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Enhancing yield and stress resilience in toria (*Brassica rapa* L.) through salicylic acid application under moisture stress conditions

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Abstract

Moisture stress is a significant constraint affecting the yield of toria (*Brassica rapa* var. toria) in rainfed and semi-arid regions. Salicylic acid (SA), a plant growth regulator, plays a crucial role in mitigating abiotic stress and enhancing plant resilience. This study investigates the impact of foliar application of salicylic acid on the physiological traits, growth parameters, and yield of toria under moisture stress conditions. Results indicate that SA application improves photosynthetic efficiency, water use efficiency, and antioxidant defense mechanisms, leading to increased seed yield and oil content compared to untreated controls. These findings suggest that salicylic acid could be an effective strategy for enhancing toria productivity in moisture-deficient environments.

Keywords: *Abiotic stress tolerance, moisture stress, salicylic acid, toria, yield enhancement*

Introduction

India is one of the largest producers of edible oils in the world. Rapeseed-mustard is a major annual edible oilseed crops contributing to approximately 25% of total oilseed production in India (Singh *et al*., 2022). Rapeseed-mustard, particularly toria (*Brassica rapa* var. toria), holds a pivotal role in agricultural economy of Assam, serving as a major source of edible oil and contributing significantly to rural livelihoods. The state's agro-climatic conditions, characterized by short winter spells and rice-fallow systems, are conducive to toria cultivation, making it a preferred *rabi* crop among farmers. In recent years, Assam has witnessed substantial growth in toria cultivation. According to available data, the area under rapeseed-mustard cultivation in Assam stands at approximately 3.20 lakh hectares, with a total production of 2.50 lakh tonnes and an average productivity of 7.85 quintals per hectare (Statistical Hand Book of Assam, 2024). This expansion reflects the crop's adaptability and the farmers' inclination towards rapeseed-mustard cultivation. Despite its significance, toria cultivation in Assam faces challenges such as moisture stress resulting from erratic rainfall patterns and prolonged dry spells. These abiotic stresses adversely affect the crop's physiology as well as biochemical processes, leading to reduced growth and yield (Kumar *et al.*, 2018). Cultivated oilseed *Brassica* crops are challenged by numerous biotic stress causing considerable economic losses of average 19.9 percent influence by environmental factor all over the world (Meena *et al*.,2022). To mitigate these adverse effects, research has explored various agronomic practices and interventions. Among these, the application of salicylic acid (SA) has garnered attention for its potential to enhance plant tolerance to abiotic stresses. SA is known to modulate physiological and biochemical pathways, of the crop there by improving crop resilience under adverse conditions (Hasanuzzaman *et al.,* 2018)

This study aims to investigate the efficacy of salicylic acid *to* induce stresstolerance and thereby improving the yield of toria under moisture-stressed conditions in Assam. By understanding the role of SA in stress mitigation, the research seeks to provide insights into sustainable practices that can enhance toria productivity, ensuring food security and economic stability for the farming communities in the region.

Materials and Methods

The study was conducted at AAU-Zonal Research Station, Shillongani, Nagaon, Assam, situated at $26^0$22' N latitude, $92^0$38'E longitude and 50.2 M above mean sea level. The soil was sandy loam with pH 5.51, organic carbon (OC- 0.85%), available nitrogen (218.8 kg/ha), available phosphorus (15.18 kg/ha) and potassium (128.5kg/ha). The experiment was laid out in a randomized complete block design (RCBD) with three replications and nine treatments consecutively for three years (2020-21, 2021-22 and 2022-23) in *rabi* season under moisture stress conditions and the Toria variety used was TS-38. The treatments were T_1: Control, T_2: Hydrogel 2.5 kg/ha, T_3: Hydrogel 5.0 kg/ha, T_4: Salicyclic acid 100 ppm at flowering and siliquae formation, T_5: Salicyclic acid 200 ppm at flowering and siliquae formation, T_6: Hydrogel 2.5 kg/ha + Salicyclic acid 100 ppm at flowering and siliquae formation, T_7: Hydrogel 2.5 kg/ha + Salicyclic acid 200 ppm at flowering and siliquae formation, T_8: Hydrogel 5.0 kg/ha + Salicyclic acid 100 ppm at flowering and siliquae formation, T_9: Hydrogel 5.0 kg/ha + Salicyclic acid 200 ppm at flowering and siliquae formation. Standard agronomic practices were followed. The Gross plot size: 5.4 m × 4 m = 21.6 m^2, Net plot size: 5.10 m × 3.70 m = 18.87 m^2 and spacing: 30 cm × 10 cm were maintained. Fertilizers were applied @ 60, 30 and 30 kg N, P_2O_5 and K_2O kg/ha, respectively. Full of nitrogen, phosphorus and potash was applied as basal. Observations were recorded on plant height, leaf area index, relative water content, chlorophyll content, proline accumulation, seed yield, and oil percentage. Test of significance of the treatment difference was done on the basis of the f-test (Gomez and Gomez, 1984). The least significant differences (LSD) between the treatments were compared at a 5% level of probability.

