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Exogenous application of osmoprotectants for improving crop physiological parameters and seed yield of rice under high temperature stress

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Abstract
An investigation was conducted during summer season of 2016-17 and 2017-18 in the Department of Seed Science and Technology, College of Agriculture, OUAT, Bhubaneswar to study the role of osmoprotectants on rice crop physiology and seed yield under high temperature stress. Rice variety Naveen (120 days duration) was chosen for the experiment. The experiment was laid out in SPD, the main plot factor being date 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. The foliar sprays included Glycine betaine 600 ppm (T_1), Salicylic acid 400 ppm (T_2), Salicylic acid 800 ppm (T_3), Ascorbic acid 10 ppm + Citric acid 1.3% (T_4), α-Tocopherol 150 ppm (T_5), KCl 1% (T_6), Brassinolides 5 ppm (T_7) and Brassinolides 10 ppm (T_8). One control (T_0) was also taken in which equal volume of water was sprayed. Significantly higher superoxide dismutase (SOD), peroxidase and catalase activity of leaves, proline content of leaves, pollen viability and seed set were recorded from leaves of first date of sowing both at vegetative and seed filling stages, as compared to the second and third dates of sowing. The treatments T_2 and T_8 were most effective in increasing the pollen viability to almost at par with the Control from the first date of sowing (D_1T_0). Similar trend was observed with regards to percent seed set and 1000-seed weight. Highest seed yield was obtained from the first date of sowing, while it declined as the sowing was delayed. Among the treatments, T_8 and T_3 gave the highest seed yields (5243 kg/ha and 5195 kg/ha, respectively), followed by T_2 and T_4 (5193 kg/ha and 5147 kg/ha, respectively). The treatments T_2 and T_8 gave highest harvest index as compared to untreated control. From the experiment, it can be concluded that rice seed production is adversely affected under heat stress leading to lower seed yield and quality. Spray of chemicals such as Salicylic acid 400 ppm, Salicylic acid 800 ppm, Brassinolides 10 ppm or Ascorbic acid 10 ppm + Citric acid 1.3% at vegetative and seed filling stages was effective in mitigating the effects of heat stress on physiological parameters, yield attributing characters, seed yield and quality to a considerable extent.

Keywords: Rice, heat stress, osmoprotectant, seed yield

Introduction
Climate change is harshly affecting cereal production all over the world through increased temperature and CO_2 concentration, which is one of the main causes of heat stress. Rice is the second most important cereal crop in the world, after maize. Major rice producing countries are in Asia, with the farmers of the sub-continent 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 this goal. Though high temperature and other abiotic stresses are limiting factors for future crop production goals, crop productivity many a times also suffers from random environmental fluctuation.

Environmental stresses lead to the generation of reactive oxygen species (ROS). Heat stress can induce oxidative stress along with tissue dehydration. Generation and reactions of ROS, such as singlet oxygen, superoxide radical (O_2-), hydrogen peroxide (H_2O_2), and hydroxyl radical (OH^-), are common events during cellular injury by high temperature (Liu and Huang, 2000) [8]. Autocatalytic peroxidation of membrane lipids and pigments by ROS leads to loss of membrane semi-permeability (Xu *et al*., 2006) [14]. The hydroxyl radical (OH^-) can damage chlorophyll, protein, DNA, lipids, and other important macromolecules, thus fatally affecting plant metabolism and limiting growth and yield (Sairam and Tyagi, 2004) [13]. Yield of dry season rice crop decreased by 15% for each 1^0C increase in mean temperature during the growing season (Peng *et al*., 2004) [10].

Reduction in yield of rice facing high temperature stress due to drier and warmer climate or late sowing can be minimised by exogenous foliar spray of some osmoprotectants.

Common osmoprotectants include Glycine betaine, Salicylic acid, Ascorbic acid, Citric acid, α-Tocopherol, Potassium chloride, Brassinolides, etc. 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 electrolytic leakage and maintaining or sometimes increasing antioxidant enzyme activities, increasing proline content and consequently the yield of the crop.

Keeping in mind the above problem relating to rice production under high temperature stress, the present investigation was undertaken to study the efficiency of some osmoprotectants in improving crop physiological parameters and seed yield of rice. The main focus was to reduce the impact of heat stress in rice during vegetative and seed filling stage.

