



Effect of Growth Regulating Compounds for Mitigating Moisture Stress in Transplanted Rice

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ABSTRACT

Background: To assess the impact of growth-regulating compounds on the root traits, nutrient uptake and yield of transplanted rice under moisture stress conditions, a field trial was conducted at the Wetland farm of SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu, Tamil Nadu, India during the *Sornavari* (Apri-Aug) season 2024.

Methods: Field experiment was laid out in split-plot design with three replications. The treatments are foliar application growth regulators and induced moisture stress viz., Moisture stress free control (conventional irrigation), where the field was irrigated with a 5 cm depth of water one day after the earlier ponded water had evaporated (M₁), moisture stress at panicle initiation stage (M₂) and moisture stress at flowering stage (M₃) in main plots and foliar application of growth regulating compounds in sub-plots, potassium silicate @ 1% (S₂), seaweed extract @ 2% (S₃), brassinolide @ 0.04% (S₄) and control without foliar application of growth regulating compounds (S₁).

Result: The moisture stress at panicle initiation stage significantly reduced all the growth and physiological parameters, including rice yield, when compared to the flowering stage. Based on the results, it could be concluded that when the crop suffered moisture stress during any critical stages, spraying one per cent potassium silicate was effective in mitigating moisture stress in order to attain the higher grain yields in rice and increased income for economic viability.

Key words: Brassinolide, Flowering stages, Growth regulating compounds, Moisture stress, Panicle initiation stages, Potassium silicate, Seaweed extract.

INTRODUCTION

Rice, or the “wonder cereal” (*Oryza sativa* L.), is grown with fluctuating productivity in a range of ecological zones. Rice is a staple food for approximately half of the world's population. India is the second-largest rice producer in the world by area, after China. Rice is grown on 44.1 million hectares in India, accounting for 105.5 million tonnes of production per year. In Tamil Nadu 2.3 million hectares is under rice cultivation and the production was about 74 lakh tonnes (Indiastat, 2022). Moisture stress has a serious impact on rice growth and development, causing changes at the morphological, physiological, biochemical and molecular levels. Decline in plant height, root length, leaf number, leaf length, leaf breadth and number of tillers as well as total dry matter are all symptoms of a reduction in growth and development of plants brought about by drought. It reduces the viability of pollen, resulting in fewer grains and ultimately declines the grain yield.

The integration of plant responses to stress was significantly aided by plant growth regulators (PGRs) (Amzallag *et al.*, 1990 and Ashraf *et al.*, 2025). Chemicals known as plant growth regulators change how plants grow by either stimulating or suppressing elements of the natural growth control system when applied in small quantities. Growth regulators, which change canopy structure and show up as yield, include growth promoters and growth inhibitors. By closure of stomata, growth regulators may enhance water use. Besides, they affect the soil and root system above the biomass, affecting the accumulation of

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antioxi-dants that protect the plants from stress. Based on the above-mentioned statement, the present study was carried out to evaluate the efficacy of growth-regulating compounds in mitigating the impact of induced moisture stress in transplanted rice. The study also sought to examine the physiological and biochemical traits of rice under moisture stress at different phenological stages.

MATERIALS AND METHODS

The field experiment was conducted at the Wetland Farm of SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu, Tamil Nadu, India during the *Sornavari* (Apri-Aug) season 2024. The experimental fields are 426.7 meters above mean sea level in the North Eastern agro climatic zone of Tamil Nadu, with latitudes 11°N and

longitudes 77°E. During cropping period, the meteorological conditions were recorded in the standard weeks of 12th to 27th. Six rainy days accounted for a total of 540.7 mm of rain. The mean maximum and minimum temperature were 28.13°C and 25.57°C, respectively. The mean relative humidity (RH) ranged from 42.68% (14.14 hrs) to 85.04% (7.14 hrs). Mean sunshine hours was 5.49 respectively. The short duration rice variety CO 55 was used as test material. Field experiment was laid out in split-plot design with three replications. All the cultural practices for rice were followed as per the recommendations of CPG (2020).

