Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2018; 7(3): 2819-2825
Received: 13-03-2018
Accepted: 16-04-2018

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Growth and yield enhancement of wheat through foliar spray of Osmoprotectants under high temperature stress condition

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Abstract
Osmoprotectants/Synthetic compounds (KNO_3, $CaCl_2$ etc.) is beneficial to mitigate the ill effects of high temperature stress occurs due to late sowing of wheat and may enhance the yield to a profitable limit. In order to estimate the effect of synthetic compounds on performance of wheat under high temperature stress condition a field experiment was carried out in experimental farm of Bihar Agricultural University, Bhagalpur during the *rabi* season of 2014-15. Treatments were laid out in split plot design with three replications. Two different varieties of wheat i.e. DBW-14 (timely sown) and K-307 (late sown) were kept in main plots, subplot received foliar spray of different osmoprotectants. The foliar spray were as followed: M_1- no spray, M_2- KNO_3 (1.0 %) at booting stage, M_3- KNO_3 (1.0 %) at anthesis stage, M_4- KNO_3 (0.5 %) both at booting & anthesis stage, M_5- $CaCl_2$ (0.2%) at booting stage, M_6- $CaCl_2$ (0.2%) at anthesis stage, M_7- $CaCl_2$ (0.1%) both at booting & anthesis stage, M_8- Glycinebetaine (100 mM) at booting stage, M_9- Glycinebetaine (100 mM) at anthesis stage, M_{10}- Glycinebetaine (50 mM) both at booting & anthesis stage, M_{11}- Arginine (2.5 mM) at booting stage, M_{12}- Arginine (2.5 mM) at anthesis stage, M_{13}- Arginine (1.25 mM) both at booting & anthesis stage and M_{14}- spray of water both at heading & anthesis stage. Result shows that ear head biomass, dry matter accumulation and grain yield was increased significantly while, growth attributes are found non-significant. Maximum yield was recorded (36.96 and 31.23 q ha^{-1} for V_1 and V_2 respectively) when the crop received foliar spray of KNO_3 at the rate of 0.5% both during booting and anthesis stage over no foliar spray. The corresponding values with the foliar spray of $CaCl_2$ showed same trend like KNO_3 and were found to be statistically at par. Thus, the study suggests that foliar spray of KNO_3 at the rate of 0.5% both during booting and anthesis in a short duration variety like DBW-14 can provide the strengthen to plant against high temperature stress and provide better yield under late sown condition in most part of the country.

Keywords: heat stress, osmoprotectants, KNO_3, $CaCl_2$, glycinebetaine, arginine, earhead biomass, LAI, and percent change in yield

Introduction
Wheat is one of the crucial grain consumed by humans and is grown around the world in different environments from cool rain-fed to hot dry-land areas. At present, India contribute approximately 15% of global wheat production but it is anticipated that climate change will transform these into a heat stressed, short season production environment (Bita and Gerats, 2013) [3]. Climate change is harshly affecting cereal production all over world (Qin *et al*., 2002) [24] through increased temperature and CO_2 concentration, which is one of the main causes of heat stress (Farooq *et al*., 2011) [9]. Late planting of wheat in India is very common due to intensive cropping system under rice-wheat cropping system due to late harvesting of paddy (Prasad *et al*., 2005) [23] up to the middle of December. Due to late sowing of wheat, anthesis and grain filling period faces increased temperature (more than 20°C) (Tewolde *et al*., 2006) [36]. Yield of wheat is much affected by relatively short periods (3-5 days) of heat stress, especially when crop coincides with reproductive phase of grain filling stage (Wardlaw *et al*, 2002; Hays *et al*., 2007; Farooq *et al*., 2011) [40, 13, 9]. High temperature stress during reproductive phase of crop is termed as terminal heat stress. Wheat crop needs about 19°C to 22°C temperature during seed setting and grain filling (Porter & Gawith, 1999) [21]. The threshold temperature i.e. value of daily mean temperature at which a detectable reduction in growth begins is 26^0C for wheat at post anthesisi stage (Stone and Nicolas, 1994) [34]. The main effect of high temperature on wheat is the acceleration of overall decrease in plant size (Midmore *et al*., 1984; Shipler and Blum, 1986) [20, 32].
Temperature controls the rate of plant metabolic processes. Heat stress during reproductive phases cause decline in photosynthesis, leaf area, water use efficiency