Materials and Methods

The field experiment was conducted during summer season of 2016-17 and 2017-18 in the Department of Seed Science and Technology, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, to study the role of some osmoprotectants on crop physiology and seed yield of rice grown under heat stress. Rice variety Naveen (120 days duration) was chosen for the experiment. The field experiment was laid out in Split Plot Design, with three replications, the main plot factor being date 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). The foliar sprays included Glycine betaine 600 ppm (T_1), Salicylic acid 400 ppm (T_2), Salicylic acid 800 ppm (T_3), Ascorbic acid 10 ppm + Citric acid 1.3% (T_4), α-Tocopherol 150 ppm (T_5), KCl 1% (T_6), Brassinolides 5 ppm (T_7) and Brassinolides 10 ppm (T_8). One control (T_0) was also taken in which equal volume of water was sprayed. Observations on superoxide dismutase (SOD) activity (units/mg of soluble protein/min) (Dhindsa *et al*., 1981) [5], peroxidase (POD) activity (units/mg of soluble protein/min) (Castillo *et al*., 1984) [4], catalase (CAT) activity (units/mg of soluble protein/min) (Aebi *et al*., 1984) [1] and proline content (µg/g of FW) (Bates *et al.*, 1973) [3] of leaves were recorded before foliar spray and 2 days after spray of chemicals during vegetative and seed filling stage. Seed yield attributing parameters and seed yield were also recorded.

Results and Discussion

Observations on various crop physiological and yield attributing parameters as well as seed yield were taken and the pooled analysis values have been presented in Tables 1 to 12. Foliar application of osmoprotectants showed positive effects in mitigating high temperature stress. The possible mechanisms of positive effects of osmoprotectants are discussed hereunder. With delay in sowing time, there was considerable decrease in the SOD, POD and CAT activity of the leaves (Table 2). Spray of KCl 1% (T_6) recorded significantly highest SOD activity, followed by Ascorbic acid 10 ppm + Citric acid 1.3% (T_4) at both the stages of observation. The treatments T_4, T_6 and T_8 recorded highest percent increase in SOD activity of leaves during vegetative and seed filling stages. During vegetative and seed filling stage, maximum POD activity was recorded from spray treatment with Ascorbic acid 10 ppm + Citric acid 1.3% (T_4) followed by Brassinolides 10 ppm (T_8). During vegetative and seed filling stage, significantly higher CAT activity was recorded from spray treatment with Ascorbic acid 10 ppm + Citric acid 1.3% (T_4) followed by Brassinolides 10 ppm (T_8). The treatments T_1, T_4 and T_8 recorded highest percent increase in POD and CAT activity of leaves during vegetative and seed filling stages. Ascorbic acid (Vitamin C) is water soluble and 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 (Barth *et al*., 2006) [2] under elevated temperature. Ascorbic acid-sprayed plants can postpone the leaf senescence by peroxide/phenolic/ascorbate system which is involved in scavenging the ROS produced during leaf senescence (El-Aziz *et al*., 2009) [6]. Ascobin (compound composed of ascorbic acid and citric acid) as one of exogenous protectants which could partially alleviate the harmful effect of certain abiotic stresses like heat, salinity *etc*. (Sadak *et al*., 2015) [12]. In rice during anthesis, plants subjected to temperature of both 35^{0}C and 40^{0}C showed increased antioxidant enzyme such as SOD and CAT with maximum activities in tolerant genotypes at 40^{0}C and maximum activity of susceptible at 35^{0}C in spikelets (Smruti *et al.*, 2013). It was also reported that in rice antioxidant isozymes can be used as a biomarker in the spikelets for characterizing high temperature stress tolerance. The antioxidant defence mechanism plays an important role in the heat stress tolerance of wheat genotypes and it was observed that the activities of SOD, CAT and POD increased significantly at all stages of growth in heat tolerant cultivar (C 306) in response to heat stress treatment, while susceptible cultivar (PBW 343) showed a significant reduction in CAT and POD activities under high temperature (Babu and Devraj, 2008).

