International Journal of Plant & Soil Science

Volume 38, Issue 5, Page 305-319, 2026; Article no.IJPSS.158380
ISSN: 2320-7035

Foliar Applications for Drought Resilience in Rice (*Oryza sativa* L.)

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Author's contributions

This work was carried out in collaboration among all authors. All authors contributed to the study conception and design. All authors have approved and gave valuable insights on materials and methods. Author Aswani S. did Material preparation, collected and analysed the data. Authors Aswani S. and S. Anitha prepared the first draft of the manuscript. All authors commented on the final version of the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i56083

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/158380

Original Research Article

Received: 07/03/2026
Published: 15/05/2026

Abstract

Drought is one of the serious inevitable causes of climate change and its impact seriously affect agriculture and livelihood. So, managing drought with a farmer friendly approach is very important. This study illustrates the effect of foliar applications on managing drought stress and how it impacts on growth, yield and biochemical characteristics. Study was conducted at Instructional farm of Kerala Agricultural University during late *Rabi* 2024. Treatments consisted of 7 foliar applicants and three levels of moisture stress. Yield parameters such as panicles per plant, grains per panicle, grain yield, 1000 grain weight and straw yield was recorded after harvest. Biochemical parameters such as Relative Water Content (RWC), proline, total

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Cite as: *S., A., Anitha, S., Prameela, P., Santhoshkumar, A. V., & Sreekumar, P. M. (2026). Foliar Applications for Drought Resilience in Rice (Oryza sativa L.). International Journal of Plant & Soil Science, 38(5), 305–319. https://doi.org/10.9734/ijpss/2026/v38i56083*

chlorophyll content was observed at MT and PI stage through standard procedure. The statistical data analysis was done using GRAPES KAU version 1.1.0. Foliar application had significant influence on growth, yield and biochemical parameters. Under 50% FC moisture stress highest grain yield was obtained from KCl @ 0.3% application (12.7 g/plant). However, kaolin application @ 5% obtained highest grain yield under moisture stress at MT and PI (13 g/plant) stage and no moisture stress (12.7g/plant). Highest proline content was observed under kaolin application at 50% FC and stress given at MT and PI stage. From this experiment, it can be concluded that the application of kaolin at 5% and KCl at 0.3% produced yields comparable to those of stress-free crops. The yield obtained through drought stress management using foliar application was also comparable to that of plants grown under irrigated conditions. Therefore, the present study should be repeated under multilocation and multiseasonal trials to obtain more conclusive results. As the trial showed a positive influence on managing drought stress through foliar application, further investigation is warranted to validate its effectiveness under diverse environmental conditions.

Keywords: Kaolin; KCl; proline; PPFM; salicylic acid; drought management; foliar application.

1. Introduction

Rice is one of the most important food crops cultivated and considered as staple food by more than half of the world's population. Productivity of rice is been challenged by climate change and its after effects. Global rise in temperature and drought is one among the climatic change factors that affect rice cultivation drastically. So, efforts must align to combat the distress and sustain yields. In the current scenario with rising temperature and water stress its need of the hour to deal with the issue seriously.

Drought tolerance in rice could be done via breeding, soil amendments, foliar application with agrochemicals, use of phyto friendly microbes for stress tolerance etc (Upadhyaya & Panda, 2019). One among the easiest and cheapest ways is to increase plants ability to tolerate the water stress and sustain yields is through foliar spray. Foliar application induce biosynthesis of osmolytes, scavenging of harmful ROS, ion homeostasis radicals, water circulation and coordination of a long distance response system (Reddy *et al*., 2004; Bekkam & Thiyagarajan, 2024; Saurabh *et al*., 2025). Exogenous application of agrochemicals is one of the farmer friendly approach to combat the water stress (Tyagi et al., 2020). Foliar application has an added advantage easier absorption by plants with larger surface area and smaller drop size (Rao & Chaitanya, 2016).

Exogenous foliar sprays used for drought management in crops can be broadly classified into several categories, including antitransparents, plant hormones, microbial formulations, growth promoters, and nutrient fertilizers. Antitranspirants are further categorized into stomatal closing, reflecting, film-forming, and growth-retarding types (Mphande *et al*., 2020). These compounds help reduce transpiration losses, maintain plant water status, and improve photosynthetic efficiency under moisture stress conditions (Ghazy *et al*., 2025). Plant hormones such as salicylic acid play an important role in sustaining plant growth during drought stress by enhancing antioxidant activity and scavenging reactive oxygen species (ROS), thereby improving stress tolerance and accelerating recovery. Microbial formulations such as Pink Pigmented Facultative Methylotrophs (PPFM) also contribute to drought tolerance by promoting plant growth, improving physiological efficiency, and maintaining productivity under stress conditions (Pandey & Shukla, 2015). Such beneficial microbes positively interact with plants and help alleviate the adverse effects of drought stress while sustaining crop yield (Aswathy *et al*., 2020).

Although several studies have independently evaluated the role of antitranspirants, plant growth regulators, and microbial formulations under drought stress, comparative information on their combined effectiveness in rice under varying moisture regimes is still limited. In addition, there is insufficient understanding regarding their influence on biochemical responses, antioxidant enzyme activity, and yield performance under field-level drought conditions. Therefore, the present study was undertaken to evaluate the effect of different foliar spray treatments on growth, yield, and biochemical parameters of rice under drought stress conditions.

2. Methodology

An experiment was conducted during the late *Rabi* season of 2024 at the Instructional Farm, Kerala Agricultural University, Vellanikkara . Objective of the study was to evaluate the effectiveness of different foliar applications in mitigating drought stress in rice. During the experimental period, the crop was exposed to severe moisture deficit conditions. It was characterized by prolonged rainless days exceeding 100 days and mean maximum temperatures above 40°C, which persisted up to crop maturity. A medium-duration rice variety, *Uma*, was used for the study (Kerala Agricultural University, 2024). Variety is a clonal selection released from regional rice research station, Mancombu, Allapuzha.

2.1 Experimental Setup

The experiment was laid out in Completely Randomized Design (CRD) factorial design with three replications. The treatments comprised of two factors. Factor A consisted of seven foliar applications *viz*., F1 – PPFM (Pink Pigmented Facultative Methylotrophs) at 1–2%, F2 – salicylic acid at 200 ppm, F3 – kaolin at 5%, F4 – KCl at 0.3%, F5 – silica (K_2SiO_3) at 400 mg/L, F6 – water spray, and F7 – control (without foliar application). Factor B included three moisture stress regimes: I1 – 50% field capacity maintained throughout all growth stages, I2 – moisture stress imposed at maximum tillering (MT) and panicle initiation (PI) stages, and I3 – no moisture stress, with water maintained at field capacity throughout the crop growth period. At I2 moisture stress was imposed at maximum tillering (MT) and panicle initiation (PI) stage by withdrawing irrigation for five days then providing irrigation after 90% of plants exhibited leaf rolling symptoms. Foliar sprays were applied twice, first at the maximum tillering stage (35 DAS) and subsequently at the panicle initiation stage (60 DAS). The study was conducted in UV stabilised grow bag with size of 40x24x24 cm3, with 600 Gauge (150 Microns) thickness. Fertilizers, lime and FYM was applied as per KAU package of practice recommendation. Urea (46% N), rock phosphate (20% P2O5), Muriate of Potash (MOP-60% KCl) was used as the source of nitrogen, phosphorus and potassium respectively. Lime was applied @ 250 kg/ha and mixed thoroughly two weeks before sowing crop. FYM @ 5t/ha was applied 3 days before sowing of crop.

