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EVALUATION OF SOME PHYSIOLOGICAL PARAMETERS IN WHEAT AS AFFECTED BY HIGH TEMPERATURE AND THEIR CORRELATION WITH YIELD

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Abstract

A field experiment was conducted during *Rabi*, 2015-16 to study the effect of temperature on performance of wheat (*Triticum* sp.) genotypes at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad. The experiment consisted of two dates of sowing *viz*., 2nd November 2015 (D_1 temperature regime), 15th December 2015 (D_2 temperature regime) and nine wheat genotypes belonging to three species, *viz*., *Triticum aestivum*, *Triticum durum* and *Triticum dicoccum*. On an average the maximum cell membrane thermostability (CMS) was recorded in HW-1098 under both temperature regimes. The reduction in CMS varied from 9.63 per cent (UAS-415) to 28.77 per cent (UAS-459). The maximum canopy temperature depression (CTD) was recorded in HW-1098 at growth temperature, at all the growth stages. The minimum reduction in chlorophyll stability index recorded was in HW-1098 (3.22 %) followed by UAS-458 (5.59 %), and UAS-415 (6.77 %). HW-1098 recorded maximum grain yield under both D_1 (8102 kg ha^{-1}) and D-$_2$ (6093 kg ha^{-1}) temperature regimes. Under D_1 temperature regime UAS- 415 recorded maximum 1000 grain weight (45.95 g) while under D_2 temperature regime HW-1098 recorded maximum 1000 grain weight (40.84 g). The genotype HW-1098 recorded higher harvest index under both the temperature regimes which might be attributed to higher yield.

Key words : Wheat, Cell Membrane thermo-Stability, Canopy Temperature Depression, Chlorophyll Stability Index, harvest index.

Introduction

Wheat is one of the most important cereals in India. Major wheat growing countries across the world include India, China, Russia, USA, Australia and Canada. In India wheat is grown over an area of 31.19 million ha with production of 95.91 million tones with an average productivity of 3,075 kg ha^{-1} (Anonymous, 2014). Wheat is grown over an area of 0.21 million ha with production of 0.23 million tones with an average productivity of 1,075 kg ha^{-1} in Karnataka (Anonymous, 2014).

Productivity is very low as compared to national average, mainly due to the fact that large area (50%) of wheat is grown under rainfed conditions and only a small part of the growing period experiences the cold climate. Wheat is grown under sub-tropical environment in Indian sub continent during mild winter that warms up towards the grain filling stage of the crop. Wheat requires cool climate for potential productivity during its early growth stages. Sowing period of wheat normally extends from last week of October to third week of November. However, it continues up to December.

Higher temperature during early growth stages is unfavorable for tillering and reduces grain filling duration if occurs during later growth stages. Late sown irrigated wheat experiences higher temperatures during grain filling stages and hence there is reduction in grain filling duration of the crop that leads to reduction in potential yield. Unusual changes in weather parameters, especially an increase in maximum/minimum temperature from normal at any growth stage of crop adversely affects the growth and ultimately the yield.

Materials and Methods

The details of materials used and techniques adopted during the course of investigation are briefly described below.

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Cell membrane thermostabity index (CMS %)

Cell membrane thermostability index was determined by recording the electrical conductivity of leaf leachates in double distilled water at 40 and 100°C (Sairam and Saxena, 2000). Measurements were taken at different stages from 50 per cent anthesis and every 15 days interval after anthesis up to maturity. Leaf samples (0.25 g) were cut into discs of uniform size and taken in test tubes containing 10 ml of double distilled water in two sets. One set was kept at 40°C for 30 min (C_1) and another set at 100°C (C_2) in boiling water bath for 15 min and their respective electric conductivities C_1 and C_2 were measured by conductivity meter. The CMS was calculated as:

$$CMS = (1 \times C_1/C_2) \times 100$$

Canopy temperature depression (CTD)

Leaf temperature is found to be a valuable indicator of plant water stress. Canopy leaf temperature at a given situation depends on transpiration rate, leaf temperature. Leaf water status directly affects the stomatal conductance, which regulates transpiration rate. Therefore, leaf water status, transpiration rate and leaf / Canopy temperature are inter-related.

