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Drought Mitigating Impact of Foliar Application of Salicylic Acid and KNO_3 on Growth, Yield and Yield Attributing Characters of Tomato (*Solanum lycopersicum* L.) under Water Stress Conditions

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ABSTRACT

Background: Water deficit is one of the most limiting factors for plant survival as it regulates growth and development and limits plant productivity. Salicylic Acid (SA) is a signaling molecule that plays a crucial role in regulating plant responses to various biotic and abiotic stresses, including water stress. When applied exogenously, SA can stimulate the expression of stress-responsive genes and activate antioxidant defense systems, helping to scavenge reactive oxygen species (ROS) generated under water stress conditions. Potassium plays a crucial role in regulating stomatal opening and closing, osmotic adjustment and enzyme activation, all of which are important processes for water stress adaptation.

Methods: A field experiment was conducted at AICRP on Vegetable Crops, OUAT, Bhubaneswar to standardize the dose of salicylic acid and KNO_3 application on tomato (*Solanum lycopersicum* L.) under water stress condition. In the present investigation growth, fruit and seed yield attributing traits of tomato for the year 2019-20 and 2020-21 was studied under randomized block design with three replications and ten treatments. Treatments include five doses of salicylic acid (10 ppm, 25 ppm, 50 ppm, 75 ppm, 100 ppm) and three doses of KNO_3 (1%, 2.5%, 5%) along with one stress check treatment (drought stress by withholding irrigation) and stress-freecontrol treatment (provided flooding irrigation).

Result: The maximum values of growth parameter, yield and yield attributing characters such as plant height (115.77 cm), leaf area (98.72 cm^2), number of truss per plant (11.83), number of fruits/plant (23.87), total fruit yield (42.28 t ha^{-1}), seed yield (148.84 kg ha^{-1}), germination % (88.17), seedling length (14.93 cm), S.V I (1315.49), S.V II (185.35) were recorded with stress free check treatment (provided flooding irrigation) followed by 100 ppm salicylic acid and KNO_3 5%. Maximum leaf area (98.72 cm^2) was recorded with 100 ppm salicylic acid followed by T8 (5% KNO_3) and stress free control.

Key words: Antioxidant enzyme, Growth, KNO_3, Salicylic acid, Water stress, Yield.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated crops worldwide. Tomato is cultivated in India in an area of 871'000 hectares with a production of 21.30 MT and productivity is 24.42 MT/ha (2023-2024). The area and production of tomato in Odisha state was 0.093 million ha and 1.432 million tonnes respectively with a productivity of 15.25 MT/ha during the year 2020-21 (Horticulture Statistics at a Glance-2018). Tomato is affected by a wide range of abiotic stresses (Liang *et al.,* 2020). Especially drought stress significantly reduces plant growth and development in vegetative stages, yield and product quality in the reproductive stage of tomato (Celik *et al.,* 2017) and rice (Sahoo *et al.,* 2024). Foliar application of plant growth regulators and chemical found to be one of the most suitable approaches for abiotic stress mitigation in tomato (Guo *et al.,* 2022 and Zahid *et al.,* 2023).

SA involves significantly in several plant processes. It is reported that salicylic acid can potentially mitigate biotic or abiotic stresses (Aires *et al.,* 2022). The positive effects of SA application were observed on the growth and biomass accumulation of *Portulaca oleracea* under drought

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conditions as it promotes the maintenance of photosynthetic pigments and increased CO_2 assimilation (Saheri *et al.,* 2020 and Kuchlan and Kuchlan, 2021). Recent results also have shown that the foliar application of salicylic acid in cherry tomatoes acts as drought mitigant (Chakma *et al.,* 2021). Potassium is also reported to reduce drought stress effects in plants (Gilani *et al.*, 2020). Applying of foliar KNO_3 is an effective way for drought stress mitigation (De Castra Filho *et al.,* 2024). Applying KNO_3 increased various growth and quality parameters such as root shoot length, dry weight, chlorophyll *etc* in spinach under drought condition (Bukhari *et al.*, 2021).

The effect of water stress on tomato growth and yield has been widely studied, but there is limited research on the potential mitigating effects of foliar application of salicylic acid and KNO3 (Sathishkumar *et al.,* 2020 and Yücel Candan, 2018). Addressing this knowledge gap is important for improving our understanding of the mechanisms underlying the effects of salicylic acid and KNO_3 on tomato growth and yield under drought stress conditions, which could ultimately lead to more effective strategies for improving tomato productivity in water-limited environments.

