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Enhancement of growth and seed yield of rice (*Oryza sativa* L.) through foliar spray of osmoprotectants under high temperature stress

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An investigation was undertaken during rabi-summer season of 2016-17 in the Department of Seed Science and Technology, OUAT, Bhubaneswar to study the efficiency of some osmoprotectants in mitigating high temperature stress by improving growth, seed yield and quality of rice cv. Naveen. The field experiment was conducted in Split Plot Design, with three replications. The main plot factor was three dates of sowing (D_1 – 30th November, D_2 – 15th December and D_3 – 30th December). The sub-plot factor was foliar spray of chemicals at vegetative and seed filling stages: Control (T_0), 600 ppm Glycine betaine (T_1), 400 ppm Salicylic acid (T_2), 800 ppm Salicylic acid (T_3), 10 ppm Ascorbic acid + 1.3% Citric acid (T_4), 150 ppm α-Tocopherol (T_5), 1.0% Potassium chloride (T_6), 5 ppm Brassinolides (T_7) and 10 ppm Brassinolides (T_8). Observations on various phenological, seed yield and quality parameters were recorded. With advancement in sowing time, there was significant decrease in the chlorophyll content of leaves. The chlorophyll content of leaves after two days of spraying as slightly higher than that prior to spraying in all the treatments. Maximum chlorophyll content was recorded with spray treatment of 800 ppm salicylic acid at both the stages of observation. Significantly higher pollen viability and seed set were recorded with first date of sowing (D_1), compared to second and third dates of sowing (D_2 and D_3, respectively). Among the treatments, pollen viability was highest with 10 ppm brassinolides and 400 ppm salicylic acid. Seed set was highest with 10 ppm brassinolides and 800 ppm salicylic acid. With advancement in sowing time, there was decrease in membrane stability index of leaves. The MSI of leaves after two days of spraying was slightly higher than that prior to spraying in all treatments. Maximum MSI was recorded with spray treatment of 400 ppm salicylic acid (T_2) during vegetative and seed filling stages. The treatments T_2, T_4 and T_8 produced highest increase in MSI compared to that before spraying during both stages. Higher seed yield was obtained from D_1, compared to delayed sowing. Mean seed yield from D_1 was 53.76 q/ha, as against 48.99 q/ha and 44.51 q/ha from D_2 and D_3, respectively. Spraying of 800 ppm salicylic acid and 10 ppm brassinolides gave highest seed yields from each date of sowing. Seed yields from D_3T_0 and D_2T_0 (35.33 q/ha and 39.72 q/ha, respectively) were significantly lower than all treatment combinations, including D_1T_0 (51.83 q/ha). Increase in seed yields due to various treatments as against the control was more pronounced in D_2 and D_3. The first date of sowing (D_1) produced seeds with higher 1000-seed weight (22.62 g), compared to D_2 and D_3 (20.27 g and 19.36 g, respectively). Among the treatments, higher 1000-seed weights were recorded with the treatments T_3 and T_8 (21.51 g and 21.43 g, respectively), while lowest 1000-seed weight (18.76 g) was recorded with the Control. Seeds produced from D_1 recorded higher germination and seed vigour. All the treatments recorded improvement in germination and vigour of seeds with three dates of sowing. Treatments T_3, T_7 and T_8 gave highest improvement in seed germination over control. Under accelerated ageing treatment, T_3 recorded highest germination followed by T_8. Dates of sowing and treatment sprays had no influence on electrical conductivity of seed leachate. Hence, the present study demonstrated that foliar sprays at vegetative and seed filling stages with 800 ppm salicylic acid or 10 ppm ascorbic acid + 1.3% citric acid or 10 ppm brassinolides were quite effective in alleviating adverse effects of high temperature during flowering and seed set, through increased chlorophyll content of leaves, improved membrane stability, higher pollen viability and seed set, thus improving seed yield and quality of rice.

Keywords: High temperature stress, Osmoprotectant, Rice, Seed yield, Seed quality
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Climate change is harshly affecting cereal production all over the world through increased temperature and CO_2 concentration[1], which is one of the main causes of heat stress[2]. Rice is the second highest produced cereal crop in the world, after maize. Major rice producing countries are in Asia, with the farmers of the subcontinent accounting for about 92% of the world's total rice production. It is estimated that there will be a need for increasing the food production by about 30-40% in the next 30 years, so as to feed the ever-increasing world population. The changing climate scenario is making it increasingly difficult, if not impossible, to achieve the goal. Though high temperature and other abiotic stresses are limiting factors for future crop production goals,

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crop productivity many a times also suffers from random environmental fluctuations.

Direct injuries due to high temperature include protein denaturation, aggregation and increased fluidity of membrane lipids. Indirect or slower heat injuries include inactivation of enzymes in chloroplast and mitochondria, inhibition of protein synthesis, protein degradation and loss of membrane integrity[3]. High temperature during seed germination may slow down or totally inhibit germination, depending on plant species and intensity of the stress. At later stages, high temperature may adversely affect vital physiological processes like photosynthesis, respiration, water relations and membrane stability and also modulate levels of hormones and primary and secondary metabolites[4]. Floral abnormalities induced by heat stress (i.e., stamen hypoplasia and pistil hyperplasia), leading to spikelet sterility, represent significant problems in rice production. High temperature stress ultimately leads to lower yields. The yield of dry season rice crop decreased by 15% for each 1ºC increase in mean temperature during the growing season[5].

