



Exploring the Synergistic Effects of Biostimulant and Hydrogel Combinations on Brinjal Growth: An Assessment of Growth Parameters

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ABSTRACT

Background: This study at Lovely Professional University, Phagwara, Punjab, evaluates the combined effects of hydrogel and Arka Vegetable biostimulants on brinjal (*Solanum melongena* L.) production. Brinjal's high water and nutrient needs make it sensitive to water scarcity and seasonal variations. Hydrogel enhances soil moisture retention, reducing irrigation needs, while Arka Vegetable biostimulants improve plant growth and stress tolerance. Using both together aims to optimize water management and plant health, addressing key challenges in brinjal cultivation.

Methods: In the study, the hydrogel was applied during the sowing stage, while Arka Vegetable Special was sprayed twice, with a 15-day interval after transplanting. The treatment designated as V_2H_2 (5 g/L+1.5 kg/acre) was utilized, where 'V' represents concentration in grams per liter and 'H' denotes application rate in kilograms per acre. This treatment is aimed at optimizing vegetative growth. Various levels of Arka Vegetable Special and hydrogel application were tested to observe their effects on growth characteristics.

Result: The study's findings revealed the effectiveness of the V_2H_2 treatment in enhancing vegetative growth. Application of Arka Vegetable Special and hydrogel at different levels significantly improved all the studied growth characteristics. This suggests the potential of integrating biostimulants and Hydrogel practices to optimize brinjal production, offering a sustainable solution to meet year-round vegetable demand and mitigate water scarcity challenges in agricultural systems.

Key words: Biostimulant, Brinjal growth, Hydrogel, Synergistic effects.

INTRODUCTION

The botanical classification of brinjal, scientifically known as *Solanum melongena* L., places it in the Solanaceae family and Solanum genus. Solanum, one of the largest genera, encompasses over 1500 described plant species, as Chen (1998) reported. This crop is also recognized under various names, such as eggplant, aubergine (French) and guinea squash (English) and it has a chromosome count of $2n=2x=24$. Brinjal is typically an annual crop that is self-fertilized and hermaphroditic, with an uncertain origin. However, it is widely acknowledged that cultivated brinjal is rooted in India.

However, India is currently facing many growing concerns. Despite achieving sufficient food production levels, India still accounts for a significant portion, approximately one-fourth, of the world's population suffering from hunger. Additionally, India is home to over a million undernourished individuals. The field of Indian horticulture is experiencing the effects of exhaustion resulting from the green revolution. The stagnation of crop yields evidences this exhaustion due to the excessive use of fertilizers. Moreover, the low efficiency of nutrient utilization caused by leaching, the depletion of soil organic matter, deficiencies in multiple nutrients, the reduction in soil organic matter and the scarcity of labor are all consequences of the evacuation of people from the agricultural sector (Godfray *et al.*, 2014).

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Biostimulants belong to a category of products that possess the ability to reduce the need for fertilizers while simultaneously enhancing plant growth and resistance to water and abiotic stresses. These substances demonstrate high efficiency even at low concentrations and promote optimal performance of vital plant processes, resulting in high yields and superior-quality crops. The type biostimulants Nutrivite Arka Vegetable Special is a micronutrient technology specific to crops and has been developed by ICAR-IIHR to increase the yield and quality of vegetables. Applying a multi-nutrient mixture in vegetables serves as a means to overcome the insufficiency of secondary and micronutrients.

The current state of water scarcity is a significant issue that requires urgent attention. The development of new

technologies aimed at the preservation of water resources is an important component in attaining sustainable economic growth. Soil hydrogel is a technique with the objective of soil hydrogel, which is to minimize the quantity of water that is lost from the soil due to evaporation.

The growth of brinjal can be significantly enhanced by the strategic combination of a biostimulant and hydrogel. This synergistic effect can lead to substantial improvements in plant development and overall productivity. Considering all the above factors, here are the following objectives to be studied and evaluated after conducting the research.

MATERIALS AND METHODS

The study on the growth, yield and post-harvest assessment of Brinjal (*Solanum melongena* L.) in response to biostimulants and Hydrogel practices was conducted at the Farm of School of Agriculture, Lovely Professional University Phagwara, Punjab, during the research years 2023 and 2024. The experimental setup followed a factorial randomized block design (FRBD), with biostimulant (Arka Vegetable Special) and Hydrogel as factors and a spacing of 60 × 45 cm. A total of 12 treatments were systematically arranged within the blocks, each replicated three times, covering a total area of 565 m². Crop management involved the use of Brinjal var. Nishant from Advanta Seeds India Pvt. Ltd.

