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Study the response of Mannitol and Nano Urea to mitigate the adverse effect of terminal heat stress on wheat (*Triticum aestivum* L.)

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Abstract

The present investigation entitled "Study the response of Mannitol and Nano Urea to mitigate the adverse effect of terminal heat stress on wheat (*Triticum aestivum* L.)" was conducted during Rabi season, 2022-23 & 2023-24 at the student instructional farm (SIF) of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya- 224229 (U.P.). The experiment was conducted in Split Plot design with three replications, seven treatments and wheat variety (HD 2967). The observations have been studied on growth, bio-chemical, yield and yield attributes of wheat. Observations were recorded at 60, 90 DAS and at maturity stages for timely sowing (15 November) and late sowing (15 December). However, yield and yield parameters were taken at the time of harvesting of the crop. Foliar spray of mannitol and nano urea were performed well at 30, 60, 90 DAS. Foliar application of nano urea with 25 ppm was recorded superior on plant height (cm), dry weight plant^{-1} (g), chlorophyll content in leaves (Arnon method), Catalase activity (g^{-1} fresh weight min^{-1}), Peroxidase activity (mg g^{-1} fresh weight min^{-1}), Super oxide dismutase activity (mg g^{-1} fresh weight min^{-1}) However, yield and yield attributes viz length of spike, number of tillers plant^{-1}, number of grains spike^{-1}, grain yield plant^{-1} It is concluded from the result that foliar spray of nano urea 25 ppm was found most effective to increasing all characters and yield parameters of wheat.

Keywords: Wheat growth, nano urea, terminal heat stress, mannitol, foliar spray

1. Introduction

Wheat (*Triticum aestivum* L.) is the most important cereal crop. Wheat is classified as belonging to the genus Triticum within the Poaceae family. It is a long-day, annual plant that spreads by itself. Among all the crops grown worldwide, wheat is the most significant food cultivar. For around one third of the world's population, it is a staple food. 21.8% of the total area planted to food grains is made up of wheat crops. Roughly 36 percent of the global population gets its calories exclusively from wheat. For the approximately 4.5 billion people on the planet, it meets their needs for protein (10-12%) and calories (21%). The majority of them are from underdeveloped nations. 2021 saw the cultivation of wheat on 215.9 million hectares worldwide, yielding an output of 765.8 million tons at an average yield of 35.4 qha-1. India produces 109.52 mt and has a productivity of 34.64 qha-1 on an area of around 31.61 mha. Uttar Pradesh's productivity is 32.42 qha-1, its production is 31.16 mt, and its area is around 9.85 mha. Uttar Pradesh leads the nation in both area (32.89%) and wheat output (31.88%) (Agricultural Statistics at a Glance 2021). Hyperthermal circumstances have a significant impact on wheat output and other yield-related characteristics (Gupta *et al*., 2013). According to research, the ideal temperatures for anthesis and grain filling are 23 °C and 21.3 °C, respectively; crops exposed to temperatures higher than these result in lower yields (Farooq *et al*., 2011). In wheat, 20 to 30°C is the ideal temperature for photosynthesis, and any temperature above that quickly reduces the rate of photosynthesis (Narayanan, 2018). The thylakoid membrane and PS-II are the components of the heat-labile cell. Chlorophyll loss results from heat-induced thylakoid destruction (Ni *et al*., 2018). In India as well as many other cereal-growing regions of the world, high temperatures are a key factor in crop yield loss. High temperatures dehydrate plant tissue, which stops plants from growing and developing. Heat stress increases the soil water content threshold *i.e.*, the amount of water that the plant can extract (Haworth *et al*., 2018). High temperature stress often favours accumulation of reactive oxygen species (ROS) such as hydrogen peroxide (H_2O_2), superoxide radical (O^{2-}), hydroxyl ion (OH^-) and oxygen (O^{-1}) in plant tissues (Lai and He, 2016). The reactive oxygen species generated due to stress in chloroplast, mitochondria and peroxisome can disrupt the normal metabolism through oxidative damage of proteins, lipids and nucleic acid leading to damage of cell structure (Qaseem *et al*., 2019). Osmoprotectants or compatible solutes are small molecules having low molecular weight, electrically neutral, highly soluble and non-toxic at molar concentrations (Ahn *et al*., 2011). They help plants to survive in extreme osmotic environment (Lang 2007). Plant stress tolerance has been widely reported to be improved with the exogenous application of mannitol. Mannitol, an important osmolyte, is normally synthesized in large amount in many plant species (Su *et al*., 1999 and Mitoi *et al*., 2009). Nano Urea (Liquid) contains nano scale nitrogen particles which have more surface area Nano urea prepared by nanotechnology contains nano scale particles of Nano Urea. One nano urea liquid particle is 30 nano meters in diameter, with 10,000 times higher surface area to volume size than normal granular urea (Deepika *et al.*, 2022). Average physical size of Nano Urea particles is in the range of 20 -50 nm. Nano Urea contains 4 % nitrogen by weight in its nano form. Nitrogen present in Nano Urea effectively meets the crop nitrogen requirement. It has better use efficiency than conventional urea.