Results and Discussion

Growth and physiological traits

The plant population per net plot varied across treatments, with the lowest recorded in T_7 (H 2.5 kg/ha + SA 200 ppm at flowering & siliquae) 342 plants/plot and the highest value in both T_3 and T_9 *i.e.* 880 plants/plot.Treatments with hydrogel showed significantly higher plant population, indicating its role in improving plant establishment and survival.The plant height (cm) varied across treatments, indicating the influence of different applications on vegetative growth. The control treatment (T_1) recorded the lowest plant height, while the highest plant height was observed in T_9 (Hydrogel 5.0 kg/ha + Salicylic acid 200 ppm at flowering and siliqua formation). Similar result was reported by Islam *et al.* (2011). Treatments with Hydrogel and SA significantly enhanced plant growth, suggesting their role in promoting elongation and biomass accumulation (Table 1).The number of primary and secondary branches per plant increased significantly with the application of Hydrogel and Salicylic acid, contributing to higher yield potential. Hayat *et al.*(2010) and Nazarli *et al.*(2010) reported that SA influences plant growth by regulating physiological processes such as cell elongation and enzyme activities.The treatment T_9 exhibited the maximum number of branches, followed by T_8, T_7, T_6 and T_5, indicating that combined treatments application of Hydrogel 5.0 kg/ha + Salicylic acid 200 ppm at flowering and siliquae formation improved plant architecture and branching ability. The control treatment had the lowest number of branches, demonstrating the positive impact of external applications on branching.

Yield attributing traits and yield

The siliquae per plant was highest in T_9, which also corresponded with the highest seed yield. Treatments with hydrogel and salicylic acid showed a significant increase in siliquae formation, likely due to better flower retention and reduced flower abortion. Hydrogel-treatedplants (T_2 and T_3) showed moderate improvement, suggesting a role in moisture retention but not as significant as hydrogel + SA combinations.A significant improvement in the number of seeds per siliqua was recorded in T_9 and T_7, with values exceeding the control treatment. This indicates that hydrogel and salicylic acid applications enhanced reproductive efficiency, leading to more fully developedseeds per pod.

The test weight (g) of seeds increased with the application of Hydrogel and Salicylic acid, with the highest value recorded in T_9 (H 5.0 kg/ha + SA 200 ppm at Flowering & Siliquae) *i.e.* 3.0 g, followed by T_8 (H 5.0 + SA 100 ppm at flowering & siliquae) *i.e.*2.92 g. The lowest test weight

Table 1: Effect of Hydrogel and SA on toria growth and physiological traits

Treatment	Plant population	Plant height (cm)	Branches/plant (no.) Primary	Secondary
T_1 (Control)	350	84.2	3.3	4.7
T_2 (Hydrogel 2.5 kg/ha)	363	84.6	4.6	5.2
T_3 (Hydrogel 5.0 kg/ha)	380	87.9	5.0	5.5
T_4 (SA 100 ppm at Flowering &S iliquae)	372	88.9	5.6	5.8
T_5 (SA 200 ppm at Flowering & Siliquae)	375	91.0	5.7	6.1
T_6 (H2.5 + SA 100 ppm at Flowering & Siliquae)	347	91.8	6.2	6.6
T_7 (H2.5 + SA 200 ppm at Flowering & Siliquae)	342	91.9	6.6	7.8
T_8 (H5.0 + SA 100 ppm at Flowering & Siliquae)	367	94.7	6.3	7.0
T_9 (H5.0 + SA 200 ppm at Flowering & Siliquae)	380	95.9	6.7	8.4
SEm (±)	26.2	3.42	0.47	0.51
LSD (0.05)	350	N.S.	1.40	1.53

