RESEARCH ARTICLE

PERFORMANCE OF OSMO-PROTECTANTS AND ANTIOXIDANTS IN AMELIORATION OF TERMINAL HEAT STRESS IN WHEAT (*TRITICUM AESTIVUM* L.)

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Abstract: Terminal heat stress causes significant yield reduction in wheat (*Triticum aestivum* L.) due to rise in temperature. The present study on the performance of osmo-protectants and antioxidants on three wheat varieties was conducted at the experimental area of Department of Plant Breeding and Genetics, PAU, Ludhiana. Two foliar sprays of osmo-protectants (Salicylic acid, KNO_3 and $ZnSO_4.7H_2O$) and antioxidants (Ascorbic acid and arginine) excluding water were done at anthesis stage and ten days after anthesis stage. The data revealed that concentration of salicylic acid (75 μgml^{-1}) had non-significant effect on wheat yield. KNO_3 and salicylic acid gave better yield as compared to all other treatments. Ascorbic acid and arginine proved significant in all the three varieties. It may be interpreted that osmo-protectants and antioxidants can neutralize heat stress. WH 1105 gave 7.7 percent higher yield than PBW 621 and 10.6 percent than PBW 550 in response to osmo-protectants and antioxidants application.

Keywords: Antioxidants, Osmo-protectants, Terminal Heat Stress, Yield, Wheat

INTRODUCTION

Wheat is one of the premier cereal crops having worldwide importance and is grown under a wide range of climatic conditions. It is an important source of carbohydrates, nutrients, dietary fibre and essential amino acids. India is one of the major producers of wheat contributing about 30 per cent to the food basket for our countrymen (Meena *et al.*, 2013). In Punjab, it was grown on 35.38 lac hectares with a production of 16.80 million tonnes during 2013-14 (Anonymous 2014).

Increasing high temperature worldwide presents an alarming threat to wheat in India as late planting of wheat is very common in Punjab. As a result, wheat crop has to face the problem of terminal heat stress. Wheat crop is found to be sensitive to temperature during reproductive phase because it may affect the source – sink relationship and as a result the yield decreases. Accumulation of reactive oxygen species (ROS) as a result of high temperature stress is a major cause of loss of crop productivity worldwide. (Tuteja 2010). The rapid production and accumulation of reactive oxygen species has been induced by high temperature stress (Xu *et al.*, 2008). These high levels of ROS are harmful to all the cellular components and negatively influence cellular metabolic processes (Breusegem *et al.*, 2001). It causes series of morphological, anatomical and biochemical changeswhich affect plant growth and results in reduced yield. Membrane fluidity is the result of ethylene production and lipid peroxidation which is related to ROS formation (Weckx *et al.*, 1989). In mature wheat plants, increased ethylene has been recorded to shorten the grain filling period, decreases kernel weight, hasten maturity and trigger premature senescence (Beltrano *et al.*,1999).

There are various methods to reduce high temperature stress in plants. Several osmo-protectants have been reported for alleviating abiotic stress in wheat. Among them, foliar application of, or pre-sowing seed treatment with low concentrations of inorganic salts, osmo-protectants, PGR's and oxidants (e.g., H_2O_2) as well as preconditioning of plants are common approaches (Wahid *et al.*, 2007). Foliar application of salicylic acid at 50$\mu gml^{-1}$and KNO_3 at 2% recorded the maximum heads per meter square, seeds per head, thousand seed weight, seed yield and seed quality in berseem which were significantly higher than the control (Kumar *et al.*, 2013). Heat stress triggers the production and accumulation of ROS (Almeselmani *et al.*,2009). Hence their detoxification by antioxidant systems is important for protecting plants against heat stress (Suzuki *et al.*, 2013). Farouk (2011) reported that ascorbic acid and α-tocopherol sprayed plants postponed the leaf senescence by peroxide/ phenolic/ ascorbate system which is involved in scavenging the reactive oxygen species (ROS) (Asthir *et al.*, 2009) produced during leaf senescence. Previous studies are reported that, exogenous applications of abscisic acid (AA) decreased adverse effects of various stress conditions including heat stress in rice, sunflower, bean, mungbean and wheat (Dolatabadian and Jouneghani 2009, Kumar *et al.*, 2011, Shah *et al* 2011, Dwivedi *et al.*, 2012 and Malik and Ashraf 2012). Hence, the present study was undertaken to focus on osmo-protectants and antioxidants as an effective tool to improve terminal heat stress tolerance in wheat.