The nursery preparation involved seeding pro trays in a playhouse, utilizing cocopeat, vermiculite and perlite substrate at a ratio of 3:1:1. Seedlings were cultivated using the "Nishant" variety of Brinjal. The main field underwent plowing, followed by applying 1.5 tons of farmyard manure and establishing paired rows with 60 × 45 cm spacing. Transplantation of approximately 35-day-old seedlings was carried out in the evening, with immediate irrigation and mixing of hydrogel in the soil. The experimental setup consists of twelve treatments combining various levels of biostimulant (V) and hydrogel (H) applications. The treatments are as follows: T₁ involves no biostimulant (0 g/L) and no hydrogel (0 kg/acre), T₂ applies no biostimulant (0 g/L) with 1.0 kg/acre of hydrogel, T₃ uses no biostimulant (0 g/L) with 1.5 kg/acre of hydrogel and T₄ includes no biostimulant (0 g/L) with 2.0 kg/acre of hydrogel. In treatments T₅ to T₈, a biostimulant concentration of 2 g/L is applied with varying hydrogel rates: T₅ with 0 kg/acre, T₆ with 1.0 kg/acre, T₇ with 1.5 kg/acre and T₈ with 2.0 kg/acre. Lastly, treatments T₉ to T₁₂ involve a biostimulant concentration of 5 g/L combined with hydrogel applications of 0 kg/acre in T₉, 1.0 kg/acre in T₁₀, 1.5 kg/acre in T₁₁ and 2.0 kg/acre in T₁₂. Each treatment explores different combinations to assess their impact on the targeted growth parameters.

Irrigation practices included immediate watering after transplanting and subsequent irrigation based on soil moisture levels using a soil moisture meter. Fertilizer application consisted of 10 tons/acre of farmyard manure

during field preparation, basal application of phosphorus and potassium as SSP and MOP, respectively and nitrogen application as urea. Arka Vegetable Special was used as a biostimulant, with two sprays given post-transplanting.

Statistical data analysis involved ANOVA to determine the significance of treatment effects on Brinjal growth parameters. Overall, the study employed rigorous experimental design, precise crop management practices and robust statistical analysis to investigate the combined effects of biostimulants and Hydrogel practices on Brinjal growth.

RESULTS AND DISCUSSION

Plant height (cm)

Table 1, unveil a significant impact on plant heights 30-, 55- and 70 days post-transplanting, showcasing the influence of both biostimulant and hydrogel. The greatest plant height (23.37 cm) (36.14 cm)(55.40 cm) was attained under H₁ - 1.5 kg/acre, surpassing all other Hydrogel levels. Conversely, the lowest plant height (21.05 cm) (34.62 cm) (52.62 cm) was evident in the control group (H₀). Regarding biostimulant application, the maximum plant height (24.60 cm) (37.25 cm) (56.22 cm) was achieved with V₂-5 g/L, while the minimum height (18.63 cm) (33.41 cm) (51.88 cm) was noted with V₀-0 g/L.

Furthermore, the interaction between biostimulants and Hydrogel proved significant. The tallest plants (26.15 cm) (38.11 cm) (60.40 cm) were observed with the combination of V₂-5 g/L and H₂-1.5 kg/acre, closely followed by the combination of V₂-5 g/L and H₃-2 kg/acre. Conversely, the shortest plants (17.10 cm) (32.60 cm) (51.47 cm) were found with the combination of V₂-5 g/L and H₀-0.0 kg/acre.

The use of hydrogel significantly contributed to an increase in plant height by maintaining consistent soil moisture levels. This moisture availability is crucial for cellular elongation and growth processes, enabling the plants to grow taller. As a result, plants treated with hydrogel exhibited greater height compared to those without (El-Saied *et al.*, 2016). The application of Arka vegetable micronutrients further enhanced plant height by providing essential nutrients that are vital for growth. These micronutrients support key metabolic processes and ensure robust cell division and elongation. Plants receiving this micronutrient treatment showed a marked increase in height, indicating that adequate nutrition is essential for optimal plant development (Kumar *et al.*, 2016). Similar results were observed by Suganiya *et al.* (2015) in brinjal, Maurya *et al.* (2020) in tomato and Panda *et al.* (2024) in knol khol.