(Shah and Paulsen, 2003) [31], crop growth, production of biomass, effective tillers, number of grains per spike and grain weight (Wollenweber *et al*., 2003; Schapendonk *et al*., 2007; Hay and Walker, 1989; Warrington *et al*., 1977) [42, 30, 12, 41] by shortening the duration of grain filling (Dias & Lidon 2009) [7]. In spite of favorable weather conditions an unexpected increase temperature during grain filling stage in wheat adversely affect the productivity of wheat in north-west India (Gupta *et al*., 2010) [10]. Wheat yield decreased by 10% for every 1°C increase in night temperature and grain yield showed a strong negative correlation with increasing minimum temperature (Lobell *et al*., 2005) [18].

The North Indian states like Uttar Pradesh, Punjab, Haryana, Uttarakhand and Himachal Pradesh are some of the major wheat producing states where the crop is more vulnerable to heat stress where, 1°C rise in temperature resulting in reduction of wheat yield (Singh *et al*., 2011) [33]. According to a report of Ministry of Agriculture, GOI, 1^0C rise temperature during the growing season causes 3-7% decrement in grain yield. Thus, loss in yield of wheat due to elevated temperature is estimated in the vicinity of 50 percent by 2050 (IFPRI 2011) [14]. This yield loss will threaten the food security of at least 1.6 billion people in South Asia. To reduce the loss of yield by improving tolerance to heat stress in future to drier and warmer climate or due to late sowing of wheat facing high temperature stress can be maintained by exogenous foliar spray of many osmoprotectants. These osmoprotectants are inorganic salts like potassium nitrate, calcium chloride, glycinebetaine and arginine.

Several studied says 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 help to maintain or sometime increase the grain yield of crop. The main function of these compounds are as follow; KNO_3- Potassium (K+) has substantial effect on enzyme activation, protein synthesis, photosynthesis, stomatal movement and water-relation (turgor regulation and osmotic adjustment) in plants (Marschner, 1995) [19]. Increased application of K^+ has been shown to enhance photosynthetic rate, growth, yield and drought resistance in different crops under abiotic stress conditions (Egilla *et al*., 2001) [8]. $CaCl_2$_– (Ca^{2+}) can maintenance of antioxidant activity in some cool season grasses (Jiang and Haung, 2001) [16], calcium application in the form of $CaCl_2$ increased the malondialdehyde (MDA) content (lipid per oxidation product) and stimulated the activities of SOD and catalase, which could be the reason for the induction of heat tolerance (Kolupaev *et al*; 2005) [17]. Glycinebetain is the low molecular weight organic compounds have been successfully applied to induce high temperature tolerance in plants. Numerus reports are also available to show beneficial effects of some compounds like potassium nitrate (Sarkar and Bandopadhyay, 1991, Sarkar and Tripathy, 1994) [28, 29], calcium chloride (Tan *et al*. 2011) [35], glyceinebetaine (Rhodes and Hanson, 1993, Ashraf *et al*., 2007) [26, 2] and arginine (Hassanein *et al*. 2013) in many crops including wheat when applied exogenously under abiotic stresses like- high temperature and drought. The main functions of these sprayed compounds are protection of chlorophyll, detoxification of reactive oxygen species, maintenance of favorable balance of water and photosynthesis in plants under stressful condition.

So, this experiment was conducted to test the efficacy of these synthetic compounds for improving growth and yield by enhancing tolerance capacity of the crop against high temperature stress. Our main focus is reducing the impact of heat stress during reproductive and grain filling stages of wheat and develop a strategy to improve tolerance in late sown wheat.