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METHODOLOGY

The present study was conducted at experimental area of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana during *rabi* 2014-15 in loamy soil. The bulk density of soil was 1.6 gm/cubic cm, low in potassium, optimum in phosphorus and moderate in nitrogen. The pH of soil was 7.8. The treatment of three osmo-protectants (Salicylic acid @ 50µgml^{-1} and 75µgml^{-1}),(KNO_3 @ 0.5 and 1.0 percent) and ($ZnSO_4.7H_2O$ @ 0.5 & 1.0 percent) and two antioxidants (Ascorbic acid @ 100 µg ml^{-1} and 200 µg ml^{-1}), Arginine (1.0 mM) and Arginine (2.0 mM), excluding control (unsprayed) and water treatment were given to three wheat varieties namely PBW 550, PBW 621 and WH 1105.

The crop was sown in a randomized block design with three replications using 100 kg seed rate per hectare at 20.0 cm row spacing. One third nitrogen, full phosphorus and potash were applied to the seed at the time of sowing and were sown by *kera* (dropping of seed in the open furrow). The seeds were treated with thiram @ 1.0g/kg seed against the seed borne diseases. The weeds were controlled by spraying weedicide and the crop was irrigated five times. Two foliar sprays of osmo-protectants and antioxidants were done when the crop reached at anthesis stage and ten days after anthesis stage. The following yield parameters were recorded viz; Spikelets per spike, Grains per spike, Grain yield (q / ha), Harvest Index were recorded. Leaf area was measured from three leaves per replication of each genotype for given treatments at 60, 90 and 120 DAS by using CI 203 Portable leaf area meter.

Statistical Analysis

The statistical analysis was carried out with CPCS-1 software using factorial RBD design.

Agrometeorological data

The meteorological data for the experimental period was attained from School of Agricultural Meteorology, PAU, Ludhiana (Appendix 1).

RESULTS AND DISCUSSIONS

Leaf area

Leaf area is one of the most important variables affecting light interception and hence affects photosynthesis and carbohydrate production. Among foliar applications of osmo-protectants, maximum leaf area was recorded in WH 1105 (13.4 cm^2, 35.5 cm^2 and 38.1 cm^2) and minimum leaf area was recorded in PBW 621 (11.3 cm^2, 28.6 cm^2 and 29.6 cm^2) at 60, 90 and 120 DAS respectively. The spray of KNO_3 (0.5%) gave maximum leaf area (38.0 cm^2) and significantly more than the rest of the treatments. The minimum leaf area was obtained in control plot (32.3 cm^2) at 120 DAS. On leaf area at 120 DAS, non-significant interaction between varieties and foliar sprays was recorded (Table 1). The maximum leaf area was recorded in PBW 621 (15.5 cm^2) at 60 DAS, in PBW 550 (32.4 cm^2) at 90 DAS and in WH 1105 (36.6 cm^2) on 120 DAS and minimum leaf area was recorded in PBW 550 (12.4 cm^2) at 60 DAS, in PBW 621 (28.0cm^2 and 29.7 cm^2) at both 90 and 120 DAS.

Among the effect of foliar sprays of antioxidants, the spray of ascorbic acid at 200µg ml^{-1} gave maximum leaf area (35.7 cm^2) and significantly more than the rest of the treatments. The minimum leaf area was obtained in control plot (33.9 cm^2) at 120 DAS. On leaf area at 120 DAS, a significant interaction was recorded (Table 2). High temperature during wheat reproductive development hastens the decline in photosynthesis and leaf area, thus affecting water-use efficiency (Kumar *et al* 2011).

Dry matter accumulation

Manipulation of dry matter accumulation by plant is the outcome of stress conditions. Under foliar application of osmo-protectants, maximum dry matter accumulation was recorded in PBW 621 (6.3 g, 13.5 g and 25.2 g) and minimum dry matter accumulation was recorded in PBW 550 (4.5 g, 12.2 g and 22.3 g) at 60, 90 and 120 DAS respectively (Table 3). Among the effect of foliar sprays of osmo-protectants, the spray of KNO_3 (0.5%) gave maximum dry matter accumulation (27.2 g) and significantly more than the rest of the treatments. The minimum dry matter accumulation was obtained by the application of $ZnSO_4.7H_2O$ at 1% (19.1 g) at 120 DAS. On dry matter accumulation at 120 DAS, significant interaction was recorded.