2. Materials and Methods

During the *Rabi* season of 2022-23 & 2023-24, the inquiry was conducted at the Acharya Narendra Deva University of Agriculture and Technology's Student Instructional Farm, Narendra Nagar, Kumarganj, Ayodhya (U.P.). Kumarganj is located at 26.47° north latitude and 81.12° east longitude, at an elevation of 113 meters, in the gangetic alluvium of eastern Uttar Pradesh. The experimental site is located in the Indo-Gangatic plains, in a sub-tropical climate with scorching summers and freezing winters. The monsoon season, which runs from July to September, receives over 80% of the total rainfall, with only a few showers in the winter. The design is Split Plot Design (S.P.D.) with seven treatments, three replications and variety HD 2967. Concentrations of Mannitol (25, 50, 100 ppm) and nano urea (25, 50, 100 ppm) foliar spray along with untreated control. Osmoprotectant and nano urea was sprayed at 52 DAS. The significance of various treatments was judged by The Fisher method of analysis of variance was used to analyze data collected on various growth and yield parameters (Fisher and Yates 1949).

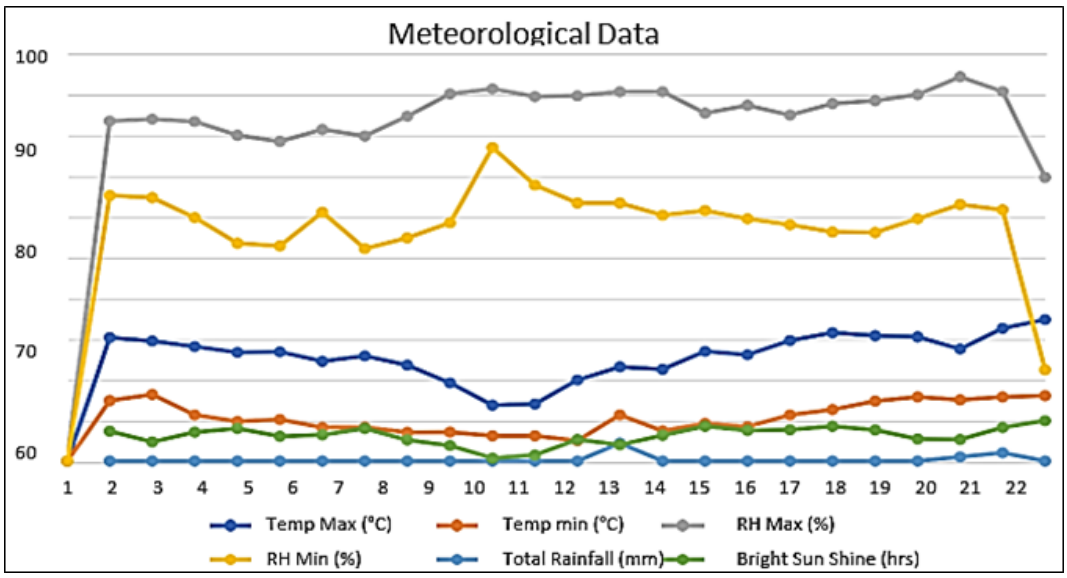

FIG 1: METEOROLOGICAL CHART DURING CROP PERIOD 2022-23 & 2023-24(POOLED)

3. Result and Discussion

3.1 Parameters

3.1.1 Plant Height (cm)

Data in given table on plant height at 30 DAS shows only the response of soil fertility and environmental factors. However, plant height ranges from (29.30 cm) to (31.98 cm) timely sown, (24.63 cm) to (28.61 cm) late sown respectively.

