Impact of Salicylic acid and Potassium silicate in ameliorating the drought stress effect on sorghum (Sorghum bicolor L. Moench)

ABSTRACT

Aims: The present study highlights the impact of salicylic acid and potassium silicate in reducing the deleterious effect of drought stress on sorghum
Study design: Split plot design
Place and Duration of Study: Agricultural College Farm, Bapatla, Andhra Pradesh during *rabi*, 2023-24.
Methodology: The experiment consist of two main treatments i.e., water stress treatments viz., M1 (stress treatment i.e., moisture stress was imposed from vegetative to flowering (25-70 DAS) and M2 (No stress treatment) and eight sub treatments *viz*., No spray (S1), K-Silicate @50ppm at 35+45 DAS (S2), K-Silicate @100ppm at 35+45 DAS (S3), SA @150ppm at 35+45 DAS (S4), SA @200ppm at 35+45 DAS (S5), K-Silicate @50ppm + SA @200ppm at 35+45 DAS (S6), K-Silicate @100ppm + SA @200ppm at 35+45 DAS (S7) and K-Silicate @150ppm + SA @200ppm at 35+45 DAS (S8) replicated thrice. The plant samples were collected on 30, 50 and 70 DAS.
Results: The sorghum plants under water stress showed drastic reductions in chlorophyll content (54.9%), relative water content (34.1%) and increase in membrane injury index (1.9 folds), proline content (1.8 folds) and catalase activity (3.6 folds). The combined spray of potassium silicate @100ppm + SA @200ppm exhibited superior performance by enhancing the chlorophyll content by 59.1%, relative water content by 32.5, proline content by 26.1%, catalase activity by 30.4% and reducing membrane injury index by 28.9%.
Conclusion: It can be concluded that the foliar application of @100ppm + SA @200ppm at 35 + 45 DAS helped the sorghum plants from the negative effects of water stress from vegetative to flowering stages.

Keywords: Potassium silicate, salicylic acid, sorghum, drought stress

1. INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is a versatile crop belongs to Poaceae family. One of the five main cultivable species in the world is sorghum. Being a C4 crop, sorghum is an effective solar energy harvester with high biomass production, yielding capacity and drought tolerance. India is the fifth-largest producer of sorghum worldwide, with 4.4 million tonnes grown on 3.90 million hectares in 2022–2023 [10]. One of the abiotic stresses is drought, which has an impact on a plant's physiological traits, biochemical components, and crop productivity. The impacts of a water deficit can affect sorghum at its early vegetative stage as well as its reproductive stages (pre and post-flowering) [28], [12]. Salicylic acid (SA), an endogenous phenolic growth regulator produced *via* the phenylpropanoid pathway, is widespread across the plant kingdom. Salicylic acid (SA) modulates tolerance to a variety of abiotic threats by controlling the opening of stomatal pores and water relations, raising photosynthetic pigments and rubisco activity, and ultimately promoting photosynthesis and growth. SA protects plants from abiotic stresses by regulating vital physiological processes like photosynthesis, nitrogen metabolism, proline metabolism, glycine betaine synthesis, antioxidant defense system, and plant-water relations under stress [16].

2. MATERIAL AND METHODS

The field experiment was conducted in Agricultural College Farm, Bapatla, Andhra Pradesh. Sorghum variety CSV 29R was used in the experiment. The experiment was laid out in split plot design replicated thrice. The treatments comprised of two main plots *i.e.,* water stress treatments *viz.,* M_1 (stress treatment *i.e.,* moisture stress was imposed from vegetative to flowering (25-70 DAS) and M_2 (No stress treatment *i.e,* irrigation is given as per schedule), and eight sub treatments *viz.,* No spray (S_1), K-Silicate @ 50 ppm at (S_2), K-Silicate @ 100 ppm (S_3), SA @ 150 ppm (S_4), SA @ 200 ppm

(S_5), K-Silicate @ 50 ppm + SA @ 200 ppm (S_6), K-Silicate @ 100 ppm + SA @ 200 ppm (S_7) and K-Silicate @ 150 ppm + SA @ 200 ppm (S_8). All the foliar sprays were given at 35 and 45 DAS. The crop was provided with 80:40:40 NPK Kg ha^{-1} (N in two equal splits 50% basal and 50 % at 30-35 days after sowing. Other crop management practises were followed for proper maintenance of crop. A total rainfall of 267.3 mm in 7 rainy days was recorded during the crop growth period, however no rainfall was received after imposition of water stress *i.e,* vegetative to flowering (25-70 DAS). The soil moisture content was recorded at 15 days interval from sowing to maturity of crop (Table 1). The physiological and biochemical parameters *viz.,* chlorophyll content, relative water content, membrane injury index, proline content and catalase activity were recorded from 30 DAS at 20 days interval.