Under foliar applications of antioxidants, maximum dry matter accumulation was recorded in PBW 621 (6.12 g, 13.9 g and 25.3 g) and minimum dry matter accumulation was recorded in PBW 550 (4.4 g, 11.7 g and 22.0 g) at 60, 90 and 120 DAS respectively. The spray of ascorbic acid at 200 µg ml^{-1} gave maximum dry matter accumulation (27.2 g) and significantly more than the rest of the treatments. The minimum dry matter accumulation was obtained in control (19.0 g) at 120 DAS. On dry matter accumulation at 120 DAS, a significant interaction was recorded (Table 4). Thus, variation in dry matter accumulation is the outcome of abiotic stress conditions. Our findings are supported by Sarlach *et al* 2013.

Number of spikelets per spike

Maximum of spikelets per spike were recorded in PBW 621 (18.9) and minimum number of spikelets per spike were recorded in PBW 550 (15.9). Non-significant difference and non-significant interaction was recorded among the treatments between the varieties and foliar sprays. It was observed that foliar sprays of osmo-protectants do not affect number of spikelets per spike much because with heat stress there was nodecrease or increase in number of spikelets per spike (Table 5).

For effect of foliar sprays of antioxidants, maximum number of spikelets per spike was recorded in WH 1105 (18.6) and minimum number of spikelets per spike was recorded in PBW 550 (15.8). Foliar spray of ascorbic acid at 200 µg ml^{-1} showed maximum spikelets per spike (18.5), followed by arginine at 2.0 mM (18.0) and minimum was recorded under unsprayed (control) condition (Table 6). There was a significant interaction observed among varieties and foliar sprays on spikelets per spike. Sarlach *et al* (2013) reported that number of spikelet per spike determines the spike length and if all the spikelets are well filled, it helps in an increase in number of grains per spike.

Number of grains per spike

PBW 621 (50.0) gave significantly more number of grains per spike, followed by PBW 550(41.2) than WH 1105 (36.4). Application of KNO_3 at both the concentrations 0.5% and 1% produced maximum (48.0 and 46.1 respectively) and minimum was recorded by the application of both the concentrations of $ZnSO_4.7H_2O$ (Table 5).

Foliar spray of Antioxidants revealed that, PBW 621 (50.1) gave significantly more number of grains per spike, followed by WH 1105 (45.8) than PBW 550 (39.2). Application of ascorbic acid at both the concentrations 200 µg ml^{-1} and 100 µg ml^{-1} produced maximum (50.8 and 48.9 respectively) and minimum (39.6) was recorded under unsprayed (control) condition (Table 6). Number of grains per spike reduced in heat stress environment it may be due to no formation of secondary grains because of heat stress. The grains per spike seemed to have decreased due to the sensitivity of the wheat plants to photoperiod and temperature. As the photoperiod and temperature increased, proper fertilization of the ovule may not have occurred to produce grains (Slafer and Whitechurch 2001). Laghari*et al* (2012) also reported reduction in grains per spike due to high temperature shocks.

Grain yield

Among varieties, PBW 621 and WH1105 were found statistically parbut significantly better than PBW 550. It may be attributed on account of duration of varieties.PBW 621 recorded 5.32 percent more yield than WH 1105 and 13.70 per cent than PBW 550. It is thus clear that PBW 621 and WH 1105 are considered suitable with respect to high yield level under timely sown wheat condition of punjab.The response of chemical treatment gave noticeable effect on grain yield. The KNO_3 and salicylic acid spray gave better yield as compare to all the other treatments. However, KNO_3 (0.5%) gave maximum grain yield (63.3 q/ha) which was found significantly superior than all other treatments except salicylic acid (50 µgml^{-1}). The higher concentration of salicylic acid (75 µgml^{-1}) proved not effective in increasing the wheat yield. It is thus clear that lower dose of salicylic acid and both the concentrations of KNO_3 showed discernible response on wheat crop. The interaction among varieties and chemicals were found non-significant (Table 4.5-a).