Exogenous foliar spray of osmoprotectants like Glycinebetaine, Salicylic acid, Ascorbic acid, Citric acid, α-Tocopherol, Potassium chloride, Brassinolides, etc. has been reported to be effective in reducing the loss of yield by improving tolerance to heat stress under drier and warmer climate or due to late sowing of rice. Several studies indicate that these compounds mitigate the ill effects of high temperature stress in plants through various mechanisms, like preventing the degradation of chlorophyll, reducing electrolyte leakage and thus, help to maintain or sometime increase pollen viability, seed setting and yield of crops.

The present investigation was undertaken to study the efficiency of some osmoprotectants in improving growth, seed yield and quality of rice by enhancing tolerance to high temperature stress. The main focus was to reduce the impact of heat stress in rice during vegetative and seed filling stages.

Methodology

The field experiment was conducted during rabi-summer season of 2016-17 in the Department of Seed Science and Technology, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar. The field experiment was laid out in Split Plot Design, with three replications, the main plot factor being three dates of sowing (D_1 – 30th November, D_2 – 15th December and D_3 – 30th December) and the sub-plot factor being foliar spray of chemicals at vegetative and seed filling stage (9 treatments). Rice variety Naveen (120 days duration) was chosen for the experiment. The foliar sprays included: Control (T_0), 600 ppm (5.121 mM) Glycine betaine (T_1), 400 ppm (2.896 mM) Salicylic acid (T_2), 800 ppm (5.792 mM) Salicylic acid (T_3), 10 ppm (0.056 mM) Ascorbic acid + 1.3% Citric acid (T_4), 150 ppm (0.348 mM) α-Tocopherol (T_5), 1.0% Potassium chloride (T_6), 5 ppm (0.0104 mM) Brassinolides (T_7) and 10 ppm (0.0208 mM) Brassinolides (T_8).The mean weekly maximum and minimum temperatures during the period of study are given in Table 1. Observations on total chlorophyll

Table 1 — Mean weekly maximum and minimum temperatures during the period of study corresponding to stages of crop growth

Days after sowing	Stage of crop growth	Mean weekly temperature (ºC)					
		D_1 (30th Nov 2016)		D_2 (15th Dec 2016)		D_3 (30th Dec 2016)	
		T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}
4-10	Seedling emergence	30.6	16.2	29.8	12.6	29.2	16.0
11-17	Seedling stage	30.5	15.8	29.5	14.6	29.5	14.6
18-24	Seedling stage	29.8	12.6	29.2	16.0	29.2	12.7
25-31	Transplanting	29.5	14.6	29.5	14.6	30.7	14.1
32-38	Seedling establishment	29.2	16.0	29.2	12.7	31.3	17.6
39-45	Vegetative growth	29.5	14.6	30.7	14.1	33.3	17.2
46-52	Tillering	29.2	12.7	31.3	17.6	33.6	17.4
53-59	Maximum tillering	30.7	14.1	33.3	17.2	35.1	22.4
60-66	Panicle initiation, primary and secondary branch primordial	31.3	17.6	33.6	17.4	35.7	20.6
67-73	Panicle development (stamen and pistil primordia, pollen mother cells)	33.3	17.2	35.1	22.4	33.2	22.6
74-80	Panicle development (meiotic division)	33.6	17.4	35.7	20.6	33.1	21.6
81-87	Panicle development (mature pollen)	35.1	22.4	33.2	22.6	35.9	22.7
88-94	Completed spikelets and anthesis	35.7	20.6	33.1	21.6	35.6	25.3
95-101	Seed development	33.2	22.6	35.9	22.7	35.6	26.0
102-108	Seed filling	33.1	21.6	35.6	25.3	37.8	26.0
109-115	Seed filling	35.9	22.7	35.6	26.0	36.0	25.9
116-122	Seed maturity	35.6	25.3	37.8	26.0	38.3	27.1

content of leaves (mg/g FW)[6] and membrane stability (%)[7] were recorded before foliar spray and 2 days after spray of chemicals. Pollen viability (%) was recorded by collecting the spikelet sample early in the morning just before anthesis (07:00-08:00 AM). After harvest, seed set (%), seed yield (q/ha), 1000-seed weight (g), seed germination (%)[8], seedling length (cm), seedling dry weight (mg), seed vigour indices I and II[9], EC of seed leachate (dS/m)[10] and germination (%) after accelerated ageing were also recorded.

Results and discussion

The present investigation was aimed at studying the role of osmoprotectants in rice cv. Naveen under high temperature stress. Foliar application of such osmoprotectants showed positive effects in mitigating high temperature stress. The possible mechanisms of positive effects of osmoprotectants are discussed here under. With delay in sowing time, there was significant decrease in the chlorophyll content of leaves (Table 2). The chlorophyll content of leaves after two days of spraying was slightly higher than that prior to spraying in all the treatments. Maximum chlorophyll content was recorded with spray treatment of 800 ppm salicylic acid (T_3) at both the stages of observation. Salicylic acid is a common phenolic compound that promotes photosynthesis under heat stress by influencing various physiological and biochemical process[11]. The treatments T_3, T_4 and T_8 recorded the highest percent increase in chlorophyll content in comparison to the chlorophyll content before spray both during vegetative and seed filling stages (Fig. 1 & Fig. 2). Application of Brassinolides under high temperature stress conditions was reported to significantly increase the chlorophyll content in rice seedlings[12].