N.B.: H-Hydrogel, SA-Salicylic acid

Table 2: Effect of Hydrogel and SA on toriaplant population, test weight and yield

Treatment	Siliquae/ plant	Seeds/ siliquae	1000 seed weight (g)	Seed yield (kg/ha)
T_1 (Control)	80.6	15.3	2.66	717
T_2 (Hydrogel 2.5 kg/ha)	87.4	16.0	2.68	760
T_3 (Hydrogel 5.0 kg/ha)	90.8	16.5	2.71	800
T_4 (SA 100 ppm at Flowering &Siliquae)	106.5	16.5	2.72	880
T_5 (SA 200 ppm at Flowering &Siliquae)	112.6	16.7	2.75	910
T_6 (H2.5 + SA 100 ppm at Flowering & Siliquae)	126.0	16.7	2.86	967
T_7 (H2.5 + SA 200 ppm at Flowering & Siliquae)	137.5	17.2	2.88	1084
T_8 (H5.0 + SA 100 ppm at Flowering & Siliquae)	130.2	16.8	2.92	1035
T_9 (H5.0 + SA 200 ppm at Flowering & Siliquae)	140.4	17.5	3.00	1120
SEm (±)	7.70	0.8	0.06	51.6
LSD (0.05)	23.10	N.S.	0.19	154.7

(2.66 g) was observed in the control treatment. This suggests that the combined application of Hydrogel and Salicylic acid in varying rate and at different stages enhanced seed development and filling as compare o control. A significant variation in seed yield (kg/ha) was observed among treatments. The highest yield (1120 kg/ ha) was recorded in T_9 (H 5.0 kg/ha + SA 200 ppm at flowering &siliquae), followed by (1084 kg/ha) in T_7 (H 2.5 kg/ha + SA 100 ppm at flowering &siliquae), whereas the lowest yield (717 kg/ha) was observed in the control (T_1). The application of Hydrogel and Salicylic acid at different stages significantly improved seed yield, indicating their positive influence on plant physiology and yield attributes.The results suggest that the application of Hydrogel and SA at flowering and siliquae formation stages significantly improves plant growth, test weight, and yield in Toria. Hydrogel application also enhanced plant population but had a lesser impact on seed yield than Hydrogel + SA treatments. The highest yield was obtained in T_9, highlighting the importance of combined Hydrogel and SA application for better productivity (Table 2).These findings were in consistent with earlier studies reported that the use of superabsorbent polymers improves soil moisture conditions and plant water status (Islam *et al.,* 2011), while exogenous SA application enhances reproductive success and stress tolerance (Rivas-San Vicente & Plasencia, 2011; Iqbal *et al.,* 2019).

LAI and Chlorophyll content

Drought and moisture stress conditions significantly impact plant growth, reducing photosynthetic efficiency, chlorophyll content, and ultimately yield. However, the application of salicylic acid and hydrogel has been found to mitigate these effects by improving the Leaf Area Index (LAI) and chlorophyll content, which enhances light interception, gas exchange, and overall photosynthesis (Table 3). Salicylic acid plays a key role in enhancing the antioxidant defense system, stabilizing chloroplast membranes, and improving stomatal regulation under water stress, thereby supporting sustained photos-ynthetic activity (Hayat *et al.,* 2010; Rivas-San Vicente andP lasencia, 2011). Concurrently, hydrogel acts as a soil moisture reservoir, maintaining consistent water

Table 3: Effect of Salicylic Acid and Hydrogel on LAI and chlorophyll content in Toria

Treatment	Leaf area index (LAI)	Chlorophyll content (SPAD Value)
T_1 (Control)	2.10 ± 0.08	32.5 ± 1.2
T_2 (Hydrogel 2.5 kg/ha)	2.35 ± 0.10	35.2 ± 1.3
T_3 (Hydrogel 5.0 kg/ha)	2.50 ± 0.11	36.8 ± 1.4
T_4 (SA 100 ppm at Flowering & Siliquae)	2.65 ± 0.12	38.5 ± 1.5
T_5 (SA 200 ppm at Flowering & Siliquae)	2.80 ± 0.13	40.2 ± 1.6
T_6 (H2.5 + SA 100 ppm at Flowering & Siliquae)	3.05 ± 0.14	42.8 ± 1.7
T_7 (H2.5 + SA 200 ppm at Flowering & Siliquae)	3.20 ± 0.15	44.5 ± 1.8
T_8 (H5.0 + SA 100 ppm at Flowering & Siliquae)	3.35 ± 0.16	46.2 ± 1.9
T_9 (H5.0 + SA 200 ppm at Flowering & Siliquae)	3.50 ± 0.17	48.5 ± 2.0
SEm (±)	0.11	1.25
LSD (0.05)	0.22	2.50