2.1 Estimation of chlorophyll content

Chlorophyll content in the leaves was estimated colorimetrically by dimethyl sulphoxide (DMSO) method of Hiscox and Stam, 1979 [9].The total chlorophyll was estimated and calculated using the formula (Arnon, 1949) [3]

mg total chlorophyll/g tissue = 20.2 (A645) + 8.02 (A663) $\times \frac{V}{1000 \times W}$ where, A = absorbance at specific wavelengths ,V = final volume of chlorophyll extract, W = fresh weigh of tissue extracted

2.2 Estimation of Membrane injury index

Membrane injury index was determined by the protocol described by Premchandra *et al.* (1990) [19]. Membrane injury index was calculated as % by using the following formula.

$$\text{Membrane injury index (\%)} = \frac{\text{conductivity at 45 °C}}{\text{conductivity at 100 °C}} \text{ x } 100$$

2.3 Estimation of Relative water content

Relative water content (RWC) of leaf discs was quantified according to Barrs and Weatherly (1962) [6]. The relative water content was estimated and expressed in percentage using the following formula.

$$\text{RWC (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \text{ x } 100$$

2.4 Estimation of Proline content

The proline content of leaves was estimated by following the method of Bates *et al.* (1973). Proline content was calculated by the formula of Bates *et al.* (1973) [7]

Proline (µg g^{-1} fresh weight) = $\frac{A520 \times 36.321 \times V}{Y \times W}$ where, A520= Absorbance at 520 nm

36.231 = Factor, V = Final volume of extract (mL), Y = Volume of aliquot taken (mL), W = Weight of the plant material (g)

2.5 Estimation of Catalase activity

The principle involved in the estimation of catalase activity is by measuring the depletion in hydrogen peroxide of the reaction mixture at 240 nm. The absorption decreases by time due to catalase activity.

Catalase (U. g^{-1}FW min^{-1}) = (Maximum absorbance – Minimum absorbance) × 60 × 2

Table 1. Data on soil moisture at different crop growth stages of sorghum during *rabi* 2023-2024

Moisture (%) at different depths	Sowing		15 DAS		30 DAS		45 DAS		60 DAS		75 DAS		90 DAS		105 DAS	
	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2
0-15 cm	27.89	28.24	28.78	26.42	22.42	26.78	19.42	27.89	16.52	26.87	27.89	28.78	26.42	25.98	23.67	22.89
15-30 cm	26.67	25.67	26.76	25.87	21.54	25.42	18.56	26.52	15.85	25.90	26.42	26.76	25.78	24.45	21.45	20.43

3. RESULTS AND DISCUSSION

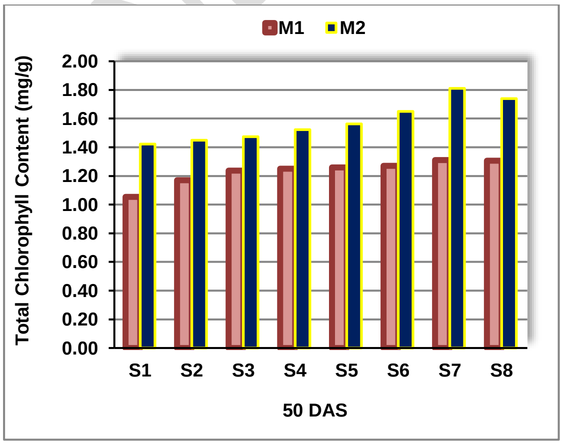
3.1 Chlorophyll content

Chlorophyll content gradually decreased in sorghum plants under water stress (Table 2 and Fig. 1). Sorghum plants under water stress recorded least chlorophyll content (M_1 - 1.18 mg g^{-1}) compared to control plants (M_2 - 2.57 mg g^{-1}) at 70 DAS. Same trend was recorded in sorghum [2] and maize [14]. Among the sub treatments, sorghum plants treated with K_2SiO_3 @ 100 ppm + SA @ 200 ppm (S_7) and K_2SiO_3 @ 150 ppm + SA @ 200 ppm at (S_8) recorded 27.9 and 22.4 per cent increase in chlorophyll content over the plants without spray (control) at 70 DAS. Among the interactions, at 70 DAS, under drought stress, K_2SiO_3 @ 100 ppm + SA @ 200 ppm recorded highest chlorophyll content (M_1S_7 - 1.40 mg g^{-1}) followed by K_2SiO_3 @ 150 ppm + SA @ 200 ppm (M_1S_8 -1.30 mg g^{-1}) and they were magnitude to 59.1 and 47.7 per cent increase respectively over the control which was recorded the least (M_1S_1- 0.88 mg g^{-1}). Similar results were obtained in sorghum [22]. Salicylic acid strengthens the antioxidant defense mechanism of cells and promotes the synthesis of new proteins, both of which protect the photosynthetic apparatus [4].

