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Evaluation of Wheat Genotypes for Protective Mechanisms of Terminal Heat Stress

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A B S T R A C T

Wheat is the one of the most important cereal crop in the world. High temperature stress is a common environmental phenomena encounter by wheat throughout the world. Wheat is sensitive to high temperature; increase in temperature is a severe threat to wheat production and quality loss, particularly when it occurs during reproductive and grain-filling phases. Keeping in view a field experiment was conducted to evaluate twenty wheat genotypes (ten heat tolerant and ten heat susceptible) for various physiological, biochemical traits at anthesis, seven days after anthesis and identify promising wheat genotypes under terminal high temperature condition. High temperature significantly influenced physiological, biochemical, yield and yield attributes at anthesis and 14 days after anthesis (DAA) in both heat susceptible and heat tolerant genotypes. Decrease in carotenoids content and cell membrane stability (CMS) was least in heat tolerant genotype *i.e.,* WH 730 (9.4%) and WH 1021 (10.5 %) respectively. WH 1021 showed high cell membrane stability (CMS), carotenoids content at anthesis and 7DAA. WH 1021 also, retained highest biomass, grain yield and 1000 grain weight. In present investigation heat tolerant genotype WH 1021 was found to be the most suitable one terminal high temperature condition on the basis of the overall picture of physiological, biochemical and yield traits studied.

Introduction

Wheat is the single most important crop on global scale in terms of total harvested weight and amount used for human and animal nutrition. It is grown across an exceptionally diverse range of environments, from the arid plains of Africa to the humid valleys of Vietnam and from the cold of Nepal to the heat of India Rao *et al.,* (1977). Currently in India, wheat is grown on an area of about 30.37 million hectares which produces 90.78 million tons of wheat with a productivity of 2.99 tons per hectare making India second largest producer of wheat in the world (Anonymous, 2015). In India wheat production is hindered by various factors like date of sowing, judicious application of fertilizers, irrigation time and temperature. Out of these, high temperature is a crucial environmental aspect (Slafer and Rawson, 1994). High temperature stress induces oxidative stress. Protective responses must be triggered quickly in response to the oxidative stress effectors to prevent plant from damage. Studies have shown that protection

mechanisms like anti-oxidative compounds, which helped to prevent the accumulation of reactive oxidant species (ROS), membrane lipid peroxidation and maintenance high cell membrane stability play an important role. Membrane is the first line of defense having many heat responsive sensors which helps plant to trigger its defense mechanism against heat stress, so the integrity of the membrane is an important parameter for heat tolerance. Cell membrane stability (CMS) is directly correlated with outside environmental temperature and leaf electrolyte leakage, as a measure of leaf membrane thermostability, may provide an efficient indirect screening technique for reproductive-stage heat-tolerance genes. High temperature stress induces intense changes in cellular membranes which results in loss of membrane stability index (MSI) resulting in ion/solute leakage Saxena *et al.,* (2016). Heat stress triggers the production and accumulation of ROS Sairam *et al.,* (2000); Mittler (2002); Almeselmani *et al.,* (2009) which causes oxidative stress may induce lipid peroxidation leading to protein degradation, membrane rupture and enzyme inactivation Sairam *et al.,* (2000). Lipid peroxidation is considered as one of the most damaging processes.

MDA content reflects the degree of damage at adverse conditions and is an indicator of lipid peroxidation. Mishra *et al.,* (2017) who reported 3 fold increases in MDA in wheat under heat stress. Dhyani *et al.,* (2013) also who reported more MDA content at anthesis and 15 days after anthesis under terminal heat stress. Sairam *et al.,* (2000).Detoxification of ROS produced in oxidative stress caused by heat stress by antioxidant systems is important for protecting plants against heat stress (Asada, 2006). The capacity of the cellular anti oxidative and photo protective defense is determined by the pool size of antioxidants and protective pigments Karin *et al.,* (2002). Carotenoids (Car) are necessary for photoprotection of photosynthesis and they play an important role as a precursor in signaling during the plant development under abiotic/biotic stress. Carotenoids protect chlorophyll from photo oxidative destruction, so a change in carotenoids could have serious consequences for the effect of UV-B radiation on chlorophyll pigments Mishra *et al.,* (2008). Physiological and Biochemical parameters like CMS, Lipid peroxidation-MDA content and Total antioxidant activity (TAA) and carotenoids content might be helpful to overcome yield loss under terminal heat stress. Keeping in view study was conducted to evaluate various physiological, biochemical traits and to identify a promising wheat genotype under terminal high temperature condition**.**