Material and Methods

Experimental site

A field experiment was conducted during *rabi* season 2014-15 at Crop Research Farm, Department of Agronomy, Bihar Agricultural University, Bhagalpur, Bihar, located between 25° 50’ N latitude and 87°19’ longitude at an altitude of 52.73 meter above mean sea-level. The soil of the experimental site was sandy loam having pH 6.92, bulk density 1.49 g cm^{-3}, organic carbon 0.49% and 125.44, 18.05 and 118.95 kg ha^{-1} N: P: K respectively.

Climatic conditions of site

Climate of Sabour, Bhagalpur is sub-tropical, hot desiccating summer, cold winter and moderate rainfall. December and January are usually the coldest month where the mean temperature normally fall as low as 8.8^0C whereas; May and June are the hottest months, having the maximum average temperature of 36.1°C. The average annual rainfall is about 1207 mm (10 years’ average) precipitating mostly between middle of June to middle of October.

Weather parameters during the experimental period

Maximum temperature varied from 18.1-32.2°C, minimum temperature ranged from 5.8-20.5°C and mean temperature period varied from 11.95-25.95°C (table 1 & fig. 1) during the experiment. So, meteorological data reveals that the wheat crop faced high temperature stress (beyond 20°C) from February 2nd week onwards, which coincides with its grain filling stage. The crop received a total rainfall of 9.48 mm from December, 2014 to March 2015.

Table 1: Temperature variability at different phonological stage of wheat during *rabi* season of 2014-15

Phenological stages of Wheat	DBW 14		K 307	
	T_{max} (°C)	T_{min} (°C)	T_{max} (°C)	T_{min} (°C)
Sowing - Booting	13.5 - 30.6	4.0 - 16.2	13.5 - 31.1	4.0 - 16.4
Booting - Anthesis	26.0 - 32.9	16.4 - 18.2	26.0 - 32.9	13.8 - 18.2
Anthesis - Physiological maturity	26.6 - 32.0	11.3 - 17.0	26.6 - 32.4	11.3 - 17.0

T_{max} – Maximum temperature (range), T_{min} – Minimum temperature (range)

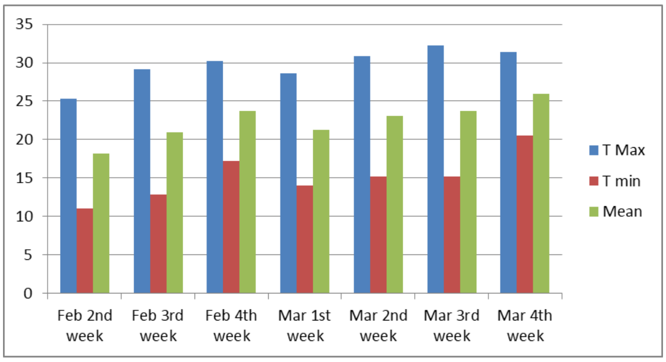

Fig. 1 Temperature variation during crop period (anthesis to grain filling stage)

Experimental details

Experiment was conducted in the split plot design with three replications and size of experimental plot was 10 m^2. Late sowing of wheat was done (December 29) under irrigated condition, with spacing 20 cm (row to row) and fertilizer dose was 80: 40: 40: (N: P_2O_5: K_2O Kg ha^{-1}). In this experiment two contrasting wheat varieties had been taken namely, DBW-14 (V1) and K-307 (V2). Variety DBW-14 is recommended for late sown irrigated conditions. The optimum sowing time of this variety is between 10^{th} December to last week of December with 110-115 days' maturity period, having average yielding potential is about 30-40 q ha^{-1}. Second variety K-307 is recommended for timely sown irrigated condition. The optimum sowing time of this variety is 15 to 30^{th} November with 125-130 days' maturity period, having average yielding ability is about 40-50 q ha^{-1}**.** Different chemical compounds are sprayed in different quantity and on different growth stage of wheat for reducing the stress of high temperature. The treatments were; M_1 - control plot, M_2 - KNO_3 at booting stage (1.0%), M_3- KNO_3 at anthesis stage (1.0%) and M_4- KNO_3 (0.5%) both at booting and anthesis stage, M_5- $CaCl_2$ at booting stage (0.2%), M_6 - $CaCl_2$ at anthesis stage (0.2%) and M_7- $CaCl_2$ (0.1%) both at booting and anthesis stage, M_8- Gycinebetain at booting stage (100 mM), M_9- Glycine betain at anthesis stage (100 mM) and M_{10}- Glycinebetain (50 mM) both at booting and anthesis stage, M_{11}- arginine (2.5 mM) at booting stage, M_{12} - arginine at anthesis stage, M_{13}- arginine (1.25 mM) both at booting and anthesis stage and M_{14} - spray of water at both heading and anthesis stage.