CTD measurements were made by handheld infrared thermometer. Infrared thermometer works with a principle that all objects which have temperature emit infrared wave radiation. Intensity of infrared radiation emitted is proportional to its body temperature. Infrared gun detects intensity of temperature via LCD in terms of degree Celsius (°C) directly. The observations were recorded at late morning to early afternoon cloudless periods (10:00 to 12:00 hours) at a distance of approximately 1 m. The data for each plot were the mean of three readings taken from the same side of each plot at an angle of approximately 45° to the horizontal in range of directions such that they cover different regions of a plot and integrated many leaves. Measurements were taken at different stages from 50 per cent anthesis and every 15 days interval after anthesis up to maturity. Canopy temperature depression was estimated using Eq. in which T_a and T_c refer to air and canopy temperature, respectively.

$$CTD = T_a - T_c$$

Chlorophyll stability index

Green plant pigments are thermosensitive and degradation occurs when they are subjected to higher temperature. This method is based on pigment changes induced heating. The chlorophyll destruction commences rapidly at critical temperature of 55 to 56^{0}C. Thus, chlorophyll stability is a function of temperature. This property of chlorophyll stability was found to correlate well with drought resistance. Two clean glass tubes are taken and five grams of representative leaf sample is placed in them with 50 ml of distilled water. One tube is subjected to heat on water bath at 56^{0}C±1^{0}C for exactly 30 minutes. Other tube is kept as control. The chlorophyll in both the sample is extracted by placing the sample in 7 ml of DMSO at 65^{0}C for 30 min. Decant the supernatant and discards the tissue, make up the volume to 10 ml with DMSO and read the absorbance of the extract at 645 and 663 nm using DMSO as blank.

$$CSI = C_s/C_c \times 100$$

Where,

CSI = Chlorophyll stability index.

C_s = Chlorophyll content of stressed plant (mg g^{-1} fresh weight).

C_c = Chlorophyll content of control plant (mg g^{-1} fresh weight).

Yield and yield components

Five plants tagged earlier for recording various morphological observations were collected at physiological maturity to record the data on following yield and yield components.

Grain yield

After threshing, the produce was cleaned and the weight of grain per net plot was recorded for each treatment and grain yield in kg ha^{-1} was worked out. At the same time, plants from five hills tagged earlier were separated used to record yield attributes.

1000 grain weight (g)

Grain samples collected from net plot grain yield were separated from husk and used for recording 1000-grain weight and it is expressed in g.

Harvest index

Harvest index (HI) is the ratio of economic yield to total biological yield (Donald, 1962) and expressed in percentage. The harvest index of wheat was calculated using the following formula.

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (kg plot}^{-1}\text{)}}{\text{Total biological yield (kg plot}^{-1}\text{)}} \times 100$$

Number of spikes (hill^{-1})

Number of spikes was counted from the collected plants which were tagged earlier and were expressed per hill.

Results and Discussion

Cell membranes are the sites of many biological activities in a plant and play a key role in heat-induced damage to wheat. The loss of membrane integrity may be due to ion leakage from plasma membranes, as a result of inhibition of membrane-bound enzymes responsible for maintaining chemical gradients in the cell under heat stress (Reynolds *et al.*, 2001). Experimental results from Almeselmani and Deshmukh (2012) showed significant reductions in membrane stability index (MSI) under late and very late planting compared to normal planting. These results are in conformity with present investigation where, significantly higher CMS (cell membrane thermostability) was observed under D_1 temperature regimes as compared to D_2 temperature regimes at all the growth stages. Among the genotypes HW-1098 recorded significantly maximum CMS at 50 per cent anthesis and 15 DAA. At 30 DAA, UAS-415 recorded maximum CMS.

Canopy temperature depression (CTD) is an important parameter to assess avoidance of heat stress in a genotype. Higher CTD indicates better cooling capacity of canopy and heat tolerance of wheat genotypes. Greater leaf conductance and better photosynthetic enzyme activity results in cooler canopy of heat tolerant genotypes and greater CTD as compared to heat sensitive genotypes (Ray and Ahmed, 2015). Canopy temperature (CT) is depressed below air temperature when water evaporates. Therefore, CT is an indirect measure of (instantaneous) transpiration at the whole-crop level (Reynolds, 2002) and of plant water status (Araus, 2003). CT also reflects the leaf's energy balance, which is determined by the environment and physiological traits (Balota *et al.*, 2008). However, genotypic variation for CT has been reported in wheat (Fischer *et al.*, 1998). These results are in conformity with present investigation where, significantly higher CTD was observed under D_2 temperature regimes as compared to D_1 temperature regimes at all the growth stages except at 50 per cent anthesis. Among the genotypes HD-3090 recorded significantly maximum CTD at 50 per cent anthesis and HW-1098 recorded significantly maximum CTD at 15 DAA and 30 DAA.