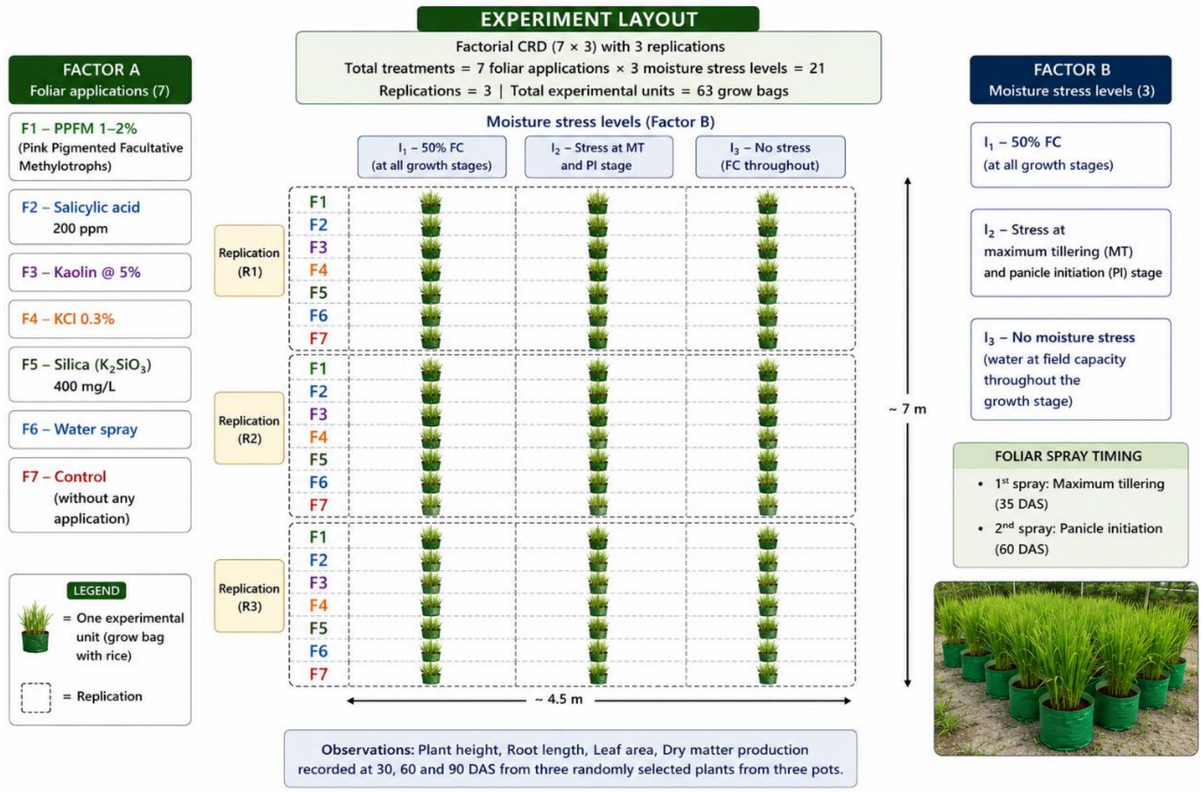

Fig. 1. Layout of experiment

2.2 Data Collection, Calculation and Analysis

Growth parameters including plant height, root length, leaf area, and dry matter production were recorded at 30, 60, and 90 DAS from three randomly selected plants in each pot.

Leaf area was measured using the formula

Total leaf area = L x B x 0.75 x total number of leaves

L- Maximum length of the 3rd leaf blade from the top (cm)
B- Maximum width of the leaf blade (cm)

Yield parameters such as panicles per plant, grains per panicle, grain yield, 1000 grain weight and straw yield was recorded after harvest. Biochemical parameters such as Relative Water Content (RWC), proline, total chlorophyll content were observed at MT and PI stage through standard procedure. DAB staining for H_2O_2 and NBT staining for ROS was done using light microscopy. The statistical data analysis was done using GRAPES KAU version 1.1.0 (Gopinath *et al*., 2021) and significance at 0.05.

3. Results and Discussion

3.1 Growth Parameters

The results of the study revealed that foliar applications significantly influenced the management of drought stress in rice under varying moisture stress conditions. Growth parameters including plant height, root length, leaf area, and dry matter production were markedly affected by the different foliar treatments. Among the treatments, foliar application of salicylic acid at 200 ppm recorded significantly higher plant height at 30 DAS under both irrigated conditions (39.0 cm) and moisture stress imposed at maximum tillering and panicle initiation stages (39.2 cm) compared to other foliar applications. The next best performance was observed with silica (K_2SiO_3) application at 400 mg/L (Table 1). A similar trend was also observed at 60 and 90 DAS, where salicylic acid treatment consistently maintained superior plant height. The beneficial effect of salicylic acid under drought stress may be attributed to its role as a signaling phenolic compound involved in regulating physiological and biochemical processes in plants exposed to moisture stress. Salicylic acid enhances stress tolerance through maintenance of cellular homeostasis by reducing transpiration water loss, inducing partial stomatal closure, promoting deeper and extensive root development, and facilitating osmotic adjustment mechanisms (Saha *et al*., 2016; Urmi *et al*., 2023).

Root growth was also significantly influenced by the exogenous application of different foliar treatments under varying moisture stress conditions. At 30 DAS, the highest root length was recorded with silica (26.2 cm) followed by kaolin application (26cm) under stress imposed at maximum tillering (MT) and panicle initiation (PI) stages. Under, irrigated conditions longer roots were observed in salicylic acid application. Whereas under 50% field capacity, longer root growth was observed with PPFM application (Table 2). PPFM (Pink Pigmented Facultative Methylotrophs), an obligate methylotrophic Gram-negative bacterium, has been reported to enhance growth and performance in rice under stress conditions (Manimala & Sundaram, 2018). The beneficial association of PPFM with plants enhances growth and stress tolerance through improved antioxidant activity, electrolyte balance, and production of growth-promoting substances. Furthermore, PPFM increases nutrient availability and synthesizes plant growth regulators such as indole-3-acetic acid (IAA), cytokinins, gibberellic acid (GA), and 1-aminocyclopropane-1-carboxylate deaminase (ACC deaminase), thereby promoting root growth and plant development (Nysanth *et al*., 2023).

