foliar impact of humic acid on the percentage increase in canopy volume of Jamun cv. Goma Priyanka plants. The data indicated that the highest overall percentage increase in canopy volume (5.83%) for Jamun plants in March (2022-23) was observed in the HA_3 (3000ppm) treatment. This effect was significantly greater in enhancing canopy volume compared to other plant treatments. In contrast, the lowest percentage increase in canopy volume (5.50%) was found in the HA_0 (Control) treatment. It was comparable to the effect seen in the HA_1 (1000ppm) treatment, yet the HA_0 treatment exhibited notable lower enhancement in canopy volume compared to HA_2 and HA_3 treatments. The significant enhancement in the canopy volume of Jamun cv. Goma Priyanka plants through HA_3 (3000 ppm) application could be ascribed to its scientific role in augmenting nutrient absorption and utilization, mitigating stress, and potentially triggering the activation of plant growth regulators like auxins, cytokinins, and gibberellins. These regulatory compounds are pivotal in overseeing processes such as cell division, differentiation, and elongation, thereby contributing to the notable improvement in growth observed.

3.3.1 Canopy spread E-W

The outcomes illustrating the specific impact of humic acid on the percentage increase in the East-West spread of Jamun cv. Goma Priyanka plants across two consecutive experimental seasons (2021-22 and 2022-23) are presented in Table 8. The findings indicated that in the first year of experimentation, the highest percentage increase in East-West spread (6.56%) occurred in the HA_3 level (3000ppm) during March 2022, which was comparable to the effects observed in HA_2 (2000ppm) and HA_1 (1000ppm) and superior to the control. Conversely, the lowest percentage increase (5.45%) in E-W spread was noted in the control (HA_0) treatment.

The findings from the second experimental season (2022-23) demonstrated an enhancement in the East-West spread as a result of applying varying concentrations of humic acid in October 2022, December 2022, and March 2023. The outcome indicated that the highest percentage increase in East-West spread (5.35%) occurred with the application of HA_3 level (3000ppm) compared to the initial value (3.22m). This effect was statistically similar to the impact of HA_2 level (2000ppm), but HA_3 level showed significant superiority over HA_1 (1000ppm) and HA0 (control) treatments. Correspondingly, the lowest percentage increase (4.65%) in E-W spread of Jamun cv. Goma Priyanka plants was observed in the HA_0 (control) treatment.

3.3.2 Pooled effect of Humic acid

The data presented encompasses a comprehensive pooled analysis that investigates the impact of humic acid on the cumulative percentage increase in the East-West spread of Jamun cv. Goma Priyanka plants across two successive experimental trials conducted during the periods 2021-22 and 2022-23. The summarized findings are documented within Table 9.

Regarding the East-West spread, the cumulative outcomes reveal that the maximum percentage increase, specifically 5.93%, transpired in March of the 2022-23 trial. This notable increase was observed in response to the application of humic acid at the HA_3 concentration level, corresponding to 3000ppm. Importantly, the impact of the HA_3 treatment was found to be statistically indistinguishable from that of the HA_2 treatment (2000ppm) and the HA_1 treatment (1000ppm). Significantly, all these humic acid treatments exhibited greater efficacy in promoting East-West spread than the control treatment.

In parallel, the minimum percentage increase in East-West spread, amounting to 5.04%, was documented within the control treatment. This observation underscores that humic acid applications at the prescribed concentrations engender notable enhancements in plant growth and the spatial distribution of foliage in contrast to the untreated control.

The graphical representation, as depicted in Fig. 3, provides a visual depiction of the cumulative percentage increase in East-West spread of Jamun cv. Goma Priyanka plants resulting from the pooled application of humic acid across the two experimental trials. This graphical representation serves to elucidate the relative impacts of varying humic acid concentration levels, showcasing the substantial augmentation associated with the HA_3 (3000ppm) treatment.

In sum, the findings of this study underscore the potential of humic acid to positively modulate the cumulative percentage increase in East-West spread of Jamun cv. Goma Priyanka plants. The results suggest that the application of humic acid, particularly at concentrations such as HA_3 (3000ppm), elicits pronounced improvements in plant growth and development, as substantiated by the aggregated analysis of the two experimental trials.

3.3.3 Canopy spread N-S

The findings detailing the individual impact of humic acid on the percentage increase of North-South (N-S) spread in Jamun cv. Goma Priyanka plants throughout consecutive experimental seasons (2021-22 and 2022-23) are presented within Table 10. The results established that during the initial year of experimentation, the highest percentage increase in N-S spread (3.71%) in March 2022 was observed at the HA_3 level, which featured a concentration of 3000ppm of humic acid. Interestingly, the data showed no significant variations among all the treatments concerning the percentage increase in N-S canopy spread. In a similar vein, the lowest percentage increase in N-S spread (3.51%) was documented in the control treatment (HA_0).