Firstly, with the application of antioxidants, PBW 621 and WH 1105 were found statistically parbut significantly better than PBW 550. WH 1105 gave 7.7 percent more yield than PBW 621 and 10.6 percent than PBW 550 (Table 4.5-b). It is thus clear that PBW 621 and WH 1105 are considered suitable with respect to high yield level under timely sown wheat condition of Punjab. The response of chemical treatment gave noticeable effect on grain yield. The ascorbic acid and arginine sprays gave better yield as compare to all the other treatments. However, Ascorbic acid @ 200 µg ml^{-1} gave maximum grain yield (53.8 q/ha) which was found significantly superior than all other treatments. The interaction among varieties and chemicals were found non-significant.

An increase in grain yield with the application of KNO_3 might be due to availability of K from KNO_3, which has important role in growth and development of plant as it increases enzyme activity and photosynthesis, improve synthesis of protein, carbohydrates and fats and translocation of photosynthates from source to sink, maintenance of turgor and transpiration in cells under environmental stress conditions. The increment of yield under heat stress conditions by foliar application of KNO_3 was also reported in Egyptian clover by Kumar *et al* (2013). Mandavia et al (2010) found that application of 50 and 100 µgml^{-1} of salicylic acid as foliar spray at vegetative (40 days after sowing) and reproductive stage (55 days after sowing) on chickpea had significantly increased the seed yield as compared to control. A decrease in pod and grain yield under salicylic acid at 100 µgml^{-1} in the study might be due to inhibition of foliar protein which leads to breakdown/degradation of chlorophyll (Kumar *et al*2013). Mahajan *et al* (2012) reported that grain yield can be improved with single spray of 1% KNO_3 at flowering stage in transplanted rice. Imas and Magen (2007) reported that potassium helps inphotosynthesis, carbohydrate distribution and starch synthesis in storage organs which helps in high grain yield.

Harvest index

Non-significant difference was recorded among the varieties. Foliar sprays and varieties, non-significantly affected harvest index (Table 7).The results showed that application of different osmo-protectants influenced all yield related parameters under terminal heat stress in wheat. The response of chemical treatment gave noticeable effect on grain yield. The KNO_3 (0.5 % and 1.0%) and salicylic acid (50 µgml^{-1}) spray gave better yield as compare to all the other treatments. However, KNO_3 (0.5%) gave maximum grain yield (63.33 q/ha) which was found significantly superior than all other treatments except salicylic acid (50 µgml^{-1}). The higher concentration of salicylic acid (75 µgml^{-1}) proved not effective in increasing the wheat yield. It is thus clear that lower dose of salicylic acid and both the concentrations of KNO_3 showed discernible response on wheat crop. Foliar sprays and varieties non-significantly affected harvest index with interaction among them. Our results are in accordance with findings of Sarlach *et al.,* 2013. Non-significant difference was recorded among the varieties. Foliar sprays and varieties, non-significantly affected harvest index, with no interaction among them (Table 8).

Table 1. Influence of different osmo-protectants on leaf area in wheat (*Triticum aestivum* L.)

Treatment	Leaf Area (cm^2)											
	60 DAS				90 DAS				120 DAS			
	PBW 550	PBW 621	WH 1105	MEAN	PBW 550	PBW 621	WH 1105	MEAN	PBW 550	PBW 621	WH 1105	MEAN
T1:- Salicylic acid (50μg ml^{-1})	12.0	11.0	14.0	**12.3**	38.0	29.0	38.0	**35.0**	38.0	30.0	40.0	**36.0**
T2:- Salicylic acid (75μg ml^{-1})	13.0	10.0	13.0	**12.0**	36.0	24.0	30.0	**30.0**	32.0	27.0	39.0	**32.7**
T3:- KNO_3 (0.5%)	14.0	12.0	14.0	**13.3**	39.0	31.0	44.0	**38.0**	38.0	34.0	42.0	**38.0**
T4:- KNO_3 (1%)	12.0	10.0	14.0	**12.0**	30.0	36.0	40.0	**35.3**	36.0	33.0	39.0	**36.0**
T5:- $ZnSO_{4.7}H2O$ (0.5%)	12.0	11.0	13.0	**12.0**	31.0	28.0	29.0	**29.3**	28.0	28.0	36.0	**30.7**
T6:- $ZnSO_4.7H_2O$ (1%)	12.0	10.0	13.0	**11.7**	25.0	25.0	32.0	**27.3**	30.0	26.0	33.0	**29.7**
T7:- Water sprayed	14.0	13.0	14.0	**13.7**	34.0	29.0	38.0	**33.7**	37.0	32.0	39.0	**36.0**
T8:- Unsprayed (control)	13.0	13.0	12.0	**12.7**	35.0	27.0	33.0	**31.7**	33.0	27.0	37.0	**32.3**
Mean	**12.8**	**11.3**	**13.4**	**12.5**	**33.5**	**28.6**	**35.5**	**32.5**	**34.0**	**29.6**	**38.1**	**33.9**
CD at 5%	Varieties (A) = 0.6 Treatments (B) = NS A x B = 1.7				Varieties (A) = 1.3 Treatments (B) = 2.1 A x B = 3.6				Varieties (A) = 1.9 Treatments (B) = 3.1 A x B = NS			