Under 50% field capacity at 60 DAS, salicylic acid, silica, and control treatments recorded almost similar root lengths. Under moisture stress at MT and PI stages, PPFM treatment maintained comparatively higher root length, whereas under irrigated conditions, KCl application resulted in superior root development. At 90 DAS, the highest root length was observed with kaolin application. The beneficial effect of kaolin may be attributed to its antitranspirant properties. Kaolin forms a reflective coating on the leaf surface, which reduces the absorption of excessive solar radiation, including ultraviolet and infrared rays, thereby lowering canopy temperature and minimizing heat stress. Increased reflectance due to kaolin application reduces the adverse effects of high temperature and moisture stress, ultimately supporting better root growth and plant performance in rice (Brillante *et al*., 2016; Faghihi *et al*., 2025).

Vegetative growth and biomass accumulation play a crucial role in determining overall crop growth and productivity. Leaf area and dry matter production are important physiological parameters that influence photosynthetic efficiency and assimilate production, thereby contributing to improved source–sink relationship and crop performance. The results of the present study indicated that foliar applications significantly influenced both leaf area and dry matter production under different moisture stress conditions. At 30 DAS, the maximum leaf area under 50% field capacity was recorded with KCl application at 0.3% (Table 3). The next highest leaf area (233.6 cm²) was observed with silica (K_2SiO_3) application at 400 mg/L. Since, potassium improves stomatal regulation, osmotic adjustment, and photosynthetic efficiency leading to greater biomass accumulation (Bagheri et al., 2011; Zhu *et al*., 2020). Under irrigated conditions without moisture stress, silica application recorded the highest leaf area, followed by kaolin application. Improved growth observed with silica application might be attributed to enhanced photosynthetic efficiency, reduced transpiration loss, maintenance of plant water status, and improved antioxidant defense under drought stress conditions (Thorne *et al*., 2021). Silicon deposition in plant tissues also strengthens cell walls and improves physiological efficiency, leading to higher biomass accumulation (Jin et al., 2024; Mandlik et al., 2020). The enhanced leaf area observed with these treatments may be attributed to improved water balance, better cell expansion, and maintenance of photosynthetic activity under stress conditions.

Dry matter production was also significantly affected by the foliar treatments. At 30 60 DAS under 50% field capacity, the highest dry matter accumulation was observed with salicylic acid application, which was followed by PPFM treatment (Table 4). The improved biomass production under these treatments may be associated with enhanced physiological activity, osmotic regulation, and maintenance of metabolic processes under drought stress conditions. Though dry matter production was higher in salicylic acid application but this didn't really influence yield might be due to poor source sink partitioning (Hassan *et al*., 2023; Bhandari *et al*., 2023). However, under irrigated conditions and stress imposed at MT and PI stages, variations among treatments in dry matter production were comparatively less pronounced. At 90 DAS, no significant differences in dry matter production were observed among the treatments, indicating that the effect of foliar applications on biomass accumulation diminished towards crop maturity.

3.2 Yield Parameters

Foliar application significantly influenced the number of panicles per plant, 1000-grain weight, and straw yield. Among the different foliar treatments, kaolin @ 5% and KCl @ 0.3% recorded a higher number of panicles per plant compared to the other treatments. The improved performance under kaolin application could be attributed to its antitranspirant effect, which reduces water loss through transpiration by forming a protective film over the leaf surface and partially regulating stomatal opening. This helps in maintaining higher leaf water status, improving photosynthetic efficiency, and ultimately enhancing crop productivity under drought conditions. Similar findings were reported by Patel *et al*. (2019), where foliar application of kaolin @ 6% increased rice yield by 8% over the control.

The 1000-grain weight did not vary markedly among the treatments; however, relatively higher values were observed with salicylic acid and KCl application, indicating their positive role in improving grain development and assimilate translocation under stress conditions. Rice yield was significantly influenced by exogenous foliar application under 50% FC moisture stress conditions. Among the treatments, foliar application of KCl @ 0.3% and kaolin @ 5% recorded the highest grain yield, with increases of 46.23% and 41.84%, respectively, over the treatment without foliar spray (Table 5). The beneficial effect of KCl might be attributed to its role in osmotic adjustment, stomatal regulation, and stress alleviation under drought conditions, as reported by Zain and Ismail et al., 2016; Aswani *et al*., (2025); Zhu *et al*. (2020). Similarly, the improved performance under kaolin application could be due to its reflective and antitranspirant properties, which reduce canopy temperature and transpiration losses, thereby improving water use efficiency and photosynthetic activity under moisture stress.

Under irrigated conditions, foliar application of kaolin @ 5% recorded the highest grain yield among all treatments, resulting in a 42% increase over the absolute control. This was closely followed by foliar application of silica (K_2SiO_3) @ 400 mg/L and KCl @ 0.3%. Silicon application improves plant growth and biomass accumulation by enhancing photosynthesis, maintaining water balance, regulating antioxidant activity, and alleviating drought-induced oxidative stress (Ahire *et al*., 2021). A similar trend was observed under moisture stress imposed at the maximum tillering (MT) and panicle initiation (PI) stages, where foliar spray applied treatments maintained yield levels comparable to those under irrigated conditions. This indicates the potential role of foliar sprays in imparting stress tolerance and minimizing yield reduction under drought stress. The enhanced yield under stressed conditions might be due to improved physiological and biochemical responses induced by foliar application, which helped to alleviate stress effects and sustain productivity.

Table 1. Effect of foliar applicants and moisture stress on plant height at different growth stages

Treatments	Plant height (cm)											
Foliar Applicants	30 DAS				60 DAS				90 DAS			
Factor A – Foliar applicants	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean
F_1-PPFM 1-2%	33.5	32.4	29.9	31.9	61.6	55.8	45.3	54.2	87.5	89.8	95.7	91.0
F_2-Salicylic acid 200ppm	35.5	39.2	39.0	37.9	57.4	64.7	57.5	59.9	92.2	94.3	96.6	94.4
F_3-Kaolin @ 5%	30.2	35.4	33.5	33.0	50.7	56.3	61.2	56.1	91.7	89.3	91.2	90.7
F_4-KCl 0.3%	33.4	30.4	36.2	33.3	54.3	46.7	42.7	47.9	85.2	89.2	87.9	87.4
F_5-Silica(K_2SiO_3) 400 mg/L	35.6	37.0	35.4	36.0	52.9	60.1	52.8	55.3	89.7	85.8	81.1	85.5
F_6-Water spray	34.3	33.9	32.0	33.4	50.2	48.0	57.0	51.7	72.7	84.3	75.8	77.6
F_7-Control	36.2	33.1	31.6	33.6	45.8	42.0	42.0	43.3	84.9	78.8	71.5	78.4
Mean	34.1	34.5	33.9		53.3	53.4	51.2		86.3	87.4	85.7	
CD (0.05)- Foliar applicants	**3.7**				**6.03**				**6.62**			
CD (0.05) -Moisture Stress	**NS**				**NS**				**NS**			
Interaction CD (0.05)	**NS**				**10.4**				**NS**			