The outcomes during the subsequent experimental season (2022-23) unveiled an enhancement in the North-South (N-S) spread as a response to the application of different levels of humic acid during the months of October 2022, December 2022, and March 2023. The findings determined that the highest percentage increase in the N-S spread (2.81%) occurred due to the application of the HA_3 treatment level (3000ppm). This increase was noted in comparison to the initial value of 2.38m. Interestingly, the HA_3 (3000ppm) treatment exhibited equivalent effects to the HA_2 level (2000ppm) and was notably superior to the HA_1 (1000ppm) treatment and the HA_0 control treatment. Furthermore, it's important to note that the HA_3 (3000ppm) treatment also showcased a statistically significant improvement compared to the HA_1 and HA_0 (control) treatments.

Similarly, the minimum percentage increase in the N-S spread (2.65%) in Jamun cv. Goma Priyanka plants was noted in the HA_0 (control) treatment. This result was comparable to the HA_1 (1000ppm) and HA_2 (2000ppm) treatments but significantly lower than the impact observed in the HA_3 (3000 ppm) treatment.

3.3.4 Pooled analysis exhibiting effect of Humic acid

The information displaying a pooled analysis of the effect of humic acid on the cumulative percentage increase of North-South (N-S) spread in Jamun cv. Goma Priyanka plants across two successive experimental trials (2021-22 and 2022-23) is presented within Table 11.

The aggregated results highlighted that the highest percentage increase (3.22%) in the N-S spread during March of the 2022-23 trial was observed under the treatment involving the application of HA_3 (3000ppm) of humic acid. Notably, the data demonstrated no statistically significant variations among all treatments in terms of the percentage increase in N-S canopy spread of Jamun cv. Goma Priyanka plants. Similarly, the minimum percentage increase (3.11%) in N-S spread of Jamun cv. Goma Priyanka plants was observed in the control treatment.

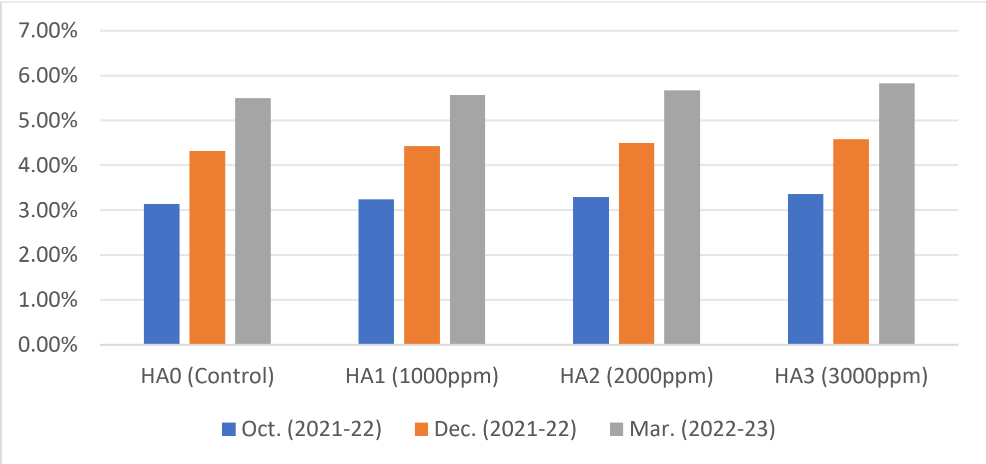

Fig. 2. Effect of Humic acid on per cent increase of Canopy volume (m^3) in Jamun cv. Goma Priyanka plants