Materials and Methods

The twenty wheat genotypes *i.e.* ten tolerant (WH 730, WH 1124, WH 1021, HD 3059, DBW 90, PBW 373, Raj 3765, HD 2851, HD 2285, PBW 550) and ten heat susceptible (HD 2967, DBW 621, WH 1105, DBW 88, HD 3086, HD 2733, WH 711, WH 1080, WH 1142 and K 0307)were evaluated under terminal high temperature condition. The crop was sown in middle of December, 2016 (late planting date). The experiments were carried out through a randomized block design consisting of 4 rows of 3m length with 20×5 cm spacing within rows and between plants, respectively with three replications in field crop research area of Wheat and Barley Section, Department of Genetics and Plant Breeding, CCS HAU, Hisar India.

Flag leaf per selected plant was randomly chosen and tagged (total of ten flag leaves per genotype was tagged).The tagged leaves were used to measure physiological and biochemical traits (cell membrane stability, lipid peroxidation-MDA content, total antioxidant activity and carotenoids content) at anthesis and 14 days after anthesis (14DAA).

Cell membrane stability (%)

To measure cell membrane stability, method of Sullivan (1972), modified later on by Ibrahim and Quick (2001) was followed. A random sample of flag leaf from 3 plants from each replication was collected from anthesis till maturity at interval of seven days. Each sample was collected in sealed plastic bags and immediately kept in ice box. At laboratory all the samples were thoroughly rinsed twice in deionized water. The mid rib of flag leaves was removed gently by hand and about 5cm portion from central flag leaf area was excised and cut in to 4 equal parts. Leaf was taken in glass test tubes containing 10ml distilled water. The test tube samples were tightly covered with aluminum foil and were maintained between 4-8 °C for 24 hrs, and after that, the test tubes were kept at room temperature and reading 1 was measured. After that tubes were heated to 49°C in the water-bath for exposing the leaf samples for 1 hour. Then, again leaf samples were maintained at 4-8°C for 24 hrs, and then samples were brought to room temperature, reading 2 was taken. Finally, tubes were autoclaved for 30 min at 121°C and then tubes were again kept at 4-8°C for 24 hrs, which were brought to room temperature for taking reading 3.

$$CMS(\%) = 1 - \frac{[1 - Reading2(waterbath\ sample)/Reading3(Autoclave\ sample)]}{[1 - Reading\ 1(Fresh\ sample)/Reading3(Autoclave\ sample)]} X\ 100$$

Lipid peroxidation-MDA content (µmole/g fresh weight)

Malondialdehyde (MDA) content was estimated according to the method of Heath and Packer (1968), where approximately 0.5 g leaf sample was homogenized in 5 ml of 0.1% trichloroacetic acid (TCA) with the help of mortar and pestle and centrifuged at 8,000 rpm for 15 min. After centrifugation, 1 ml of the supernatant was mixed with 2.3 ml 0.5% TBA in 20% TCA and incubated in hot water (95°C) for 30 min. Thereafter, it was cooled immediately on ice to stop the reaction. Absorbance at 532 and 600 nm was determined, and MDA concentration was estimated by subtracting the non-specific absorption at 600 nm from the absorption at 532 nm, using an absorbance coefficient of extinction (155 mM^{-1} cm^{-1}).

Total antioxidant activity (µmole/g fresh weight)

Total antioxidant activity was estimated by the method of Prieto *et al.*, (1999) where Sample material of 0.5 g was homogenized in 5 ml of 95% methanol, contents was transferred into 150 ml conical flasks. Conical flask was sealed with parafilm, kept on shaker for one hour, centrifuged the contents at 10,000 rpm for 20 minutes, transferred and the supernatant was used for estimation.