MATERIALS AND METHODS

An experiment was conducted during *rabi* season of the year 2019-20 and 2020-21 at AICRP on Vegetable Crops, OUAT, Bhubaneswar. The experimental site comes under the agro-climatic zoneeast and south eastern coastal plain of odisha and east coastal plains of India. The experiment was laid out in randomized block design (RBD) with three replications and ten treatments. The seeds of the BT-10 variety were procured from AICRP on Vegetable Crops, College of Agriculture, OUAT, Bhubaneswar and were surface sterilized with 5% sodium hypochlorite, followed by repeated washing with water. The seeds were sown in nursery beds filled with sandy loam soil and farmyard manure in the ratio of 6:1. Seedlings of 10 cm height having sturdy stems were carefully uprooted and transplanted into the main field; taking into account the appropriate environmental conditions. The distance between row to row and plant to plant were kept at 60 cm × 40 cm. 100% recommended dose was common to all treatments of tomato and different levels of salicylic acid and KNO_3 were applied as per treatment. The recommended dose of fertilizer for tomato was 150:100:50 kg ha^{-1} N, P and K that were applied from urea, diammonium phosphate and muriate of potash, respectively. Water stress condition was imposed in all treatments except T_{10} (irrigated control) at two stages pre-flower initiation stage *i.e.*, 21 DAT or 3 weeks after transplanting for a week and one week prior to 50% fruiting stage *i.e.*, 56 DAT or 8 weeks after transplanting for a week by withholding irrigation at these two stages. There was no rainfall during the stress imposed period and flood irrigation was provided to T_{10} (stress free check) throughout the growing period. In this experiment, foliar application of salicylic acid (10 ppm, 25 ppm, 50 ppm, 75 ppm, 100 ppm) and potassium nitrate (1%, 2.5%, 5%) were applied under water stress condition at pre-flowering stage (21 DAT) and 1 week prior to 50% fruiting stage (56 DAT). Five plants from each plot were selected randomly and tagged after spray of salicylic acid and KNO_3 and observations were recorded manually on growth parameters, fruit yield, seed yield and its attributing traits. Leaf area meter (Systronics Model No 211) was used to measure the leaf area of the sample. Desirability index of different treatments was calculated by combining all the seed quality parameters *i.e.* germination count, seedling length, seedling vigour index-I, seedling vigour index-II. The data so generated was statistically analyzed and ANOVA (analysis of variance) technique was used to test the overall significance of the data by using SPSS Software and MS excel 2010.

RESULTS AND DISCUSSION

Growth parameters

The pooled results of the present studies revealed (Table 1) that the growth parameters of tomato like plant height, leaf area and number of trusses per plant were significantly influenced by graded doses of SA and KNO_3 application. In this study, plant height of tomato were significantly varied from 87.18 cm in T_9 (stress check) to 115.77 cm in T_{10} (irrigated control) with a mean value of 101.23 cm (SEm (±)= 4.18, CD (0.05)= 8.47) 7 (Table 1). Under drought stress (stress check) plant height reduced to 24.70% as compared to irrigated control. Among the different doses of foliar application of SA and KNO_3, 100 ppm S.A (T_5) showed minimum reduction (4.52%) followed by 5% KNO_3 (T_8) with 6.71%, however maximum reduction was observed in 10 ppm S.A (T_1) *i.e.* 20.01% in plant height from the irrigated control. Similarly, number of trusses per plant varied from 9.48 in T_9 (stress check) to 11.63 in T_{10} (irrigated control) with a mean value of 10.62 (SEm (±)= 0.4 , CD (0.05)= 0.82) (Table 1). As compared to irrigated control, in stress check treatment trusses per plant was reduced to 18.49%. Under drought, among different doses of foliar applications of SA and KNO_3, 5% KNO_3 (T_8) showed minimum reduction (3.44%) followed by 100 ppm S.A (T_5) and 10 ppm S.A (T_1) showed maximum reduction (12.21%) in trusses per plant as compared to irrigated control. The leaf area significantly varied from 84.79 cm^2 in T_9 (stress check) to 98.72 cm^2 in stress free check (T_{10}) with a mean value of 91.97 cm^2 [SEm (±)=3.03, CD (0.05)= 6.14] (Table 1). As compared to irrigated control, under drought condition minimum reduction in leaf area (0.02%) was observed in 100 ppm S.A (T_5) followed by 0.08% reduction in 5% KNO_3 (T_8) and maximum reduction (11.64%) was observed in 10 ppm S.A (T_1). All these parameters were found minimum in the stress check control plots T_9 (Drought stress). These similar findings were in accordance with the results obtained by Qadir *et al.* (2019) in cherry tomato. Alam *et al.* (2020) also reported similar result in Okra where in case

Table 1: Effect of salicylic acid and KNO_3 on growth and yield parameters of tomato.