Table 2. Influence of different antioxidants on leaf area in wheat (*Triticum aestivum* L.)

Treatments	Leaf Area (cm^2)											
	60 DAS				90 DAS				120 DAS			
	PBW 550	PBW 621	WH 1105	Mean	PBW 550	PBW 621	WH 1105	Mean	PBW 550	PBW 621	WH 1105	Mean
T1- (Ascorbic acid 100 μgml^{-1})	13.7	10.8	13.1	**12.5**	37.8	30.4	27.0	**31.7**	35.6	29.2	37.1	**34.0**
T2- (Ascorbic acid 200 μgml^{-1})	11.9	11.8	12.8	**12.2**	36.2	27.4	31.7	**31.8**	38.9	30.8	37.5	**35.7**
T3- (Arginine 1.0 mM)	11.7	9.2	14.4	**11.8**	30.6	29.0	32.6	**30.7**	27.8	34.0	40.6	**34.1**
T4- (Arginine 2.0 mM)	12.4	9.93	14.1	**12.1**	34.0	29.1	34.1	**32.4**	30.9	32.9	38.7	**34.8**
T5- (Water sprayed)	12.0	10.8	13.5	**12.1**	30.3	26.4	31.9	**29.5**	33.6	27.6	42.3	**34.5**
T6- (Unsprayed control)	12.6	40.4	14.6	**22.6**	25.2	23.8	29.8	**26.3**	36.8	25.7	39.1	**33.9**
Mean	**12.4**	**15.5**	**13.7**	**13.9**	**32.4**	**28.0**	**33.8**	**31.4**	**33.7**	**29.7**	**36.6**	**33.3**
CD at 5%	Varieties (A) = 1.1 Treatments (B) = NS A x B = NS				Varieties (A) = 2.4 Treatments (B) = NS A x B = 3.4				Varieties (A) = 1.4 Treatments (B) = 2.0 A x B = 5.9			

Table 3. Effect of different concentrations of osmo-protectants on Dry Matter Accumulation (g) in wheat (*Triticum aestivum* L.)

Treatment	Dry Matter Accumulation (g/plant)											
	60 DAS				90 DAS				120 DAS			
	PBW 550	PBW 621	WH 1105	Mean	PBW 550	PBW 621	WH 1105	Mean	PBW 550	PBW 621	WH 1105	Mean
T1:- Salicylic acid (50μg ml^{-1})	4.5	6.4	6.1	**5.7**	11.2	14.1	14.3	**13.2**	23.6	27.6	23.3	**24.8**
T2:- Salicylic acid (75μg ml^{-1})	4.6	6.0	5.3	**5.3**	11.3	13.5	13.0	**12.6**	22.7	25.7	22.5	**23.6**
T3:- KNO_3 (0.5%)	4.6	6.7	5.7	**5.7**	12.4	15.2	15.1	**14.2**	27.1	28.1	26.5	**27.2**
T4:- KNO_3 (1%)	4.5	6.4	5.3	**5.4**	12.6	14.6	12.8	**13.4**	24.4	28.4	25.9	**26.2**
T5:- $ZnSO_{4.7}H2O$ (0.5%)	4.6	6.4	5.3	**5.4**	10.7	12.9	11.5	**12.3**	19.5	21.8	21.8	**21.0**
T6:- $ZnSO_4.7H_2O$ (1%)	4.4	6.1	5.3	**5.3**	13.9	13.6	10.8	**12.7**	13.6	23.1	20.7	**19.1**