Highest proline content of leaves during vegetative stage was recorded from spray treatment with Brassinolides 10 ppm (T_8), followed by Ascorbic acid 10 ppm + Citric acid 1.3% (T_4). During seed filling stage, treatment T_2 (Salicylic acid 400 ppm) resulted significantly highest proline content followed by treatment T_3 (Salicylic acid 800 ppm). The treatments T_2, T_3 and T_8 recorded highest percent increase in proline content of leaves during vegetative and seed filling stages. Tocopherol (Vitamin E) is a lipophylic antioxidant which establishes membranes, scavenges various ROS (Maeda and Dellapenna, 2007) [9] and preserves PS II photo inactivation and membrane lipids from photo oxidation. Accumulation of proline is very useful and plays a highly beneficial role in plants exposed to various stress conditions (Verbruggen and Hermans, 2008). Changes in the concentration of proline have been observed in rice exposed to drought stress (Lum *et al*., 2014 and Maisura *et al*., 2014).

Significantly higher pollen viability (%) was recorded with first date of sowing, as compared to second and third dates of sowing. With delay in sowing time, there was gradual decrease in pollen viability. High temperatures ≥ 30^{0}C have been reported to cause pollen sterility in rice. Among the treatments, pollen viability was highest in T_8 (Brassinolides 10 ppm), followed by T_2 (Salicylic acid 400 ppm), though both the treatments were statistically at par. The treatment T_8 and T_2 recorded highest percent increase in pollen viability over untreated Control. There was gradual decrease in seed set as the sowing was delayed. Among the treatments, seed set was highest in T_8 (Brassinolides 10 ppm).

With delay in sowing, there was drastic reduction in the seed yield. Among the treatments, T_8 and T_3 gave the highest seed yields (5243 kg/ha and 5195 kg/ha, respectively), followed by T_2 and T_4 (5193 kg/ha and 5147 kg/ha, respectively). The seed yields from D_3T_0 and D_2T_0 (3661 kg/ha and 4124 kg/ha, respectively) were significantly lower than all the other treatments, as well as D_1T_0 (5259 kg/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 second and third dates of sowing. Foliar spray of the osmoprotectants had a positive influence on the seed yield attributing characters of rice. The first date of sowing produced seeds with significantly higher 1000-seed weight, compared to second and third dates of sowing. Among the treatments, significantly higher 1000-seed weights were recorded from spray of Salicylic acid 400 ppm, Salicylic acid 800 ppm and Brassinolides 10 ppm, while the untreated Control produced seeds with lowest 1000-seed weight. Highest harvest index was obtained from first date of sowing as compared to second and third date of sowing. Foliar application of Salicylic acid 800 ppm recorded highest harvest index followed by Brassinolides 10 ppm, though the difference among the treatments were statistically non-significant.

From the present investigation, it can be concluded that rice seed production is adversely affected under heat stress leading to lower seed yield. High temperatures, especially during panicle development, anthesis and seed set, adversely affect crop physiological parameters and yield attributing parameters, causing drastic reduction in seed yield of summer rice. In case of late sowing of the crop in summer and if the variety is a heat susceptible one, spray of certain chemicals such as Salicylic acid 400 ppm, Salicylic acid 800 ppm, Brassinolides 10 ppm or Ascorbic acid 10 ppm + Citric acid 1.3% at vegetative and seed filling stages can be effective in mitigating the effects of heat stress on crop physiological parameters, yield attributing parameters and seed yield to a considerable extent.

Table 1: Leaf superoxide dismutase (SOD) activity during vegetative stage of summer rice grown under heat stress as influenced by spray of osmo protectants

Treatment	Leaf SOD activity (units/mg of soluble protein/min) during vegetative stage							
	Before spray				Two days after spray			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
T_0 : Control	7.21	6.84	6.08	6.71	7.22	6.86	6.08	6.72
T_1 : GB 600	7.27	6.91	6.24	6.80	7.30	6.95	6.28	6.84
T_2 : SA 400	7.29	6.95	6.16	6.80	7.34	7.00	6.21	6.85
T_3 : SA 800	7.23	6.87	6.13	6.74	7.28	6.92	6.17	6.79
T_4 : AA + CA	7.33	6.98	6.33	6.88	7.40	7.05	6.41	6.95
T_5 : α-T	7.31	6.97	6.28	6.85	7.33	7.01	6.32	6.88
T_6 : KCl	7.36	7.10	6.37	6.91	7.44	7.08	6.46	6.99
T_7 : Br 5	7.24	6.86	6.10	6.73	7.29	6.91	6.15	6.78
T_8 : Br 10	7.26	6.89	6.19	6.78	7.33	6.95	6.25	6.84
Mean	7.28	6.92	6.21	6.80	7.32	6.97	6.26	6.85
	D	**T**	**D within T**	**T within D**	**D**	**T**	**D within T**	**T within D**
SEm (±)	0.007	0.012	0.333	0.014	0.003	0.008	0.333	0.009
$CD_{0.05}$	0.02	0.03	0.95	0.04	0.01	0.02	0.94	0.02