Table 2. Effect of Potassium Silicate and Salicylic acid on Chlorophyll content of Sorghum under water stress

Treatments	Chlorophyll Content (mg g^{-1})								
Sub treatments	30 DAS			50 DAS			70 DAS		
	M_1	M_2	Mean	M_1	M_2	Mean	M_1	M_2	Mean
S_1 :No spray (control)	1.22	1.25	1.24	1.05	1.42	1.24	0.88	2.42	1.65
S_2 :K_2SiO_3 @50ppm	1.23	1.28	1.26	1.15	1.45	1.30	0.97	2.43	1.70
S_3 :K_2SiO_3 @100ppm	1.27	1.24	1.26	1.24	1.47	1.36	1.14	2.47	1.81
S_4 :SA @150 ppm	1.24	1.30	1.27	1.25	1.52	1.39	1.23	2.50	1.87
S_5 :SA @200 ppm	1.26	1.27	1.27	1.26	1.56	1.41	1.22	2.56	1.89
S_6 :K_2SiO_3 @50 ppm + SA @200 ppm	1.25	1.27	1.26	1.27	1.65	1.46	1.30	2.64	1.97
S_7:K_2SiO_3@100ppm + SA @200 ppm	1.21	1.29	1.25	1.31	1.81	1.56	1.40	2.82	2.11
S_8 :K_2SiO_3@ 150ppm + SA @ 200 ppm	1.21	1.28	1.24	1.31	1.74	1.52	1.30	2.74	2.02
Mean	1.24	1.27		1.23	1.58		1.18	2.57	

	30 DAS			50 DAS			70 DAS		
	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction
SEm ±	0.01	0.02	0.03	0.01	0.26	0.04	0.02	0.03	0.05
CD(p=0.05)	NS	NS	NS	0.04	0.07	0.10	0.08	0.08	0.11
CV (%)	4.57	4.43		2.49	4.36		3.53	3.43	



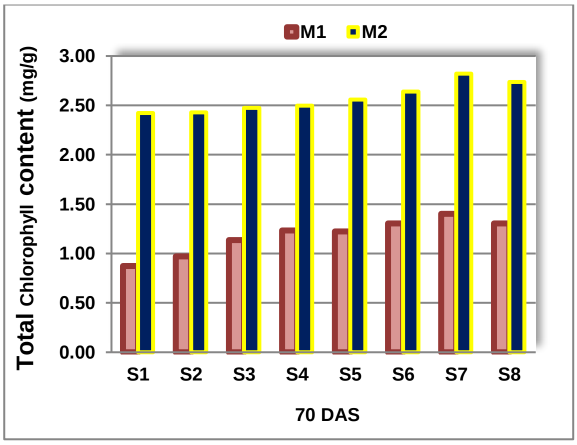


Fig. 1. Effect of Potassium Silicate and Salicylic acid on Chlorophyll Content (mg g^{-1}) of sorghum leaves under Drought stress

3.2 Membrane injury index

Plants under water stress had the highest MII (M_1 - 29.31 %), whereas the unstressed plants had the lowest MII (M_2 - 15.81%) (Table 3 anf Fig. 2). Stressed sorghum plants recorded 1.9 folds increase in MII at 70 DAS. Drought stress led to an increase in membrane injury index (Pooja *et al.,* 2019). Among the sub treatments, S_7 and S_8 recorded 22.8 and 20.4 percent reduction in MII over the plants with no spray at 70 DAS. Similar effect in sorghum when plants were treated with Salicylic acid [2]. Among the interactions, under drought conditions, treatments included, K_2SiO_3 @ 100 ppm + SA @ 200 ppm (M_1S_7 - 24.77 %) and K_2SiO_3 @ 150 ppm + SA @ 200 ppm (M_1S_8 -26.36 %) recorded lesser MII over the control (M_1S_1 -34.86 %). However, lowest MII was recorded by the unstressed plants sprayed with K_2SiO_3 @ 100 ppm + SA @ 200 ppm (M_2S_7-14.28%). %). Increasing the amount of salicylic acid in the system reduce oxidative stress brought on by the production of reactive oxygen species (ROS) during drought stress [8] and silicon application significantly reduced the membrane damage in soybean by preventing lipid peroxidation [25].

Table 3. Effect of K_2SiO_3 and SA on Membrane Injury Index of Sorghum under water stress

Treatments	Membrane Injury Index (%)								
Sub treatments	30 DAS			50 DAS			70 DAS		
	M_1	M_2	Mean	M_1	M_2	Mean	M_1	M_2	Mean
S_1 :No spray (control)	18.69	18.40	18.54	30.81	18.33	24.57	34.86	16.73	25.79
S_2 :K_2SiO_3 @50ppm	18.09	18.36	18.23	29.11	17.43	23.27	32.80	16.47	24.64
S_3 :K_2SiO_3 @100ppm	18.53	16.74	17.64	27.58	17.10	22.34	29.95	16.44	23.20
S_4 :SA @150 ppm	22.59	17.47	20.03	27.13	16.49	21.81	29.39	16.10	22.75
S_5 :SA @200 ppm	18.55	16.10	17.33	26.04	16.47	21.25	28.81	15.99	22.40
S_6 :K_2SiO_3 @50 ppm + SA @200 ppm	18.05	18.74	18.40	25.69	16.39	21.04	27.54	15.74	21.64
S_7:K_2SiO_3@100ppm + SA @200 ppm	19.36	17.83	18.59	22.75	15.15	18.95	24.77	14.28	19.53
S_8 :K_2SiO_3@ 150ppm + SA @ 200 ppm	18.69	16.85	17.77	24.22	16.18	20.20	26.36	14.70	20.53
Mean	19.07	17.56		26.67	16.69		29.31	15.81	