Application of mannitol (T2-25, T3-50, T4-100 ppm) and nano urea (T5-25, T6-50, T7-100 ppm) foliar spray at 45 DAS was found effective in increasing plant height significantly at 60 and at physiological maturity of observations in all the different date of sowing. Maximum plant height at 60 DAS was obtained in T6 (70.92) timely sown, (56.47) late sown followed by T4 (69.24) timely sown, (55.22) late sown respectively as compared to control in different date of sowing. Similarly, at physiological maturity maximum plant height was obtained in T6 (102.09) timely sown, (89.65) late sown followed by T4 (101.88) timely sown, (85.76) late sown sown respectively as compared to control in different date of sowing. The interaction effect of time of sowing and various treatments of mannitol and nano urea on wheat crop were found significant during both the years of study.This result is similar to Shamary and Ansari (2022), the height of wheat crop is influenced by nutrient applications and nano fertilizers.

Treatments	Plant height (cm)					
	Timely sown			Late sown		
	30DAS	60DAS	At physiological maturity	30DAS	60DAS	At physiological maturity
T1 – Control	29.30	65.14	94.55	24.50	49.21	82.43

T2 – Mannitol (25ppm)	30.40		67.56		96.03		24.63		52.11		83.14	
T3 - Mannitol (50ppm)	31.10		65.81		100.72		25.19		50.51		85.38	
T4 - Mannitol (100ppm)	30.68		69.24		101.88		27.82		53.32		85.76	
T5 - Nano urea (25ppm)	30.12		67.22		99.64		25.02		51.36		84.32	
T6 - Nano urea (50ppm)	30.51		70.92		102.09		28.61		56.47		89.65	
T7 - Nano urea (100ppm)	31.98		68.21		100.71		26.67		55.22		87.13	
Interaction	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**
Sowing (S)	0.44	1.96	0.26	1.03	0.34	1.25	0.44	1.95	0.27	1.05	0.31	1.12
Treatments (T)	0.68	1.97	0.90	2.57	1.17	3.33	0.66	1.89	0.76	2.17	0.98	2.80
S×T	1.13	3.25	1.59	4.55	2.20	6.29	1.08	3.12	1.34	3.85	1.86	5.29

Dry weight plant^{-1} (g)

Data in given table on dry weight at 30 DAS shows only the response of soil fertility and environmental factors. However, dry weight ranges from (0.62 g) to (0.93 g) timely sown, (0.61 g) to (0.83 g) late sown respectively.

Application of mannitol (T2-25, T3-50, T4-100 ppm) and nano urea (T5-25, T6-50, T7-100 ppm) foliar spray at 45 DAS was found effective in increasing dry weight significantly at 60 and at physiological maturity of observations in all the different date of sowing. Maximum dry weight at 60 DAS was obtained in T6 (27.54) timely sown, (25.24) late sown followed by T3 (26.94) timely sown, (24.55) late sown respectively as compared to control in different date of sowing. Similarly, at physiological. maturity maximum dry weight was obtained in T6 (38.87) timely sown, (35.97) late sown followed by T3 (37.65) timely sown, (34.73) late sown respectively as compared to control in different date of sowing. The data showed non-significant variation at 30 DAS but showed significant variation at 60 DAS and at maturity among different sowing dates with respect to dry weight plant^{-1}.With the increase the dose of nitrogen the dry weight of plant will also increases. These similar results were also reported by Ahmed and Abdul (2022).