Table 2: Leaf superoxide dismutase (SOD) activity during seed filling stage of summer rice grown under heat stress as influenced by spray of osmo protectants

Treatment	Leaf SOD activity (units/mg of soluble protein/min) during seed filling stage							
	Before spray				Two days after spray			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
T_0 : Control	7.10	6.75	6.05	6.63	7.11	6.77	6.07	6.65
T_1 : GB 600	7.15	6.82	6.16	6.71	7.18	6.86	6.20	6.74
T_2 : SA 400	7.18	6.84	6.12	6.71	7.22	6.89	6.17	6.76
T_3 : SA 800	7.12	6.80	6.10	6.67	7.16	6.84	6.14	6.71
T_4 : AA + CA	7.24	6.91	6.25	6.80	7.30	6.98	6.32	6.87
T_5 : α-T	7.15	6.83	6.19	6.72	7.17	6.85	6.22	6.75
T_6 : KCl	7.26	6.92	6.30	6.82	7.34	7.10	6.38	6.90
T_7 : Br 5	7.16	6.82	6.12	6.70	7.20	6.88	6.18	6.75
T_8 : Br 10	7.18	6.84	6.17	6.73	7.24	6.90	6.23	6.79
Mean	7.17	6.83	6.16	6.72	7.21	6.88	6.21	6.77
	D	**T**	**D within T**	**T within D**	**D**	**T**	**D within T**	**T within D**
SEm (±)	0.007	0.007	0.333	0.010	0.003	0.006	0.333	0.007
$CD_{0.05}$	0.02	0.02	0.98	0.03	0.01	0.02	0.95	0.02

Table 3: Leaf peroxidase activity during vegetative stage of summer rice grown under heat stress as influenced by spray of osmo protectants

Treatment	Leaf peroxidase activity (units/mg of soluble protein/min) during vegetative stage							
	Before spray				Two days after spray			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
T_0 : Control	19.99	19.63	19.09	19.57	20.00	19.65	19.12	19.59
T_1 : GB 600	20.11	19.73	19.22	19.68	20.24	19.87	19.38	19.83
T_2 : SA 400	20.04	19.67	19.16	19.62	20.13	19.77	19.28	19.72
T_3 : SA 800	20.00	19.65	19.13	19.59	20.06	19.72	19.22	19.66
T_4 : AA + CA	20.16	19.80	19.31	19.76	20.33	19.99	19.50	19.94
T_5 : α-T	20.01	19.70	19.23	19.65	20.08	19.78	19.33	19.73
T_6 : KCl	20.07	19.74	19.25	19.69	20.17	19.85	19.38	19.80
T_7 : Br 5	20.10	19.72	19.24	19.68	20.20	19.84	19.39	19.81
T_8 : Br 10	20.13	19.76	19.24	19.71	20.29	19.92	19.42	19.88
Mean	20.07	19.71	19.21	19.66	20.17	19.82	19.33	19.77
	D	**T**	**D within T**	**T within D**	**D**	**T**	**D within T**	**T within D**
SEm (±)	0.006	0.008	0.333	0.010	0.003	0.006	0.333	0.007
$CD_{0.05}$	0.02	0.02	0.96	0.03	0.01	0.02	0.95	0.02

Table 4: Leaf peroxidase activity during seed filling stage of summer rice grown under heat stress as influenced by spray of osmo protectants