	30 DAS			50DAS			70 DAS		
	Main plots	**Sub plots**	**Interacti on**	**Main plots**	**Sub plots**	**Interacti on**	**Main plots**	**Sub plots**	**Interacti on**
SEm ±	0.37	0.70	1.00	0.32	0.50	0.71	0.28	0.57	0.81
CD (p=0.05)	NS	NS	NS	1.97	1.45	2.06	1.71	1.66	2.34
CV (%)	9.92	9.94		7.33	5.67		6.11	6.21	

3.3 Relative Water Content

The sorghum plants subjected to water stress recorded the lowest relative water content (M_1 - 58.45 %,), whereas the highest RWC was recorded in unstressed plants (M_2 - 88.63 %), there was 34.1 per cent reduction in RWC at 70 DAS over the control (unstressed plants) (Table 4 and Fig. 3). A decrease in the RWC in response to drought stress was observed in a wide range of plants, when leaves were exposed to dryness, they showed significant reductions in RWC [17]. Among the sub treatments, at 50 and 70 DAS, the plants which were sprayed with K_2SiO_3 @ 100 ppm + SA @ 200 ppm recorded the highest RWC (S_7 -82.48 and 78.43 %, respectively), followed by K_2SiO_3@ 150 ppm + SA @ 200 ppm (S_8 - 80.64 and 77.20 %, respectively). Among the interactions, under drought conditions, at 50 DAS, the highest RWC was observed in plants sprayed with K_2SiO_3 @ 100 ppm + SA @ 200 ppm (M_1S_7 -74.50 %), followed by the K_2SiO_3 @ 150 ppm + SA @ 200 ppm (M_1S_8 -71.71 %), and the lowest RWC was recorded in control (M_1S_1- 56.22 %), which was 32.5 and 27.6 per cent increase in relative water content over the stressed plants without spray (control). The exogenous application of SA might control stomatal openings and minimize transpirational water loss, allowing the plants to retain turgor, sustain photosynthesis, and remain productive [20]. When silica polymerizes, the stomata's walls lost some of their elasticity, which made them more likely to stay closed [22].

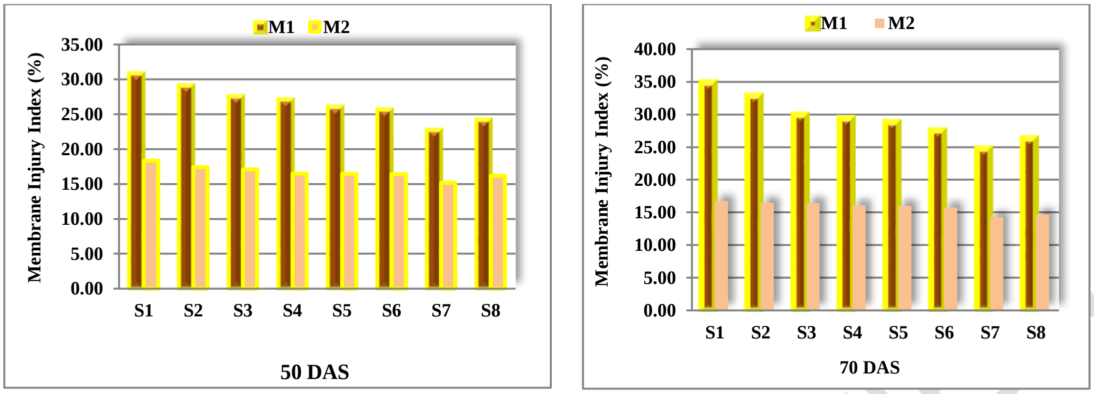


Fig. 2. Effect of Potassium Silicate and Salicylic acid on Membrane Injury Index (MII) (%) of sorghum under Drought stress

Table 4. Effect of Potassium Silicate and Salicylic acid on Relative water content of Sorghum under water stress

Treatments	Relative Water Content (%)								
Sub treatments	30 DAS			50 DAS			70 DAS		
	M_1	M_2	Mean	M_1	M_2	Mean	M_1	M_2	Mean
S_1 :No spray (control)	86.06	86.37	86.22	56.22	84.04	70.13	52.00	86.71	69.35
S_2:K_2SiO_3@50ppm	82.72	87.47	85.10	58.73	84.73	71.73	53.07	87.44	70.26
S_3:K_2SiO_3@100ppm	81.39	87.11	84.25	63.51	85.61	74.56	57.14	87.77	72.46
S_4 :SA @150 ppm	81.72	87.47	84.60	65.33	86.80	76.07	57.38	87.81	72.60
S_5 :SA @200 ppm	86.06	86.06	86.06	66.98	87.77	77.38	58.56	88.44	73.50
S_6 :K_2SiO_3 @50 ppm + SA @200 ppm	84.72	87.28	86.00	67.75	88.14	77.95	60.41	88.61	74.51
S_7:K_2SiO_3@100ppm + SA @200 ppm	86.06	88.08	87.07	74.50	90.46	82.48	65.41	91.46	78.43
S_8 :K_2SiO_3@150ppm + SA @ 200 ppm	86.06	86.13	86.09	71.71	89.57	80.64	63.60	90.79	77.20
Mean	84.35	87.00		65.59	87.14		58.45	88.63	