T7:- Water sprayed	4.5	6.2	5.3	**5.3**	15.4	12.8	12.5	**13.6**	24.8	24.6	24.4	**24.6**
T8:- Unsprayed (control)	4.6	6.2	5.5	**5.4**	10.2	11.8	11.4	**11.1**	22.9	22	22.5	**22.4**
Mean	**4.5**	**6.3**	**5.5**	**5.4**	**12.2**	**13.5**	**12.5**	**12.8**	**22.3**	**25.2**	**23.4**	**23.6**
CD at 5%	Varieties (A) = 0.2 Treatments (B) = NS 0A x B = NS				Varieties (A) = 0.7 Treatments (B) = NS A x B = NS				Varieties (A) = 1.1 Treatments (B) = 1.8 A x B = 3.0			

Table 4: Effect of different concentrations of ascorbic acid and arginine on Dry Matter Accumulation (g) in wheat (*Triticum aestivum* L.)

Treatment	**Dry Matter Accumulation (g/plant)**											
	60 DAS				**90 DAS**				**120 DAS**			
	PBW 550	**PBW 621**	**WH 1105**	**Mean**	**PBW 550**	**PBW 621**	**WH 1105**	**Mean**	**PBW 550**	**PBW 621**	**WH 1105**	**Mean**
T1- (Ascorbic acid 100 $\mu g ml^{-1}$)	4.6	6.4	6.2	**5.7**	12.4	14.1	11.8	**12.8**	24.8	27.6	25.9	**26.1**
T2- (Ascorbic acid 200 $\mu g ml^{-1}$)	4.5	6.0	6.2	**5.6**	12.6	13.5	12.8	**13.0**	27.1	28.1	26.4	**27.2**
T3- (Arginine 1.0 mM)	4.6	6.7	6.1	**5.8**	10.7	15.2	14.3	**13.4**	22.9	24.6	22.5	**23.3**
T4- (Arginine 2.0 mM)	4.4	6.4	5.3	**5.4**	13.8	14.6	13.0	**13.8**	24.4	25.7	23.3	**24.4**
T5- (Water sprayed)	4.1	5.6	5.1	**5.0**	9.8	12.9	12.8	**11.8**	19.5	24.0	21.8	**21.8**
T6- (Unsprayed control)	4.2	5.4	5.1	**4.9**	11.2	12.9	12.5	**12.2**	13.6	22.0	21.5	**19.0**
Mean	**4.4**	**6.1**	**5.7**	**5.4**	**11.7**	**13.9**	**12.9**	**12.8**	**22.0**	**25.3**	**23.6**	**23.6**
CD at 5%	Varieties (A) = 0.2 Treatments (B) = 0.3 A x B = NS				Varieties (A) = 0.9 Treatments (B) = 1.3 A x B = NS				Varieties (A) = 1.2 Treatments (B) = 1.7 A x B = 3.0			

Table 5. Effect of osmo-protectants on spikelets per spike and grains per spike in wheat (*Triticum aestivum* L.)

Treatments	**Number of spikelets per spike**				**Number of grains per spike**			
	PBW 550	**PBW 621**	**WH 1105**	**Mean**	**PBW 550**	**PBW 621**	**WH 1105**	**Mean**
T1- Salicylic acid (50µg ml^{-1})	15.0	19.0	18.0	**17.3**	43.7	49.3	36.8	**43.3**
T2- Salicylic acid (75µg ml^{-1})	16.0	18.0	17.0	**17.0**	44.3	49.0	36.8	**43.4**
T3- KNO_3 (0.5%)	16.0	20.0	20.0	**18.7**	45.7	57.7	40.7	**48.0**
T4- KNO_3 (1%)	16.0	19.0	19.0	**18.0**	42.3	57.0	39.1	**46.1**
T5- $ZnSO_4.7H_2O$ (0.5%)	16.0	18.0	18.0	**17.3**	34.0	48.3	33.2	**38.5**
T6- $ZnSO_4.7H_2O$ (1%)	16.0	19.0	17.0	**17.3**	35.3	46.0	32.9	**38.1**
T7- Water sprayed	16.0	19.0	17.0	**17.3**	43.3	49.0	36.6	**43.0**
T8- Unsprayed (control)	16.0	19.0	17.0	**17.3**	41.0	47.3	35.2	**41.2**
Mean	**15.9**	**18.9**	**17.9**	**17.5**	**41.2**	**50.5**	**36.4**	**42.7**
CD 5%	Varieties (A) = 0.6 Treatments (B) = NS A x B = NS				Varieties (A) = 2.3 Treatments (B)= 3.7 A x B = NS			