Reena *et al.* (2011) reported that decline in chlorophyll stability index (CSI) in terms of loss of chlorophyll content (%) was noted in all genotypes under high temperature stress conditions. The loss of chlorophyll was less in tolerant genotypes than in susceptible genotypes. The results obtained in present investigation are in agreement with Reena *et al.* (2011). The results of present study revealed that, irrespective of genotypes CSI was decreased significantly in high temperature as compared to low temperature. The data on CSI indicated decreasing trend from 50 per cent anthesis up to 30 DAA. HW-1098 recorded significantly maximum CSI at all the growth.

The results of present investigation indicated that

Table 1 : Effect of temperature regimes on cell membrane thermostability (CMS, %) at different growth stages in wheat genotypes.

Genotypes	At 50 % anthesis			15 DAA			30 DAA		
	Temperature regimes								
	D_1	D_2	Mean	D_1	D_2	Mean	D_1	D_2	Mean
UAS-304	75.77^{ab}	70.12^{b-d}	72.95^{a}	66.63^{ab}	48.21^{h}	57.42^{bc}	56.72^{cd}	32.49^{g}	44.61^{b}
NIAW-34	75.89^{ab}	63.04^{e}	69.47^{ab}	67.60^{ab}	50.33^{gh}	58.96^{a-c}	60.00^{a-d}	38.80^{e-g}	49.40^{ab}
HD-3090	74.39^{a-c}	67.87^{c-e}	71.13^{ab}	66.33^{a-c}	50.68^{gh}	58.51^{a-c}	65.05^{a-c}	40.37^{e-g}	52.71^{ab}
UAS-415	77.26^{a}	70.16^{b-d}	73.71^{a}	63.97^{a-b}	58.90^{d-f}	61.44^{ab}	59.00^{b-d}	52.04^{d}	55.52^{a}
UAS-458	62.99^{e}	66.15^{de}	64.57^{b}	56.39^{e-g}	49.89^{gh}	53.14^{c}	66.87^{ab}	36.63^{e-g}	51.75^{ab}
UAS-459	75.41^{ab}	65.65^{de}	70.53^{ab}	69.67^{a}	52.95^{f-h}	61.31^{ab}	65.01^{a-c}	32.89^{fg}	48.95^{ab}
HW-1098	77.88^{a}	69.53^{b-e}	73.70^{a}	69.72^{a}	59.48^{c-f}	64.60^{a}	69.24^{a}	38.74^{e-g}	53.99^{ab}
DDK-1045	69.54^{b-e}	65.63^{de}	67.58^{ab}	64.39^{a-d}	41.48^{i}	52.94^{c}	60.00^{a-d}	42.34^{ef}	51.17^{ab}
DDK-1046	73.54^{a-c}	65.43^{de}	69.49^{ab}	60.89^{b-e}	55.86^{e-g}	58.38^{a-c}	64.41^{a-c}	43.47^{e}	53.94^{ab}
Mean	**73.63**	**67.06**		**65.07**	**51.98**		**62.92**	**39.75**	

	S.Em.±	LSD @ 0.05	S.Em.±	LSD @ 0.05	S.Em.±	LSD @ 0.05
Temperature regimes	1.45	4.17	1.54	4.42	2.07	5.94
Genotypes	0.68	1.97	0.73	2.09	0.97	2.80
Interaction	2.05	5.90	2.18	6.26	2.92	8.39

Note:- DAA- Days after anthesis, D_1- Early sown (Low temperature regime), D_2- Late sown (High temperature regime), DMRT- Values in the column followed by the same letters do not differ significantly

Table 2: Effect of temperature regimes on canopy temperature depression (CTD, °C) at different growth stages in wheat genotypes.