Significantly higher pollen viability (%) and seed set (%) were recorded with first date of sowing, as compared to second and third dates of sowing (Table 2). With delay in sowing time, there was gradual decrease in both the parameters. High temperatures $\geq 30^0$C have been reported to cause pollen sterility in rice[13]. Among the treatments, pollen viability was highest in T_8 (10 ppm brassinolides), followed by T_2 (400 ppm salicylic acid), though both the treatments were statistically at par. However, seed set was highest in T_8, followed by T_3 (800 ppm salicylic acid), though both the treatments were statistically at par. The treatments T_8 and T_2 recorded highest percent increase in pollen viability over Control (Fig. 3), whereas the treatments T_8 and T_3 recorded highest percent increase in seed set over Control (Fig. 4). Salicylic acid is a phenolic compound that naturally exists in plants at a very low concentration. Salicylic acid can reduce pollen sterility when encountering high temperature stress at the pollen mother cell meiosis stage. Under heat stress, rice plants sprayed with Salicylic acid at 0.1–10 mM is reported to have attained a significantly higher seed-setting rate and pollen viability compared to those of the non-Salicylic acid treatment[14]. The most effective Salicylic acid concentration was found to be 10 mM under heat stress and no inhibition was found on the rice plants when they were sprayed with 50 mM Salicylic acid. Similarly, exogenous application of Vitamin E, Glycine betaine and Salicylic acid has been reported to significantly improve pollen germination and spikelet fertility in rice[15]. Two rice cultivars, IR-64 and Huanghuazhan, subjected to high day temperature (HDT), high night temperature (HNT) and control temperature (CT) in controlled growth chambers showed severely reduced the pollen fertility, anther dehiscence, pollen retention, germination and metabolites synthesis in pollens of both rice cultivars[16]. Exogenous application of four different combinations of growth regulators (Ascorbic acid, α-Tocopherol, Brassinosteroides, Methyl jasmonates and Traiazoles) could mitigate high temperature stress by increased pollen fertility, anther dehiscence, pollen retention, germination rate of both rice cultivars.

As the sowing time was delayed, there was significant decrease in the membrane stability index of leaves (Table 3). The membrane stability index of leaves after two days of spraying was slightly higher than that prior to spraying in all the treatments. Maximum membrane stability index was recorded with spray treatment of 400 ppm salicylic acid (T_2) at both the stages of observation. The treatments T_2, T_4 and T_8 recorded the highest percent increase in membrane stability index in comparison to that before spray both during vegetative and seed filling stages (Fig. 5 & Fig. 6).

Higher seed yield was obtained with first date of sowing (Table 3), owing mainly to exposure of the crop to relatively lower temperatures during vegetative and seed filling stages, thus recording higher pollen viability and higher seed set percentage. The mean seed yield from first date of sowing was 53.76 q/ha, as against 48.99 q/ha and 44.51 q/ha from the second and third dates of sowing, respectively. Among the treatments, T_3 (800 ppm salicylic acid) and T_8 (10 ppm brassinolides) gave the highest seed yields from each date of sowing, which were significantly higher than rest of the treatments. With delay in sowing, there was drastic reduction in the seed yield. The seed yields from D_3T_0 and D_2T_0 (35.33 q/ha and 39.72 q/ha, respectively) were significantly

Table 2 — Chlorophyll content of leaves, pollen viability and seed set of rice cv. Naveen as influenced by date of sowing and foliar application of osmoprotectants