Number of leaves

Table 2 unveil a significant impact on the number of leaves 30-, 55- and 70 days post-transplanting, showcasing the influence of both biostimulant and Hydrogel. The maximum number of leaves (17.87) (29.57) (47.44) was attained under H₂-1.5 kg/acre, surpassing all other Hydrogel levels.

Conversely, the minimum number of leaves (15.88) (27) (44.46) was evident in the control group (H_0). Regarding biostimulant application, the highest number of leaves (19.25) (30.77) (49.57) was achieved with V_2 -5 g/L, while the lowest number (14.46) (25.31) (41.78) was noted with V_0 -0 g/L.

Furthermore, the interaction between biostimulants and Hydrogel proved significant. The maximum number of leaves (19.84) (31.72) (50.82) was observed with the combination of V_2 -5 g/L and H_2 -1.5 kg/acre, closely followed by the combination of V_2 -5 g/L and H_3 -2 kg/acre. Conversely, the minimum leaves (12.91) (22.87) (39.47) were found with the combination of V_2 -5 g/L and H_0 -0.0 kg/acre.

The presence of hydrogel in the soil helped in maintaining adequate moisture levels, which is essential for the formation and maintenance of leaves. Consistent water availability prevented water stress, promoting the growth of more leaves. Consequently, plants treated with hydrogel had a higher leaf count. Rajakumar and Sankar, 2016).

The Arka vegetable micronutrient application provided a balanced supply of essential nutrients, facilitating the healthy development of leaves. These nutrients are crucial for chlorophyll production and overall leaf health, leading to an increased number of leaves in treated plants compared to those without the micronutrient supplementation (Kalroo *et al.*, 2014). Similar findings were observed by Mahgoub (2020) and Sultana *et al.* (2016) in tomato.

Leaf length (cm)

Table 3 unveil a significant impact on the maximum leaf length 30-, 55- and 70 days post-transplanting, showcasing the influence of both biostimulant and Hydrogel. The greatest leaf length (13.25 cm) (16.57 cm) (19.65 cm) was attained under H_2 -1.5 kg/acre, surpassing all other Hydrogel levels. Conversely, the minimum leaf length (12.27 cm) (15.34 cm) (18.09 cm) was evident in the control group (H_0). Regarding biostimulant application, the highest number of leaves (14.12 cm) (17.54 cm) (20.51 cm) was achieved with V_2 -5 g/L, while the lowest number (11.48 cm) (14.39 cm) (17.11 cm) was noted with V_0 -0 g/L.

Furthermore, the interaction between biostimulants and Hydrogel proved significant. The highest leaf length (14.71 cm) (18.13 cm) (21.91 cm) was observed with the combination of V_2 -5 g/L and H_2 -1.5 kg/acre, closely followed by the combination of V_2 -5 g/L and H_3 -2 kg/acre. Conversely, the shortest leaf length (11.06 cm) (13.73 cm) (16.53 cm) was found with the combination of V_2 -5 g/L and H_0 -0.0 kg/acre.

Hydrogel's water retention properties prevented dehydration and water stress, factors that can limit leaf expansion. By ensuring a stable water supply, hydrogel allowed for optimal leaf elongation, resulting in longer leaves in treated plants (Abobatta, 2018). The micronutrient treatment supported the growth of longer leaves by providing necessary nutrients such as nitrogen, which is vital for the synthesis of proteins and chlorophyll. This nutrient

availability promoted cellular growth and elongation, contributing to increased leaf length (Tripathi *et al.*, 2015), which aligns with similar findings reported by Dubey *et al.* (2013) in chili and Dixit *et al.* (2018) in tomato.

Leaf width (cm)

Table 4 unveil a significant impact on the leaf width 30-, 55- and 70 days post-transplanting, showcasing the influence of both biostimulant and Hydrogel. The highest leaf width (12.36 cm) (15.21 cm) (18.32 cm) was attained under H_2 -1.5 kg/acre, surpassing all other Hydrogel levels. Conversely, the lowest leaf width (10.21 cm) (12.28 cm) (16.31 cm) was evident in the control group (H_0). Regarding biostimulant application, the maximum leaf width (13.94 cm) (16.74 cm) (20.05 cm) was achieved with V_2 -5 g/L, while the minimum leaf width (8.87 cm) (10.61 cm) (14.86 cm) was noted with V_0 -0 g/L.