	30 DAS			50DAS			70 DAS		
	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction
SEm ±	0.62	1.08	1.53	0.80	1.16	1.64	0.79	0.98	1.39
CD (p=0.05)	NS	NS	NS	4.87	3.36	4.75	4.81	2.85	4.03
CV (%)	3.57	3.13		5.13	3.72		5.27	3.28	

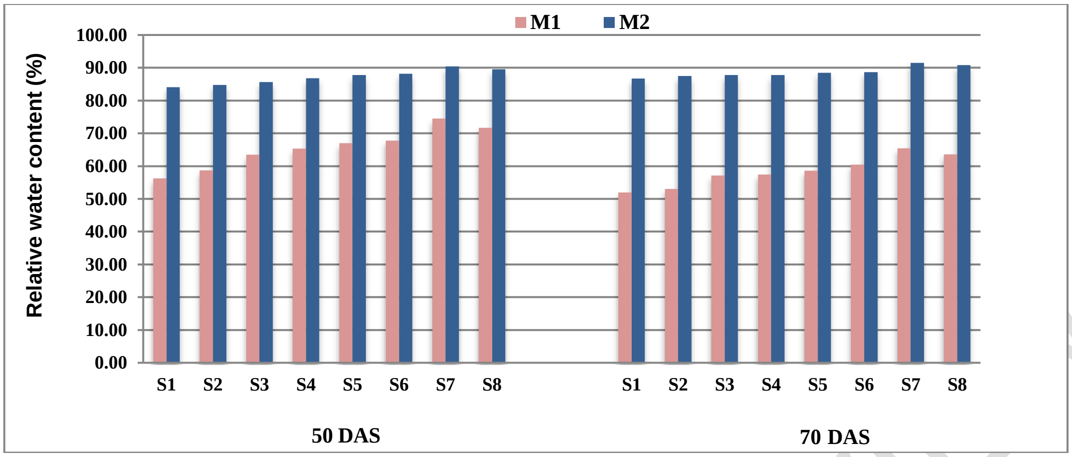


Fig 3. Effect of Potassium Silicate and Salicylic acid on Relative water Content (RWC) (%) of sorghum under Drought stress

3.4 Proline content

Stressed plants recorded the maximum proline content (M_1 - 448.28 µg g^{-1} fr. wt.), whereas unstressed plants recorded the minimum proline content (M_2 -251.41 µg g^{-1} fr. wt.) (Table 5 and Fig. 4). In the current study, stressed plants recorded 1.8 folds increase in proline content compared to the unstressed plants (irrigated) at 70 DAS. Similar results were obtained in sorghum [24]. Among the sub treatments, at 50 DAS, the highest proline content was recorded in plants sprayed with K_2SiO_3 @ 100 ppm + SA @ 200 ppm (S_7 -334.82 µg g^{-1} fr.wt.), followed by K_2SiO_3 @ 150 ppm + SA @ 200 ppm (S_{8}- 325.69 µg g^{-1} fr. wt.). Similar trend was obtained at 70 DAS also. Among the interactions, at 70 DAS, highest proline content was recorded by the stressed plants sprayed with K_2SiO_3 @ 100 ppm + SA @200 ppm (M_1S_7 - 495.65 µg g^{-1}fr.wt.), followed by the stressed sprayed with K_2SiO_3 @ 150 ppm + SA @ 200 ppm (M_1S_8 **-**484.45 µg g^{-1}fr.wt.) over the plants with no spray (M_1S_1- 393.00 µg g^{-1}fr.wt), however minimum proline content was recorded by the unstressed plants (irrigated) with no spray (M_2S_1 - 228.53 µg g^{-1}fr.wt.). Sorghum plants treated with M_1S_7 and M_1S_8 recorded 26.1 and 23.3 per cent increase in proline content over the unsprayed control plants (M_1S_1). Exogenous application of SA enhances proline content [23]. The increased proline levels caused by silicon change plant hormones and osmolytes, allowing plants to continue growing even when stressed by dryness [21].

3.5 Catalase Activity

At 50 and 70 DAS, sorghum plants which were subjected to water stress recorded the highest catalase activity (M_1- 45.46 and 91.61 U. g^{-1} FW min^{-1}, respectively) compared to plants which were not under water stress recorded the lowest catalase activity in leaves (M_2 - 19.91 and 25.68 U. g^{-1} FW min^{-1}, respectively) (Table 6anf Fig. 5). Sorghum plants subjected to water stress recorded 3.6 folds increase in catalase activity over the plants without stress. The increase in catalase activity in leaves under drought stress [5]. Among the sub treatments, sorghum plants treated with K_2SiO_3 @ 150 ppm + SA @ 200 ppm recorded 31.2 and 21.3 per cent and K_2SiO_3 @ 100 ppm + SA @ 200 ppm recorded 22.0 and 17.8 per cent increase in catalase activity over unsprayed control plants at 50 and 70 DAS, respectively. Among the interactions, at 50 DAS, under drought conditions, higher catalase activity was recorded by the stressed plants

Table 5. Effect of Potassium Silicate and Salicylic acid on Proline content of Sorghum under water stress