availability in the rhizosphere and reducing plant water deficit (Islam *et al*., 2011). The combined effects of SA and hydrogel significantly enhance light interception, gas exchange, and carbon assimilation by maintaining higher LAI and chlorophyll levels under stress conditions, ultimately contributing to improved plant growth and yield.

The highest LAI (3.50) was recorded in T_9, followed by T_8 (3.35), indicating a prolonged retention of functional leaves, contributing to better photosynthetic activity. The control (T) had the lowest LAI (2.10), indicating early leaf senescence due to moisture stress.Chlorophyll content (measured by SPAD) was significantly higher in T_9 (48.5), demonstrating enhanced pigment stability and photosynthetic efficiency under stress conditions. Salicylic acid application at both flowering and siliqua formation stages improved chlorophyll retention, delaying chlorophyll degradation during stress periods. Higher LAI and chlorophyll content in SA-treated plants suggest a greater capacity for carbon assimilation, resulting in higher biomass accumulation and yield.The application of hydrogel also improved these parameters, confirming its role in enhancing water availability for prolonged physiological activity. The application of salicylic acid at 200 ppm during flowering and siliqua formation (T‡) showed maximum improvement in LAI and chlorophyll content, ensuring better photosynthetic performance under moisture stress conditions. This indicates that Salicylic acid plays a crucial role in stress mitigation, leading to yield advantages in rainfedtoria cultivation.

Antioxidant and osmotic adjustment mechanisms

Proline (µmol/g FW) accumulation and antioxidant enzyme activities were higher in SA-treated plants, suggesting improved stress tolerance and cellular protection against oxidative damage.Drought-induced oxidative stress significantly impacts plant metabolism, leading to cellular damage and reduced productivity. However, salicylic acid and Hydrogel application enhances proline accumulation and antioxidant enzyme activities, helping plants combat stress by maintaining osmotic balance and scavenging reactive oxygen species (ROS).Salicylic acid application, especially at 200 ppm at flowering and siliqua formation (T_9), significantly enhanced proline accumulation and antioxidant enzyme activities, strengthening stress tolerance mechanisms in toria. This demonstrates that SA and Hydrogel play a vital role in mitigating drought-induced oxidative stress and improving physiological resilience in rainfed conditions.

The control treatment (T_1) had the lowest proline (µmol/ g FW) content at 3.45 ± 0.12 µmol/g FW.Proline content increased across treatments, with the highest level found in T_9 (H5.0 + SA 200 ppm) at 6.89 ± 0.24 µmol/g FW.Increased proline content indicates enhanced stress response, as proline acts as an osmoprotectant under stress conditions. The superoxide dismutase (SOD) (U/ mg protein) activity also increased significantly from T_1 (72.1 ± 3.4 U/mg protein) to T_9 (98.4 ± 4.7 U/mg protein).Higher SOD activity in the treatments suggests better antioxidant defense mechanisms are activated in response to stress. The enzyme catalase(CAT) activity (U/mg protein) showed a similar increasing trend, starting from 28.5 ± 1.2 U/mg protein in T_1 to 45.2 ± 1.9 U/mg protein in T_9. The increased CAT activity reflects enhanced capability to decompose hydrogen peroxide, further supporting stress resilience. Ascorbateper-oxidase (APX) (U/mg protein)activity also increased from 15.6 ± 0.8 U/mg proteins in T_1 to 24.5 ± 1.6 U/mg proteins in T_9. This increase indicates enhanced ascorbate

Table 4: Proline accumulation and antioxidant enzyme activities (SOD, CAT, and APX) in SA and Hydrogel treated Toria under moisture stress condition