Treatments	Plant height (cm)	Leaf area (cm^2)	Number of truss/ plant	Fruit yield /ha (t)	No. of fruit/plant	Seed yield /ha (in kg)	Germination (%)	Seedling length (cm)	S.V I	S.V II
T_1 (10 ppm S.A)	92.60	87.23	10.21	28.64	18.55	91.39	75.83	11.40	864.03	114.57
T_2 (25 ppmS.A)	94.96	89.78	10.46	30.56	20.05	92.78	79.00	12.71	1004.19	123.24
T_3 (50 ppm S.A)	97.20	89.25	10.22	31.19	21.54	96.42	77.33	11.97	926.36	128.37
T_4 (75 PPM S.A)	106.07	94.77	10.80	34.60	21.88	112.67	83.83	13.17	1104.68	146.37
T_5 (100 ppm S.A)	110.54	98.70	10.99	40.15	22.96	124.97	84.83	13.87	1170.19	153.37
T_6 (1% KNO_3)	98.50	90.71	10.24	31.62	20.72	114.29	83.83	12.34	1034.41	146.81
T_7 (2.5% KNO_3)	101.51	91.20	10.89	32.47	22.58	115.56	80.17	13.35	1069.06	138.46
T_8 (5% KNO_3)	108.00	98.64	11.23	41.74	23.21	133.66	84.33	13.74	1166.57	149.8
T_9 Stress check	87.18	84.79	9.48	24.64	18.00	85.73	67.33	10.74	725.99	91.36
T_{10} Stress free check	115.77	98.72	11.83	42.28	23.87	148.84	88.17	14.93	1315.49	185.35
SEm (±)	4.18	2.55	0.37	1.04	0.84	4.72	1.15	0.32	33.64	8.88
CD (0.05)	8.47	5.18	0.75	2.11	1.7	9.57	2.33	0.66	68.23	18

of exogenous application of salicylic acid at 240 mgl^{-1} had maximum plant height (130.75 cm), maximum number of leaves (30.39) and maximum number of pods (24.24) per plant.

Salicylic acid treatments effectively ameliorated the negative effects of drought stress by improving the leaf chlorophyll content, photosynthetic rate, stomatal conductance, carboxylation efficiency, transpiration rate and stability in membrane permeability, induction of stress proteinsand enhancing the activity of antioxidant enzymes (Khalvandi *et al.,* 2021 and Amiri Adel *et al.,* 2023). SA functions as a cofactor in enzyme systems and acts as an electron carrier, playing a crucial role in the oxidation and reduction mechanisms within plants (Zulfiqar *et al.*, 2021 and Hasan *et al.,* 2018). Auxin is synthesized in the meristem of the plant which is responsible for plant height, while their function is regulated by salicylic acid (Li *et al.,* 2022). The effect of salicylic acid on plant and flower yield could be due to increased vegetative growth, photosynthetic pigments, minerals and some bio constituents that affect plant growth. Similar findings were documented (Qadir *et al.,* 2019) who reported that plant height was found to be ameliorated by application of salicylic acid in tomato. Umebese *et al.* (2009) and Gerszberg and Hnatuszko-Konka (2017) found that water stress reduced tomato and amaranth stem height significantly at the vegetative stages and 3 mM application of salicylic acid was effective in keeping plant height similar to the control which was related to the ability of Salicylic acid to induce antioxidant responses that protect them from damage. Similar findings were reported (Baltacıer *et al.,* 2023) in tomato where Salicylic acid applications increase leaf area more effectively. Abdelaziz and Taha (2018) indicated that supplementary spraying of K caused significant increase in terms of plant height, leaf area, number of leaves and dry weight of water-stressed tomato. These positive effects may be explained by the fact that foliar spraying increases available potassium uptake by plants, which is essential for enzyme utilization, IAA formation, regulating plant water status and optimizing plant growth performance. Likewise, plants treated with graded doses of potassium nitrate exhibited a higher number of flower clusters per plant compared to the stress control. These results could be attributed to potassium's role in promoting shoot elongation, enhancing enzyme activity, facilitating protein synthesis, supporting photosynthetic transport and influencing chlorophyll content (Abdelhameed and El-Hady, 2018).