Result and Discussion

Effect of osmoprotectants on ear head biomass (fig. 2 & 3)

Application of synthetic compounds produced significant varietal response in ear head biomass production at 90 DAS. The ear head biomass production at 90 DAS was significantly high in variety DBW-14 (216.22g m^{-2}) over K-307 (206.91g m^{-2}). Among the synthetic compounds, maximum earhead biomass was recorded with M_4 (254.90g m^{-2}) followed by M_7 (236.67 g m^{-2}), M_3 (228.53 g m^{-2}) and M_6 (223.78 g m^{-2}) for DBW-14 while, in K-307 maximum biomass was obtained in M_4 (233.37 g m^{-2}) followed by M_3 (226.89 g m^{-2}), M_6 (223.82 g m^{-2}) and M_7 (223.36 g m^{-2}). These treatments were at par with each other and significantly superior than M_1 (203.45 and 202.88 g m^{-2} in DBW-14 and K-307, respectively). Due to the application of 0.5% KNO_3 at booting and anthesis stage in M_4 the biomass accumulation in earhead was increased by 25.29% in DBW-14 while, in K-307 only 15.03% over M_1.

At harvest stage the ear head biomass production was significantly high in variety DBW- 14 (498.67 g m^{-2}) than in K-307 (456.31 g m^{-2}). Among the sub plots, the highest earhead biomass was recorded with M_4 (604.24 g m^{-2}) followed by M_3, M_7 and M_6 for DBW-14 while, in K-307 maximum biomass was obtained in M_4 followed by M_6, M_7 and M_3. Due to the application of M_4 treatment biomass accumulation was increased by 27.93% over M_1 in DBW-14 while, in K-307 the increase was 9.51%. Application of M_6 and M_7 resulted in 17.26% and 19.46% increased earhead biomass in DBW-14 and 7.09% and 5.95% in K-307 variety over M_1 respectively. It was observed that on an average M_4 treatment resulted in 18.91% increase in biomass production over M_1 followed by M_7, M_3 and M_6 treatments where the increase ranged between 12.28 to 12.85% over M_1 respectively.

Application of synthetic compounds provide protection against ill effects of high temperature stress in plants through various mechanisms like- maintain osmotic regulation, preventing the degradation of chlorophyll, reducing electrolytic leakage from cells etc. Foliar spray of KNO_3 helps in protecting the photosynthetic apparatus of flag leaf throughout the anthesis and post anthesis period, which is considered to be the principal contributory organ for the supply of photosynthates to the developing grain (Borril *et al.*, 2015) [4] and if photosynthesis will be normal plant can grow well and able to produce much biomass. According to Wahid *et al.*, (2007) [37] photosynthesis is the most sensitive process to elevated temperature and it affects growth, development and yield of wheat (Al-Khatib and Paulsen, 1999) [1]. It has also has been shows that exogenous Ca^{++} increased heat tolerance in several plants, which might be associative with high errant oxidative enzyme activities and reduced lipid peroxidation of cell membranes (Wang *et al.*, 2009) [38] resulting, better growth and development of plants.