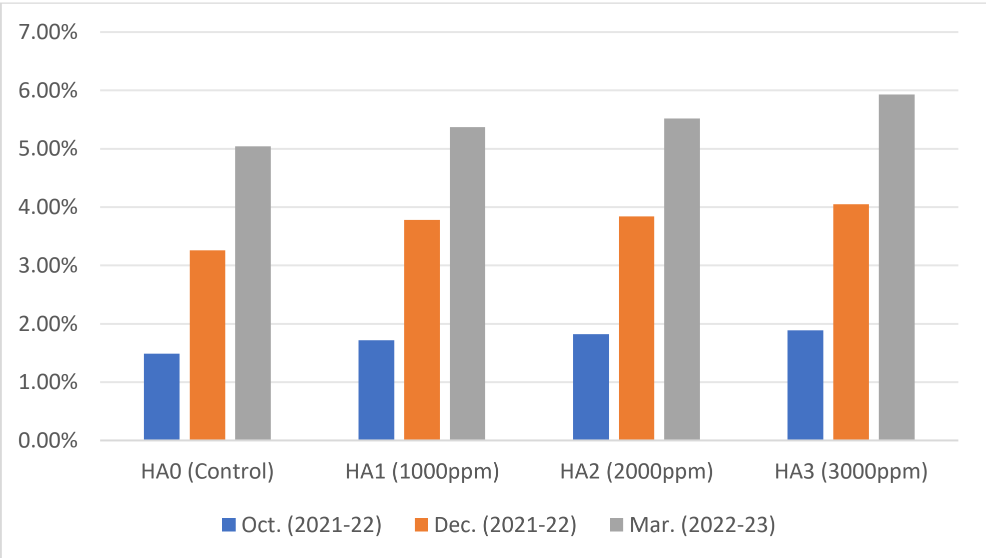

Fig. 3. Effect of Humic acid on per cent increase in East West spread (m) of Jamun cv. Goma Priyanka plants

Table 7. Pooled analysis exhibiting effect of Humic acid on per cent increase of Canopy volume (m^3) in Jamun cv. Goma Priyanka plants

Treatments	Pooled Analysis (I and II experimental year)			
	Initial Value (m^3)	Oct. (2021-22)	Dec. (2021-22)	Mar. (2022-23)
HA_0 (Control)	41.05	45.03 (3.14%)	48.62 (4.32%)	53.53 (5.50%)
HA_1 (1000ppm)	41.92	46.20 (3.24%)	50.02 (4.43%)	55.49 (5.57%)
HA_2 (2000ppm)	42.64	47.17 (3.30%)	51.14 (4.50%)	56.33 (5.67%)
HA_3 (3000ppm)	43.80	48.65 (3.36%)	52.05 (4.58%)	58.75 (5.83%)
SEm(±)	0.44	0.02	0.04	0.03
CD (5%)	1.29	0.07	0.11	0.11

Values in parenthesis indicate square root transformed values

Table 8. Effect of Humic Acid on per cent increase in East West spread (m) of Jamun cv. Goma Priyanka plants

Treatments	Initial Value (m)	I Experimental Year			Initial Value (m)	II Experimental Year		
		Oct. 2021	Dec. 2021	March 2022		Oct. 2022	Dec. 2022	Mar. 2023
HA_0 (Control)	2.99	3.04(1.84%)	3.10 (3.87%)	3.14 (5.45%)	3.19	3.22 (1.17%)	3.27 (2.68%)	3.34 (4.65%)
HA_1 (1000ppm)	2.98	3.04 (2.06%)	3.11 (4.50%)	3.17 (6.15%)	3.19	3.24 (1.40%)	3.29 (3.12%)	3.34 (4.66%)
HA_2 (2000ppm)	2.98	3.05 (2.18%)	3.11 (4.27%)	3.15 (5.95%)	3.19	3.24 (1.49%)	3.30 (3.45%)	3.35 (5.12%)
HA3 (3000ppm)	2.98	3.05 (2.23%)	3.12 (4.55%)	3.18 (6.56%)	3.22	3.27 (1.57%)	3.33 (3.59%)	3.39 (5.35%)
SEm(±)	0.02	0.08	0.22	0.32	0.02	0.11	0.11	0.21
CD (5%)	0.07	0.24	0.65	0.92	0.07	0.33	0.34	0.60

Values in parentheses indicate square root transformed values

Table 9. Pooled analysis exhibiting effect of Humic acid on per cent increase in East West spread (m) of Jamun cv. Goma Priyanka plants

Treatments	Pooled Analysis (I and II experimental year)			
	Initial Value (m)	Oct. (2021-22)	Dec. (2021-22)	Mar. (2022-23)
HA_0 (Control)	3.09	3.14(1.49%)	3.19 (3.26%)	3.25 (5.04%)
HA_1 (1000ppm)	3.09	3.14 (1.72%)	3.20 (3.78%)	3.25 (5.37%)
HA_2 (2000ppm)	3.09	3.14 (1.82%)	3.21 (3.84%)	3.26 (5.52%)
HA_3 (3000ppm)	3.10	3.16 (1.89%)	3.23 4.05%)	3.29 (5.93%)
SEm(±)	0.02	0.07	0.13	0.19
CD (5%)	0.07	0.21	0.40	0.57

**Values in parentheses indicate square root transformed values*

Table 10. Effect of Humic Acid on per cent increase in N-S Canopy spread (m) of Jamun cv. Goma Priyanka plants