Treatments details

Main Plot: Moisture stress induced at critical growth stages

- M₁:** Moisture stress free control (conventional Irrigation).
M₂: Moisture stress at the panicle Initiation stage (30 to 40 DAT).
M₃: Moisture stress at the flowering stage (55 to 65 DAT).
 (Note: Moisture stress is imposed by withholding irrigation for 10 days and re-flooding on the plots after the moisture stress periods).

Sub plot: Growth regulating compounds

- S₁:** Control (No spray).
S₂: Foliar spray of potassium silicate @ 1%.
S₃: Foliar spray of seaweed extract @ 2%.
S₄: Foliar spray of brassinolide @ 0.04%.

Conventional method of irrigation

Irrigation was provided up to a depth of 5 cm one day after the previously ponded water disappeared and this continued until ten days prior to harvest. A wooden peg was inserted into each plot to indicate the depth of standing water while maintaining a 5 cm level. A “water meter” that was positioned at the head of the experimental field was used to regulate the amount of water that was irrigated during each irrigation.

Imposition of moisture stress

Water was completely withdrawn from the respective treatment plots to impose moisture stress in two phases: the first at panicle initiation (30 to 40 DAT) and the second at flowering stage (55 to 65 DAT) (Fig 2). In order to prevent seepage of water, a 30-mm-high polythene sheet was used on every plot's four boundaries (Fig 1 and 2). After the intervals of moisture stress, the plots were irrigated again (Fig 1).

Time of foliar application to alleviate moisture stress

Foliar spray given at one day after the stress was imposed in the critical growth stages, the growth-regulating chemical compounds were dissolved in water according to their concentration requirements and sprayed at a rate of 500 litres per hectare in the panicle initiation and flowering stages.

Observations recorded

Crop growth parameters (plant height, total number of tillers, DMP, LAI and CGR), physiological and biochemical



Fig 1: Inserting polythene sheets on the plots to prevent water seepage.



Fig 2: Moisture stress imposition at panicle initiation and flowering stage.

parameters Chlorophyll index (Peng *et al.*, 1996), RLWC (Barrs and Weatherley, 1962), Proline content (Bates *et al.*, 1973), Soluble protein (Lowry *et al.*, 1950) and Catalase activity (Gopalachari, 1963) and grain yield of rice under various moisture stress treatments and foliar application of growth regulating compounds were studied.

RESULTS AND DISCUSSION

Growth attributes

At the panicle initiation stage, plant growth regulators and moisture stress were imposed; before that, all agronomic procedures were similar for all treatment. Therefore, there is no significant difference in the effects of foliar spray and moisture stress treatments on rice development during active tillering and panicle initiation. When there is no moisture stress (conventional irrigation), taller plants were observed during the flowering and harvesting periods (Fig 3).

If irrigation was applied a day after the ponded water at a depth of 5 cm disappeared, the height of the rice plants increased. In the absence of moisture stress, the crop may have increased meristematic cell activity and cell elongation, which would have increased the stem's growth rate and, consequently, the rice plant's height (Chowdhury *et al.*, 2014). When moisture stress at the panicle initiation stage, shorter plant heights were noted. According to Thangaraj *et al.* (1998), applying moisture stress to rice at any stage of growth before anthesis drastically decreased plant height. When it came to the foliar application of growth-regulating substances, 1% potassium silicate spraying was comparable to 2% seaweed extract in terms of increasing plant height. This may be explained by the fact that silicon encourages upright leaves, which raises photosynthetic capability and raises plant height. Mrudhula and Krishna, (2020) found similar outcomes while growing rice in saline soil.