Treatments	**Dry weight plant^{-1} (g)**					
	Timely sown			**Late sown**		
	30 DAS	**60 DAS**	**At physiological maturity**	**30 DAS**	**60 DAS**	**At physiological maturity**
T1 – Control	0.64	24.88	34.30	0.61	20.61	31.94
T2 – Mannitol (25ppm)	0.66	25.11	36.66	0.63	22.26	33.28
T3 - Mannitol (50ppm)	0.69	26.94	37.65	0.65	24.55	34.73
T4 - Mannitol (100ppm)	0.70	26.21	36.74	0.67	22.71	32.89
T5 - Nano urea (25ppm)	0.68	25.71	35.71	0.64	21.37	33.68
T6 - Nano urea (50ppm)	0.71	27.54	38.87	0.68	25.24	35.97
T7 - Nano urea (100ppm)	0.72	25.32	35.68	0.69	23.98	32.92

Interaction	S.Em ±	C.D. at 5%	S.Em ±	C.D. at 5%	S.Em ±	C.D. at 5%	S.Em ±	C.D. at 5%	S.Em ±	C.D. at 5%	S.Em ±	C.D. at 5%
Sowing (S)	0.43	1.95	0.29	1.16	0.19	0.68	0.42	1.92	0.29	1.15	0.18	0.66
Treatments (T)	1.95	1.66	0.52	1.49	0.48	1.36	NS	1.63	0.51	1.45	0.44	1.26
S×T	0.95	2.74	0.92	2.65	0.90	2.57	0.93	2.70	0.90	2.57	0.84	2.39

3.2.1 Total Chlorophyll Content in Leaves (Arnon method)

Data in given table on chlorophyll content at 30 DAS shows only the response of soil fertility and environmental factors. However, chlorophyll content ranges from (2.85) to (3.57) timely sown, (2.75 to 3.06) late sown respectively.

Application of mannitol (T2-25, T3-50, T4-100 ppm) and nano urea (T5-25, T6-50, T7-100 ppm) foliar spray at 45 DAS was found effective in increasing chlorophyll content significantly at 60 DAS of observations in all the different date of sowing. Maximum chlorophyll content at 60 DAS was obtained in T6 (6.08) timely sown, (4.90) late sown followed by T4 (5.60) timely sown, T3 (4.55) late sown respectively as compared to control in different date of sowing. Similarly, at 90 DAS maximum chlorophyll content was obtained in T6 (5.27) timely sown, (3.95) late sown followed by T4 (5.11) timely sown, T3 (3.66) late sown respectively as compared to control in different date of sowing. The interaction effect of time of sowing and various treatments of mannitol and nano urea on wheat crop were found significant during both the years of study. The similar findings were also reported by Muhammad *et al*. (2022)

Treatments	Total chlorophyll (mg g^{-1} fresh weight)					
	Timely sown			Late sown		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T1-Control	2.85	4.88	3.47	2.75	3.50	2.86
T2-Mannitol(25ppm)	2.91	5.12	4.63	2.82	3.75	3.02
T3 - Mannitol (50ppm)	3.57	5.36	4.79	2.94	4.55	3.66
T4 - Mannitol (100ppm)	3.21	5.60	5.11	2.99	4.36	3.41
T5 - Nano urea (25ppm)	3.09	4.84	4.43	3.01	4.50	2.98
T6 - Nano urea (50ppm)	3.34	6.08	5.27	3.05	4.90	3.95
T7 - Nano urea (100ppm)	3.13	4.95	4.32	3.06	3.00	3.14

Interaction	S.Em ±	C.D. at 5%	S.Em ±	C.D. at 5%	S.Em ±	C.D. at 5%	S.Em ±	C.D. at 5%	S.Em ±	C.D. at 5%	S.Em ±	C.D. at 5%
Sowing (S)	0.43	1.94	0.31	1.20	0.11	0.39	0.42	1.93	0.31	1.21	0.11	0.39
Treatments (T)	0.58	1.67	0.45	1.29	0.26	0.73	0.56	1.65	0.45	1.29	0.25	0.72
S×T	0.95	2.75	0.80	2.29	0.48	1.38	0.93	2.72	0.80	2.28	0.48	1.36

3.2.2 Catalase activity (g-1 fresh weight min-1) in leaves

Data in given table on catalase activity at 30 DAS shows only the response of soil fertility and environmental factors. However, catalase activity ranges from (66.27) to (68.45) timely sown, (61.58 to 63.83) late sown respectively.