Treatments	Chlorophyll content (mg/g FW) of leaves during vegetative stage		Chlorophyll content (mg/g FW) of leaves during seed filling stage		Pollen viability* (%)	Seed set** (%)
	Before spray	2 days after spray	Before spray	2 days after spray		
D_1	2.326	2.398	2.313	2.381	78.06 (62.10)	90.16 (9.49)
D_2	2.233	2.397	2.220	2.379	76.68 (61.17)	86.42 (9.29)
D_3	2.231	2.398	2.224	2.386	69.65 (56.59)	85.10 (9.22)
S.E.m (±)	0.0005	0.0003	0.0006	0.0006	0.082	0.008
$CD_{0.05}$	0.0021	NS	0.0024	0.0022	0.323	0.033
T_0	1.894	1.895	1.876	1.882	67.77 (55.45)	81.22 (9.01)
T_1	2.258	2.385	2.246	2.372	75.18 (60.19)	86.08 (9.28)
T_2	2.274	2.427	2.265	2.410	76.98 (61.40)	88.54 (9.41)
T_3	2.388	2.571	2.378	2.544	75.72 (60.53)	90.07 (9.49)
T_4	2.354	2.529	2.357	2.513	75.15 (60.13)	88.82 (9.42)
T_5	2.231	2.328	2.217	2.332	74.02 (59.41)	85.01 (9.22)
T_6	2.308	2.439	2.298	2.447	75.25 (60.22)	87.44 (9.35)
T_7	2.299	2.454	2.285	2.432	75.95 (60.71)	87.53 (9.35)
T_8	2.362	2.549	2.347	2.509	77.14 (61.51)	90.34 (9.50)
S.E.m (±)	0.0010	0.0006	0.0010	0.0010	0.122	0.020
$CD_{0.05}$	0.0028	0.0018	0.0028	0.0028	0.346	0.056
D_1T_0	2.010	2.013	1.992	1.996	72.18 (58.17)	86.50 (9.30)
D_1T_1	2.316	2.367	2.302	2.359	78.98 (62.71)	90.89 (9.53)
D_1T_2	2.331	2.415	2.329	2.405	79.85 (63.33)	90.63 (9.52)
D_1T_3	2.444	2.558	2.438	2.533	78.34 (62.26)	92.27 (9.61)
D_1T_4	2.406	2.512	2.384	2.468	77.88 (61.95)	90.72 (9.52)
D_1T_5	2.288	2.315	2.276	2.321	77.09 (61.40)	87.77 (9.37)
D_1T_6	2.362	2.423	2.357	2.438	78.64 (62.47)	89.81 (9.48)
D_1T_7	2.354	2.441	2.340	2.418	79.04 (62.76)	90.88 (9.53)
D_1T_8	2.419	2.535	2.402	2.493	80.52 (63.81)	91.96 (9.59)
D_2T_0	1.887	1.889	1.873	1.879	68.36 (55.77)	79.76 (8.93)
D_2T_1	2.226	2.388	2.213	2.372	77.16 (61.45)	83.38 (9.13)
D_2T_2	2.241	2.427	2.233	2.411	79.36 (62.98)	88.09 (9.39)
D_2T_3	2.355	2.571	2.339	2.539	77.86 (61.93)	89.91 (9.48)
D_2T_4	2.322	2.531	2.296	2.482	76.18 (60.79)	88.78 (9.42)
D_2T_5	2.195	2.324	2.182	2.329	76.15 (60.77)	83.68 (9.15)
D_2T_6	2.277	2.442	2.267	2.449	77.06 (61.38)	86.95 (9.32)
D_2T_7	2.268	2.457	2.252	2.432	78.86 (62.63)	86.33 (9.29)
D_2T_8	2.324	2.542	2.322	2.519	79.17 (62.85)	90.93 (9.54)
D_3T_0	1.785	1.784	1.762	1.771	62.78 (52.40)	77.39 (8.80)
D_3T_1	2.231	2.399	2.223	2.384	69.40 (56.42)	83.97 (9.16)
D_3T_2	2.251	2.438	2.234	2.413	71.73 (57.88)	86.89 (9.32)
D_3T_3	2.365	2.583	2.356	2.561	70.97 (57.40)	88.02 (9.38)
D_3T_4	2.333	2.544	2.391	2.588	71.40 (57.67)	86.95 (9.32)
D_3T_5	2.211	2.344	2.194	2.345	68.81 (56.05)	83.58 (9.14)
D_3T_6	2.285	2.453	2.270	2.454	70.04 (56.82)	85.56 (9.25)
D_3T_7	2.274	2.465	2.264	2.446	69.95 (56.76)	85.38 (9.24)
D_3T_8	2.344	2.569	2.318	2.514	71.73 (57.88)	88.12 (9.39)
S.E.m (±)	0.0017	0.0011	0.0017	0.0017	0.211	0.034
$CD_{0.05}$	0.0049	0.0031	0.0048	0.0048	0.599	0.097

N.B.: Figures in the parenthesis are arc sine (*) / square root (**) transformed values.

lower than all the other treatments, as well as D_1T_0 (51.83 q/ha). All the treatments had a positive influence in minimising the adverse effect of high temperature on the seed yield of rice. The increase in seed yields due to various treatments as against the control (T_0) was more pronounced in the 2nd and 3rd dates of sowing (Fig. 7). Correlation studies revealed highly significant correlation of the seed yield with chlorophyll content in seed filling stage after the spray treatments, pollen viability, seed set and membrane stability in seed filling stage after the spray treatments (0.559**, 0.912**, 0.884**, 0.497**, respectively). Foliar spray of the osmoprotectants had

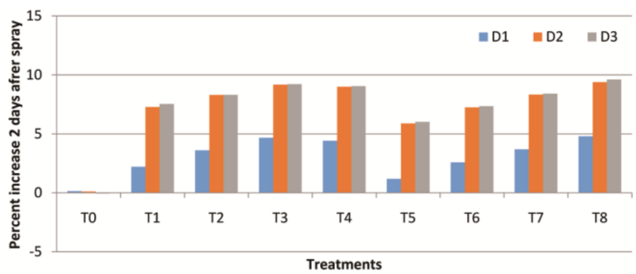

Fig. 1 — Percent increase in leaf chlorophyll content 2 days after spray during vegetative stage of rice cv. Naveen due to foliar spray of osmoprotectants under high temperature stress