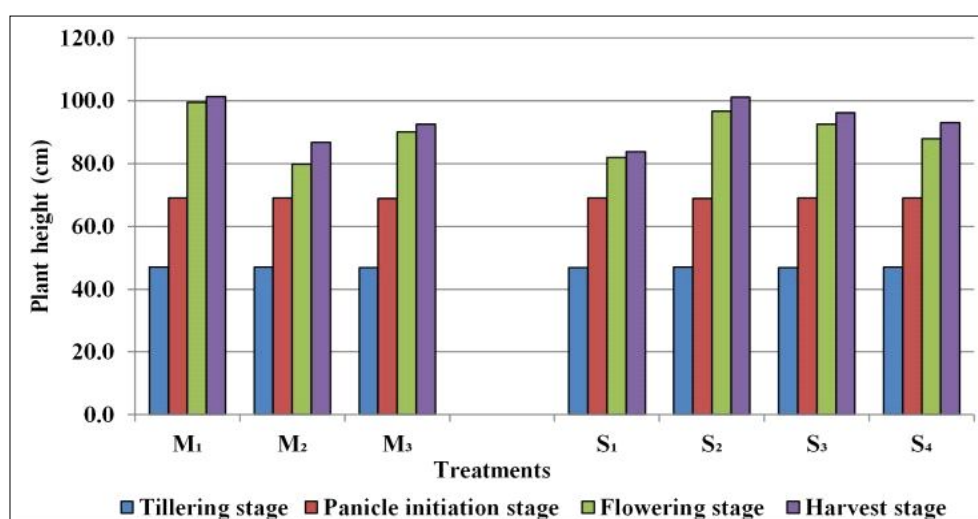


Fig 3: Effect of moisture stress and growth regulating compounds on plant height (cm) at different growth stages of rice.

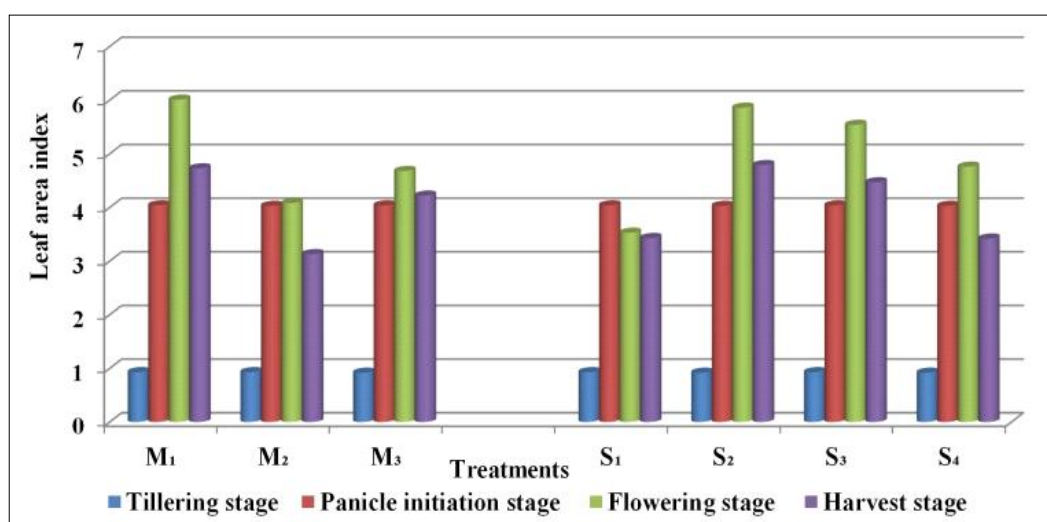


Fig 4: Effect of moisture stress and growth regulating compounds on leaf area index at different growth stages of rice.

The highest number of tillers per hill⁻¹ was observed in moisture stress-free control (conventional irrigation) among the different moisture stress treatments. This was followed by moisture stress during the flowering stage. This could be due to adequate aeration, which promoted greater nutrient uptake and higher plant growth and tiller formation by facilitating the absorption of more nutrients. These findings align with those of Hameed *et al.* (2011). At the flowering and harvest stages, a 1% potassium silicate foliar spray resulted in a significantly higher number of tillers hill⁻¹ in terms of growth-regulating compounds. It was comparable to 2% seaweed extract foliar spray. This might have led to more cell division activity, which improves plant establishment and tillers formation. Plants with silicon deposits have more upright leaves. Silicon has a synergistic effect with other nutrients, making the nutrients available to the plant. These findings are consistent with those of (Punniyamoorthi, *et al.*, 2024). In the current study, the total number of tillers generally reduced where moisture stress was imposed. However, it is possible to overcome this with proper supplementation of stress management strategies. This was also in agreement with the findings of Vijayalakshmi and Nagarajan (1994).