Transferred 0.3 ml of supernatant, 3 ml of phosphomolybdate reagent into polycarbon capped tubes, incubated the contents on water bath at 95°C for 90 minutes, cooled the contents to room temperature and absorbance was read against blank at 695 nm. Total antioxidant activity was estimated from standard curve of ascorbic acid (10–100 µg) and expressed in terms of ascorbic acid equivalent.

Carotenoids content (mg g^{-1})

Carotenoids content was estimated by the method of Hiscox and Isrealstam (1979), where 100 mg washed and finely chopped leaves' (excluding veins) was placed in a tube containing 5 ml DMSO.

These tubes were incubated at 65°C for one hour. Extract was transferred to a 10 ml graduated cylinder and volume was made up

to mark with DMSO. Absorbance was measured at 450 nm. Cartenoids content was calculated by following formula:

$$\text{Carotenoids content} = \frac{10 \times A\,450 \times V}{2500 \times W}$$

V = Volume of the solution used / Dilution factor
W = Weight of the sample

Yield and yield attributes

Biomass (kg/m^2)

Plants were cut from the base of stem at maturity and weight was taken using spring balance in kilograms and average was taken.

Grain yield (kg/m^2)

Grain yield from each plot was recorded in kilograms.

Thousand grain weight (g)

Weight of randomly chosen clean and filled 1000 grains was measured in grams from each replication using electronic balance and average was recorded.

Harvest index (%)

Harvest index for each of the genotype was computed using the following formula;

$$\text{Harvest Index}\,(\%) = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

Statistical analysis

Statistical analysis was done using Indian NARS Statistical Computing Portal: http:// stat.iasri.res.in/sscnarsportal of IASRI New Delhi.

Results and Discussion

Physiological and biochemical traits

Significant differences existed among wheat genotypes tested for total antioxidant activity (TAA), cell membrane stability (CMS), lipid peroxidation in term of MDA content and carotenoids content at the anthesis and 14DAA stages (Table 1). At anthesis TAA ranged from 11.09 µmole/g fresh weight in K 0307 to 66.95 µmole/g fresh weight. In WH 1124 same trend was observed at 14DAA. CMS decreased from anthesis to 14DAA. At anthesis CMS ranged from 54.54% in K 0307 to 75.16% in WH 1021 also 14DAA it ranged from 23.84% in K 0307 to 67.29% in WH 1021. The Lipid peroxidation was measured in terms of MDA content. MDA content ranged from 2.71 µmole/g fresh weight in PBW373 to 9.10µmole/g fresh in HD 2967 at anthesis whereas, at 14DAA MDA content ranged from 7.10µmole/g fresh weight in HD 3059 to 12.19µmole/g fresh weight in WH711. Carotenoids content decreased from anthesis to 14DAA. At anthesis carotenoids content ranged from 0.49 mg g^{-1} in K 0307 to 1.07 mg g^{-1} in WH 1021 whereas it ranged from 0.35 mg g^{-1} in K 0307 to 0.69 mg g^{-1} in WH 1021 14DAA. Average TAA, CMS, lipid peroxidation-MDA content, Carotenoids content was 48.88, 66.86, 6.52, 0.79 respectively at anthesis and 66.74, 40.30, 9.66 and 0.52 respectively at 14DAA which indicates significant effect of heat stress at anthesis and 14DAA.

WH 730 (9.4 %) and WH 1021 (10.5%) showed minimum decrease in carotenoids content and CMS respectively whereas WH 1080 (56.1%) and K 0307 (56.3%) showed maximum decrease for Carotenoids content and CMS respectively. PBW 373 (60 %) and HD 2967 (69.8%) showed maximum increase for lipid peroxidation – MDA content and total antioxidant activity whereas K 0307

(23.0 %) and HD 3059 (13.0%) showed for minimum increase for lipid peroxidation - MDA content and TAA respectively (Table 2).