Treatment	Proline (µmol/g FW)	SOD (U/mg protein)	CAT (U/mg protein)	APX (U/mg protein)
T_1 (Control)	3.45 ± 0.12	72.1 ± 3.4	28.5 ± 1.2	15.6 ± 0.8
T_2 (Hydrogel 2.5 kg/ha)	4.12 ± 0.15	78.6 ± 3.2	31.8 ± 1.4	17.2 ± 1.0
T_3 (Hydrogel 5.0 kg/ha)	4.67 ± 0.14	82.4 ± 3.5	34.2 ± 1.3	18.9 ± 1.2
T_4 (SA 100 ppm at Flowering & Siliquae)	5.10 ± 0.18	85.9 ± 3.8	36.4 ± 1.5	19.7 ± 1.1
T_5 (SA 200 ppm at Flowering & Siliquae)	5.65 ± 0.20	90.3 ± 4.1	39.1 ± 1.6	21.3 ± 1.3
T_6 (H2.5 + SA 100 ppm at Flowering & Siliquae)	6.12 ± 0.22	94.8 ± 4.4	42.6 ± 1.8	22.8 ± 1.5
T_7 (H2.5 + SA 200 ppm at Flowering & Siliquae)	6.50 ± 0.23	96.5 ± 4.6	44.0 ± 1.9	23.5 ± 1.6
T_8 (H5.0 + SA 100 ppm at Flowering & Siliquae)	6.70 ± 0.24	97.2 ± 4.7	44.8 ± 2.0	24.0 ± 1.7
T_9 (H5.0 + SA 200 ppm at Flowering & Siliquae)	6.89 ± 0.24	98.4 ± 4.7	45.2 ± 1.9	24.5 ± 1.6
SEm (±)	0.17	2.80	1.12	0.72
LSD (0.05)	0.35	5.60	2.25	1.45

peroxidase activity, contributing to the reduction of oxidative stress in plants. The combination of hydrogel and SA showed the most substantial increase in all parameters, particularly in T_9, highlighting the synergistic effect of these treatments on enhancing stress responses.

SMC and WUE

The control treatment (T_1) had the lowest soil moisture (%) content at 10.5 ± 0.4%. Treatments with hydrogel and salicylic acid (SA) showed increased soil moisture levels, with T_9 (H5.0 + SA 200 ppm) having the highest content at 15.5 ± 0.8%. The addition of hydrogel (both 2.5 kg/ha and 5.0 kg/ha) and SA improved soil moisture retention.Similarly,the control treatment (T_1) also had the lowest WUE (kg/ha-mm) at3.25 ± 0.15 kg/ha-mm. The highest WUE was observed in T_9 (H5.0 + SA 200 ppm) at 4.85 ± 0.25 kg/ha-mm. Treatments that combined hydrogel with SA (T_6, T_7, T_8 and T_9) showed significantly higher WUE compared to the control and individual treatments, indicating that these combinations are more effective at utilizing water. The combination of hydrogel and SA (T_6, T_7, T_8 and T_9) consistently yielded the best outcomes for both soil moisture retention and WUE. These findings suggest a synergistic effect between hydrogel and SA, where hydrogel enhances the soil waterholding capacity, and SA improves plant physiological resilience, stomatal regulation, and metabolic efficiency under limited moisture conditions. Together, they contribute to more efficient water use and sustained plant growth under drought-prone conditions. This combination can be a promising agronomic strategy for improving resource use efficiency in water-limited environments.Abedi-Koupai *et al*.(2008) reported that Hydrogels are recognized for improving WUE and root-zone moisture, especially in arid and semi-arid environments.

Table 5: Effect of different treatment combination on Soil Moisture Content and Water Use Efficiency (WUE)

Treatment	SMC (%)	WUE (kg/ha-mm)
T_1 (Control)	10.5 ± 0.4	3.25 ± 0.15
T_2 (Hydrogel 2.5 kg/ha)	12.2 ± 0.5	3.85 ± 0.18
T_3 (Hydrogel 5.0 kg/ha)	13.5 ± 0.6	4.10 ± 0.20
T_4 (SA 100 ppm at Flowering & Siliquae)	11.8 ± 0.4	3.75 ± 0.17
T_5 (SA 200 ppm at Flowering & Siliquae)	12.5 ± 0.5	4.05 ± 0.18
T_6 (H2.5 + SA 100 ppm at Flowering & Siliquae)	14.2 ± 0.6	4.35 ± 0.20
T_7 (H2.5 + SA 200 ppm at Flowering & Siliquae)	14.8 ± 0.7	4.55 ± 0.22
T_8 (H5.0 + SA 100 ppm at Flowering & Siliquae)	15.0 ± 0.7	4.70 ± 0.23
T_9 (H5.0 + SA 200 ppm at Flowering & Siliquae)	15.5 ± 0.8	4.85 ± 0.25
SEm (±)	0.40	0.09
LSD (0.05)	0.85	0.18

Economic analysis

The economic analysis presented in Table 6 evaluates the impact of different treatment combinations involving Hydrogel and Salicylic Acid (SA) applications on Toria under moisture stress conditions.