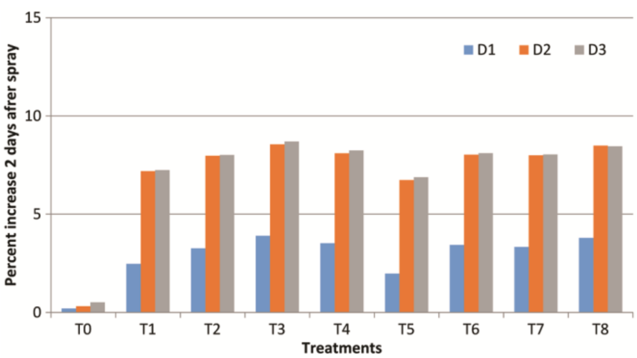

Fig. 2 — Percent increase in leaf chlorophyll content 2 days after spray during seed filling stage of rice cv. Naveen due to foliar spray of osmoprotectants under high temperature stress

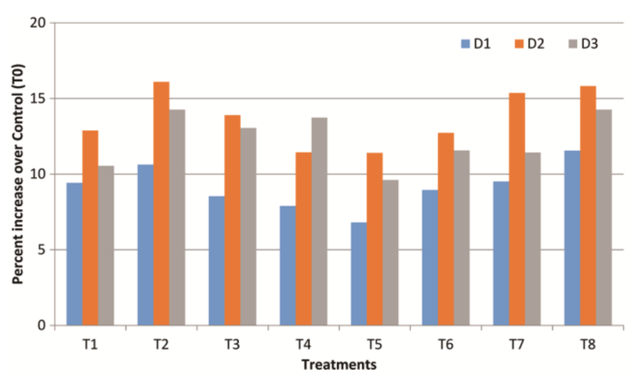

Fig. 3 — Percent increase in pollen viability of rice cv. Naveen over Control as influenced by foliar spray of osmoprotectants under high temperature stress

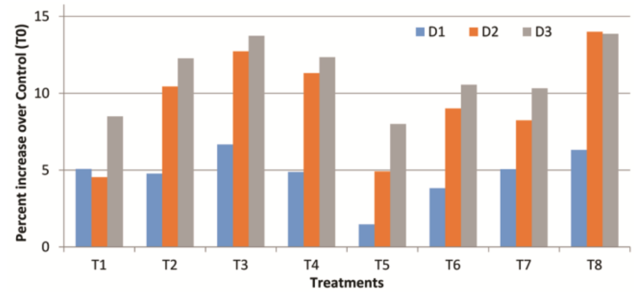

Fig. 4 — Percent increase in seed set of rice cv. Naveen over Control as influenced by foliar spray of osmoprotectants under high temperature stress

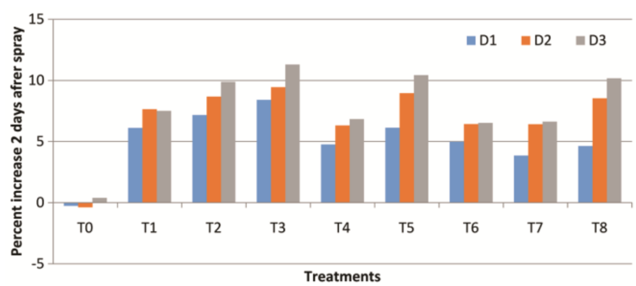

Fig. 5 — Percent increase in membrane stability index 2 days after spray during vegetative stage of rice cv. Naveen due to foliar spray of osmoprotectants under high temperature stress

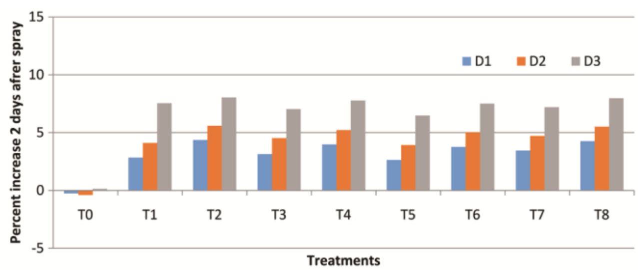

Fig. 6 — Percent increase in membrane stability index 2 days after spray during seed filling stage of rice cv. Naveen due to foliar spray of osmoprotectants under high temperature stress

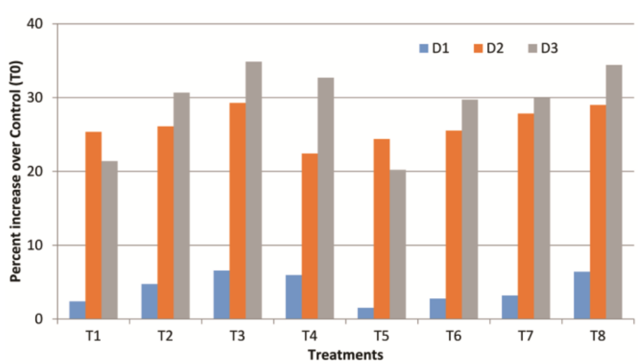

Fig. 7 — Percent increase in seed yield of rice cv. Naveen over Control as influenced by foliar spray of osmoprotectants under high temperature stress

a positive influence on the seed yield attributing characters of rice, which corroborates the findings of previous workers. Glycine betaine is a low molecular weight organic compound, which has been successfully applied to induce high temperature tolerance in plants. Capacity to synthesize glycine betaine under stress conditions differs from species to species[17]. In assessing the functional significance of accumulation of compatible solutes, it is suggested that proline or glycine betaine synthesis may buffer