Table 2. Effect of seed treatments and moisture stress on root length weight at different growth stages

Treatments	Root length (cm)											
Foliar Applicants	30 DAS				60 DAS				90 DAS			
Factor A – Foliar applicants	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean
F_1-PPFM 1-2%	36.7	21.4	18.2	25.4	24.5	25.5	24.3	24.8	31.2	32.4	33.0	**32.2**
F_2-Salicylic acid 200ppm	34.0	18.4	28.0	26.8	27.2	24.7	23.9	25.2	31.3	26.5	27.3	**28.4**
F_3-Kaolin @ 5%	29.6	26.0	26.2	27.2	23.0	24.8	15.0	20.9	34.7	32.1	29.5	**32.1**
F_4-KCl 0.3%	33.5	23.0	23.5	26.7	23.1	24.3	34.3	27.2	29.3	24.4	30.3	**28.0**
F_5-Silica(K_2SiO_3) 400 mg/L	25.3	26.3	24.5	25.4	27.3	19.7	25.3	24.1	33.4	31.3	26.5	**30.4**
F_6-Water spray	11.7	17.0	22.5	17.1	16.5	15.8	23.5	18.6	29.1	31.1	33.2	**31.1**
F_7-Control	15.5	11.0	14.3	13.6	27.6	21.6	21.9	23.7	30.0	26.5	25.8	**27.4**
Mean	26.6	20.4	22.5		24.2	22.3	24.0		31.3	29.2	29.4	
CD (0.05)- Foliar applicants	**4.41**				**4.95**				**3.22**			
CD (0.05) -Moisture Stress	**2.89**				**NS**				**NS**			
Interaction CD (0.05)	**7.65**				**NS**				**NS**			

Table 3. Effect of foliar application and moisture stress on leaf area

Treatments	Leaf Area (cm^2)											
Foliar Applicants	**30 DAS**				**60 DAS**				**90 DAS**			
Factor A – Foliar applicants	**I_1**	**I_2**	**I_3**	**Mean**	**I_1**	**I_2**	**I_3**	**Mean**	**I_1**	**I_2**	**I_3**	**Mean**
F_1-PPFM 1-2%	208.3	189.6	150.5	182.8	497.9	266.4	255.6	340.0	534.9	517.0	666.6	**572.8**
F_2-Salicylic acid 200ppm	182.9	241.1	160.6	194.9	315.9	287.2	279.5	294.2	671.2	703.9	549.6	**641.6**
F_3-Kaolin @ 5%	156.8	198.2	268.2	207.7	401.0	351.8	336.0	363.0	572.8	511.3	650.3	**578.1**
F_4-KCl 0.3%	249.4	290.0	252.7	264.0	482.2	268.2	262.5	337.6	600.9	699.4	814.1	**704.8**
F_5-Silica(K_2SiO_3) 400 mg/L	214.0	217.4	269.6	233.6	309.5	421.1	234.2	321.6	622.8	705.3	651.2	**659.8**
F_6-Water spray	212.2	194.4	204.7	203.8	245.0	208.8	320.1	258.0	553.7	634.1	690.5	**626.1**
F_7-Control	156.2	173.0	142.2	157.1	203.4	305.8	180.2	229.8	529.2	573.5	501.2	**534.6**
Mean	197.1	214.8	206.9		350.7	301.3	266.9		583.6	620.6	646.2	
CD (0.05)- Foliar applicants	**53.96**				**NS**				**108.2**			
CD (0.05) -Moisture Stress	**NS**				**66.14**				**NS**			
Interaction CD (0.05)	**NS**				**NS**				**NS**			

Table 4. Effect of foliar application and moisture stress on dry matter production

Treatments	Dry Matter Production (g/plant)											
Foliar Applicants	**30 DAS**				**60 DAS**				**90 DAS**			
Factor A – Foliar applicants	**I_1**	**I_2**	**I_3**	**Mean**	**I_1**	**I_2**	**I_3**	**Mean**	**I_1**	**I_2**	**I_3**	**Mean**
F_1-PPFM 1-2%	3.2	2.1	3.7	3.0	7.9	7.3	7.8	7.6	20.5	18.4	20.7	**19.9**
F_2-Salicylic acid 200ppm	4.4	2.0	2.8	3.1	10.3	6.2	9.5	8.6	22.2	20.4	19.3	**20.6**
F_3-Kaolin @ 5%	1.6	2.7	2.7	2.3	4.2	7.3	7.3	6.3	20.3	23.1	19.2	**20.9**
F_4-KCl 0.3%	2.4	2.0	2.7	2.4	6.3	5.5	6.9	6.2	23.3	21.6	20.2	**21.7**
F_5-Silica($K_2Si_2O_3$) 400 mg/L	1.7	2.2	2.1	2.0	7.8	4.6	5.6	6.0	21.0	22.2	20.4	**21.2**
F_6-Water spray	1.1	2.8	2.4	2.1	3.4	3.3	7.0	4.5	21.9	19.9	22.6	**21.4**
F_7-Control	1.4	1.2	1.0	1.2	5.9	3.7	4.2	4.6	20.6	19.7	20.2	**20.1**
Mean	2.2	2.1	2.5		6.5	5.4	6.9		21.4	20.7	20.4	
CD (0.05)- Foliar applicants	**0.77**				**1.69**				**NS**			
CD (0.05) -Moisture Stress	**NS**				**1.12**				**NS**			
Interaction CD (0.05)	**1.33**				**2.93**				**NS**			

Table 5. Effect of foliar applicants and moisture stress on yield parameters

Treatments	**Yield parameters**											
Foliar Applicants	**Number of panicles per plant**				**1000 grain weight**				**Straw yield (g/plant)**			
Factor A – Foliar applicants	**I_1**	**I_2**	**I_3**	**Mean**	**I_1**	**I_2**	**I_3**	**Mean**	**I_1**	**I_2**	**I_3**	**Mean**
F1-PPFM 1-2%	9.0	9.3	9.7	9.3	20.2	21.0	21.9	21.1	56.9	48.9	**59.9**	**55.3**
F2-Salicylic acid 200 ppm	11.7	10.0	9.7	10.4	19.5	21.2	21.4	20.7	53.6	50.7	**44.9**	**49.7**
F3-Kaolin @ 5%	11.3	13.0	12.7	12.3	21.0	20.9	20.6	20.8	52.1	59.6	**63.5**	**58.4**
F4-KCl 0.3%	12.7	11.7	12.3	12.2	21.6	22.6	21.8	22.0	46.3	56.7	**57.2**	**53.4**
F5-Silica (K_2SiO_3) 400 mg/L	11.3	12.3	11.0	11.6	20.7	21.6	19.6	20.6	47.4	56.9	**48.8**	**51.0**
F6-Water spray	8.7	8.3	8.0	8.3	22.4	20.8	20.5	21.2	42.1	48.4	**46.9**	**45.8**
F7-Control	8.0	7.7	8.0	7.9	18.5	19.6	20.0	19.4	38.3	39.8	**43.0**	**40.4**
Mean	**10.4**	**10.3**	**10.2**		**20.6**	**21.1**	**20.8**		**48.1**	**51.6**	**52.0**	
CD (0.05)- Foliar applicants	**1.96**				**1.19**				**7.25**			
CD (0.05) -Moisture Stress	**NS**				**NS**				**NS**			
Interaction CD (0.05)	**NS**				**NS**				**NS**			