Application of mannitol (T2-25, T3-50, T4-100 ppm) and nano urea (T5-25, T6-50, T7-100 ppm) foliar spray at 45 DAS was found effective in increasing catalase activity significantly at 60 DAS of observations in all the different date of sowing. Maximum catalase activity at 60 DAS was obtained in T4 (132.79) timely sown, (136.41) late sown followed by T6 (130.78) timely sown, (132.95) late sown respectively as compared to control in different date of sowing. At 90 DAS maximum catalase activity was obtained in T4 (159.73) timely sown, (163.93) late sown followed by T6 (155.80) timely sown, (160.00) late sown respectively as compared to control in different date of sowing. The interaction effect of time of sowing and various treatments of mannitol and nano urea on wheat crop were found significant during both the years of study.The activities of enzymes *viz*, catalase, nitrate reductase etc. gradually increase with the age of crop up to 90 DAS under different foliar application of plant nutrients. In order to limit oxidative damage under stress condition plants have developed a series of detoxification system that break down highly toxic reactive oxygen species (Ezzat-Ollah Esfandiari *et al.* 2007).

Treatments	**Catalase activity (g^{-1} fresh weight min^{-1})**											
	Timely sown						**Late sown**					
	30 DAS		**60 DAS**		**90 DAS**		**30 DAS**		**60 DAS**		**90 DAS**	
T1 - Control	66.27		127.7		150.85		61.58		131.58		155.05	
T2 – Mannitol (25ppm)	66.93		129.37		153.86		63.99		134.10		158.06	
T3 - Mannitol (50ppm)	68.45		132.24		155.62		62.48		135.11		159.82	
T4 - Mannitol (100ppm)	67.59		**132.79**		**159.73**		63.38		**136.41**		**163.93**	
T5 - Nano urea (25ppm)	66.60		129.42		153.02		62.03		132.17		157.22	
T6 - Nano urea (50ppm)	67.66		130.78		155.80		62.93		132.95		160.00	
T7 - Nano urea (100ppm)	67.26		131.28		153.74		63.83		133.87		157.94	
Interaction	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**
Sowing (S)	0.49	2.22	0.37	1.47	0.51	1.87	0.48	2.18	0.40	1.56	0.54	1.96
Treatments (T)	0.99	2.85	1.59	4.55	1.96	5.59	0.95	2.73	1.59	4.56	1.99	5.68
S×T	1.23	3.95	2.81	8.06	3.70	10.57	1.56	4.05	2.82	8.08	3.76	10.73

3.2.3 Peroxidase activity (mg g-1 fresh weight min-1) in leaves

Data in given table on peroxidase activity at 30 DAS shows only the response of soil fertility and environmental factors. However, peroxidase activity ranges from (141.36) to (145.52) timely, (158.96 to 160.68) late sown respectively.

Application of mannitol (T2-25, T3-50, T4-100 ppm) and nano urea (T5-25, T6-50, T7-100 ppm) foliar spray at 45 DAS was found effective in increasing peroxidase activity in plant significantly at 60 DAS and 90 DAS of observations in all the different date of sowing. Maximum peroxidase activity at 60 DAS was obtained in T3 (145.87) timely sown, (197.51) late sown followed by T6 (144.76) timely sown, (196.32) late sown respectively as compared to control in different date of sowing. Similarly, at 90 DAS maximum peroxidase activity was obtained in T3 (225.23) timely sown, (247.56) late sown followed by T6 (220.12) timely sown, (245.99) late sown respectively as compared to control in different date of sowing. The similar findings were also reported by Sharma et al (2021).