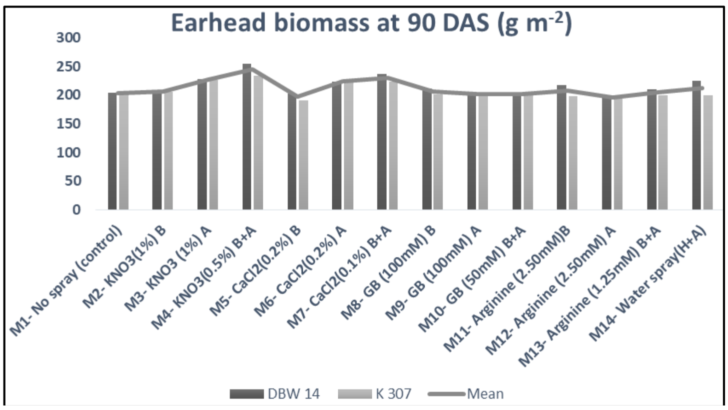

Fig 2: Effect of foliar spray of osmoprotectants on earhead biomass at 90 DAS

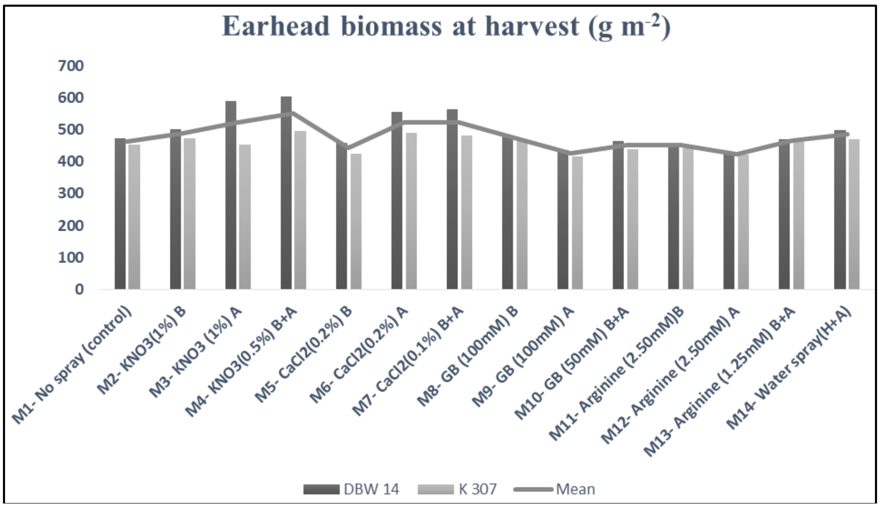

Fig 3: Effect of foliar spray of osmoprotectants on earhead biomass at harvest

Effect of the osmoprotectants on growth (Table 2)

The number of plant emergence (15 DAS) was shows no significant difference thereby, rendering a uniform establishment of the wheat crop and numbers of tillers m^{-2} at different growth stages was also found non-significant due to foliar spray of synthetic compounds on the wheat crop at the successive growth stages. When comparison was made between the two varieties, no significant effect was found in number of tillers m^{-2} at initial stage but at latter stage it was found to be significantly higher in K-307 at 60 DAS (303) and 90 DAS (306) than DBW-14 (250 and 249 at 60 and 90 DAS, respectively).

Plant height and leaf area index of wheat crop was not significantly affected by foliar spray of synthetic compounds at the successive growth stages. Among the two varieties, DBW-14 (V_1) produced significantly higher plant height than K-307 (V_2) at initial stage but, at the later stages no significant effect was found in plant height between the two varieties. However, K-307 produced marginally higher plant height at 90 DAS (86.32 cm) than DBW-14 (84.24 cm). When comparison was made between the two varieties, LAI was found to be significantly higher in K-307 at 90 DAS (4.52) than DBW-14 (3.77).