Furthermore, the interaction between biostimulants and Hydrogel proved significant. The maximum leaf width (15.92 cm) (20.17 cm) (21.31 cm) was observed with the combination of V_2 -5 g/L and H_2 -1.5 kg/acre, closely followed by the combination of V_2 -5 g/L and H_3 -2 kg/acre. Conversely, the minimum leaf width (8.46 cm) (10.40 cm) (14.04 cm) was found with the combination of V_2 -5 g/L and H_0 -0.0 kg/acre.

With hydrogel maintaining soil moisture, plants were able to achieve full leaf expansion, leading to broader leaves. The prevention of water stress through consistent moisture availability allowed leaves to develop to their maximum width (El-Hady *et al.*, 2012). The Arka vegetable micronutrient provided essential minerals that supported the growth of broader leaves. Nutrients like potassium and magnesium are vital for the formation of wide, healthy leaves, enhancing the plant's photosynthetic surface area and overall health Haque *et al.* (2011), which is consistent with the findings of Ali *et al.* (2015) in tomato, Pandiyan *et al.* (2018) in tomato and Goyal *et al.* (2017) in onion.

Pedicle length (cm)

Table 5 unveil a significant impact on the Pedicle length 70 days post-transplanting, showcasing the influence of both biostimulant and Hydrogel. The highest pedicle length (5.5 cm) was attained under H_2 -1.5 kg/acre, surpassing all other Hydrogel levels. Conversely, the lowest Pedicle length (4.95 cm) was evident in the control group (P_0). Regarding biostimulant application, the highest Pedicle length (5.68 cm) was achieved with V_2 -5 g/L, while the lowest Pedicle length (4.73 cm) was noted with V_0 -0 g/L.

Furthermore, the interaction between biostimulants and Hydrogel proved significant. The maximum pedicle length (6.50) was observed with the combination of V_2 -5 g/L and H_2 -1.5 kg/acre, closely followed by the combination of V_2 -5 g/L and H_3 -2 kg/acre. Conversely, the minimum pedicle length (4.47 cm) was found with the combination of V_2 -5 g/L and H_0 -0.0 kg/acre.

Table 1: Effect of biostimulant and hydrogel on plant height (cm) after 30, 55 and 70 DAT.

T	Plant height																						
	30 DAT					55 DAT					70 DAT												
	H ₀	H ₁	H ₂	H ₃	Mean	T	H ₀	H ₁	H ₂	H ₃	Mean	T	H ₀	H ₁	H ₂	H ₃	Mean						
V ₀	17.10	18.10	20.68	18.62	18.63	V ₀	32.60	33.07	34.29	33.66	33.41	V ₀	51.47	51.73	52.21	52.09	51.88						
V ₁	22.38	22.95	23.29	23.27	22.97	V ₁	34.71	35.06	36.01	35.51	35.33	V ₁	52.60	52.95	53.60	53.18	53.08						
V ₂	23.66	24.02	26.15	24.56	24.60	V ₂	36.54	36.92	38.11	37.44	37.25	V ₂	53.77	54.43	60.40	56.30	56.22						
Mean	21.05	21.69	23.37	22.15		Mean	32.60	33.07	34.29	33.66	33.41	Mean	52.62	53.04	55.40	53.86							
	V						V						V × H						H				
	H						H						V × H						H				
	V × H						V × H						V × H						V × H				
C.D.	0.379		0.438		0.759	C.D.	0.016		0.018		0.032	C.D.	0.615		0.71		1.23						
SE(m)	0.128		0.148		0.257	SE(m)	0.005		0.006		0.011	SE(m)	0.208		0.241		0.417						

Hydrogel plays a key role in maintaining the necessary moisture levels for optimal pedicle development. The consistent availability of water prevented stress conditions that could restrict pedicle growth, resulting in longer pedicles in treated plants (Narjary *et al.*, 2012). The application of Arka vegetable micronutrients facilitated longer pedicle growth by supplying critical nutrients that support tissue development and strength. These nutrients help in the elongation and structural integrity of the pedicle, crucial for supporting the plant's reproductive structures. (Mousavi, 2011). This is consistent with the results observed by Haleema *et al.* (2017) in tomato and Sarika (2021) in tomato.

Petiole girth (mm)

Fig 1 unveils a significant impact on the Petiole girth 70 days post-transplanting, showcasing the influence of both biostimulant and hydrogel. The maximum petiole girth (15.43 mm) was attained under H₂-1.5 kg/acre, surpassing all other Hydrogel levels. Conversely, the minimum petiole girth (14.99 mm) was evident in the control group (H₀). Regarding biostimulant application, the highest Petiole girth petiole girth (15.84 mm) was achieved with V₂-5 g/L, while the lowest petiole girth (14.55 mm) was noted with V₀-0 g/L.