Table 6. Effect of seed treatments and moisture stress on grain yield

Treatments	**Grain yield(g/plant)**			
Foliar Applicants	**I_1- 50% FC (at all growth stages) (g/plant)**	**I_2- Stress at MT and PI stage (g/plant)**	**I_3- No moisture stress (g/plant)**	**Mean**
Factor A – Foliar applicants				
F1-PPFM 1-2%	20.3	15.5	19.7	18.5
F2-Salicylic acid 200ppm	16.7	12.9	21.0	16.9
F3-Kaolin @ 5%	21.1	24.1	24.1	23.1
F4-KCl 0.3%	22.8	23.2	21.9	22.7
F5-Silica (K_2SiO_3) 400 mg/L	16.8	23.3	22.2	20.8
F6-Water spray	13.5	11.9	13.1	12.9
F7-Control	12.3	11.9	13.8	12.7
Mean	**17.7**	**17.6**	**19.4**	
CD (0.05)- Foliar applicants	**5.6**			
CD (0.05) -Moisture Stress	**NS**			
Interaction CD (0.05)	**NS**			

In addition to grain yield, straw yield was also significantly influenced by foliar application treatments. Under irrigated conditions, the highest straw yield was recorded with kaolin application (63.5 g plant^{-1}), followed by PPFM application (59.9 g plant^{-1}). Patel *et al*. (2019) reported improved biomass production and higher straw yield due to reduced transpiration and better water conservation with kaolin spray. A similar trend was observed under stress imposed at the MT and PI stages. However, under 50% FC moisture stress, the highest straw yield was obtained with PPFM foliar application, followed by salicylic acid application. The increased straw yield under these treatments might be associated with improved vegetative growth, higher leaf area retention, and enhanced dry matter accumulation under stress conditions.

3.3 Biochemical Parameters

Foliar applications and moisture stress significantly influenced malondialdehyde (MDA) and proline content (Figs. 2–4). Malondialdehyde is an important indicator of lipid peroxidation and oxidative stress in plants, where higher MDA content reflects greater membrane damage caused by stress conditions. In the present study, higher MDA content was observed with KCl application under moisture stress imposed at the maximum tillering (MT) and panicle initiation (PI) stages, whereas the lowest MDA content was recorded with kaolin application under the same stress conditions. The reduced MDA accumulation in kaolin-treated plants might be attributed to its antitranspirant and reflective properties, which help in minimizing water loss, reducing canopy temperature, and alleviating oxidative stress. Under severe stress conditions, increased generation of reactive oxygen species (ROS) enhances membrane lipid peroxidation, thereby increasing MDA accumulation as part of the stress response mechanism to maintain cellular homeostasis.

Proline content also increased under moisture stress conditions, indicating its role in osmotic adjustment, protection of cellular structures, and scavenging of reactive oxygen species during drought stress. Enhanced proline accumulation under stress acts as an adaptive mechanism that helps plants tolerate moisture deficit conditions.

Relative water content (RWC) was also assessed; however, no significant differences were observed among the treatments, indicating that foliar applications were able to maintain comparable plant water status across stress conditions.

Proline content another important parameter signifying the importance of stress, foliar application under different moisture stress condition influenced proline content. Higher proline content was observed in control without any foliar application under irrigated condition. Even though ambient irrigated condition didn't really keep up the plant under homeostasis without any drought management practices. Next higher content of proline was observed in water spray under stress imposed at MT and PI stage. Generally, in plants high proline content signifies severe stress and proline gives strength to scavenge the high ROS generated in plant. In this study in control and water spray plant itself have created a self-defense by increasing the proline content to combat the drought stress. Many research works have contributed the importance of proline in rice and its potential to stabilize the structure of protein and cell membrane, role in protective action of protein *etc* (Kavi & Sreenivasulu, 2014; Dien *et al*., 2019).

ROS is the potential indicator of the stress, DAB staining to find H_2O_2 accumulation and NBT to find the ROS generation was done in rice leaves (Fig. 5a-5g). The image indicate that more stain was in control and least in KCl followed by kaolin treatments signifying less accumulation of ROS species. Many findings have shown ROS accumulation is more in plants due to stress either moisture stress or salinity stress. Here less stain was observed in KCl and Kaolin indicating plants are less stressed due to the foliar spray.

3.4 Economics

The economics of rice cultivation as influenced by different foliar applications under varying moisture stress conditions were evaluated in terms of gross returns, net returns, and benefit–cost (B:C) ratio, and the results are presented in Table 7. The economic analysis clearly indicated that foliar application treatments considerably improved the profitability of rice cultivation compared to the untreated control under both irrigated and moisture stress conditions.

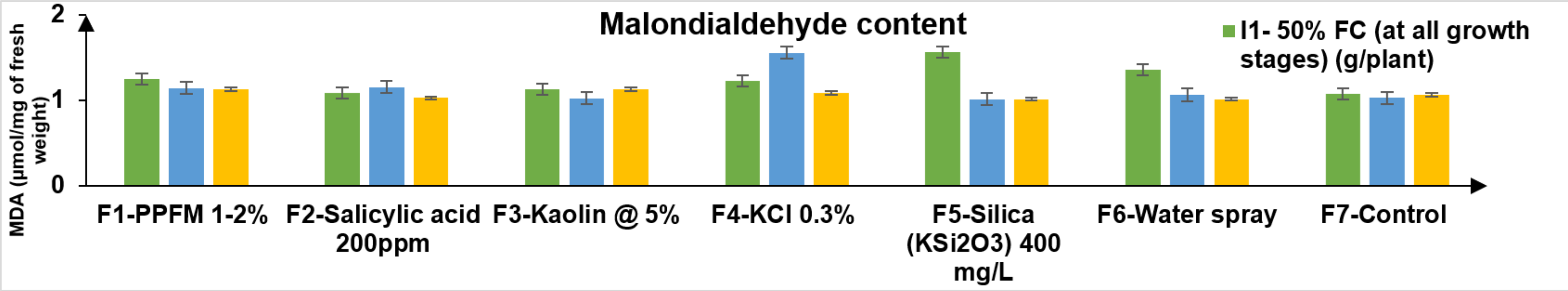

Fig. 2. Effect of foliar applicants and moisture stress on malondialdehyde content of rice at MT