Treatments	Initial Value(m)	I Experimental Year			Initial Value (m)	II Experimental Year		
		Oct. 2021	Dec. 2021	March 2022		Oct. 2022	Dec. 2022	Mar. 2023
HA_0 (Control)	2.05	2.11 (1.82%)	2.17 (2.53%)	2.29 (3.51%)	2.35	2.41 (1.69%)	2.46 (2.20%)	2.52 (2.65%)
HA_1 (1000ppm)	2.04	2.09 (1.78%)	2.16 (2.54%)	2.28 (3.52%)	2.34	2.39 (1.70%)	2.45 (2.25%)	2.50 (2.72%)
HA_2 (2000ppm)	2.04	2.10 (1.87%)	2.17 (2.59%)	2.29 (3.58%)	2.35	2.41 (1.67%)	2.46 (2.27%)	2.51 (2.71%)
HA_3 (3000ppm)	2.04	2.10 (1.85%)	2.17 (2.60%)	2.32 (3.71%)	2.38	2.44 (1.72%)	2.49 (2.32%)	2.54 (2.81%)
SEm(±)	0.02	0.02	0.02	0.08	0.01	0.03	0.04	0.03
CD (5%)	0.06	NS	NS	NS	0.05	NS	NS	0.11

**Values in parenthesis indicate square root transformed values*

Table 11. On per cent increase in N-S Canopy spread (m) of Jamun cv. Goma Priyanka plants

Treatments	Pooled Analysis (I and II experimental year)			
	Initial Value (m)	Oct. (2021-22)	Dec. (2021-22)	Mar. (2022-23)
HA_0 (Control)	2.20	2.23 (1.35%)	2.32 (2.37%)	2.41 (3.11%)
HA_1 (1000ppm)	2.19	2.22 (1.32%)	2.30 (2.39%)	2.40 (3.13%)
HA_2 (2000ppm)	2.20	2.23 (1.37%)	2.32 (2.42%)	2.41 (3.15%)
HA_3 (3000ppm)	2.21	2.25 (1.36%)	2.34 (2.45%)	2.43 (3.22%)
SEm(±)	0.01	0.01	0.02	0.04
CD (5%)	0.05	NS	0.06	NS

**Values in parenthesis indicate square root transformed values*

4. DISCUSSION

The notable influence of humic acid on the mentioned growth characteristics can be attributed to its complex composition, which includes various organic compounds derived from plant and animal decomposition. Applying humic acid to leaves is believed to impact physiological and biochemical processes, ultimately enhancing plant growth attributes [8]. The significant effects of humic acid can be inferred from established scientific principles. This intricate organic mixture likely facilitated essential mechanisms. Firstly, the diverse organic compounds in humic acid probably enhanced nutrient absorption, enriching plant nutrition. Secondly, humic acid application potentially stimulated root growth, leading to a more efficient and extensive root system [9]. This, in turn, could improve the plants' access to soil water and nutrients. Furthermore, humic acid's impact on the physiological processes of photosynthesis is noteworthy [10].

The complex compounds from humic acid could potentially promote more efficient photosynthetic activity, which is the cornerstone of energy production in plants. This improved photosynthetic capacity could lead to increased production of energy-rich molecules, contributing to enhanced growth [11].

Moreover, the application of humic acid might have influenced water relations within the plants. By promoting more efficient water uptake and retention, humic acid could have contributed to maintaining optimal hydration levels, even during challenging conditions. This could lead to improved stress tolerance and overall resilience in the plants [12].

Another significant aspect is the potential elevation in antioxidant activity due to the presence of humic acid. Antioxidants play a crucial role in protecting plant cells from oxidative stress and damage. By bolstering antioxidant activity, humic acid might have provided an additional layer of defense, allowing the plants to allocate more resources towards growth and development [13,14].

Collectively, the availability of a diverse range of organic compounds through humic acid application could have orchestrated a synergistic effect, resulting in improved growth attributes [15,11]. The cumulative impact includes enhanced nutrient absorption, stimulated root development, heightened photosynthetic capacity, improved water management, and augmented antioxidant defense mechanisms, all of which collectively facilitated the robust growth of Jamun plants. This interpretation aligns with established scientific principles that underscore the multifaceted role of humic acid in plant physiology and growth enhancement [16].

The sequence of findings in the current study aligns chronologically with those documented by various researchers in their respective investigations. Nardi et al. [17], Arancon et al. [18], and Aseri et al. [19] observed congruent outcomes in pomegranate. Following this, Fathy et al*.* [20] reported similar trends in apricot, while Ferrara and Brunetti [21] did so in grape. Subsequently, Ameri and Tehranifar [22] documented analogous findings in strawberry. Expanding this timeline, Hosseini-Farahi et al. [23] reported comparable results in peach [24,25].

5. CONCLUSION

From a concluding perspective, it is evident that the HA_3 (HA 3000ppm) treatment yielded the most substantial improvements across various parameters. These enhancements included a maximum percentage increase in rootstock girth (69%), scion girth (2.46%), plant height (3.39%), canopy volume (5.83%), east-west canopy spread (5.93%), north-south canopy spread (3.22 when compared to the outcomes achieved with other treatments.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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