Furthermore, the interaction between biostimulants and hydrogel proved significant. The maximum Petiole girth (16.02 mm) was observed with the combination of V₂-5 g/L and H₂-1.5 kg/acre, closely followed by the combination of V₂-5 g/L and H₃-2 kg/acre. Conversely, minimum petiole girth (14.32 mm) was found with the combination of V₂-5 g/L and H₀-0.0 kg/acre.

The use of hydrogel ensured adequate moisture, which is crucial for maintaining cell turgor and supporting the thickening of the petiole. This led to a noticeable increase in petiole girth in treated plants, providing better support and nutrient transport (El-Saied *et al.*, 2016). The Arka vegetable micronutrient contributed to a greater petiole girth by supplying essential nutrients that aid in cell wall formation and strengthening. This nutrient support enabled the development of thicker and sturdier petioles, which are vital for the overall stability and nutrient distribution within the plant (Kumar *et al.*, 2016). These findings align with those of Dixit *et al.* (2018) in tomato and Kumar *et al.* (2018) in chili.

Petiole length (cm)

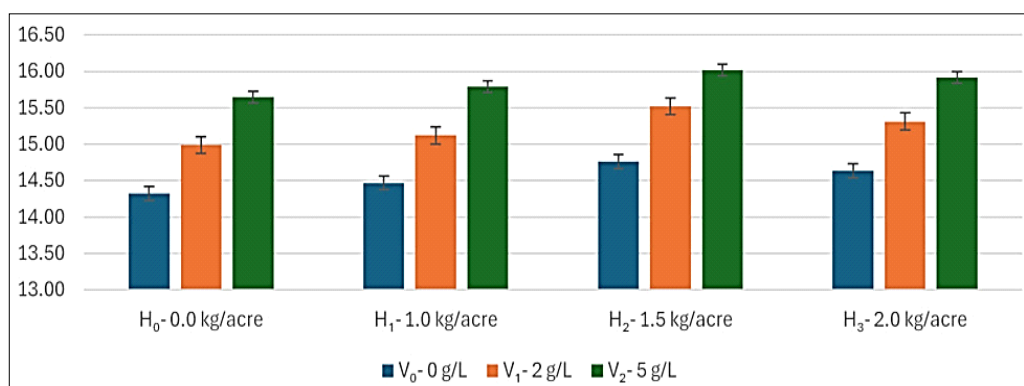
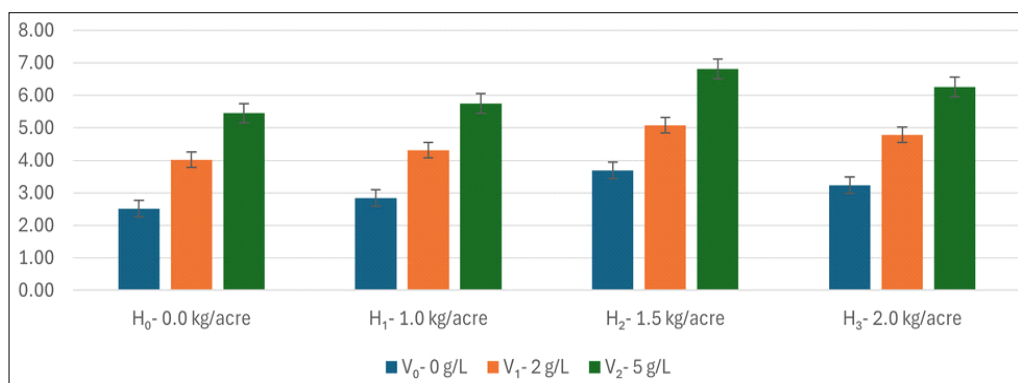
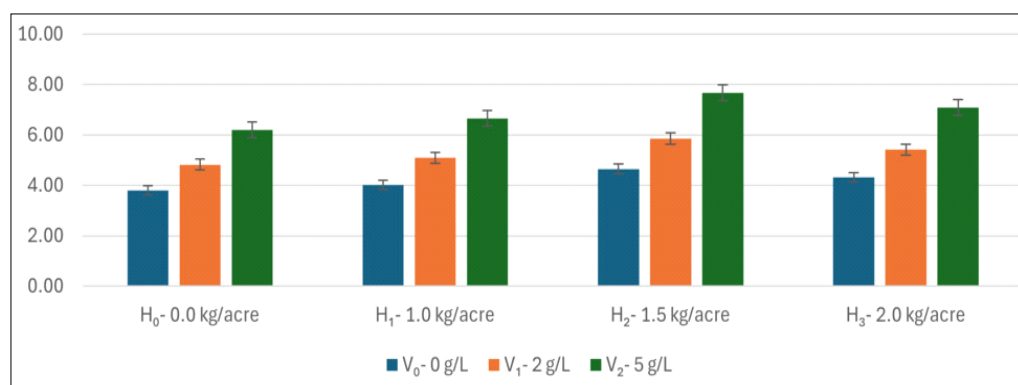
Fig 2,3 and 4 unveil a significant impact on the number of leaves 30-, 55- and 70-days post-transplanting, showcasing the influence of both biostimulant and Hydrogel. The highest petiole length (5.20 cm) (6.05 cm) (6.16 cm) was attained under H₂-1.5 kg/acre, surpassing all other Hydrogel levels. Conversely, the lowest petiole length (3.99 cm) (4.94 cm) (5.06 cm) was evident in the control group (H₀). Regarding biostimulant application, the highest petiole length (6.07 cm) (6.90 cm) (7.02 cm) was achieved with V₂-5 g/L, while the lowest petiole length (3.07 cm) (4.20 cm) (4.31 cm) was noted with V₀-0 g/L.