Relation between cell membrane stability and total antioxidant activity, lipid peroxidation, carotenoids content under terminal heat stress condition

The results pertaining to relation between cell membrane stability and total antioxidant activity, CMS and lipid peroxidation – MDA content, CMS and carotenoids is shown in Figures 1, 2 and 3. A positive relation was found between CMS and TAA for all the genotypes. A positive relation between CMS and carotenoids content was observed in all genotypes. But negative relation between CMS and lipid peroxidation was observed in few genotypes (HD 3059, PBW 550, WH1124, WH 1021). TAA, carotenoids content and less lipid peroxidation could be possible reason for high cell membrane stability.

Table.1 Various physiological and biochemical traits under terminal heat stress condition

Genotypes	Total antioxidant activity(TAA)		Cell membrane stability (CMS)		Lipid peroxidation-MDA content		Carotenoids content	
	Anthesis	14DAA	Anthesis	14DAA	Anthesis	14DAA	Anthesis	14DAA
DBW621	45.10^{H}	62.55^{IJ}	61.52^{I}	30.03^{JK}	7.55^{CD}	10.61^{BCD}	0.66^{K}	0.42^{JK}
DBW88	49.80^{FGH}	64.48^{HI}	64.05^{H}	32.24^{IJ}	7.05^{EF}	10.19^{CDE}	0.68^{IJK}	0.45^{IJK}
DBW90	58.41^{BCD}	71.01^{BCDE}	71.46^{BC}	47.61^{D}	5.85^{L}	8.95^{IJ}	0.91^{CDE}	0.59^{DE}
HD2285	52.29^{EFG}	68.55^{DEFG}	68.75^{DEF}	41.78^{F}	6.42^{HIJ}	9.48^{FGHI}	0.80^{FG}	0.55^{EFG}
HD2733	47.32^{GH}	63.07^{IJ}	61.67^{I}	31.45^{IJ}	7.32^{DE}	10.26^{CDE}	0.68^{JK}	0.43^{JK}
HD2851	52.00^{EFG}	68.46^{EFG}	68.06^{EFG}	39.32^{FG}	6.53^{GHI}	9.76^{EFGH}	0.78^{GH}	0.54^{EFG}
HD2967	18.21^{J}	60.35^{J}	56.21^{K}	27.11^{KL}	**9.10^{A}**	11.19^{B}	0.58^{L}	0.38^{LM}
HD3059	63.31^{AB}	71.57^{BC}	73.69^{AB}	53.44^{C}	5.47^{MN}	**7.10^{M}**	0.97^{BC}	0.64^{BC}
HD3086	50.97^{EFG}	68.17^{EFG}	67.78^{EFG}	38.28^{G}	6.58^{GHI}	9.90^{EFG}	0.75^{GHI}	0.52^{FGH}
K0307	**11.09^{K}**	**23.09^{K}**	**54.54^{K}**	**23.84^{L}**	8.79^{B}	10.81^{BC}	**0.49^{M}**	**0.35^{M}**
PBW373	53.60^{DEF}	69.17^{CDEFG}	69.53^{CDE}	42.21^{EF}	**2.71^{O}**	9.37^{GHIJ}	0.85^{EF}	0.56^{EF}
PBW550	63.62^{AB}	72.24^{B}	74.58^{A}	57.55^{B}	5.19^{N}	8.29^{KL}	1.01^{AB}	0.68^{AB}
Raj3765	56.04^{CDE}	70.32^{BCDEF}	70.48^{CD}	45.40^{DE}	5.98^{KL}	9.13^{HIJ}	0.90^{DE}	0.58^{DE}
WH1021	59.66^{BC}	71.50^{BCD}	**75.16^{A}**	**67.29^{A}**	6.29^{IJ}	7.79^{L}	**1.07^{A}**	**0.69^{A}**
WH1080	50.06^{FGH}	66.28^{GH}	64.40^{H}	32.94^{IJ}	6.81^{FG}	10.13^{DE}	0.70^{IJK}	0.47^{HIJ}
WH1105	50.42^{FGH}	66.69^{GH}	66.07^{GH}	34.72^{HI}	6.73^{G}	10.05^{DEF}	0.71^{HIJK}	0.48^{HI}
WH1124	**66.95^{A}**	**76.89^{A}**	73.27^{AB}	51.49^{C}	5.56^{M}	8.81^{JK}	0.95^{BCD}	0.62^{CD}
WH1142	50.42^{FGH}	67.31^{FGH}	67.07^{FG}	37.32^{GH}	6.64^{GH}	9.95^{EFG}	0.74^{GHIJ}	0.50^{GH}
WH711	23.72^{I}	61.83^{IJ}	59.06^{J}	29.60^{JK}	7.63^{C}	**12.19^{A}**	0.64^{KL}	0.41^{KL}
WH730	54.58^{CDEF}	69.81^{BCDEF}	69.93^{CDE}	42.32^{EF}	6.24^{JK}	9.32^{GHIJ}	0.86^{EF}	0.58^{DE}
Mean	**48.88**	**66.74**	**66.86**	**40.3**	**6.52**	**9.66**	**0.79**	**0.52**
C.V (%)	**5.23**	**2.16**	**1.61**	**4.03**	**2.11**	**3.17**	**4.35**	**9.45**