Table 6. Effect of ascorbic acid and arginine on spikelets per spike and grains per spike weight in wheat (*Triticum aestivum* L.)

Treatment	**No. of spikelets per spike**				**No. of grains per spike**			
	PBW 550	**PBW 621**	**WH 1105**	**Mean**	**PBW 550**	**PBW 621**	**WH 1105**	**Mean**
T1- (Ascorbic acid 100 $\mu g ml^{-1}$)	16.1	18.1	19.1	**17.8**	42.3	57.0	47.3	**48.9**
T2- (Ascorbic acid 200 $\mu g ml^{-1}$)	16.3	19.1	20.2	**18.5**	45.7	57.7	49.0	**50.8**
T3- (Arginine 1.0 mM)	15.7	17.8	18.5	**17.3**	38.3	49.0	45.7	**44.3**
T4- (Arginine 2.0 mM)	15.9	18.7	19.5	**18.0**	39.3	49.3	47.0	**45.2**
T5- (Water sprayed)	15.4	17.5	17.3	**16.8**	35.3	45.0	43.8	**41.4**
T6- (Unsprayed control)	15.2	17.2	17.3	**16.6**	34.0	42.7	42.2	**39.6**
Mean	**15.8**	**18.1**	**18.6**	**17.5**	**39.2**	**50.1**	**45.8**	**45.0**
CD at 5%	Varieties (A) = 0.4 Treatments (B) = 0.6 A x B = 1.0				Varieties (A) = 2.4 Treatments (B) = 3.4 A x B = 5.8			

Table 7. Performance of different osmo-protectants on grain yield and harvest index in wheat (*Triticum aestivum* L.)

Treatments	Grain yield (q/ha)				Harvest index			
	PBW 550	PBW 621	WH 1105	Mean	PBW 550	PBW 621	WH 1105	Mean
T1- Salicylic acid (50µg ml^{-1})	52.0	66.0	59.0	**59.0**	0.4	0.4	0.4	**0.4**
T2- Salicylic acid (75µg ml^{-1})	49.0	57.0	51.0	**52.3**	0.4	0.4	0.3	**0.4**
T3- KNO_3 (0.5%)	55.0	68.0	67.0	**63.3**	0.4	0.4	0.4	**0.4**
T4- KNO_3 (1%)	57.0	61.0	58.0	**58.7**	0.4	0.4	0.4	**0.4**
T5-$ZnSO_4.7H_2O$ (0.5%)	47.0	47.0	46.0	**46.7**	0.3	0.3	0.3	**0.3**
T6- $ZnSO_4.7H_2O$ (1%)	40.0	50.0	43.0	**44.3**	0.3	0.3	0.3	**0.3**
T7- Water sprayed	50.0	52.0	52.0	**51.3**	0.4	0.3	0.3	**0.3**
T8- Unsprayed (control)	51.0	55.0	57.0	**54.3**	0.3	0.3	0.3	**0.3**
Mean	**50.1**	**57.0**	**54.1**	**53.7**	**0.4**	**0.4**	**0.3**	**0.3**
CD 5%	Varieties (A) = 3.1 Treatments (B) = 5.1 A x B = NS				Varieties (A) = NS Treatments (B) = 0.03 A x B = 0.05			

Table 8. Performance of different antioxidants on straw grain yield and harvest index in wheat (*Triticum aestivum* L.)