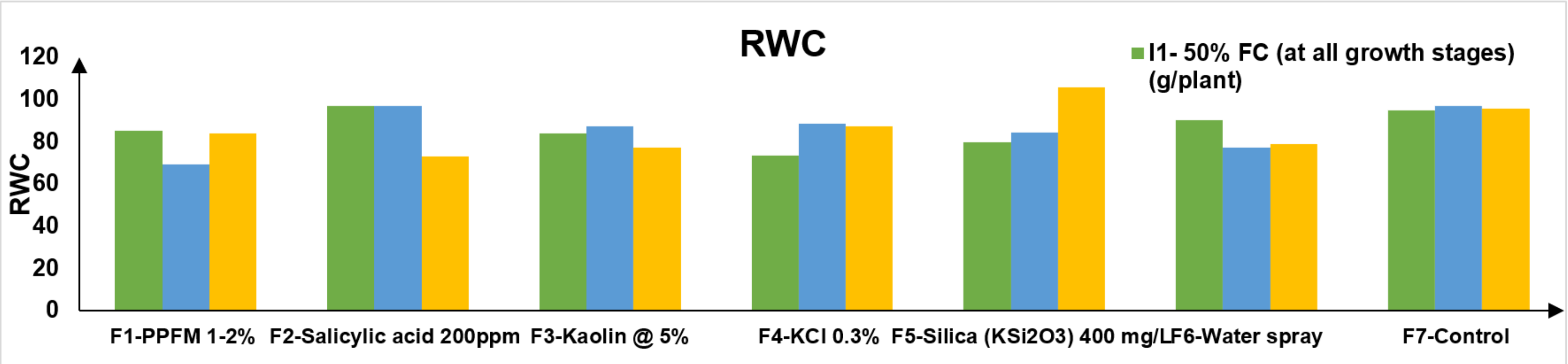

Fig. 3. Effect of foliar applicant and moisture stress on RWC at MT

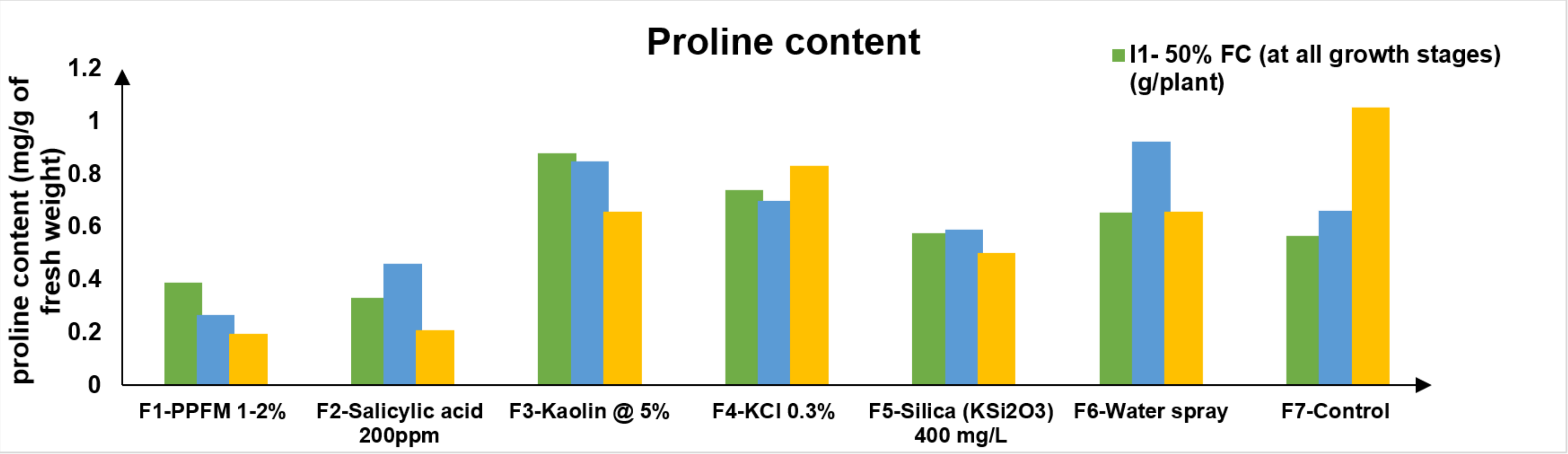

Fig. 4. Effect of foliar applicants and moisture stress on proline content at MT

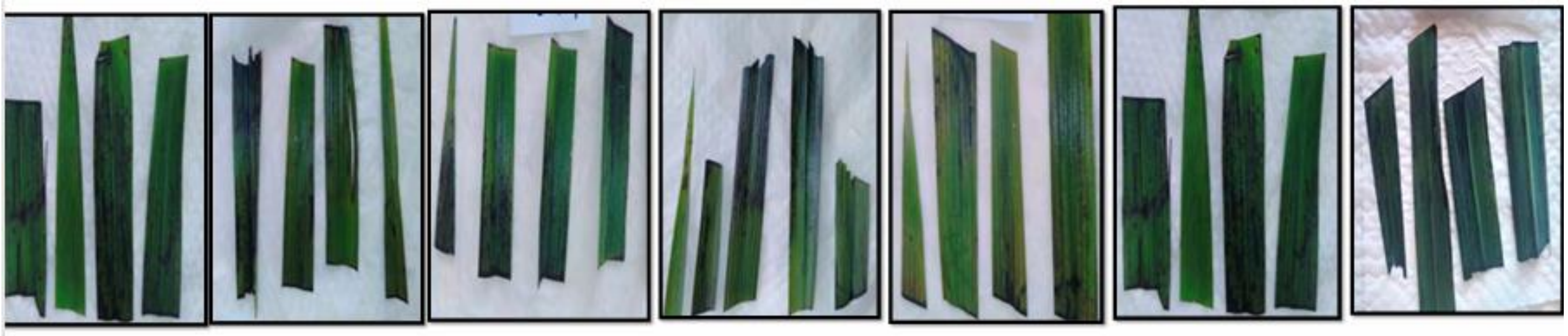

Fig. 5a. PPFM, Fig. 5b. Salicylic acid, Fig. 5c. Kaolin, Fig. 5d. KCl, Fig. 5e. Silica, Fig. 5f. Water Fig. 5g. Control

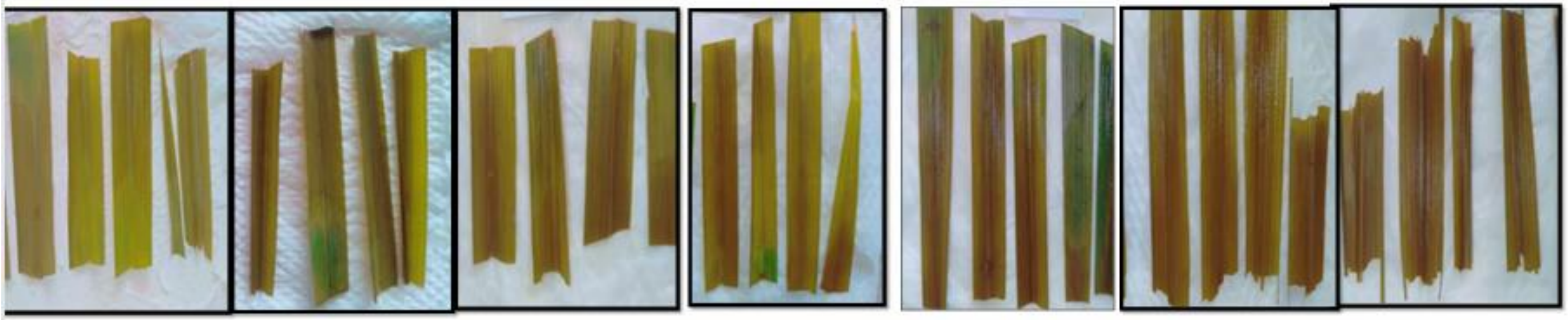

Fig. 6a. PPFM, Fig. 6b. Salicylic acid, Fig. 6c. Kaolin, Fig. 6d. KCl, Fig. 6e. Silica, Fig. 6f. Water Fig. 6g. Control