*Mean values followed by the same letters in TAA, CMS, lipid peroxidation -MDA and carotenoid content columns are not significantly different at 5% level of probability according to Duncan's multiple range test

Table.2 Increase or decrease in various physiological and biochemical traits in wheat genotypes from anthesis to 14DAA under terminal heat stress condition

Genotypes	% Increase		% Decrease	
	TAA	MDA	CAR	CMS
DBW 621	38.7	40.5	36.4	51.2
DBW88	29.5	44.5	33.8	49.7
DBW90	21.6	53.0	35.2	33.4
HD2285	31.1	47.7	31.3	39.2
HD2733	33.3	40.2	36.8	49.0
HD2851	31.7	49.5	30.8	42.2
HD2967	**69.8**	23.0	34.5	51.8
HD3059	**13.0**	29.8	34.0	27.5
HD3086	33.7	50.5	30.7	43.5
K0307	52.0	**23.0**	28.6	**56.3**
PBW373	29.0	**60.0**	34.1	39.3
PBW550	13.5	50.1	32.7	22.8
Raj3765	25.5	52.7	35.6	35.6
WH1021	19.8	31.8	19.8	**10.5**
WH1080	32.4	48.8	**56.1**	48.9
WH1105	32.3	49.3	31.4	47.4
WH1124	14.8	58.5	12.7	29.7
WH1142	33.5	49.8	47.4	44.4
WH711	61.6	59.8	44.6	49.9
WH730	27.9	49.4	**9.4**	39.5
Range	**13.0 -69.8**	**23.0 - 60.0**	**9.4 - 56.1**	**10.5 – 56.3**

TAA-Total antioxidant activity, MDA-Malondialdehyde content, CAR-Carotenoids content, CMS-Cell membrane stability

Table.3 Yield and Yield Attributes under terminal heat stress condition

Genotypes	Biomass (kg/m^2)	Grain yield (kg/m^2)	1000 grain weight (g)	Harvest index (%)
DBW 621	0.24^{JKL}	0.24^{JKL}	27.4^{ABC}	34.70^{DE}
DBW 88	0.82^{DEF}	0.25^{FG}	29.1^{ABCDE}	34.30^{DE}
DBW 90	0.96^{BCDE}	0.35^{BCDEF}	39.9^{A}	34.30^{ABCDE}
HD 2285	0.94^{BCDE}	0.28^{EF}	34.0^{DEFG}	35.00^{DE}
HD 2733	0.84^{DE}	0.24^{FG}	28.0^{H}	34.00^{DE}
HD 2851	0.71^{EF}	0.28^{EF}	33.0^{BCDEFG}	**33.30**^{ABCD}
HD 2967	0.67^{EF}	0.22^{DEF}	22.5^{AB}	36.70^{ABCDE}
HD 3059	1.48^{A}	0.43^{AB}	37.7^{ABCDE}	**37.30**^{DE}
HD 3086	0.78^{EF}	0.33^{BCDEF}	31.9^{A}	35.00^{ABCD}
K 0307	**0.50**^{F}	**0.16**^{G}	**18.5**^{EFGH}	33.70^{CDE}
PBW 373	0.93^{BCDE}	0.32^{CDEF}	34.5^{FGH}	36.30^{CDE}
PBW 550	1.12^{BCD}	0.48^{BCD}	36.3^{BCDEF}	36.70^{ABC}
Raj 3765	0.86^{CDE}	0.42^{ABC}	35.9^{CDEFG}	35.00^{A}
WH 1021	**1.19**^{AB}	**0.53**^{A}	**40.5**^{BCDEF}	35.00^{BCDE}
WH 1080	0.96^{BCDE}	0.31^{DEF}	29.8^{ABCDE}	34.70^{CDE}
WH 1105	0.88^{BCDE}	0.28^{EF}	31.1^{GH}	35.30^{CDE}
WH 1124	0.92^{BCDE}	0.39^{EFG}	39.3^{ABCDE}	34.30^{DE}
WH 1142	0.76^{EF}	0.37^{BCDE}	31.5^{ABCD}	34.70^{AB}
WH 711	0.80^{DEF}	0.21^{FG}	25.5^{ABCDE}	34.00^{ABCDE}
WH 730	1.18^{ABC}	0.29^{EF}	35.5^{A}	35.00^{E}
Mean	**0.91**	**0.32**	**35.0**	**34.96**
LSD at 5%	**0.12**	**0.04**	**9.68**	**NS**
CV (%)	8.34	**8.48**	**16.27**	**5.74**