Treatments	Grain yield (q/ha)				Harvest index			
	PBW 550	PBW 621	WH 1105	Mean	PBW 550	PBW 621	WH 1105	Mean
T1- (Ascorbic acid 100 μgml^{-1})	53.1	51.5	57.4	**54.0**	0.3	0.3	0.4	**0.4**
T2- (Ascorbic acid 200 μgml^{-1})	50.9	51.6	57.6	**53.8**	0.4	0.3	0.4	**0.4**
T3- (Arginine 1.0 mM)	51.1	53.5	56.6	**53.5**	0.3	0.4	0.4	**0.4**
T4- (Arginine 2.0 mM)	50.9	53.9	56.2	**53.0**	0.3	0.3	0.4	**0.3**
T5- (Water sprayed)	46.3	51.2	52.3	**49.9**	0.4	0.4	0.3	**0.4**
T6- (Unsprayed control)	46.4	45.0	49.0	**46.8**	0.4	0.3	0.3	**0.4**
Mean	**49.8**	**51.2**	**55.1**	**52.0**	**0.3**	**0.3**	**0.4**	**0.4**
CD at 5%	Varieties (A) = 1.7 Treatments (B) = 2.4 A x B = NS				Varieties (A) = NS Treatments (B) = NS A x B = 0.06			

Appendix 1. Meteorological data during experimental period at PAU, Ludhiana

Month	Standard week	Temp (°C)			Normal Temp (°C)			RH (%)	Total rainfall (mm)	No. of rainy days	Pan evapor-ration(mm)	Sun-shine hours
		Max.	Min.	Mean	Max.	Min.	Mean					
October	44	29.1	14.1	21.6	29.5	12.8	21.2	64	0	0	22.2	7.2
November	45	28.7	14.2	21.4	28.1	11.3	19.7	63	0	0	17.2	5.5
	46	26.1	8.9	17.5	27.1	10.3	18.7	61	0	0	17.6	8.1
	47	25.4	8.3	16.8	25.3	8.8	17.1	63	0	0	14.8	7.7

	48	26.2	9.8	18.0	23.8	7.4	15.6	66	0	0	14.0	7.4
December	49	25.1	7.7	16.4	22.9	6.4	14.7	68	0	0	15.0	7.9
	50	18.6	7.2	12.9	21.6	6.3	14.0	76	42.2	1	11.2	4.0
	51	12.5	6.9	9.7	20.7	5.6	13.2	88	0	0	5.4	1.4
	52	13.3	5.2	9.3	19.1	5.9	12.5	89	0	0	6.2	1.8
January	1	16.2	8.2	12.2	19.1	5.0	12.1	86	0.4	0	7.2	0.9
	2	13.3	7.3	10.3	18.9	5.1	12.0	87	4.6	1	6.1	0.3
	3	17.4	6.2	11.8	19.1	5.0	12.1	83	6.2	1	7.2	5.7
	4	14.7	7.7	11.2	19.8	6.0	12.9	87	14.6	1	6.0	3.1
February	5	18.6	7.1	12.9	19.6	6.0	12.8	77	11.6	1	13.2	5.9
	6	20.9	7.2	14.1	20.9	6.2	13.6	77	0	0	13.6	7.4
	7	23.9	11.2	17.5	21.6	7.9	14.8	77	8.4	1	17.2	5.8
	8	23.5	14.5	19.0	22.3	7.7	15.0	86	19.0	3	15.4	3.7
March	9	20.3	10.6	15.5	23.9	8.8	16.4	80	24.8	2	14.8	8.3
	10	22.5	9.2	15.8	25.4	10.1	17.8	78	8.2	1	16.4	8.2
	11	24.1	12.5	18.3	27	11.2	19.1	78	36.2	3	18.5	6.1
	12	29.0	15.2	22.1	27.4	12.1	19.8	74	0	0	28.2	10.2
April	13	30.2	17.7	23.9	29.4	13.5	21.5	69	15.8	1	34.2	6.8
	14	27.1	17.3	22.2	31.2	14.6	22.9	73	3.4	0	28.0	6.7
	15	32.6	18.1	25.4	33.6	16.2	24.9	64	17.6	1	40.6	9.4
	16	34.7	20.3	27.5	35.1	17.3	26.2	63	8.0	1	50.0	9.0

CONCLUSION

It may be concluded that grain yield is an important selection criterion for breeding programmes. Grain yield is related with yield components. These yield related traits like number of spikelets per spike, thousand grain weight, straw yield and grain yield per plot etc. The information obtained from these traits during the studies may be used to evolve high yielding varieties which can produce economic yield and help the yield sustainability in those areas where terminal heat stress is a major threat.

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