Table 4: Effect of biostimulant and hydrogel on leaf width after 30, 55 and 70 DAT.

T	Leaf width											
	30 DAT				55 DAT				70 DAT			
	H ₀	H ₁	H ₂	H ₃	H ₀	H ₁	H ₂	H ₃	H ₀	H ₁	H ₂	H ₃
V ₀	8.46	8.65	9.42	8.94	10.40	10.45	11.02	10.58	14.04	14.56	15.64	15.19
V ₁	10.05	10.23	11.73	10.33	11.88	12.66	14.44	13.59	16.25	16.91	18.00	17.56
V ₂	12.10	13.44	15.92	14.28	14.57	15.45	20.17	16.77	18.63	19.83	21.31	20.41
Mean	10.21	10.77	12.36	11.18	12.28	12.85	15.21	13.65	16.31	17.10	18.32	17.72
	V				V				V			
	0.402				0.59				0.011			
C.D.	0.464				0.681				0.012			
SE(m)	0.157				0.231				0.004			
	0.272				0.804				0.399			
	0.804				1.179				0.022			
	0.272				0.399				0.007			

Table 5: Effect of biostimulant and hydrogel on pedicle length after 70 DAT.

Treatment	H ₀ - 0.0 kg/acre	H ₁ - 1.0 kg/acre	H ₂ - 1.5 kg/acre	H ₃ - 2.0 kg/acre	Mean
V ₀ - 0 g/L	4.47	4.64	4.91	4.89	4.73
V ₁ - 2 g/L	5.03	5.08	5.18	5.18	5.12
V ₂ - 5 g/L	5.36	5.38	6.50	5.48	5.68
Mean	4.95	5.04	5.53	5.18	
	Factor A	Factor B	Factor A×B		
C.D.	0.103	0.119	0.206		
SE(m)	0.035	0.04	0.07		

**Fig 1:** Graphical representation of the effect of biostimulant and hydrogel on petiole girth after 70 DAT.**Fig 2:** Graphical representation of the effect of biostimulant and hydrogel on petiole length after 30 days after treatment (DAT).**Fig 3:** Graphical representation of the effect of biostimulant and hydrogel on petiole length after 55 days after treatment (DAT).

Furthermore, the interaction between biostimulants and hydrogel proved significant. The highest petiole length (6.82 cm) (7.66 cm) (7.75 cm) was observed with the combination of V_2 -5 g/L and H_2 -1.5 kg/acre, closely followed by the combination of V_2 -5 g/L and H_3 -2 kg/acre. Conversely, the lowest petiole length (2.52 cm) (3.79 cm) (3.91 cm) was found with the combination of V_2 -5 g/L and H_0 -0.0 kg/acre.

Hydrogel improves soil moisture retention, which can lead to better overall plant health. With consistent moisture, plants may show improved growth, including the development of pedicels. This could result in longer pedicels as the plant maintains optimal hydration levels (Narjary *et al.*, 2012).