Treatment	Leaf peroxidase activity (units/mg of soluble protein/min) during seed filling stage							
	Before spray				Two days after spray			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
T_0 : Control	19.90	19.58	19.03	19.50	19.91	19.60	19.06	19.52
T_1 : GB 600	20.08	19.72	19.20	19.66	20.23	19.87	19.36	19.82
T_2 : SA 400	20.00	19.66	19.14	19.60	20.10	19.78	19.27	19.72
T_3 : SA 800	19.95	19.62	19.12	19.56	20.01	19.71	19.22	19.65
T_4 : AA + CA	20.13	19.80	19.26	19.73	20.31	19.98	19.45	19.91
T_5 : α-T	19.97	19.64	19.12	19.58	20.06	19.73	19.23	19.67
T_6 : KCl	20.02	19.67	19.17	19.62	20.14	19.81	19.31	19.75
T_7 : Br 5	20.05	19.70	19.18	19.64	20.19	19.85	19.33	19.79
T_8 : Br 10	20.11	19.75	19.22	19.69	20.27	19.92	19.39	19.86
Mean	20.02	19.68	19.16	19.62	20.13	19.80	19.29	19.74
	D	**T**	**D within T**	**T within D**	**D**	**T**	**D within T**	**T within D**
SEm (±)	0.005	0.007	0.333	0.009	0.004	0.007	0.333	0.008
$CD_{0.05}$	0.02	0.02	NS	NS	0.01	0.02	0.95	0.02

Table 5: Leaf catalase activity during vegetative stage of summer rice grown under heat stress as influenced by spray of osmo protectants

Treatment	Leaf catalase activity (units/mg of soluble protein/min) during vegetative stage							
	Before spray				Two days after spray			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
T_0 : Control	2.80	2.41	1.89	2.36	2.80	2.42	1.90	2.37
T_1 : GB 600	2.93	2.55	2.03	2.50	2.99	2.61	2.08	2.56
T_2 : SA 400	2.87	2.48	2.00	2.43	2.90	2.52	1.99	2.47
T_3 : SA 800	2.85	2.46	1.93	2.41	2.88	2.49	1.96	2.44
T_4 : AA + CA	2.96	2.60	2.07	2.54	3.05	2.68	2.14	2.62
T_5 : α-T	2.82	2.43	1.91	2.38	2.84	2.45	1.93	2.40
T_6 : KCl	2.89	2.51	1.98	2.46	2.93	2.56	2.02	2.50
T_7 : Br 5	2.91	2.53	2.00	2.48	2.97	2.59	2.04	2.53
T_8 : Br 10	2.95	2.58	2.05	2.52	3.02	2.65	2.11	2.59
Mean	2.88	2.50	1.98	2.45	2.93	2.55	2.02	2.50
	D	**T**	**D within T**	**T within D**	**D**	**T**	**D within T**	**T within D**
SEm (±)	0.003	0.005	0.333	0.005	0.005	0.006	0.333	0.008
$CD_{0.05}$	0.01	0.01	NS	NS	0.02	0.02	NS	NS

Table 6: Leaf catalase activity during seed filling stage of summer rice grown under heat stress as influenced by spray of osmo protectants

Treatment	Leaf catalase activity (units/mg of soluble protein/min) during seed filling stage							
	Before spray				Two days after spray			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
T_0 : Control	2.64	2.24	1.63	2.17	2.64	2.25	1.63	2.17
T_1 : GB 600	2.80	2.40	1.81	2.33	2.86	2.46	1.86	2.39
T_2 : SA 400	2.73	2.34	1.74	2.27	2.77	2.37	1.77	2.30
T_3 : SA 800	2.72	2.31	1.70	2.24	2.75	2.34	1.73	2.27
T_4 : AA + CA	2.84	2.45	1.86	2.38	2.92	2.53	1.93	2.46
T_5 : α-T	2.69	2.27	1.67	2.21	2.71	2.29	1.69	2.23
T_6 : KCl	2.75	2.36	1.76	2.29	2.80	2.41	1.80	2.33
T_7 : Br 5	2.78	2.38	1.78	2.31	2.84	2.43	1.82	2.36
T_8 : Br 10	2.82	2.42	1.83	2.35	2.89	2.49	1.89	2.42

Mean	2.75	2.35	1.75	2.28	2.79	2.39	1.79	2.33
	D	**T**	**D within T**	**T within D**	**D**	**T**	**D within T**	**T within D**
SEm (±)	0.002	0.004	0.333	0.004	0.003	0.005	0.333	0.006
$CD_{0.05}$	0.01	0.01	0.95	0.01	0.010	0.01	NS	NS

Table 7: Leaf proline content during vegetative stage of summer rice grown under heat stress as influenced by spray of osmo protectants