Table 3 — Membrane stability index, seed yield and 1000-seed weight of rice cv. Naveen as influenced by date of sowing and foliar application of osmoprotectants

Treatments	Membrane stability index (%) during vegetative stage		Membrane stability index (%) during seed filling stage		Seed yield (q/ha)	1000-seed weight (g)
	Before spray	2 days after spray	Before spray	2 days after spray		
D_1	77.61	85.59	87.67	89.08	53.76	22.62
D_2	78.48	85.86	87.79	89.28	48.99	20.27
D_3	78.72	86.13	88.07	89.58	44.51	19.36
S.E.m (±)	0.436	0.377	0.116	0.178	0.120	0.131
$CD_{0.05}$	NS	NS	NS	NS	0.471	0.513
T_0	78.83	77.80	76.50	74.93	42.29	18.76
T_1	78.63	85.10	87.70	89.70	48.58	20.80
T_2	78.67	88.90	91.23	92.90	50.18	21.23
T_3	78.97	85.67	88.53	90.30	51.41	21.51
T_4	77.13	88.13	90.20	91.90	50.14	20.61
T_5	78.73	83.80	86.77	89.13	48.16	20.60
T_6	77.73	87.60	89.67	91.47	49.65	20.93
T_7	77.80	87.17	89.20	90.93	50.06	20.89
T_8	77.93	88.57	90.77	92.53	51.29	21.43
S.E.m (±)	0.605	0.604	0.610	0.444	0.378	0.171
$CD_{0.05}$	NS	1.717	1.735	1.262	1.075	0.487
D_1T_0	79.40	78.40	77.60	75.70	51.83	20.97
D_1T_1	77.50	84.80	87.20	89.30	53.07	22.67
D_1T_2	78.60	88.60	90.80	92.60	54.28	22.93
D_1T_3	78.70	85.40	88.30	89.90	55.24	23.27
D_1T_4	74.50	87.60	89.80	91.60	54.92	22.07
D_1T_5	76.30	83.50	86.60	88.70	52.61	22.40
D_1T_6	77.20	87.10	89.40	91.10	53.26	22.73
D_1T_7	78.40	86.70	88.80	90.50	53.48	23.20
D_1T_8	77.90	88.20	90.50	92.30	55.15	23.30
D_2T_0	80.20	77.70	76.10	74.80	39.72	18.07
D_2T_1	79.80	85.10	87.70	89.70	49.79	20.40
D_2T_2	79.50	88.90	91.30	92.90	50.09	20.90
D_2T_3	78.40	85.70	88.50	90.30	51.35	21.10
D_2T_4	77.60	88.10	90.10	91.80	48.63	20.30
D_2T_5	79.30	83.80	86.80	89.10	49.41	20.20
D_2T_6	77.80	87.70	89.70	91.50	49.86	20.48
D_2T_7	76.50	87.10	89.20	90.90	50.78	20.18
D_2T_8	77.20	88.60	90.70	92.50	51.24	20.80
D_3T_0	76.90	77.30	75.80	74.30	35.33	17.23
D_3T_1	78.60	85.40	88.20	90.10	42.89	19.33
D_3T_2	77.90	89.20	91.60	93.20	46.17	19.87
D_3T_3	79.80	85.90	88.80	90.70	47.65	20.15
D_3T_4	79.30	88.70	90.70	92.30	46.88	19.46
D_3T_5	80.60	84.10	86.90	89.60	42.47	19.19
D_3T_6	78.20	88.00	89.90	91.80	45.83	19.58
D_3T_7	78.50	87.70	89.60	91.40	45.91	19.28
D_3T_8	78.70	88.90	91.10	92.80	47.49	20.19
S.E.m (±)	1.048	1.046	1.057	0.769	0.655	0.296
$CD_{0.05}$	NS	NS	NS	NS	1.862	NS

cellular redox potential under heat and other environmental stresses[18]. Ascorbic acid (Vitamin C) acts as a modulator of plant development through hormone signalling and as coenzyme in reactions by which carbohydrates and proteins are metabolized. They catch the free radicals or the reactive oxygen species produced during altered photosynthesis and respiration process under heat stress. They also regulate photosynthesis flowering and senescence[19] under elevated temperature. High night temperature was reported to increase the malondialdehyde (MDA) content in two varieties of rice, while exogenous application of ascorbic acid reduced it almost to the level of control night temperature[20]. Tocopherol (Vitamin E) is a lipophylic antioxidant which establishes membranes, scavenges various ROS[21] and preserves PS-II photo inactivation and membrane lipids from photo oxidation. Brassinolide is a relatively new phytohormone with pleiotropic effect[22] and influences varied physiological processes like germination, growth, flowering and senescence and confers resistance to plants against various abiotic stresses, through its induced effects on membrane stability and osmo-regulation[23]. Citric acid increases high temperature stress tolerance during different growth stages of plants. The main functions of these sprayed compounds are protection of chlorophyll, detoxification of reactive oxygen species, maintenance of favourable balance of water and photosynthesis in plants under stressful condition. Lower spikelet fertility at elevated temperature has been reported to result in fewer filled grains, lower grain weight per panicle, and decreased harvest index in rice[13].