The moisture stress-free control group showed the highest Leaf Area Index (LAI) among the different moisture stress treatments (Fig 4). Several factors could contribute to the higher LAI under one day after disappearance (DAD) of ponded water at a 5 cm depth of rice irrigation, including increased nutrient uptake, favourable moisture regimes, delayed leaf senescence and a greater photosynthetic rate. Moisture stress during the panicle initiation stage resulted in lower LAI. This might be due to a loss of cell turgor, leading to reduced cell enlargement and less transport of assimilates from the leaves to the developing sink. The decrease in LAI during the panicle initiation stage was caused by a rapid decline in leaf elongation combined with increased leaf senescence, as found by Lilley and Fukai

(1994). Regarding foliar growth regulator application, spraying 1% potassium silicate increased LAI, which was comparable to 2% seaweed extract. This could be attributed to their beneficial role in cell division and elongation, resulting in increased LAI (Li *et al.*, 2008). The combination of 1% potassium silicate and moisture stress-free control resulted in a higher LAI. A moisture stress-free control using 2% seaweed extract was the next highest. Maintaining elevated LAI was positively impacted by potassium silicate application, especially in stressful conditions. At the panicle initiation stage, lower LAI was observed under moisture stress in addition to the control (no spray).

DMP increased steadily with each growth stage and peaked at harvest. Without moisture stress (conventional irrigation), there was increased DMP (Fig 5). Dry matter accumulation could have increased because of sufficient nutrient availability and a larger photosynthetic surface area, leading to rapid accumulation. These findings align with those of Hameed *et al.* (2011). Decreased DMP was observed with moisture stress at panicle initiation stage, likely because poor moisture availability affects photosynthetic rate, water and nutrient uptake and photo assimilate transport. Lower dry matter production was a result of moisture stress inhibiting plant growth, leaf number, leaf size and tillers (Ashraf and Ragavan, 2019). Increased DMP was recorded with foliar application of one percent potassium silicate and two percent seaweed extract under moisture stress. This might be because Silicon (Si) promotes growth, strengthens rice culms and increases resistance and photosynthesis. Similar findings were reported by Ashraf *et al.* (2024). At harvest, there was a significant interaction between moisture stress and foliar spraying of growth-regulating chemicals. DMP increased when combining moisture stress-free control (standard irrigation) with 1% potassium silicate spraying and then with moisture stress-free control plus 2% seaweed extract.

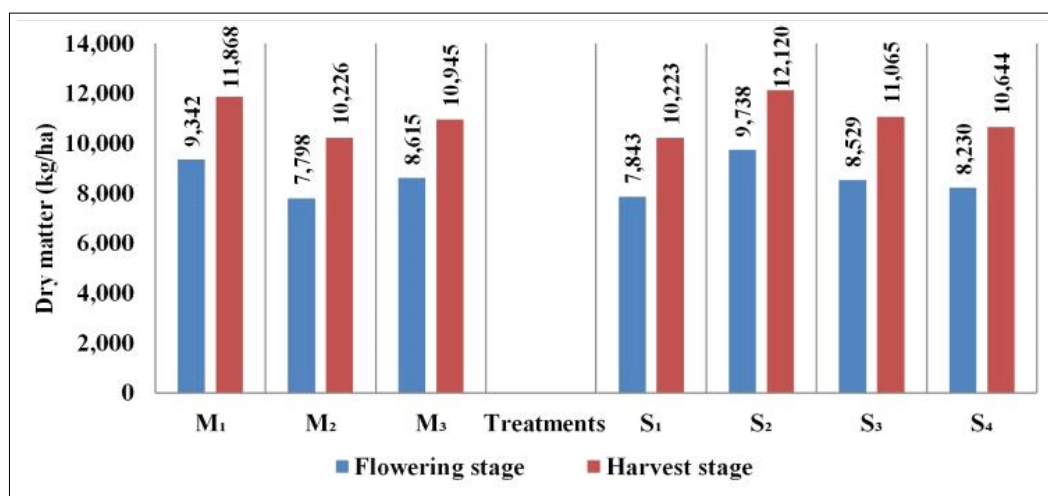


Fig 5: Effect of moisture stress and growth regulating compounds on dry matter production (kg ha⁻¹) at different growth stages of rice.