Treatments	**Peroxidase activity (g^{-1} fresh weight min^{-1})**					
	Timely sown			**Late sown**		
	30 DAS	**60 DAS**	**90 DAS**	**30 DAS**	**60 DAS**	**90 DAS**
T1 - Control	141.36	144.12	219.35	158.96	192.92	242.74
T2 – Mannitol (25ppm)	143.61	143.53	221.03	161.52	196.21	245.78

T3 - Mannitol (50ppm)	145.52		**145.87**		**225.23**		161.10		**197.51**		**247.56**	
T4 - Mannitol (100ppm)	144.36		144.35		223.24		160.68		194.07		243.69	
T5 - Nano urea (25ppm)	142.11		143.81		219.36		159.42		193.25		242.65	
T6 - Nano urea (50ppm)	145.11		144.76		220.12		160.26		196.32		245.99	
T7 - Nano urea (100ppm)	142.86		144.16		220.52		159.84		193.27		243.57	
Interaction	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**
Sowing (S)	0.73	3.28	0.46	1.80	0.66	2.41	0.78	3.53	0.60	2.36	0.74	2.69
Treatments (T)	1.81	5.22	2.15	6.17	2.75	7.84	2.01	5.78	2.65	7.59	3.21	9.15
S×T	2.99	8.61	3.82	10.93	5.19	14.82	3.31	9.52	4.69	13.45	6.06	17.30

3.2.4 Super oxide dismutase activity (mg g-1 fresh weight min-1) in leaves

Data in given table on SOD activity at 30 DAS shows only the response of soil fertility and environmental factors. However SOD activity ranges from (224.61) to (225.88) timely, (239.81 to 241.27) late sown respectively.

Application of mannitol (T2-25, T3-50, T4-100 ppm) and nano urea (T5-25, T6-50, T7-100 ppm) foliar spray at 45 DAS was found effective in increasing SOD activity in plant significantly at 60 DAS and 90 DAS of observations in all the different date of sowing. Maximum SOD activity at 60 DAS was obtained in T3 (275.25) timely sown, (291.08) late sown followed by T6 (274.48) timely sown, (289.59) late sown respectively as compared to control in different date of sowing. Similarly, at 90 DAS maximum peroxidase activity was obtained in T3 (341.28) timely sown, (371.16) late sown followed by T6 (340.28) timely sown, (370.37) late sown respectively as compared to control in different date of sowing. The combined impact of different mannitol and nano urea treatments on super oxide dismutase activity at various sowing dates was significant across both years. The similar findings were also reported by Karki et al. (2021).

Treatments	**Super oxide dismutase activity (mg g^{-1} fresh weight min^{-1})**					
	Timely sown			**Late sown**		
	30 DAS	**60 DAS**	**90 DAS**	**30 DAS**	**60 DAS**	**90 DAS**
T1 - Control	224.41	270.61	335.22	239.81	285.12	366.11
T2 – Mannitol (25ppm)	224.71	272.47	338.01	240.41	287.65	368.96
T3 - Mannitol (50ppm)	225.01	275.25	341.28	241.01	291.08	371.16
T4 - Mannitol (100ppm)	225.88	274.33	337.41	240.71	288.15	369.02
T5 - Nano urea (25ppm)	224.56	271.54	336.81	240.11	286.11	367.42
T6 - Nano urea (50ppm)	225.61	274.48	340.28	241.08	289.59	370.37
T7 - Nano urea (100ppm)	225.31	273.40	339.13	241.27	286.67	367.89

Interaction	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**	**S.Em ±**	**C.D. at 5%**
Sowing (S)	1.03	4.67	0.90	3.53	1.01	3.67	1.10	4.95	0.96	3.76	1.65	7.42
Treatments (T)	2.76	7.95	3.69	10.58	4.47	12.75	2.94	8.47	3.76	11.19	4.45	12.83
S×T	4.15	11.10	5.42	13.75	5.55	16.09	4.65	13.96	6.32	15.84	6.64	16.14

Treatments	length of spike (cm)		Number of grains spike^{-1}	
	S1 (15th Nov.)	S2 (15th Dec.)	S1 (15th Nov.)	S2 (15th Dec.)
T1 – Control	8.57	7.12	40.33	37.33

3.2.5 Length of spike (cm)

It is apparent from data in given table that different treatment of mannitol and nano urea influence the length of spike significantly influence due to various treatments. The data revealed that maximum length of spike was measured i.e. (11.50) timely sown, (10.73) late sown recorded in T4 foliar spray of mannitol 100 ppm followed by T6 foliar spray of nano urea 50 ppm was (11.47) timely sown, (10.29) late sown as compared to rest of treatments and control at all stages of growth respectively over the control. The similar result was reported by Satish *et al.* (2022).