Yield and yield attributing characters

The results of the pooled studies (Table 1) revealed that the maximum fruit yield per hectare (44.28 t/ha), number of fruits per plant (23.87), seed yield per hectare(266.39 kg/ha), seed germination % (88.17%), seedling length(14.93 cm), seed vigour index I(1315.49) and seed vigour index II(1201.82) noticed by T10(Irrigated up to field capacity), which was significantly superior than all other treatments and at par with T_5 (100 ppm SA) along with T_8 (5% KNO_3).

Fruit yield per hectare varied from 26.64 tonnes in T_9 (stress check) to 44.28 tonnes in T_{10} (Irrigated control) with a mean value of 35.80 tonnes (Table 1). As compared to irrigated control 39.84% reduction in stress check was observed in fruit yield. Under drought, among different doses of foliar application of SA and KNO_3, 100 ppm S.A (T_5) showed minimum reduction (1.22%) followed by 5% KNO_3 (T_8) and 10 ppm S.A (T_1) showed maximum reduction (30.80%) in fruit yield as compared to irrigated control. Number of fruits per plant varied from 18 in T_9 (Stress check) to 23.87 in T_{10} (Irrigated control) with a mean value of 21.34 and in stress check, it is reduced to 24.59% as compared to irrigated control in number of fruits per plant. Under drought, among different doses of foliar application of SA and KNO_3, 5% KNO_3 (T_8) showed minimum reduction (2.76%) followed by 75 ppm SA (T4) with 3.81% reduction and 10 ppm S.A (T1) showed maximum reduction (22.29%) in number of fruits per plant as compared to irrigated control. Seed yield per hectare varied from 181.94 kg in T_9 (Stress check) to 266.39 kg in T_{10} (Irrigated control) with a mean value of 229.09 kg (Table 1). In stress check, it is reduced to 31.70% as compared to irrigated control in seed yield per hectare. Under drought, among different doses of foliar application of SA and KNO_3, 5% KNO_3 (T_8) showed minimum reduction (0.73%) followed by 75 ppm SA (T_4) with 8.24% reduction in seed yield. However, maximum reduction was observed in 10 ppm SA (T1) with 23.57% in seed yield per hectare as compared to irrigated control. Seed germination % varied from 67.33% in T_9 (stress check) to 88.17% in T_{10} (irrigated control) with a mean value of 80.47 (Table 1). In stress check, it is reduced to 23.64% as compared to irrigated control in seed germination %. Under drought, among different doses of foliar application of SA and KNO_3, 100 ppm SA (T_5) showed minimum reduction (3.79%) and 10 ppm SA (T_1) showed maximum reduction (14.00%) in seed germination % as compared to irrigated control. Seedling length varied from 10.74 cm in T_9 (stress check) to 14.93 cm in T_{10} (irrigated control) with a mean value of 12.82 cm (Table 1). In stress check, it is reduced to 28.06% as compared to irrigated control in seedling length. Under drought, among different doses of foliar application of SA and KNO_3, 5% KNO_3 (T_8) showed minimum reduction (7.10%) followed by 100 ppm SA with 7.97% reduction and 10 ppm SA (T_1) showed maximum reduction (23.64%) in seedling length as compared to irrigated control. Similarly, S.V I (seed vigour index I) and S.V II (seed vigour index II) varied from 725.99 in T_9 to 1315.49 in T_{10} and 506.90 in T_9 to 1201.82 in T_{10} respectively. In stress check, S.V I and S.V II reduced to 44.81% and 57.82% as compared to irrigated control respectively. Under drought, among different doses of foliar application of SA and KNO_3, 5% KNO_3 (T_8) showed minimum reduction with 11.05% and 75 ppm S.A (T4) with 5.90%, however maximum reduction in S.V I and S.V II as were observed in10 ppm S.A (T_1) with 34.32% and 10 ppm S.A (T_1) with 27.10% respectively as compared to irrigated control. Similar results were reported by Soni *et al.* (2021) in garden pea where, exogenous application of SA resulted in an increase of yield components. Exogenous application of SA at 150 mg L^{-1} as a foliar spray enhanced fruit yield by 41% compared with the control (Chakma *et al.*, 2021).

Application of KNO_3 also significantly increased yield parameters of tomato in accordance to control plots in water stress condition. Similar results were obtained in Tomato (Abdelaziz and Taha, 2018) where single foliar K application recorded the highest number of fruits with control under water stress treatment, that justifying the crucial role of K in fruit bearing in tomato.