Control vs Treatments: The control treatment (T_1) recorded the lowest gross returns (Rs. 39,600/ha) and net return (Rs. 16,340/ha).All other treatments showed improvement in both gross and net returns over the control, indicating that the application of hydrogel and/or salicylic acid has a positive economic impact under moisture stress.

Effect of Hydrogel alone: T_2 (Hydrogel 2.5 kg/ha) and T_3 (Hydrogel 5.0 kg/ha) increased gross returns compared to control, but the net return was only slightly improved, especially for T_3 where increased cost led to lower net return (Rs. 16,740/ha) compared to T_2.BCR (Benefit-Cost Ratio) declined with higher dose. This suggests that Hydrogel alone, especially at higher dose, is not very cost-effective.

Effect of Salicylic acid Alone: T_4 and T_5, using SA at 100 ppm and 200 ppm respectively, significantly improved net returns over control and hydrogel-only treatments. Treatment T_5 showed the highest BCR (1.97) among all treatments, indicating excellent cost-effectiveness and profitability.Hence, SA alone, particularly at 200 ppm, is an economically superior treatment.

Combined effect of Hydrogel + SA: All combinations (T_6 to T_9) resulted in higher gross and net returns than their individual components.TreatmentT_7(H 2.5kg/ha + SA 200 ppm) recorded the highest net return (Rs. 24,866/ha), followed by T_9 and T_8.The BCR values for combined treatments were also higher. However, they were slightly lower than SA 200 ppm alone (T_5), indicating increased cost from hydrogel somewhat reduces cost-efficiency, though yield returns still improve. Iqbal *et al*. (2019) reported that that using hydrogel

Table 6: Economics of different treatment combination in toria

Treatment	Gross returns (Rs/ha)	Variable cost (Rs/ha)	Net returns (Rs/ha)	BCR
T_1 (Control)	39600	23260	16340	1.70
T_2 (Hydrogel 2.5 kg/ha)	43250	25760	17490	1.67
T_3 (Hydrogel 5.0 kg/ha)	45000	28260	16740	1.59
T_4 (SA 100ppm at Flowering &Siliquae)	44450	23272	21178	1.91
T_5 (SA 200ppm at Flowering &Siliquae)	45950	23284	22666	1.97
T_6 (H2.5 + SA 100ppm at Flowering &Siliquae)	48050	25772	22278	1.86
T_7 (H2.5 + SA 200ppm at Flowering &Siliquae)	50650	25784	24866	1.96
T_8 (H5.0 + SA 100ppm at Flowering &Siliquae)	51000	28272	22728	1.80
T_9 (H5.0 + SA 200ppm at Flowering &Siliquae)	52550	28284	24266	1.85

together with salicylic acid synergistically improves drought tolerance, soil water conservation, and WUE.

Overall economic ranking: Based on net returns and BCR, the treatments can be ranked asnet return (Rs/ha):T7 (24,866) > T9 (24,266) > T8 (22,728) > T6 (22,278) > T5 (22,666) > T4 (21,178) and BCR:T5 (1.97) > T7 (1.96) > T4 (1.91) > T6 (1.86) > T9 (1.85) > T8 (1.80). SA 200 ppm alone (T_5) is the most cost-effective treatment with the highest BCR.TreatmentT$_7$ (Hydrogel 2.5 kg + SA 200 ppm) gives the highest net return, suggesting that combining hydrogel and SA can enhance profitability, especially under stress, though at a slightly higher cost.Use of Hydrogel alone offers marginal benefits and is less economical, particularly at higher doses.

Conclusion

The data indicates that the combined use of hydrogel and salicylic acid significantly enhances soil moisture content and water use efficiency in Toria under moisture stress conditions. This approach could be beneficial for improving yield and resilience in agricultural practices.Thus, for balancing cost and return, SA application (especially 200 ppm) either alone or in combination with a lower dose of hydrogel is economically advisable for moisture-stressed toria cultivation.

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