*Mean values followed by the same letters in Biomass, Grain yield, 1000 grain weight and Harvest Index columns are not significantly different at 5% level of probability according to Duncan's multiple range
Yield and Yield Attributes under terminal heat stress condition

Fig.1 Relation between CMS and total antioxidant activity in wheat genotypes under terminal heat stress condition

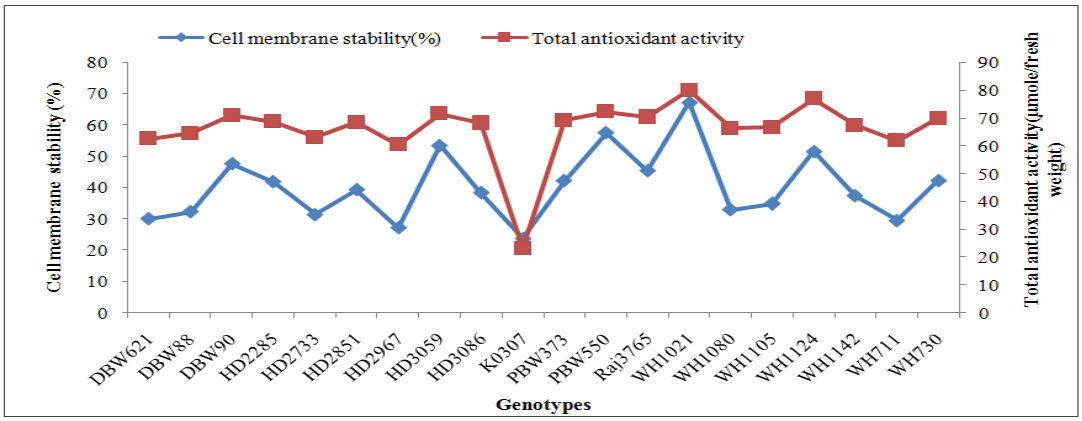


Fig.2 Relation between CMS and lipid peroxidation – MDA content in wheat genotypes under terminal heat stress condition