3.2.6 Number of grains spike^{-1}

It is apparent from data in given table that different treatment of mannitol and nano urea influence the number of grains spike-1 significantly influence due to various treatments. The data revealed that maximum number of grains spike^{-1} was measured i.e. (47.67) timely sown, (45.74) late sown recorded in T4 foliar spray of mannitol 100 ppm followed by T6 foliar spray of nano urea 50 ppm was (45.00) timely sown, (42.64) late sown as compared to rest of treatments and control at all stages of growth respectively over the control. The similar data was reported by Ahmed and Abdul (2022).

T2 – Mannitol (25ppm)	10.17		9.28		41.67		39.79	
T3 - Mannitol (50ppm)	10.93		9.04		43.67		38.91	
T4 - Mannitol (100ppm)	11.50		10.73		47.67		45.74	
T5 - Nano urea (25ppm)	10.57		8.65		43.67		43.83	
T6 - Nano urea (50ppm)	11.47		10.29		45.00		42.64	
T7 - Nano urea (100ppm)	10.33		9.54		42.67		41.36	
Interaction	**S.Em±**	**C.D. at 5%**	**S.Em±**	**C.D. at 5%**	**S.Em±**	**C.D. 5%**	**S.Em±**	**C.D. at 5%**
Sowing (S)	0.43	1.93	0.29	1.13	0.45	2.04	0.23	0.90
Treatment (T)	0.59	1.71	0.47	1.35	0.78	2.24	0.76	2.18
S × T	0.98	2.81	0.83	2.39	1.28	3.69	1.35	3.86

3.2.7 Grain yield plant^{-1} (g)

It is apparent from data in the given table that different treatment of mannitol and nano urea influence the grain yield plant^{-1} (g) significantly influence due to various treatments. The data revealed that increase in grain yield plant^{-1} (g) was measured i.e. (14.28) timely sown, (9.46) late sown recorded in T4 foliar spray of mannitol 100 ppm followed by T6 foliar spray of nano urea 50 ppm was (13.65) timely sown, (8.74) late sown as compared to rest of treatments and control at all stages of growth over the control. The rise in grain yield per plant could be attributed to the foliar application of mannitol and nano urea, which helps alleviate the negative effects of abiotic stress and boosts enzymatic activity. The buildup of nitrogen and osmoprotectant had a favorable impact on grain yield plant^{-1}, resulting in a rise in the weight of the grains plant^{-1}. These results are accordance with Jat *at al.* (2013).

3.2.8 Test weight (g)

It is apparent from data in given table that different treatment of mannitol and nano urea influence the test weight significantly influence due to various treatments. The data revealed that increase in test weight was measured i.e. (44.53) timely sown, (35.39) late sown recorded in T4 foliar spray of mannitol 100 ppm followed by T6 foliar spray of nano urea 50 ppm was (43.93) timely sown, (34.15) late sown as compared to rest of treatments and control at all stages of growth respectively over the control. Interaction between date of sowing and various mannitol and sorbitol treatments for test weight was found statistically non-significant. The weight of seed is also increased due to bio- chemical activities of osmoprotectant and nitrogen. The similar findings were also given by Satish *et al.* (2022).

Treatments	**Grain yield plant^{-1} (g)**		**Test weight(g)**	
	S1 (15th Nov.)	**S2 (15th Dec.)**	**S1 (15th Nov.)**	**S2 (15th Dec.)**
T1 – Control	10.51	7.15	40.92	32.38
T2 – Mannitol (25ppm)	11.14	7.87	41.72	33.23
T3 - Mannitol (50ppm)	13.03	7.59	42.43	33.94