Treatments	Proline Content (µg g^{-1}fr.wt.)								
Sub treatments	30 DAS			50 DAS			70 DAS		
	M_1	M_2	Mean	M_1	M_2	Mean	M_1	M_2	Mean
S_1 :No spray (control)	235.64	227.86	231.75	315.33	227.86	271.60	393.00	228.53	310.76
S_2:K_2SiO_3@50ppm	226.80	219.77	223.29	322.00	231.44	276.72	411.22	233.11	322.16
S_3:K_2SiO_3@100ppm	233.32	216.22	224.77	347.33	250.19	298.76	438.28	249.89	344.08
S_4 :SA @150 ppm	239.60	236.80	238.20	351.67	254.46	303.07	443.10	254.46	348.78
S_5 :SA @200 ppm	237.42	232.26	234.84	354.67	255.60	305.13	453.44	255.60	354.52
S_6 :K_2SiO_3 @50ppm + SA @200 ppm	259.65	233.38	246.51	361.67	257.74	309.71	467.14	258.04	362.59
S_7:K_2SiO_3@100ppm + SA @200 ppm	229.21	229.94	229.57	398.67	270.97	334.82	495.65	271.61	383.63
S_8:K_2SiO_3@150ppm + SA @ 200 ppm	248.05	237.38	242.72	386.00	265.38	325.69	484.45	260.05	372.25
Mean	238.71	229.20		354.67	251.71		448.28	251.41	

	30 DAS			50 DAS			70 DAS		
	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction
SEm ±	6.08	8.20	11.60	1.92	3.80	5.37	1.63	5.19	7.34
CD(p=0.05)	NS	NS	NS	11.66	11.01	15.57	9.94	15.03	21.25
CV (%)	12.73	8.59		3.10	3.07		2.29	3.63	

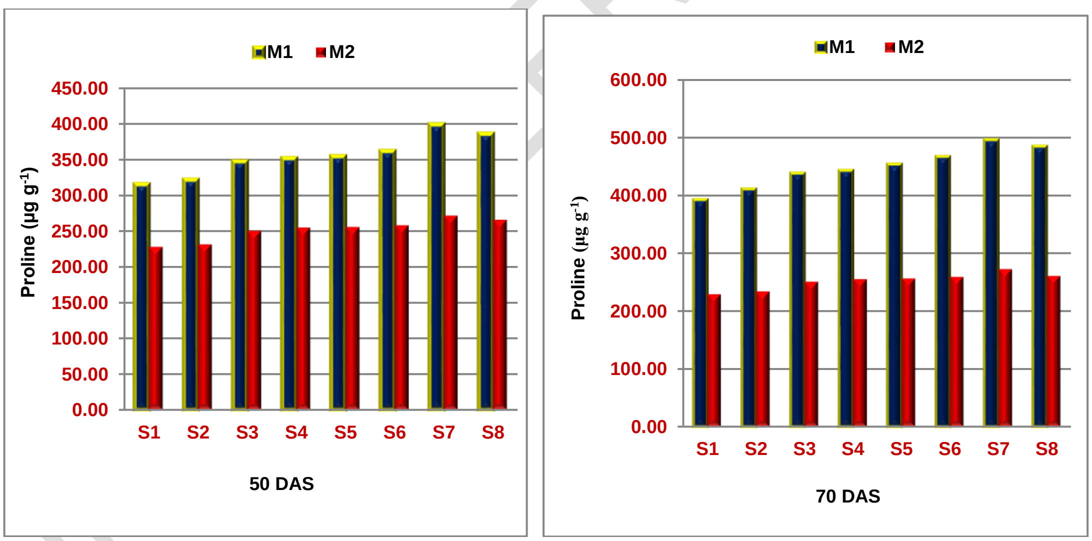


Fig 4. Effect of Potassium Silicate and Salicylic acid on Proline content (µg g^{-1} fr.wt.) of sorghum under Drought stress

sprayed with K_2SiO_3 @ 150 ppm + SA @ 200 ppm (M_1S_7 - 51.46 U. g^{-1} FW min^{-1}), followed by K_2SiO_3 @ 100 ppm + SA @ 200 ppm (M_1S_8 - 49.63 U. g^{-1} FW min^{-1}) compared to the plants with no spray (M_1S_1- 39.46 U. g^{-1} FW min^{-1}), indicated that treatment M_1S_7 and M_1S_8

recorded 30.4 and 25.8 per cent increase in catalase activity over the plants with no spray (M_1S_1 - control). The lowest catalase activity was recorded by the unstressed plants (irrigated) with no spray (M_2S_1 -17.79 U. g^{-1} FW min^{-1}). Silicon enhances the activity of antioxidant enzymes in plants, detoxifying ROS damage triggered by drought stress. Application of external osmoprotectant and the antioxidative activity of several enzymes under various abiotic stress situations [26]. SA helps to mitigate oxidative stress by encouraging the production of protective chemicals [15].