This biostimulant contains various nutrients and growth enhancers that can positively affect plant growth. By stimulating physiological processes, Arka Vegetable

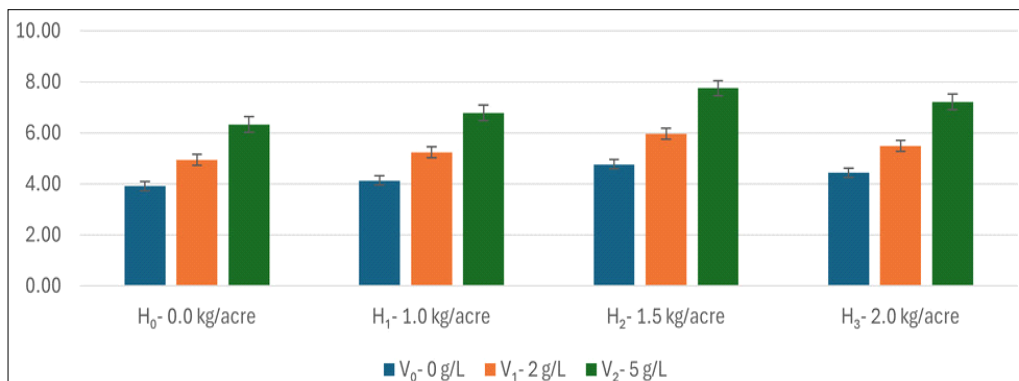


Fig 4: Graphical representation of the effect of biostimulant and hydrogel on petiole length after 70 days after treatment (DAT).

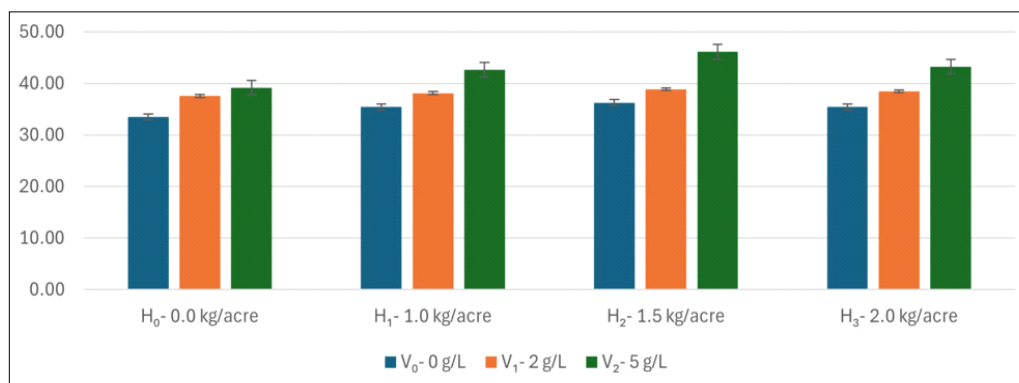


Fig 5: Graphical representation of the effect of biostimulant and hydrogel on plant spread after 30 DAT.

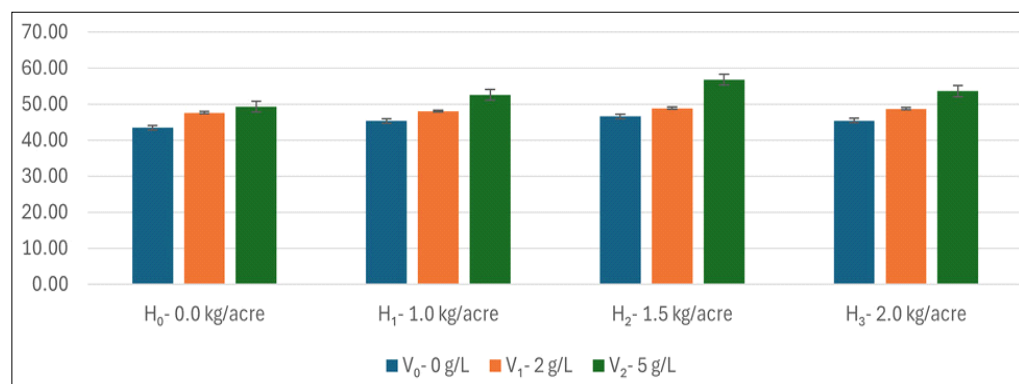


Fig 6: Graphical representation of the effect of biostimulant and hydrogel on plant spread after 55 DAT.