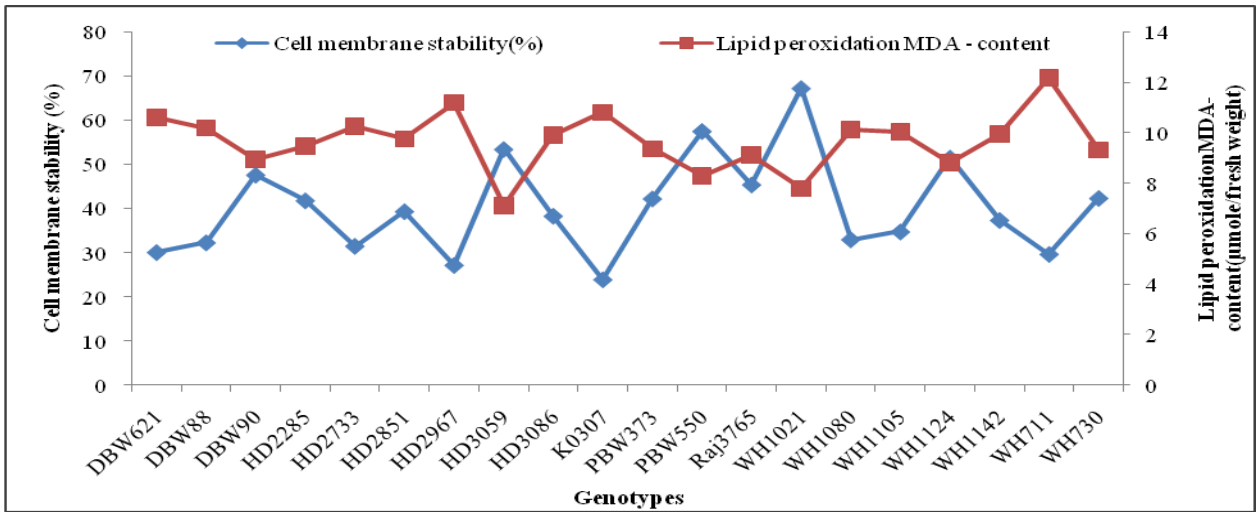
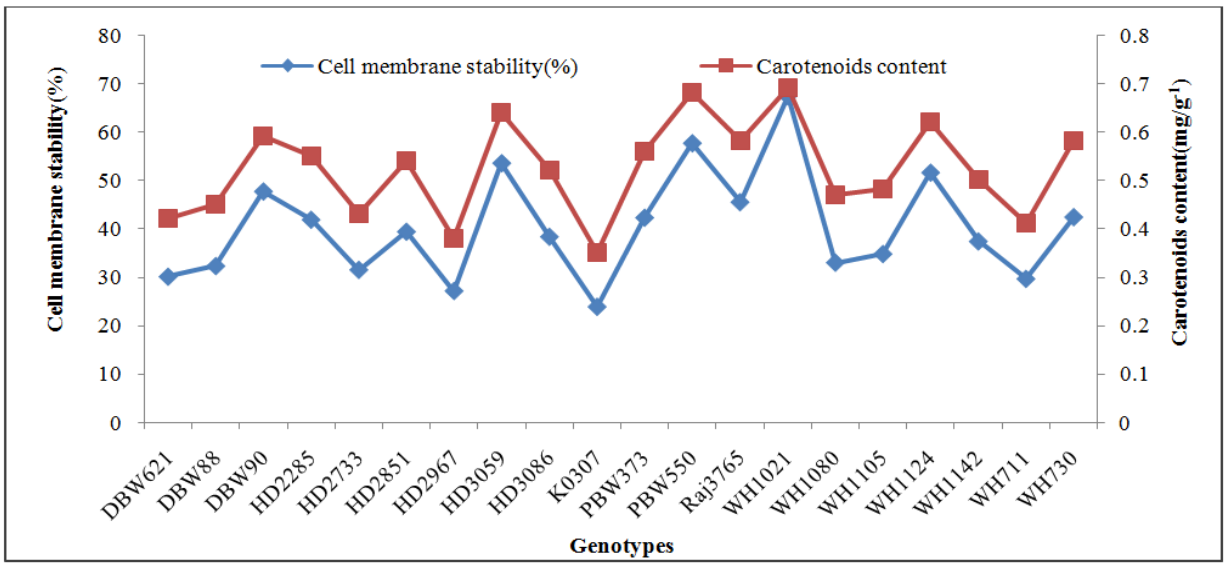


Fig.3 Relation between CMS and carotenoids content in wheat genotypes under terminal heat stress condition