Physiological and biochemical parameters

Chlorophyll index

The total chlorophyll content of the plant influenced its photosynthetic rate, which in turn affected biomass production and yield. Stress-induced reduction in leaf chlorophyll content could be attributed to reduced biosynthesis or accelerated pigment degradation. The plants were not under moisture stress, showed a higher chlorophyll index (SPAD). The reduced chlorophyll index during moisture at panicle initiation stage was tabulated in Table 1. According to the finding of Jahan *et al.* (2014), moisture stress decreased the amount of chlorophyll in leaves, which suppressed crop output by reducing CO₂ assimilation. The levels of chlorophyll 'a', chlorophyll 'b' and total chlorophyll were significantly reduced by moisture stress. Conversely, under moisture stress conditions, there would be degradation in pigment composition, which induced a decrease in chlorophyll content (Khairi *et al.*, 2015). Among the foliar applications of growth-regulating compounds, increased chlorophyll index (SPAD) was observed with one percent potassium silicate, followed by seaweed extract at 2%. This might be due to the improvement in chlorophyll content. Various studies indicated that plant growth regulators increased the chlorophyll content when under moisture stress.

Relative leaf water content

One of the most important indicators of plant water stress is relative leaf water content (RWLC), which indicated ability

of the plants to preserve tissue water status in the face of moisture stress. The relative leaf water level of the moisture stress-free control was higher than that of the other moisture stress treatments and moisture stress during the flowering stage came next was tabulated in Table 2. Under situations of moisture stress, yield was significantly impacted by rapid early development and the maintenance of RWLC at a reasonably high level during the reproductive period. Further, at the panicle initiation stage, a reduced relative water content was noted in response to moisture stress. Khairi *et al.* (2015) noted a similar result. Under conditions of moisture stress, foliar treatment of 1% potassium silicate preserved the leaf cells' high relative water content status. Nonetheless, this was comparable to using 2% seaweed extract topically. Osmotic adjustment may be the cause of this and growth regulators' positive effects may be connected to an increase in photosynthetic equipment, which in turn boosted the production of osmotic solutes during drought (Ashraf *et al.*, 2021).

Proline content

The concentration of proline varied significantly based on the type of moisture stress and growth-regulating chemicals were applied. At the panicle initiation stage, proline content was higher under moisture stress, but lower without moisture stress free control. Among the growth-regulating compounds sprayed, one percent potassium silicate resulted in lower proline content was tabulated in Table 3. This could be because growth-regulating substances minimized stress effects, leading to less proline. According

Table 1: Effect of moisture stress and growth regulating compounds on chlorophyll index (SPAD value) at different growth stages of rice.

Treatment	Flowering stage				Harvest stage			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
S ₁	27.96	32.07	30.92	30.32	27.01	30.10	29.27	28.79
S ₂	32.08	38.57	35.37	35.34	31.22	36.69	33.82	33.91
S ₃	30.39	35.69	34.61	33.56	30.12	34.41	33.66	32.73
S ₄	30.15	35.38	34.04	33.19	29.88	34.10	33.18	32.39
Mean	30.15	35.43	33.74		29.79	33.82	32.49	
	M	S	M at S	S at M	M	S	M at S	S at M
SEd	1.43	1.64	2.84	2.85	1.15	1.74	3.02	2.86
CD at 5%	3.97	3.45	NS	NS	3.21	3.66	NS	NS

Table 2: Effect of moisture stress and growth regulating compounds on relative water content (%) at different growth stages of rice.

Treatment	Flowering stage				Harvest stage			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
S ₁	79.48	65.52	72.50	66.75	69.47	55.41	61.9	62.26
S ₂	90.78	76.82	83.80	83.80	80.79	65.90	73.91	73.53
S ₃	87.02	73.05	80.03	80.03	77.10	63.98	69.92	70.33
S ₄	83.25	69.29	76.27	76.27	73.21	59.31	66.21	66.24
Mean	85.13	71.17	78.15		75.14	61.15	67.99	
	M	S	M at S	S at M	M	S	M at S	S at M
SEd	3.71	3.84	6.66	6.85	3.6	3.71	6.54	6.76
CD at 5%	10.28	8.07	NS	NS	9.98	7.99	NS	NS

to Ashraf *et al.* (2020), using Si can reduce transpiration loss by up to 30%. Silicon lowers water loss by helping the plant maintain its ideal transpiration rate. However, proline content was higher in the absolute control. Proline serves as a compatible solute and protects cytoplasmic enzymes and structures. The main reason for increased proline concentration during moisture stress might be the reduced incorporation of the continuously synthesized amino acid, proline, during its synthesis.