Table 6. Effect of Potassium Silicate and Salicylic acid on Catalase Activity of Sorghum under water stress

Treatments	Catalase Activity (U. g^{-1}FW min^{-1})								
Sub treatments	30 DAS			50 DAS			70 DAS		
	M_1	M_2	Mean	M_1	M_2	Mean	M_1	M_2	Mean
S_1 :No spray (control)	21.66	21.43	21.54	39.46	17.79	28.63	83.79	21.92	52.86
S_2:K_2SiO_3@50ppm	22.96	23.23	23.10	39.79	17.82	28.81	86.46	22.46	54.46
S_3:K_2SiO_3@100ppm	23.86	22.46	23.16	44.12	19.92	32.02	89.82	24.59	57.21
S_4 :SA @150 ppm	26.93	20.46	23.69	45.13	19.92	32.52	91.13	25.55	58.34
S_5 :SA @200 ppm	20.33	21.03	20.68	46.26	19.92	33.09	92.15	26.37	59.26
S_6 :K_2SiO_3 @50ppm + SA @200 ppm	22.46	21.09	21.78	47.86	19.97	33.92	93.23	27.32	60.28
S_7:K_2SiO_3@100ppm + SA @200 ppm	19.46	19.09	19.28	51.46	23.66	37.56	99.13	29.15	64.14
S_8:K_2SiO_3@150ppm + SA @ 200 ppm	21.45	20.46	20.96	49.63	20.25	34.94	97.14	28.06	62.60
Mean	22.39	21.16		45.46	19.91		91.61	25.68	

	30 DAS			50 DAS			70 DAS		
	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction
SEm ±	0.32	1.30	1.84	0.36	0.92	1.30	0.49	1.30	1.84
CD(p=0.05)	NS	NS	NS	2.16	2.66	3.76	2.99	3.76	NS
CV (%)	7.09	14.67		5.33	6.88		4.11	5.43	

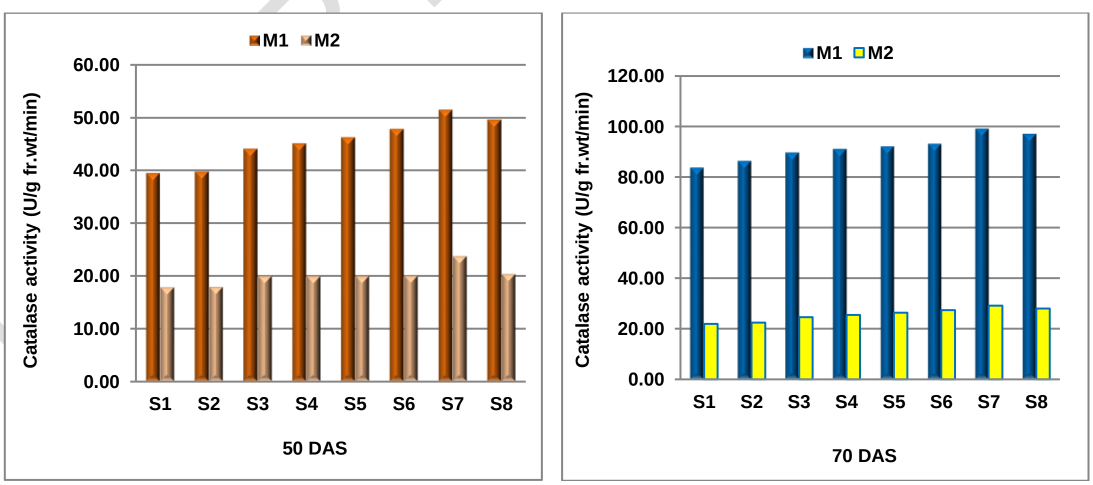


Fig 5. Effect of Potassium Silicate and Salicylic acid on Catalase Activity (U. g^{-1}FW min^{-1}) of sorghum leaves under Drought stress

4. CONCLUSION

In the current study, sorghum plants subjected to water stress from vegetative to flowering showed reductions in cholorophyll content, relative water content. This led to reduction in plant growth and metabolism. Drought stress also led to increase in membrane injury index, osmolyte accumulation like proline as well as antioxidant enzyme such as catalase. Among the various sprays, K_2SiO_3 @ 100 ppm + SA @ 200ppm at 35+45 DAS and K_2SiO_3 @ 150 ppm + SA @ 200 ppm at 35+45 DAS were the most effective foliar spray that enhanced the physiological characteristics such as chlorophyll content and relative water content and reduced membrane injury index. Apart from this, these sprays also enhanced the biochemical parameters such as proline content and catalase activity.

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Details of the AI usage are given below:
1.
2.
3.

REFERENCES

1. Ahmed M, Hassen FU, Qadeer U, Aslam MA. Silicon application and drought tolerance mechanism of sorghum. African Journal of Agricultural Research. 2011; 6 (3): 594-607.
2. Arivalagan M, Somasundaram R. Induction of drought stress tolerance by propiconazole and salicylic acid in *Sorghum bicolor* is mediated by enhanced osmoregulation, compatible solutes and biochemical accumulation. Journal of Advances in Applied Research. 2016; (1): 41-52.
3. Arnon DI. Copper enzymes in isolated chloroplasts. Polyphenol oxidase in *Beta vulgaris*. Plant Physiology. 1979;24: 1-15.
4. Avancini G, Abreu IN, Saldana, MDA, Mohamed RS, Mazzafera P. Induction of pilocarpine formation in jaborandi leaves by salicylic acid and methyljasmonate. Phytochemistry. 2003;63:171-175.
5. Aziz HA, Sharaf M, Omar M, El-Yazied AA, AlJwaizea NI, Ismail S, Omar MM, Alharbi K, Elkelish A, Tawfik M. Improvement of selected morphological, physiological, and biochemical parameters of banana (*Musa acuminata* L.) using potassium silicate under drought stress condition grown in vitro. Phyton-International Journal of Experimental Botany. 2023.
6. Barrs HD, Weatherley PE. A re-examination of the relative turgidity techniques for estimating water deficits in leaves. Australian Journal of Biological Sciences. 1962;15: 413-428.
7. Bates S, Waldren RP, Teare ID. Rapid determination of the free proline in water stress studies. Plant and Soil. 1973;39: 205-208.