Table 7. Effect of foliar application and moisture stress on economics of cultivation

Treatments	Gross returns			Net returns			B:C		
Foliar applicants	I_1	I_2	I_3	I_1	I_2	I_3	I_1	I_2	I_3
F_1-PPFM 1-2%	31025.7	34927.7	30562.0	-7756.4	-3454.4	-8620.1	0.8	0.91	0.78
F_2-Salicylic acid 200ppm	35218.9	35246.2	43485.3	-3913.2	-3485.9	3953.2	0.9	0.91	1.1
F_3-Kaolin @ 5%	54315.9	49916.2	48604.4	15518.8	11519.1	9407.3	1.4	1.3	1.24
F_4-KCl 0.3%	46472.5	42159.8	45151.4	7745.4	3832.7	5889.3	1.2	1.1	1.15
F_5-Silica(K_2SiO_3) 400 mg/L	43787.6	30680.1	35356.6	5037.5	-7670.0	-3928.5	1.13	0.8	0.9
F_6-Water spray	33653.4	29860.0	34118.8	-5028.7	-8422.1	-5098.2	0.87	0.78	0.87
F_7-Control	30945.7	32922.6	30589.3	-7736.4	-5359.5	-8627.8	0.8	0.86	0.78

Among the foliar treatments, kaolin @ 5% (F3) recorded the highest gross returns across all moisture regimes, registering ₹54,315.9 ha^{-1} under irrigated condition (I1), ₹49,916.2 ha^{-1} under stress imposed at the maximum tillering stage (I2), and ₹48,604.4 ha^{-1} under stress imposed at the panicle initiation stage (I3). The higher gross returns obtained with kaolin application were mainly attributed to its superior performance in maintaining grain yield and biomass production under moisture stress conditions. Kaolin also recorded the highest net returns of ₹15,518.8 ha^{-1}, ₹11,519.1 ha^{-1}, and ₹9,407.3 ha^{-1} under I1, I2, and I3 conditions, respectively. Correspondingly, the highest B:C ratio was also observed with kaolin application, with values of 1.40, 1.30, and 1.24 under I1, I2, and I3 conditions, respectively, indicating the economic viability and profitability of this treatment even under drought stress. The next best treatment was foliar application of KCl @ 0.3% (F4), which recorded gross returns of ₹46,472.5 ha^{-1}, ₹42,159.8 ha^{-1}, and ₹45,151.4 ha^{-1} under I1, I2, and I3 conditions, respectively. This treatment also resulted in comparatively higher net returns and B:C ratio than most other treatments, suggesting that potassium-mediated stress alleviation contributed positively towards sustaining yield and economic returns under moisture deficit conditions.

Foliar application of salicylic acid @ 200 ppm (F2) exhibited moderate economic performance. Although the treatment showed negative net returns under irrigated and MT stress conditions, it recorded a positive net return of ₹3,953.2 ha^{-1} and a B:C ratio of 1.10 under PI stage stress, indicating its beneficial role in improving productivity during reproductive-stage moisture stress.

Application of silica (K_2SiO_3) @ 400 mg/L and PPFM showed relatively lower economic returns compared to kaolin and KCl treatments. In several stress conditions, these treatments recorded negative net returns due to comparatively lower yield realization and higher cultivation costs. Similarly, water spray and untreated control treatments recorded the lowest economic returns and B:C ratios, with values remaining below unity under most stress conditions, indicating poor economic feasibility.

Overall, the economic analysis revealed that foliar application of kaolin @ 5% and KCl @ 0.3% effectively mitigated the adverse effects of moisture stress and improved productivity, resulting in higher profitability and better economic sustainability of rice cultivation. The consistently higher B:C ratio observed under these treatments suggests that foliar application could serve as a practical and economically feasible strategy for managing drought stress in rice cultivation.

4. Conclusion

Drought stress seriously affects productivity and in this study management of drought stress was found effective using foliar applicants. From this experiment it could be concluded that application of kaolin @ 5 % and KCl @ 0.3 % fetched comparable yield as of stress-free crops. Yield obtained from stress management using foliar application was comparable with plants under irrigated condition. Hence, the present study has to be repeated in multilocation and multiseasonal trials to obtain conclusive results. Since this study trial had positive influenced on managing drought stress using foliar application.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript. ChatGPT was used for drawing the layout of experiment and some grammar checking.

Acknowledgements

The research work was financially supported by Kerala Agricultural University. All authors contributed for the design, collection, analysis and interpretation of data; in the writing of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

References

Ahire, M. L., Mundada, P. S., Nikam, T. D., Bapat, V. A., & Penna, S. (2021). Multifaceted roles of silicon in mitigating environmental stresses in plants. *Plant Physiology and Biochemistry,* 169, 291–310. https://doi.org/10.1016/j.plaphy.2021.11.010

Aswani, S., Anitha, S., Prameela, P., Parvathy, M. S., Prashanthi, P., & Santhoshkumar, A. V. (2025). Drought responses and its management in rice: A review. *International Journal of Research in Agronomy* 8(3): 107-111

Aswathy, J. C., Pillai, P. S., John, J., & Meenakumari, K. S. (2020). Effect of pink pigmented facultative methylotrophs (PPFM) on growth and growth attributes of rice (Oryza sativa L.). *International Journal of Chemical Studies*, *8*(4), 3209-3213.

Bagheri, R., Mobasser, H. R., Ghanbari-Malidarreh, A., & Dastan, S. (2011). Effect of seedling age and potassium rates on morphological traits related-lodging, yield and yield components of rice (Oryza sativa L.) in Iran. *Journal Agriculture and Environmental Science*, 11(2), 261-268

Bekkam, R., & Thiyagarajan, C. (2024). Foliar application of rice husk derived nanosilica for mitigating drought stress in hybrid maize by boosting antioxidant defense system. *Journal of Hazardous Materials Advances, 16*, 100482. https://doi.org/10.1016/j.hazadv.2024.100482

Bhandari, U., Gajurel, A., Khadka, B., Thapa, I., Chand, I., Bhatta, D., *et al*. (2023). Morpho-physiological and biochemical response of rice (*Oryza sativa* L.) to drought stress: A review. *Heliyon, 9*(3), e13744. https://doi.org/10.1016/j.heliyon.2023.e13744

Brillante, L., Belfiore, N., Gaiotti, F., Lovat, L., Sansone, L., Poni, S., & Tomasi, D. (2016). Comparing kaolin and pinolene to improve sustainable grapevine production during drought. *PLoS One*, *11*(6), e0156631.