Under water stress conditions, plants treated with KNO_3 showed higher relative chlorophyll content, leaf area, photosynthetic rate, stomatal conductance, transpiration, carboxylation efficiency and higher levels of P, K, Mg, S, Cu and Fe than those not treated with KNO_3 (Ávila *et al.,* 2022). These findings are in close conformity with earlier findings (Ali *et al.,* 2021) where they found that KNO_3, SiO_2 and SA

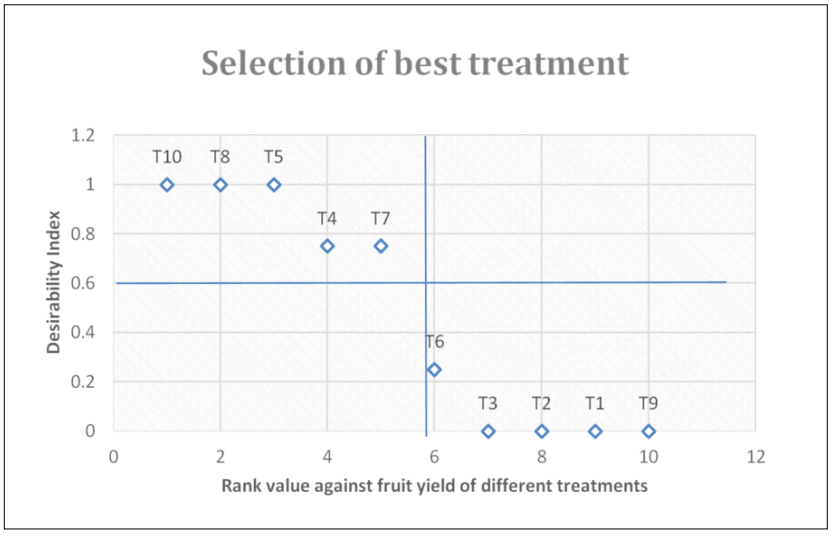


Fig 1: Scatter plot of rank value against fruit yield and desirability index of treatments under water stress condition.

priming substantially improved emergence percentage, emergence index, seedling growth, seedling biomass and vigour of FARO44 rice under drought. Application of SA in drought–stressed plants resulted in growth recovery, increased photosynthesis and reduced oxidative stress (Zulfiqar *et al.,* 2021 and Poór, 2020). The highest desirability index is found in case of T_8 (1.0), T_{10} (1.0) and T_5 (1.0) followed by T_4 (0.75). This result reveals that T_8 and T_5 was similar to stress free check followed by T_4 with respect to yield and quality parameters.

Selection of best treatment

For the selection of best treatment(s) two criteria were taken into consideration *i.e.* fruit yield and desirability index. The treatment having higher value in respect of these two parameters is considered as the best treatment. It was observed that T_5 (100 ppm S.A), T_8 (5% KNO_3), T_{10} (Stress Free Check) and T_4 (75 PPM S.A) present in quadrant I and belongs to one cluster. T_{10}, T_8 and T_5 have highest rank for fruit yield and desirability index (Fig 1). T_4 is present in quadrant I and have above average rank for fruit yield and desirability index. The treatments T_6 (1% KNO_3), T_3(50 ppm S.A), T_2(25 ppm S.A), T_1 (10 ppm S.A) and T_9 (stress check) are present in quadrant IV and have below average rank for fruit yield and desirability index. Therefore T_8 (5% KNO_3) and T_5 (100 ppm of salicylic acid) is selected as the best treatment and among T_8 and T_5, T_8 (5% KNO_3) is considered as the optimum dose to be sprayed under water stress condition to improve yield and quality parameters of tomato seeds.

The scatter plot quadrant analysis was done through MS-excel 2010. In this analysis four clusters have been formed based on X- axis and Y-axis from where we identify the best suited treatments for drought tolerant tomato cultivation.

CONCLUSION

It can be summed up that in water stress condition 5% KNO_3 showed significant result which was at par with 100 ppm SA with respect to growth, fruit and seed yield andyield attributing characters of tomato. Thus, investigations carried out on the studies on effect of foliar application of salicylic acid and KNO_3 on growth and yield of tomato (*Solanum lycopersicum* L.) under water stress condition revealed that foliar application of 5% KNO_3 at pre flowering and fruiting stage proved to be best among other treatments and significantly increased the growth and yield of tomato under deficit moisture content. The findings of this study justified the reliability of foliar spray, an easy and affordable technique to be adopted by farmers in dry regions of the world for improving growth, yield and yield attributing parameters under drought conditions.

Conflict of interest

All authors declared that there is no conflict of interest.

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