8. Eyidogan F, Oz MT, Yucel M, Oktem HA. Signal transduction of phytohormones under abiotic stresses. Phytohormones and Abiotic Stresses Tolerance in Plants. Springer. 2012;1-48.
9. Hiscox D, Stam JGF. A method for the extraction of chlorophyll from leaf tissue without maceration. Canadian Journal of Botany. 1979;57: 1332-1334.
10. https://fas.usda.gov/data/production/commodity/0459200
11. Kebede H, Subudhi PK, Rosenow DT, Nguyen HT. Quantitative trait loci influencing drought tolerance in grain sorghum (*Sorghum bicolor* L. Moench). Theoritical and Applied Genetics. 2001;103: 266–276.
12. Ma JF, Yamaji N. Silicon uptake and accumulation in higher plants. Trends in Plant Science. 2006;11: 392-397.
13. Manzoor K, Ilyas N, Batool N, Ahmad B, Arshad M. Effect of Salicylic Acid on the Growth and Physiological Characteristics of Maize under Stress Conditions. *Journal of the Chemical Society of Pakistan*. 2015;37 (3).
14. Meenakshi M, Prakash. Impact of foliar application of salicylic acid on growth and lipid peroxidation in water stress tolerance of *Glycine max* (L.) Merrill. International Journal of Bioassays. 2013; 3 (01): 1721-1728.
15. Miura K, Tada Y.Regulation of water, salinity and cold stress responses by salicylic acid. Frontiers in Plant Science. 2014; 5:4
16. Nayyar H, Gupta D. Differential sensitivity of C3 and C4 plants to water deficit stress: association with oxidative stress and antioxidants. Environmental and Experimental Botany. 2006;58: 106–113.
17. Pooja NAS, Chand M, Singh K, Mishra AK, Kumar A, Kumari A, Rani B. Varietal variation in physiological and biochemical attributes of sugarcane varieties under diferent soil moisture regimes. Indian Journal of Experimantal Biology. 2019;57: 721–732.
18. Premchandra GS, Saneoka H, Ogata S. Cell membrane stability index, as an indicator of drought tolerance as affected by applied nitrogen in soyabean. Journal of Agricultural Sciences. 1990;115: 63-66.
19. Rao SR, Qayyum A, Razzaq A, Ahmad M, Mahmood I, Sher A. Role of foliar application of salicylic acid and L-tryptophan in drought tolerance of maize. Journal of Animal and Plant Sciences. 2012;22 (3): 768-772.
20. Rizwan M, Ali S, Ibrahim M, Farid M, Adrees M, Bharwana SA, Zia-ur-Rehman M, Qayyum MF, Abbas F. Mechanisms of silicon-mediated alleviation of drought and salt stress in plants: A review. Environmental Science and Pollution Research. 2015;22: 15416–15431.
21. Saad M, Abo-Koura HA. Improvement of sorghum (*Sorghum bicolor* L. Moench) growth and yield under drought stress by inoculation with Bacillus cereus and foliar application of potassium silicate. Environment, Biodiversity and Soil Security. 2018;2: 205-221.
22. Sayyari M, Ghavami M, Ghanbari F, Kordi S. Assessment of salicylic acid impacts on growth rate and some physiological parameters of lettuce plants under drought stress conditions. International Journal of Agriculture and Crop Sciences. 2013;5 (17): 1951-1957.
23. Shaikh RS, Bharud RW, Deshmukh DV. Proline, glycine, betaine and dry matter accumulation in *rabi* sorghum under moisture stress. Madras Agricultural Journal. 2015;102 (10-12): 336-343.
24. Shen X, Zhou Y, Duan L, Li Z, Eneji AE and Li J. Silicon effects on photosynthesis and antioxidant parameters of soybean seedlings under drought and ultraviolet-B radiation. Journal of plant physiology. 2010;167 (15): 1248-1252.
25. Sivanesan I, Jeong BR. Silicon promotes adventitious shoot regeneration and enhances salinity tolerance of *Ajuga multiflora* Bunge by altering activity of antioxidant enzyme. The Scientific World Journal. 2014;1: 521703.

26. Tarabih ME, El-Eryan EE, El-Metwally MA. Physiological and pathological impacts of potassium silicate on storability of Anna apple fruits. American Journal of Plant Physiology. 2014;9 (2): 52-67.
27. Tuinstra MR, Grote EM, Goldsbrough PB, Ejeta G. Genetic analysis of post-flowering drought tolerance and components of grain development in *Sorghum bicolor* (L.). Moench. Molecular Breeding. 1997;3: 439-448.