Total biomass accumulation in wheat increased steadily up to maturity of crop. Significantly higher total biomass accumulation was recorded in K-307 at 30 DAS (26.99 g m^{-2}) and 60 DAS (402.79 g m^{-2}) as compared to DBW-14 (24.60 and 367.22 g m^{-2} at 30 and 60 DAS, respectively). But, it was found to be at par at 90 DAS (729.67 and 728.77 g m^{-2} in K-307 and DBW 14, respectively). Finally, at harvest, DBW-14 crossed K-307 in total dry matter accumulation and it was found to be varied significantly (1031.49 and 967.58 g m^{-2} in DBW-14 and K-307, respectively). Foliar spray of different osmoprotectants did not influence the total biomass accumulation at initial stage but, at harvest it influence total dry matter significantly, maximum total dry matter was accumulated in M_4 treatment where 0.5% KNO_3 was sprayed at booting and anthesis stage (1151g m^{-2} at harvest) and was found to be at par with M_3 (KNO_3@1% sprayed at anthesis stage), M_6 ($CaCl_2$@ 0.2% sprayed at anthesis stage) and M_7 ($CaCl_2$ @ 0.1% sprayed at both booting and anthesis stage) but significantly superior over M_1 (700.56 and 967.92 at 90 DAS and at harvest, respectively). Thus, the result shows that across the varieties, application of KNO_3@0.5% at booting and anthesis stage (M4) improved dry matter accumulation at harvesting stage by 11.63% over M_1. These above findings were also collaborated with the statements of Sarkar and Tripathy, (1994) [29]; Cakmak (2005) [5]; Wang *et al*., (2013) [39], who stated that application of above osmoprotectants can reduce the ill effect of high temperature stress by several modifications in metabolic activities in plants.

Effect of the osmoprotectants on yield attributes and yield

The yield parameters of wheat such as earhead m^{-2} and length of earhead shows non-significant result while, grains earhead^{-1} and test weight (1000 grain weight) significantly affected by foliar application of synthetic compounds (table 2). With the application of synthetic compounds, the number of earhead m^{-2} was found to be significantly higher in variety K-307 over DBW-14. maximum number of earheads was recorded in M_4 treatment followed by M_7 treatment. The highest number of grains per earheads was recorded in variety DBW-14 (41.63). Due to application of synthetic compounds, maximum number of grains per earhead was recorded in M_4 (50.5) treatment which was at par with M_3 (48.33), M_6 (48.33) and M_7 (46.33) and was 32.92% higher over M_1 treatment. On an average, total number of grains per earhead was recorded highest in M_4 (46.76) treatment which was 26.36% more over M_1 followed by M_7, M_6 and M_3 where it varied from 20.72% to 25.67%. The highest test weight was recorded in variety DBW-14 (38.30 g). In sub plot treatment, DBW-14 was recorded highest test weight in M_4 treatment (42.26 g). Overall, on an average highest test was found in M_4 treatment (40.56 g) which was 14.10% higher than M_1 treatment.

Grain yield of late sown wheat was significantly influenced by the foliar spray of osmoprotectants like- KNO_3 and $CaCl_2$ (fig. 4). Irrespective of varieties, two foliar applications of 0.5% KNO_3 each at booting and anthesis stage, maximized grain yield of late sown wheat and was significantly superior over no foliar spray as well as water spray at heading and anthesis. However, grain yield was found also statistically at par with the single foliar application of 1.0% KNO_3 or 0.2% $CaCl_2$ only at anthesis or two foliar applications of 0.1% $CaCl_2$ each at booting and anthesis. Across the two varieties, an increment of 10.99%, 10.59%, 9.45% and 9.31% in grain yield was observed in M_4, M_7, M_3 and M_6, respectively over control. However, a varietal difference was observed between DBW-14 & K-307 with respect to grain yield when sprayed with different synthetic compounds. The quantum response in grain yield was found to be more pronounced in DBW-14 than in K-307. In DBW-14, M_4 treatment produced the highest yield (36.96 q ha^{-1}) and treatments M_3, M_7 and M_6

were found at par (17.28%, 15.88%, 14.93% and 14.88% higher over the yield of M_1 /control, respectively). But in K-307, highest yield was obtained in M_7 (31.73 q ha^{-1}) followed by M_4 and were 6.03% and 4.36% higher over the yield of M_1 /control, respectively. This results clearly shows that the KNO_3 and $CaCl_2$ at their respective higher doses at anthesis or half the higher doses each at booting and anthesis could restore yield in late sown wheat. Ratnakumar *et al.* (2016) [25] also documented positive response of KNO_3 or $CaCl_2$ (K and Ca based compounds) which attributed to alleviation of terminal heat stress by improving stress tolerance and grain yield in crop plants.