T4 - Mannitol (100ppm)	14.28		9.46		44.53		35.39	
T5 - Nano urea (25ppm)	11.77		8.02		41.13		33.02	
T6 - Nano urea (50ppm)	13.65		8.74		43.93		34.15	
T7 - Nano urea (100ppm)	12.40		8.31		43.07		33.74	
Interaction	**S.Em±**	**C.D. at 5%**	**S.Em±**	**S.Em±**	**S.Em±**	**C.D. at 5%**	**S.Em±**	**C.D. at 5%**
Sowing (S)	0.43	1.94	0.29	0.45	0.45	2.02	0.24	1.08
Treatment (T)	0.60	1.72	0.47	0.77	0.77	2.22	0.72	1.36
S × T	0.98	2.83	0.84	1.27	1.27	3.66	1.27	2.41

3.2.9 Biological yield plant^{-1}

It is apparent from data in given table that different treatment of mannitol and nano urea influence the biological yield significantly influence due to various treatments. The data revealed that increase in biological yield was measured i.e. (26.84) timely sown, (26.19) late sown recorded in T4 foliar spray of mannitol 100 ppm followed by T6 foliar spray of nano urea 50 ppm was (24.70) timely sown, (23.64) late sown as compared to rest of treatments and control at all stages of growth and the lowest biological yield was recorded among all treatments in T2 foliar spray of mannitol 25 ppm was (20.34) timely sown, T2 foliar spray of mannitol 25 ppm was (19.05) late sown respectively over the control. The interaction effect of various mannitol and nano urea treatments on the variety were found significant during both years. The similar result was also found by Partha *et al*. (2017).

3.2.10 Harvest index (%)

It is apparent from data in given table that different treatment of mannitol and nano urea influence the biological yield significantly influence due to various treatments. The data revealed that maximum harvest index was measured i.e. (51.32) timely sown, (41.64) late sown recorded in T4 foliar spray of mannitol 100 ppm followed by T6 foliar spray of nano urea 50 ppm was (50.41) timely sown, (40.99) late sown as compared to control. Harvest index was also influenced by the foliar applications of plant nutrients. Nutrient-use efficiency refers to the ability of plants to transport and utilize nutrients effectively for growth and yield. The similar findings were observed by Mohd. Arif et al.,(2019).

Treatments	**Biological yield plant^{-1}**		**Harvest index (%)**	
	S1 (15th Nov.)	**S2 (15th Dec.)**	**S1 (15th Nov.)**	**S2 (15th Dec.)**
T1 – Control	19.98	17.52	53.46	47.23
T2 – Mannitol (25ppm)	20.34	19.05	51.86	43.82
T3 - Mannitol (50ppm)	22.86	20.58	55.97	44.08
T4 - Mannitol (100ppm)	26.84	26.19	51.32	41.64
T5 - Nano urea (25ppm)	22.45	22.11	49.53	42.73
T6 - Nano urea (50ppm)	24.70	23.64	50.41	40.99
T7 - Nano urea (100ppm)	23.78	25.17	48.10	39.48

Interaction	**S.Em±**	**C.D. at 5%**	**S.Em±**	**C.D. at 5%**	**S.Em±**	**C.D. at 5%**	**S.Em±**	**C.D. at 5%**
Sowing (S)	0.43	1.95	0.25	1.00	0.45	2.04	0.24	0.94

Treatment (T)	0.64	1.84	0.55	1.58	0.86	2.47	0.84	2.39
S × T	1.05	3.03	0.98	2.89	1.41	4.07	1.48	4.24

Conclusion

Present investigation clearly indicate that Foliar spray of mannitol and nano urea were performed well at 60, 90 DAS and at maturity parameters. Foliar application of nano urea with 25 ppm was recorded superior on Plant height (cm), dry weight plant^{-1} (g), chlorophyll content in leaves (Arnon method), Catalase activity (g^{-1} fresh weight min-1), Peroxidase activity (mg g-1 fresh weight min-1), Super oxide dismutase activity (mg g-1 fresh weight min-1) However, yield and yield attributes viz length of spike, number of tillers plant^{-1}, number of grains spike^{-1}, grain yield plant^{-1} It is concluded from the result that foliar spray of nano urea 25 ppm was found most effective to increasing all characters and yield parameters of wheat. Present finding needs further validation.

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