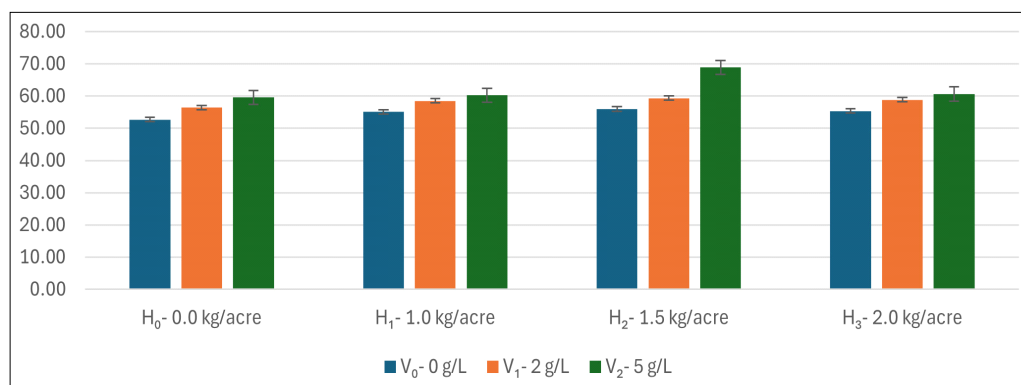


Fig 7: Graphical representation of the effect of biostimulant and hydrogel on plant spread after 70 DAT.

Special might encourage the development of longer pedicels through enhanced nutrient uptake and improved plant health (Kumar *et al.*, 2016). These findings align with those of Kumar *et al.* (2018) in ginger and Dawlatzai *et al.* (2017) in coleus.

Plant spread (cm²)

Fig 5, 6 and 7 unveil a significant impact on the plant spread 30, 55 and 70 days post-transplanting, showcasing the influence of both biostimulant and hydrogel. The maximum plant spread (40.41 cm) 50.74 cm) (61.39 cm) was attained under H₂-1.5 kg/acre, surpassing all other Hydrogel levels. Conversely, the minimum plant spread (36.74cm²) (46.79 cm²) (56.21 cm²) was evident in the control group (H₀). Regarding biostimulant application, the highest plant spread (42.75 cm²) (53.06 cm²) (62.31 cm²) was achieved with V₂-5 g/L, while the lowest plant spread (35.15 cm²) (45.20 cm²) (54.79 cm²) was noted with V₀-0 g/L.

Furthermore, the interaction between biostimulants and Hydrogel proved significant. The maximum plant spread (46.11 cm²) (56.77 cm²) (68.85 cm²) was observed with the combination of V₂-5 g/L and H₂-1.5 kg/acre, closely followed by the combination of V₂-5 g/L and H₃-2 kg/acre. Conversely, the minimum plant spread (33.47 cm²) (43.47 cm²) (52.70 cm²) was found with the combination of V₂-5 g/L and H₀-0.0 kg/acre.

Hydrogel's ability to retain water facilitated the uniform growth of branches and leaves, leading to a wider plant spread. The maintained moisture levels allowed for the extensive vegetative growth and expansion of the plant's canopy (Abobatta, 2018).

The Arka vegetable micronutrient further promoted plant spread by providing a comprehensive nutrient profile that supports branching and foliage development. The increased nutrient availability led to a more extensive and healthier plant spread, enhancing the plant's overall architecture (Kumar *et al.*, 2016). These findings align with those of Dubey *et al.* (2013) in bell pepper, Dewang and Devi (2022) in tomato and Mishra *et al.* (2023) in brinjal.

CONCLUSION

The experimental investigation revealed that the application of biostimulants, particularly at higher concentrations (V₂-5 g/L), significantly enhanced plant height, regardless of Hydrogel levels. This finding underscores the potential of biostimulants to improve crop productivity. Additionally, the Hydrogel practice at H₂-1.5 kg/acre was effective in promoting taller plants, emphasizing the importance of moisture management in crop production. The interaction between biostimulants and Hydrogel, particularly the combination of V₂-5 g/L and H₂-1.5 kg/acre, yielded the tallest plants, suggesting that integrated management practices are crucial for optimizing plant growth. These results highlight the potential of biostimulants and Hydrogel practices in advancing sustainable agricultural productivity, aligning with the goals of enhancing food security. Further research is needed to validate these findings and explore their application across different agricultural contexts.

Conflict of interest

All authors declared that there is no conflict of interest.

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