Dien, D. C., Mochizuki, T., & Yamakawa, T. (2019). Effect of various drought stresses and subsequent recovery on proline, total soluble sugar and starch metabolisms in Rice (Oryza sativa L.) varieties. *Plant Production Science*, 22(4), 530-545

Faghihi, E., Aghamir, F., Mohammadi, M., & Eghlima, G. (2025). Kaolin application improved growth performances, essential oil percentage, and phenolic compound of *Thymus vulgaris* L. under drought stress. *BMC Plant Biology, 25*(1), 892. https://doi.org/10.1186/s12870-025-06847-6

Ghazy, H. A., Gharieb, A. S., Hashem, I. M., & El-Refaee, I. S. (2025). Amelioration of Rice Productivity under Irrigation Treatment Using Anti-Transpirants Sprays and Amino Acids. *Journal of Plant Production*, *16*(7), 435-443.

Gopinath, P. P., Parsad, R., Joseph, B., & Adarsh, V. S. (2021). grapesAgri1: Collection of Shiny Apps for data analysis in agriculture. *Journal of Open Source Software*. https://doi.org/10.21105/joss.03437

Hassan, M. A., Dahu, N., Hongning, T., Qian, Z., Yueming, Y., Yiru, L., *et al*. (2023). Drought stress in rice: Morpho-physiological and molecular responses and marker-assisted breeding. *Frontiers in Plant Science,* 14, 1215371. https://doi.org/10.3389/fpls.2023.1215371

Jin, W., Li, L., He, W., & Wei, Z. (2024). Application of silica nanoparticles improved the growth, yield, and grain quality of two salt-tolerant rice varieties under saline irrigation. *Plants, 13*(17), 2452. https://doi.org/10.3390/plants13172452

Kavi Kishor, P. B., & Sreenivasulu, N. E. S. E. (2014). Is proline accumulation per se correlated with stress tolerance or is proline homeostasis a more critical issue?. *Plant, cell & environment*, *37*(2), 300-311. https://onlinelibrary.wiley.com/doi/abs/10.1111/pce.12157

Kerala Agricultural University. (2024). *Package of practices recommendations: Crops* (16th ed.). Directorate of Extension, KAU Press. https://kau.in

Mandlik, R., Thakral, V., Raturi, G., Shinde, S., Nikolić, M., Tripathi, D. K., *et al*. (2020). Significance of silicon uptake, transport, and deposition in plants. *Journal of Experimental Botany, 71*(21), 6703–6718. https://doi.org/10.1093/jxb/eraa301

Manimala, M. R. A., & Sundaram, S. P. (2018). Isolation and characterization of pink-pigmented, facultative Methylobacterium (PPFM) and its positive interaction effect on root colonization of AM fungi. *Biochemical & Cellular Archives*, *18*(1).

Mphande, W., Kettlewell, P. S., Grove, I. G., & Farrell, A. D. (2020). The potential of antitranspirants in drought management of arable crops: A review. Agricultural Water Management, 236, 106143

Nysanth, N. S., Anu Rajan, S., Sivapriya, S. L., & Anith, K. N. (2023). Pink Pigmented Facultative Methylotrophs (PPFMs): Potential Bioinoculants for Sustainable Crop Production. *Journal of Pure & Applied Microbiology*, 17(2)

Pandey, V., & Shukla, A. (2015). Acclimation and tolerance strategies of rice under drought stress. *Rice Science, 22*(4), 147–161. https://doi.org/10.1016/j.rsci.2015.04.001

Patel, R., Raha, P., Sri Laxmi, & Paul, A. (2019). Effect of antitranspirants on rice (*Oryza sativa*) grown under submerged and water stressed condition in an inceptisol of Varanasi, Uttar Pradesh. *Journal of Crop and Weed*. https://doi.org/10.22271/09746315.2019.v15.i3.1244

Rao, D. E., & Chaitanya, K. V. (2016). Photosynthesis and antioxidative defense mechanisms in deciphering drought stress tolerance of crop plants. *Biologia Plantarum,* 60(2), 201–218. https://doi.org/10.1007/s10535-016-0584-8

Reddy, A. R., Chaitanya, K. V., & Vivekanandan, M. (2004). Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. *Journal of plant physiology*, *161*(11), 1189-1202.

Saha, P., Sade, N., Arzani, A., Wilhelmi, M.D.M.R., Coe, K.M., Li, B. and Blumwald, E., 2016. Effects of abiotic stress on physiological plasticity and water use of Setaria viridis (L.). Plant Science, 251, pp.128-138

Saurabh, K., Kumar, S., Kumar, R., Mishra, J. S., Das, A., Srivastava, A. K., *et al*. (2025). Biofortifying drought-tolerant rice: Enhancing growth and nutritional quality with foliar iron and zinc applications in Eastern India. *Journal of Plant Nutrition, 48*(1), 164–176. https://doi.org/10.1080/01904167.2024.2378925

Thorne, S. J., Hartley, S. E., & Maathuis, F. J. (2021). The effect of silicon on osmotic and drought stress tolerance in wheat landraces. *Plants*, *10*(4), 814.

Tyagi, V., Nagargade, M., & Singh, R. K. (2020). Agronomic interventions for drought management in crops. In A. Rakshit, H. B. Singh, A. K. Singh, U. S. Singh, & L. Fraceto (Eds.), *New frontiers in stress management for durable agriculture* (pp. 461–476). Springer, Singapore. https://doi.org/10.1007/978-981-15-1322-0_24

Upadhyaya, H., & Panda, S. K. (2019). Drought stress responses and its management in rice. In M. Hasanuzzaman, M. Fujita, K. Nahar, & J. K. Biswas (Eds.), *Advances in rice research for abiotic stress tolerance* (pp. 177–200). Elsevier. https://doi.org/10.1016/B978-0-12-814332-2.00009-5

Urmi, T. A., Islam, M. M., Zumur, K. N., Abedin, M. A., Haque, M. M., Siddiqui, M. H., ... & Hoque, M. A. (2023). Combined effect of salicylic acid and proline mitigates drought stress in rice (Oryza sativa L.) through the modulation of physiological attributes and antioxidant enzymes. *Antioxidants*, *12*(7), 1438.

Zhu, B., Xu, Q., Zou, Y., Ma, S., Zhang, X., Xie, X., *et al*. (2020). Effect of potassium deficiency on growth, antioxidants, ionome and metabolism in rapeseed under drought stress. *Plant Growth Regulation,* 90(3), 455–466

Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/158380