Treatment	**Leaf proline content (µg/g FW) during vegetative stage**							
	Before spray				**Two days after spray**			
	D_1	**D_2**	**D_3**	**Mean**	**D_1**	**D_2**	**D_3**	**Mean**
T_0 : Control	11.55	11.13	10.77	11.15	11.56	11.14	10.79	11.16
T_1 : GB 600	11.62	11.25	10.88	11.25	11.70	11.33	10.97	11.33
T_2 : SA 400	11.65	11.17	10.85	11.22	11.76	11.30	10.98	11.34
T_3 : SA 800	11.60	11.22	10.87	11.23	11.71	11.34	10.99	11.34
T_4 : AA + CA	11.70	11.25	10.87	11.27	11.77	11.32	10.95	11.35
T_5 : α-T	11.62	11.27	10.92	11.27	11.68	11.33	10.99	11.33
T_6 : KCl	11.68	11.20	10.85	11.24	11.73	11.26	10.91	11.30
T_7 : Br 5	11.63	11.21	10.88	11.24	11.72	11.30	10.98	11.33
T_8 : Br 10	11.67	11.23	10.89	11.26	11.76	11.34	11.01	11.37
Mean	11.63	11.21	10.86	11.24	11.71	11.30	10.95	11.32
	D	**T**	**D within T**	**T within D**	**D**	**T**	**D within T**	**T within D**
SEm (±)	0.004	0.003	0.333	0.005	0.003	0.004	0.333	0.005
$CD_{0.05}$	0.01	0.01	1.00	0.01	0.01	0.01	0.97	0.01

Table 8: Leaf proline content during seed filling stage of summer rice grown under heat stress as influenced by spray of osmo protectants

Treatment	**Leaf proline content (µg/g FW) during seed filling stage**							
	Before spray				**Two days after spray**			
	D_1	**D_2**	**D_3**	**Mean**	**D_1**	**D_2**	**D_3**	**Mean**
T_0 : Control	11.09	10.70	10.43	10.74	11.10	10.72	10.46	10.76
T_1 : GB 600	11.25	10.89	10.42	10.85	11.33	10.97	10.50	10.93
T_2 : SA 400	11.36	11.02	10.54	10.97	11.48	11.14	10.66	11.09
T_3 : SA 800	11.33	11.00	10.50	10.94	11.44	11.11	10.61	11.05
T_4 : AA + CA	11.22	10.85	10.37	10.81	11.28	10.92	10.45	10.88
T_5 : α-T	11.19	10.81	10.35	10.78	11.24	10.88	10.41	10.84
T_6 : KCl	11.17	10.78	10.30	10.75	11.22	10.83	10.36	10.80
T_7 : Br 5	11.27	10.92	10.45	10.88	11.36	11.01	10.54	10.97
T_8 : Br 10	11.29	10.96	10.49	10.91	11.39	11.06	10.59	11.01
Mean	11.24	10.88	10.43	10.85	11.31	10.96	10.51	10.93
	D	**T**	**D within T**	**T within D**	**D**	**T**	**D within T**	**T within D**
SEm (±)	0.002	0.004	0.333	0.005	0.002	0.005	0.333	0.005
$CD_{0.05}$	0.01	0.01	0.96	0.01	0.01	0.01	0.95	0.02

Table 9: Pollen viability of summer rice grown under heat stress as influenced by spray of osmo protectants

Treatment	**Pollen viability (%)**			
	D_1	**D_2**	**D_3**	**Mean**
T_0 : Control	72.88 (58.62)	68.25 (55.73)	62.51 (52.24)	67.88 (55.53)
T_1 : GB 600	79.48 (63.09)	77.70 (61.83)	69.70 (56.61)	75.63 (60.51)
T_2 : SA 400	80.40 (63.74)	79.57 (63.14)	71.84 (57.96)	77.27 (61.61)
T_3 : SA 800	79.30 (62.95)	78.37 (62.29)	71.11 (57.49)	76.26 (60.91)
T_4 : AA + CA	78.38 (62.30)	76.90 (61.29)	71.64 (57.83)	75.64 (60.47)
T_5 : α-T	78.16 (62.16)	76.92 (61.31)	69.02 (56.19)	74.70 (59.88)
T_6 : KCl	79.21 (62.88)	77.57 (61.74)	70.91 (57.36)	75.90 (60.66)
T_7 : Br 5	79.66 (63.21)	79.20 (62.89)	70.11 (56.87)	76.33 (60.99)
T_8 : Br 10	80.61 (63.89)	79.42 (63.04)	73.22 (58.85)	77.75 (61.92)
Mean	78.68 (62.54)	77.10 (61.47)	70.01 (56.82)	75.26 (60.28)
	D	**T**	**D within T**	**T within D**
SEm (±)	0.137	0.260	0.333	0.294
$CD_{0.05}$	0.45	0.73	NS	NS