This clearly suggests that repeated applications of KNO_3 or $CaCl_2$ in lower concentrations were more effective in preventing yield drop of late sown wheat facing high temperature stress. (Das and Sarkar, 1981; Sarkar and Bandopadhyay 1991) [28]. The maximum responsiveness of anthesis stage of wheat towards foliar spray of KNO_3 may be attributed to high sensitivity of this stage against elevated temperature (30/20^{0}C, day/night) for 3 days (Saini and Aspinall 1982) [27]. However, if we want to maximize the yield repeated spray at lower concentration is desirable both at booting and anthesis. The simple reason is that repeated spray ensures high insurance against yield loss if staggered spells of high temperature stress occurs during pre-anthesis stage (microsporogenesis) of a crop season which causes poor pollen viability, fewer pollen grains and ultimately leads to lower seed set in cereals like wheat and rice (Prasad *et al.*, 2008) [22]. The present study clearly suggests that about one-third, out of the total magnitude of yield drop can be compensated by foliar application of KNO_3 or $CaCl_2$ without any extra application of irrigation to the crop (Jena *et al.*, 2017) [15]. Sakar and Tripathy (1994) [29] also found more or less same trend in case of $CaCl_2$ whereby repeated spray of low dose $CaCl_2$ at booting and anthesis gives higher yield however, maximum responsiveness of yield was found when spraying was done at higher concentration during anthesis stage.

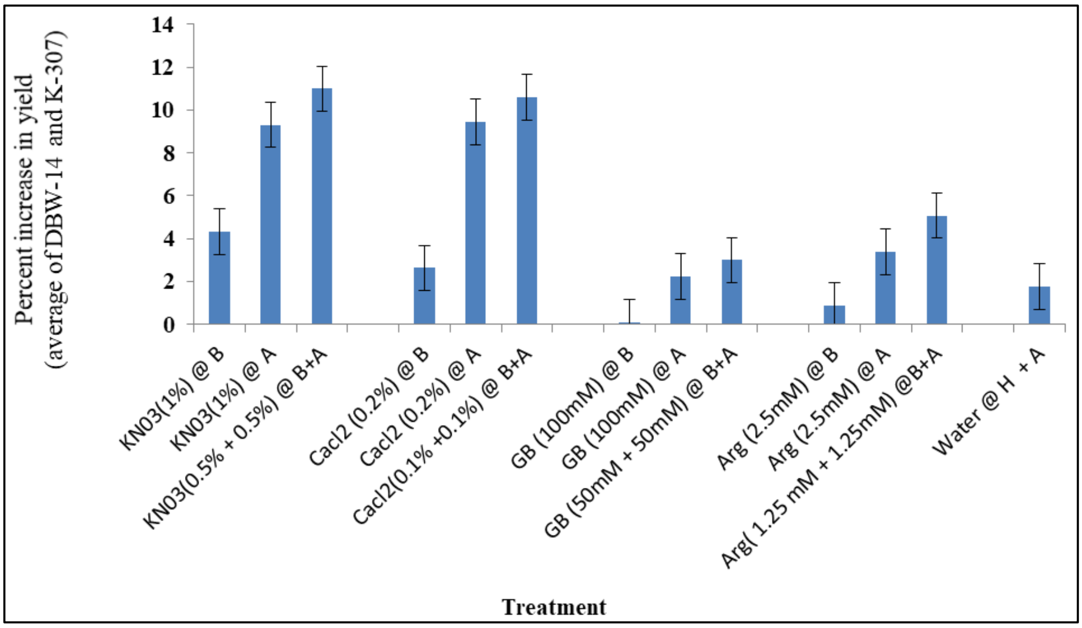

Fig 4: Effect of foliar spray of osmoprotectants on percent change in grain yield over control

Table 2: Effect of foliar spray of osmoprotectants on growth and yield attributes of wheat