Yield and Yield Attributes

Highest biomass (kg/m^2) was found in WH 1021 (1.19 kg/m^2) followed by PBW 550 (1.12 kg/m^2) and HD 2851 (0.71 kg/m^2). Lowest biomass (kg/m^2) was found in K 0307 (0.50 kg/m^2) followed by WH 711 (0.80kg/m^2), WH 1142(0.76 kg/m^2). Grain yield (kg/m^2) was observed maximum in WH 1021 (0.53 kg/m^2) followed by PBW 550 (0.48kg/m^2) and HD 3059 (0.43 kg/m^2). Lowest grain yield was in K 0307 (0.16 kg/m^2) followed by WH 711 (0.21 kg/m^2), HD 2967 (0.22 kg/m^2) and DBW 621 (0.24 kg/m^2). Maximum 1000 grain weight was observed in WH 1021 (40.5 g) followed by DBW 90 (39.9 g) and HD 3059 (37.7 g). Minimum 1000 grain weight was found in K

0307 (18.5 g) followed by HD 2967 (22.5 g), WH 711 (25.5) and DBW 621 (27.4 g). Maximum harvest index (%) was found in HD 3059 (37.30 %) followed by HD 2967 (36.70 %), PBW 550 (36.70 %), PBW 373 (36.30 %) and WH 1105 (35.30 %). Minimum harvest index was in HD 2851 (33.30 %) followed by K 0307 (33.70 %), WH 711 (34.00 %), WH 1124 (34.30 %) and HD 2733 (34.30 %).

In stress condition plants produce various protective cellular compounds. The results of the present study are in accordance with the results of Usha and Bhumika (2012) who reported that the overall total antioxidant activity of wheat varieties increase under of stress. Mohammed and Tarpley (2009) showed that susceptible genotypes have low antioxidant activity as compare to tolerant at different growth stages. Thermo tolerance capacity was analyzed using total antioxidant capacity parameter and was found high in thermo tolerant genotypes as compared to thermo susceptible genotypes Kumar *et al.*, (2013). Similar results were found by Almeselmani *et al.*, (2006); (Asthir 2015). Membrane is the first line of defense having many heat responsive sensors which helps plant to trigger its defense mechanism against heat stress, so the integrity of the membrane is an important parameter for heat tolerance Kumar *et al.*, (2012).

The results observed in present study are strongly supported by earlier investigation by Kumar *et al.*, (2013) who observed decrease in the cell membrane stability (CMS) at different stages of growth. Thermo tolerant cultivar showed the highest cell membrane stability index. Lipid peroxidation is considered as one of the most damaging processes known to occur in every living organism. Malondialdehyde (MDA) is produced when polyunsaturated fatty acids in the membrane undergone lipid peroxidation. MDA content reflects the degree of damage at adverse conditions and is an indicator of lipid peroxidation. Our findings are in accordance with Sairam *et al.*, (2000) reported lowest MDA content in tolerant genotype and highest MDA content in susceptible genotype of wheat under high temperature stress conditions. Mahla *et al.*, (2011) also found more MDA content in heat susceptible cultivar then in a heat tolerant cultivar. Carotenoids are acknowledged for protection in cellular structure from oxidative damage, which stabilizes the membrane fluidity Wahid *et al.*, (2007). Biomass (kg/m^2), grain yield (kg/m^2), 1000 grain weight (g) and harvest Index (%) were high in heat tolerant genotypes as compare to heat sensitive genotypes as indicated in Table 3. The results are corroborated with the results of many investigators Dhyani *et al.*, (2013); Saxena *et al.*, (2016); Dwivedi *et al.*, (2017).

The selection of wheat genotypes with better grain yield and heat tolerance at reproductive stage is the principal aim of wheat production. In this study, late sown condition caused significant changes in total antioxidant activity (TAA), cell membrane stability (CMS), lipid peroxidation in term of MDA content, carotenoids content and yield attributes in different wheat genotype studied. Significant reductions in CMS, Carotenoids content and increase in TAA and lipid peroxidation-MDA content from anthesis to 14DAA under terminal heat stress conditions were observed. The protective role of TAA and carotenoids content was evident in tolerant genotypes associated with cell membrane stability and stable yield under terminal heat stress condition. This study concludes that the wheat WH 1021 was found as tolerant genotypes as it is least affected by heat stress and found to differ in their ability to respond which could be useful to develop wheat tolerant varieties in breeding programs.

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