Figures in the parenthesis are arc sine transformed values

Table 10: Percent seed set of summer rice grown under heat stress as influenced by spray of osmo protectants

Treatment	**Seed set (%)**			
	D_1	**D_2**	**D_3**	**Mean**
T_0 : Control	82.62 (9.09)	81.65 (9.04)	78.51 (8.86)	80.93 (8.99)
T_1 : GB 600	91.01 (9.54)	84.48 (9.19)	84.22 (9.18)	86.57 (9.30)
T_2 : SA 400	92.73 (9.63)	89.52 (9.46)	87.49 (9.35)	89.91 (9.48)
T_3 : SA 800	92.24 (9.60)	89.69 (9.47)	87.60 (9.36)	89.84 (9.48)
T_4 : AA + CA	89.75 (9.47)	89.20 (9.44)	87.14 (9.33)	88.69 (9.42)

T_5 : α-T	88.30 (9.40)	83.51 (9.14)	83.84 (9.16)	85.22 (9.23)
T_6 : KCl	90.39 (9.51)	87.34 (9.35)	86.17 (9.28)	87.96 (9.38)
T_7 : Br 5	91.81 (9.58)	86.63 (9.31)	85.75 (9.26)	88.06 (9.38)
T_8 : Br 10	93.33 (9.66)	91.22 (9.55)	88.18 (9.39)	90.91 (9.53)
Mean	90.24 (9.50)	87.02(9.33)	85.43 (9.24)	87.57 (9.36)
	D	**T**	**D within T**	**T within D**
SEm (±)	0.007	0.014	0.333	0.015
$CD_{0.05}$	0.02	0.04	0.95	0.04

Figures in the parenthesis are square root transformed values

Table 11: 1000-seed weight and seed yield of summer rice grown under heat stress as influenced by spray of osmo protectants

Treatment	1000-seed weight (g)				Seed yield (kg/ha)			
	D_1	**D_2**	**D_3**	**Mean**	**D_1**	**D_2**	**D_3**	**Mean**
T_0 : Control	19.90	19.12	18.58	19.20	5259	4124	3661	4348
T_1 : GB 600	21.50	20.65	19.92	20.69	5482	5118	4335	4978
T_2 : SA 400	22.24	21.58	21.34	21.72	5603	5225	4750	5193
T_3 : SA 800	22.12	21.24	20.98	21.44	5614	5260	4711	5195
T_4 : AA + CA	20.74	20.18	19.99	20.30	5603	5127	4711	5147
T_5 : α-T	21.19	20.43	20.00	20.54	5387	5037	4277	4901
T_6 : KCl	21.80	21.58	20.59	21.32	5501	5156	4590	5083
T_7 : Br 5	22.07	21.17	20.24	21.16	5520	5223	4614	5120
T_8 : Br 10	22.36	21.95	21.20	21.84	5644	5281	4804	5243
Mean	21.55	20.88	20.31	20.91	5513	5061	4495	5023
	D	**T**	**D within T**	**T within D**	**D**	**T**	**D within T**	**T within D**
SEm (±)	0.065	0.120	0.333	0.137	10.9	21.8	33.3	24.4
$CD_{0.05}$	0.21	0.34	NS	NS	36	61	95	68

Table 12: Harvest index of summer rice grown under heat stress as influenced by spray of osmo protectants

Treatment	Harvest index (%)			
	D_1	**D_2**	**D_3**	**Mean**
T_0 : Control	35.3	34.8	34.3	34.8
T_1 : GB 600	41.5	41.2	40.9	41.2
T_2 : SA 400	43.7	43.3	42.9	43.3
T_3 : SA 800	43.5	43.2	42.7	43.1
T_4 : AA + CA	43.1	42.8	42.5	42.8
T_5 : α-T	40.5	40.2	39.9	40.2
T_6 : KCl	42.1	41.7	41.1	41.6
T_7 : Br 5	42.5	42.2	41.7	42.1
T_8 : Br 10	43.7	43.2	42.9	43.3
Mean	41.8	41.4	41.0	41.4
	D	**T**	**D within T**	**T within D**
SEm (±)	0.24	0.32	0.33	0.40
$CD_{0.05}$	NS	0.9	NS	NS

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