Treatments	Emergence count m^{-2}	Plant height (cm)	No. of tillers m^{-2}	Total dry matter (g m^{-2})	LAI	Earhead m^{-2}	Earhead length (cm)	Grains $earhead^{-1}$	Test weight (g)
Cultivars									
V1- DBW 14	99.79	84.24	249	1031.49	3.77	246.78	11.19	41.63	38.30
V2- K 307	102	86.32	306	967.58	4.52	301.02	11.47	39.80	36.42
SEm(±)	1.34	0.79	3.89	9.4	0.08	5.90	0.25	0.89	0.44
CD (P=0.05)	NS	NS	23.71	57.21	0.46	35.87	NS	NS	NS
Sprayed osmoprotectants									
M1- No spray (control)	99	86.88	268	967.92	4.09	264.78	11.63	37.00	35.46
M2- KNO_3(1%) B	98	86.38	269	1022.45	4.30	280.22	11.31	42.17	36.63
M3- KNO_3(1%) A	99	83.97	290	1091.26	4.48	287.01	11.78	44.67	39.10
M4- KNO_3(0.5%) B+A	104	85.08	295	1151.00	4.30	294.30	11.77	46.76	40.56
M5- $CaCl_2$(0.2%) B	101	84.82	270	925.99	4.38	267.31	11.26	38.67	36.01
M6- $CaCl_2$(0.2%) A	99	86.35	276	1088.77	4.35	274.66	11.04	44.83	39.19
M7- $CaCl_2$(0.1%) B+A	101	85.47	293	1092.31	3.98	293.33	11.27	46.50	39.97
M8- GB (100mM) B	100	86.08	272	992.83	3.88	268.46	10.68	39.00	36.89
M9- GB (100mM) A	100	85.53	279	890.85	4.05	263.58	11.17	38.13	35.59
M10- GB (50mM) B+A	101	84.52	273	945.01	4.14	270.17	11.53	38.52	37.02
M11- Arginine (2.50mM)B	102	85.53	272	942.45	4.05	272.34	11.27	38.17	36.78
M12- Arginine (2.50mM) A	101	83.12	274	887.63	4.07	269.59	11.64	38.42	36.12
M13- Arginine (1.25mM) B+A	98	85.27	279	972.75	4.00	275.76	10.99	38.67	37.51
M14- Water spray (H+A)	101	84.20	273	1022.27	3.97	253.08	11.28	38.50	36.19

SEm(±)	2.41	1.02	10.43	22.09	0.19	10.10	0.38	1.04	0.53
CD (P=0.05)	NS	NS	NS	62.68	NS	NS	NS	3.00	1.53
Interaction VxM	-	-	-	-	-	NS	NS	4.23	2.15

B= Booting, A= Anthesis, H= Heading stage, SEm(±)= Standard error of mean, CD= Critical difference, NS= Non significant, GB= Glycinebetain, KNO_3= Potassium nitrate, $CaCl_2$= Calcium chloride, B:C ratio= Benefit: Cost ratio

Conclusion

Based on one-year experiment, it can be concluded that spray of osmoprotectants like- KNO_3 and $CaCl_2$ were identified for helping in alleviation of terminal heat stress in late sown wheat and able to restore yield loss. Maximum improvement in grain yield of wheat was recorded with sprayed at its respective lower dose (0.5% KNO_3 and 0.1% $CaCl_2$) both at booting and anthesis stage. Improvement in grain yield marginally reduced with a single spray of KNO_3 and $CaCl_2$ during anthesis at its respective higher dose (1.0% KNO_3 and 0.2% $CaCl_2$). These compounds play a beneficial role by increasing stomatal movement, protein synthesis, enzyme activation, water balance as well as maintain chlorophyll content (photosynthetic ability) in leaves against high temperature loss. However, beneficial effects of KNO_3 and $CaCl_2$ on improvement of heat stress tolerance was more pronounced in DBW-14, due to its shorter grain development period, than in K-307. These osmoprotectants may be beneficial approach for the farmers where wheat crop suffers from terminal heat stress due to late sowing of wheat and also help to combating climate change scenario in future.

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