Catalase activity

Catalase enzyme activity gradually increased at different growth stages, as indicated by the trend of decreasing H_2O_2 levels (Ashraf *et al.*, 2020a). Catalase is one important enzyme that removes H_2O_2 from the mitochondria and microorganisms (Shigeoka *et al.*, 2002). Drought may be the cause of the maximum catalase activity observed in the current investigation, which occurred with moisture stress at the panicle start stage was tabulated in Table 4. According to Sultana *et al.* (2001), moisture stress enhanced catalytic activity by 30% during the reproductive stage and 35% during the vegetative stage. Catalase activity was shown to be reduced when 1% potassium silicate was sprayed. Under abiotic stress circumstances, catalase (CAT), a significant and potent antioxidant enzyme, counteracted the effect of H_2O_2 and shielded plants from harm. In general, this enzyme is regarded as an H_2O_2 scavenger that helps lessen oxidative damage (Reddy *et al.*, 2004).

Soluble protein

In the current study, the control that was not under any moisture stress had a greater soluble protein content, whereas moisture stress at the panicle initiation stage had the lowest soluble protein content. Both a decrease in enzyme synthesis and the breakdown of accessible soluble protein in plants may be responsible for the drop in soluble protein concentration was tabulated in Table 5. However, the presence of binding inhibitors inside the catalytic region is the reason for the reduction in rubisco activity (Parry *et al.*, 1999 and Ashraf *et al.*, 2018). The rubisco enzyme is degraded by abiotic stress, as shown by a decrease in soluble protein in leaves. The foliar spray of 1% potassium silicate produced the highest amount of soluble protein among the moisture stress management treatments, followed by 2% seaweed extract.

Grain and straw yield

The moisture stress-free treatment led to higher grain and straw yields was tabulated in Table 6. This might be due to a higher fertility percentage, more grain panicles and more productive tillers. Additionally, the fields' rotating irrigation (watering and drying) increases soil aeration, root development and nutrient availability during crop growth, while also reducing weed growth. These factors all contributed to enhanced yield components and greater rice output. The results are in line of Ceesay *et al.* (2006) and Ashraf *et al.*, (2020), who discovered that repeated cycles

Table 3: Effect of moisture stress and growth regulating compounds on proline content ($\mu\text{mol g}^{-1}$) at different growth stages of rice.

Treatment	Flowering stage				Harvest stage			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
S ₁	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
S ₂	5.31	6.09	5.65	5.68	6.46	7.90	7.31	7.22
S ₃	1.50	4.99	3.47	3.32	2.35	5.18	4.54	4.02
S ₄	3.37	5.48	4.76	4.53	4.71	6.63	6.00	5.78
Mean	4.86	5.67	5.30	5.28	5.17	7.45	6.42	6.34
	3.76	5.56	4.79		4.67	6.79	6.07	
	M	S	M at S	S at M	M	S	M at S	S at M
CD at 5%	0.41	0.40	0.6	0.7	0.54	0.65	1.12	1.13

Table 4: Effect of moisture stress and growth regulating compounds on soluble protein (mg g^{-1}) at different growth stages of rice.

Treatment	Flowering stage				Harvest stage			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
S ₁	12.92	10.67	11.79	11.79	9.85	8.15	9.01	9.00
S ₂	14.98	12.73	13.86	13.86	11.42	9.72	10.57	10.57
S ₃	14.29	12.05	13.17	13.17	10.9	9.2	10.05	10.05
S ₄	13.6	11.36	12.48	12.48	10.37	8.67	9.52	9.52
Mean	13.95	11.70	12.83		10.63	8.94	9.79	
	M	S	M at S	S at M	M	S	M at S	S at M
SEd	0.60	0.70	1.21	1.21	0.45	0.53	0.93	0.92
CD at 5%	1.66	1.47	NS	NS	1.26	1.12	NS	NS

Table 5: Effect of moisture stress and growth regulating compounds on catalase activity ($\mu\text{g of H}_2\text{O}_2 \text{ g}^{-1}\text{min}^{-1}$) at different growth stages of rice.