The first date of sowing (D_1) produced seeds with significantly higher 1000-seed weight (22.62 g), compared to the second and third dates of sowing (20.27 g and 19.36 g). Among the treatments, significantly higher 1000-seed weights were recorded in T_3 and T_8 (21.51 g and 21.43 g, respectively), while the untreated control produced seeds with the least 1000-seed weight (18.76 g). The other treatments were also able to significantly improve the seed weight (Fig. 8). Seeds produced from the first date of sowing recorded higher germination and seed vigour (Table 4). All the treatments were able to improve germination and vigour of seeds from three dates of sowing. The treatments T_3, T_7 and T_8 gave the highest improvement in seed germination over control (T_0) (Fig. 9).

For seeds subjected to accelerated ageing treatment, T_3 (800 ppm salicylic acid) recorded highest germination followed by T_8 (10 ppm brassinolides) (Table 3). Moreover, the two treatments produced highest increase in germination after accelerated ageing, as compared to the Control (T_0) (Fig. 10). Electrical conductivity (EC) of seed leachate was neither influenced by the date of sowing nor by any of the treatment sprays (Table 4).

Delayed sowing of rice in rabi-summer season adversely affects the crop due to exposure to high temperatures during flowering and seed filling stages.

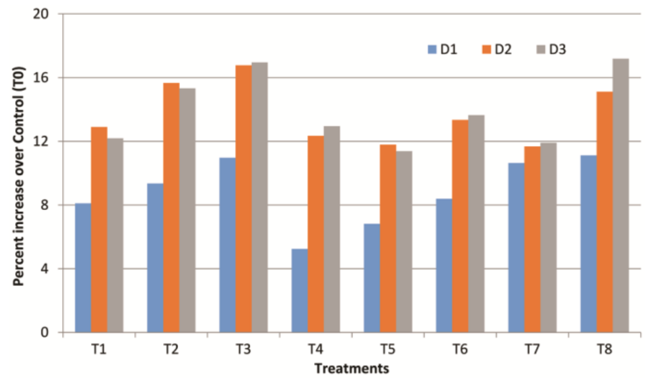

Fig. 8 — Percent increase in 1000-seed weight of rice cv. Naveen over Control as influenced by foliar spray of osmoprotectants under high temperature stress

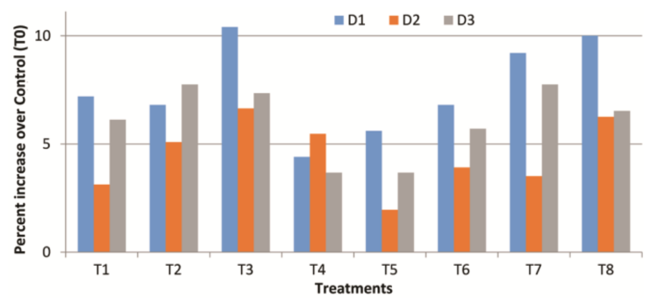

Fig. 9 — Percent increase in seed germination of rice cv. Naveen over Control as influenced by foliar spray of osmoprotectants under high temperature stress

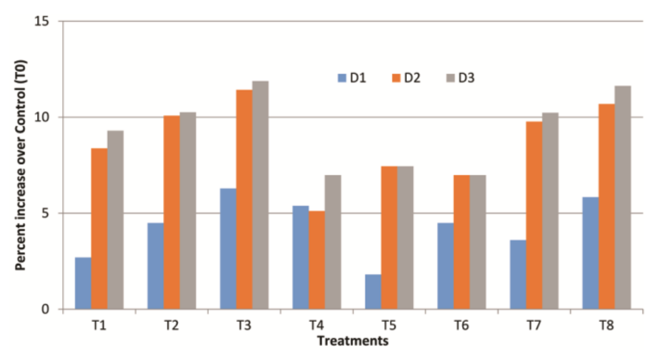

Fig. 10 — Percent increase in seed germination after accelerated ageing of rice cv. Naveen over Control as influenced by foliar spray of osmoprotectants under high temperature stress

The effects of high temperature is manifested through lower chlorophyll content of leaves, reduced membrane stability, decreased pollen viability and seed set, and ultimately lower seed yield. Exposure to high temperature also lowers 1000-seed weight in the crop. In case a long duration rice cultivar was grown in kharif season and the sowing of rabi rice crop is delayed, farmers may choose heat-tolerant varieties to minimize the yield losses. The present study demonstrated the role of a few osmoprotectants in

Table 4 — Seed germination and vigour of rice cv. Naveen as influenced by date of sowing and foliar application of osmoprotectants