Treatment	Flowering stage				Harvest stage			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
S ₁	27.10	38.47	36.77	34.11	24.31	37.54	31.43	31.09
S ₂	16.81	28.17	26.67	23.88	14.89	26.97	21.87	21.24
S ₃	18.26	30.41	28.85	25.84	18.69	29.9	24.78	24.46
S ₄	21.82	34.09	32.18	29.36	22.16	34.44	28.63	28.41
Mean	21.00	32.79	31.12		20.01	32.21	26.68	
	M	S	M at S	S at M	M	S	M at S	S at M
SEd	3.42	3.55	6.15	6.33	3.28	3.43	5.94	6.10
CD at 5%	9.50	7.46	NS	NS	9.10	7.20	NS	NS

Table 6: Effect of moisture stress and growth regulating compounds on grain yield (kg ha^{-1}) and straw yield (kg ha^{-1}) of rice.

Treatment	Grain yield (kg ha^{-1})				Straw yield (kg ha^{-1})			
	M ₁	M ₂	M ₃	Mean	M ₁	M ₂	M ₃	Mean
S ₁	4.916	4.270	4.680	4.622	6.486	5.294	5.758	5.846
S ₂	6.076	4.889	5.581	5.515	7.510	5.576	6.821	6.635
S ₃	5.567	4.532	5.172	5.090	6.849	5.547	6.364	6.253
S ₄	5.271	4.335	4.896	4.834	6.789	5.334	6.183	6.102
Mean	5.457	4.506	5.082		6.908	5.437	6.281	
	M	S	M at S	S at M	M	S	M at S	S at M
SEd	69	79	157	158	67	80	159	161
CD at 5%	170	161	333	321	165	164	335	327

of wetting and drying enhanced rice plant growth by boosting nutrient availability, leading to increased yields of grain and straw. Moisture stress during panicle initiation had a greater negative impact on rice yield than during flowering. Grain and straw yields were increases under 1% potassium silicate foliar spray. However, this was comparable with foliar spray of 2% seaweed extract. This could be due to the fact that applying silicon to upland paddy increased plant sturdiness and allowed it to grow erect without lodging. The plant's erect position exposed it to sunlight, which increased photosynthetic activity and organic constituent assimilation. These assimilates lower the prevalence of pests and diseases while simultaneously promoting crop growth and development. The crop produces a profitable yield of rice by growing quickly and using the soil's nutrients and moisture. The results align with the findings of Patil *et al.* (2018) and Ashraf and Ragavan, (2021). The yield of grain and straw was significantly impacted by both moisture stress and the foliar application of growth-regulating substances. Grain production was raised by combining foliar spray of 1% potassium silicate with moisture stress-free control. This was followed by a 2% foliar spraying of seaweed extract to minimize moisture stress. The foliar application of silicon levels led to a considerable increase in straw yield. This may be explained by silicon's ability to boost photosynthetic activity and the effectiveness of water and nutrient utilization. In the end, this leads to better vegetative development. The

number of tillers per hill and plant height were the main factors associated with higher straw output. Plant sections that accumulate silicon have better tolerance to biotic and abiotic stressors and less lodging. It's possible that each of these elements helped to increase the amount of straw produced. Singh *et al.* (2008) reported similar results.

CONCLUSION

When the crop experience severe moisture stress for 10 days during either panicle initiation or flowering, it led to reduced growth, physiological traits and yield. The panicle initiation stage of the rice crop is more vulnerable to stress than the flowering stage. Moisture stress during the panicle initiation stage negatively impacted rice growth and yield more than the moisture stress during the flowering stage. Spraying with potassium silicate had a significant positive impact on the growth characteristics, physiological, biochemical and yield components of the rice crop. It performed better than other foliar treatments and reduced the negative effects of moisture stress. Therefore, it can be concluded that combining 1% potassium silicate with without moisture stress conditions improved physiological attributes and considerably increased grain and straw yield. So these mitigation strategies were effective in reducing moisture stress to achieve maximum crop productivity when the crop faced stress at critical stages. This approach can help ensure sustainability in rice production and increase income for economic viability.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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