Treatments	Seed germination (%)	Seedling length (cm)	Seed Vigour Index-I	Seedling dry weight (g)	Seed Vigour Index-II	Seed germination (%) after AA	EC of seed leachate (dS/m)
D_1	88.93 (9.43)	31.50	2801.8	0.077	6.85	77.19 (8.78)	0.155
D_2	88.74 (9.42)	31.04	2755.7	0.077	6.86	77.23 (8.79)	0.156
D_3	86.08 (9.28)	30.52	2628.4	0.079	6.81	77.62 (8.81)	0.159
S.E.m (±)	0.013	0.068	13.04	0.0004	0.027	0.028	0.0012
$CD_{0.05}$	0.049	0.268	51.19	0.0015	NS	NS	NS
T_0	83.44 (9.13)	29.45	2458.3	0.074	6.18	72.56 (8.52)	0.152
T_1	88.00 (9.38)	30.88	2717.7	0.078	6.84	77.44 (8.80)	0.157
T_2	88.89 (9.43)	31.35	2786.7	0.078	6.93	78.53 (8.86)	0.156
T_3	90.22 (9.50)	31.54	2846.5	0.080	7.22	79.68 (8.92)	0.161
T_4	87.22 (9.34)	31.17	2719.3	0.078	6.77	76.78 (8.76)	0.156
T_5	86.56 (9.30)	30.62	2650.6	0.077	6.69	76.56 (8.75)	0.158
T_6	88.00 (9.38)	30.65	2697.2	0.078	6.86	77.00 (8.77)	0.156
T_7	89.11 (9.44)	31.61	2817.0	0.078	6.98	78.22 (8.84)	0.158
T_8	89.78 (9.47)	31.90	2864.7	0.079	7.09	79.33 (8.91)	0.155
S.E.m (±)	0.025	0.183	21.81	0.0007	0.085	0.060	0.0027
$CD_{0.05}$	0.071	0.522	62.01	0.0019	0.241	0.170	NS
D_1T_0	83.33 (9.13)	30.49	2540.7	0.072	6.00	74.33 (8.62)	0.152
D_1T_1	89.33 (9.45)	31.24	2790.5	0.078	6.97	76.33 (8.74)	0.154
D_1T_2	89.00 (9.43)	31.69	2820.4	0.079	7.03	77.67 (8.81)	0.155
D_1T_3	92.00 (9.59)	31.89	2934.4	0.078	7.18	79.00 (8.89)	0.156
D_1T_4	87.00 (9.33)	31.92	2776.9	0.076	6.61	78.33 (8.85)	0.157
D_1T_5	88.00 (9.38)	30.97	2725.5	0.077	6.78	75.67 (8.70)	0.153
D_1T_6	89.00 (9.43)	31.66	2817.7	0.077	6.85	77.67 (8.81)	0.157
D_1T_7	91.00 (9.54)	31.53	2869.4	0.079	7.19	77.00 (8.77)	0.156
D_1T_8	91.67 (9.57)	32.08	2940.9	0.077	7.06	78.67 (8.87)	0.157
D_2T_0	85.33 (9.24)	29.36	2505.2	0.075	6.40	71.67 (8.47)	0.153
D_2T_1	88.00 (9.38)	30.81	2711.3	0.077	6.78	77.67 (8.81)	0.158
D_2T_2	89.67 (9.47)	31.55	2828.8	0.077	6.91	78.89 (8.88)	0.159
D_2T_3	91.00 (9.54)	31.71	2885.5	0.079	7.19	79.85 (8.92)	0.158
D_2T_4	90.00 (9.49)	30.89	2780.3	0.078	7.02	75.33 (8.68)	0.153
D_2T_5	87.00 (9.33)	30.65	2666.8	0.076	6.61	77.00 (8.77)	0.156
D_2T_6	88.67 (9.42)	30.01	2660.9	0.078	6.92	76.67 (8.76)	0.154
D_2T_7	88.33 (9.40)	32.18	2842.4	0.077	6.80	78.67 (8.87)	0.157
D_2T_8	90.67 (9.52)	32.21	2920.3	0.078	7.07	79.33 (8.91)	0.153
D_3T_0	81.67 (9.04)	28.51	2328.9	0.075	6.13	71.67 (8.47)	0.150
D_3T_1	86.67 (9.31)	30.59	2651.2	0.078	6.76	78.33 (8.85)	0.160
D_3T_2	88.00 (9.38)	30.81	2711.0	0.078	6.86	79.02 (8.89)	0.153
D_3T_3	87.67 (9.36)	31.02	2719.6	0.083	7.28	80.18 (8.95)	0.168
D_3T_4	84.67 (9.20)	30.71	2600.6	0.079	6.69	76.67 (8.76)	0.159
D_3T_5	84.67 (9.20)	30.23	2559.6	0.079	6.69	77.00 (8.77)	0.164
D_3T_6	86.33 (9.29)	30.27	2612.8	0.079	6.82	76.67 (8.76)	0.158
D_3T_7	88.00 (9.38)	31.13	2739.4	0.079	6.95	79.00 (8.89)	0.160
D_3T_8	87.00 (9.33)	31.41	2732.7	0.082	7.14	80.00 (8.94)	0.156
S.E.m (±)	0.043	0.318	37.77	0.0012	0.147	0.104	0.0047
$CD_{0.05}$	NS	NS	NS	NS	NS	NS	NS

N.B.: Figures in the parenthesis are square root transformed values.

enhancing seed yield and quality of rice cv. Naveen under high temperature stress. Among various foliar spray treatments done at vegetative and seed filling stages, 800 ppm salicylic acid, 10 ppm ascorbic acid + 1.3% citric acid and 10 ppm brassinolides proved to be quite effective in alleviating the adverse effects of high temperature during flowering and seed set, through increased chlorophyll content of leaves, improved membrane stability, higher pollen viability and seed set. All these parameters had a positive influence on seed yield and quality of rice.

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