Genotypes	At 50 % anthesis			15 DAA			30 DAA		
	Temperature regimes								
	D_1	D_2	Mean	D_1	D_2	Mean	D_1	D_2	Mean
UAS-304	4.28^{c-g}	5.13^{ab}	4.71^{a-c}	3.81^{f-i}	5.44^{cd}	4.62^{bc}	3.08^{de}	4.93^{a}	4.00^{ab}
NIAW-34	3.82^{g}	5.10^{ab}	4.46^{bc}	3.34^{hi}	4.98^{c-e}	4.16^{c}	3.04^{de}	3.58^{cd}	3.31^{b}
HD-3090	4.89^{b-d}	5.60^{a}	5.24^{a}	4.48^{d-f}	5.35^{cd}	4.92^{a-c}	2.77^{de}	4.68^{ab}	3.73^{ab}
UAS-415	3.78^{g}	4.74^{b-e}	4.26^{bc}	3.17^{i}	5.25^{c-e}	4.21^{c}	3.09^{de}	4.09^{bc}	3.59^{ab}
UAS-458	3.99^{fg}	4.08^{e-g}	4.03^{c}	3.42^{g-i}	5.78^{bc}	4.60^{bc}	3.44^{c-e}	4.55^{ab}	4.00^{ab}
UAS-459	4.28^{c-g}	4.97^{a-c}	4.62^{a-c}	4.32^{e-g}	4.68^{d-f}	4.50^{bc}	3.26^{de}	4.98^{a}	4.12^{ab}
HW-1098	5.09^{ab}	4.62^{b-f}	4.86^{ab}	4.60^{d-f}	6.72^{a}	5.66^{a}	3.50^{cd}	5.15^{a}	4.32^{a}
DDK-1045	4.42^{b-g}	4.23^{d-g}	4.33^{bc}	4.26^{e-h}	6.63^{ab}	5.45^{ab}	2.63^{e}	5.04^{a}	3.84^{ab}
DDK-1046	4.21^{d-g}	4.01^{fg}	4.11^{c}	4.49^{d-f}	5.77^{bc}	5.13^{a-c}	2.92^{de}	4.61^{ab}	3.77^{ab}
Mean	**4.30**	**4.72**		**3.99**	**5.62**		**3.08**	**4.62**	

	At 50 % anthesis S.Em.±	At 50 % anthesis LSD @ 0.05	15 DAA S.Em.±	15 DAA LSD @ 0.05	30 DAA S.Em.±	30 DAA LSD @ 0.05
Temperature regimes	0.15	0.44	0.21	0.61	0.18	0.50
Genotypes	0.07	0.21	0.10	0.29	0.08	0.24
Interaction	0.22	0.62	0.30	0.86	0.25	0.71

Note:- DAA- Days after anthesis, D_1- Early sown (Low temperature regime), D_2- Late sown (High temperature regime)
DMRT- Values in the column followed by the same letters do not differ significantly.

Table 3 : Effect of temperature regimes on chlorophyll stability index (CSI, %) at different growth stages in wheat genotypes.

Genotypes	At 50 % anthesis			15 DAA			30 DAA		
	Temperature regimes								
	D_1	D_2	Mean	D_1	D_2	Mean	D_1	D_2	Mean
UAS-304	80.39^{a-c}	77.79^{b-d}	79.09^{ab}	75.87^{a-c}	65.82^{e}	70.84^{ab}	69.23^{a}	55.17^{e}	62.20^{ab}
NIAW-34	80.93^{a-c}	74.52^{de}	77.72^{ab}	73.93^{a-d}	67.66^{de}	70.79^{ab}	67.16^{ab}	56.26^{de}	61.71^{ab}
HD-3090	78.62^{a-d}	71.59^{e}	75.11^{b}	76.56^{ab}	69.26^{c-e}	72.91^{ab}	68.07^{ab}	61.00^{b-e}	64.54^{ab}
UAS-415	82.88^{ab}	81.13^{a-c}	82.00^{a}	78.90^{a}	74.46^{a-d}	76.68^{a}	69.84^{a}	61.05^{b-e}	65.44^{ab}
UAS-458	79.44^{a-d}	77.69^{b-d}	78.56^{ab}	71.01^{b-e}	68.41^{de}	69.71^{b}	63.72^{a-d}	56.77^{c-e}	60.24^{b}
UAS-459	83.55^{a}	79.09^{a-d}	81.32^{a}	78.99^{a}	72.08^{b-e}	75.53^{ab}	69.49^{a}	61.46^{b-e}	65.48^{ab}
HW-1098	82.77^{ab}	83.18^{ab}	82.97^{a}	79.86^{a}	73.68^{a-d}	76.77^{a}	69.66^{a}	67.96^{ab}	68.81^{a}
DDK-1045	78.41^{a-d}	71.31^{e}	74.86^{b}	73.56^{a-d}	68.53^{de}	71.04^{ab}	69.43^{a}	58.32^{c-e}	63.88^{ab}
DDK-1046	76.56^{c-e}	72.34^{e}	74.45^{b}	73.90^{a-d}	68.73^{de}	71.32^{ab}	64.38^{a-c}	58.40^{c-e}	61.39^{ab}
Mean	**80.39**	**76.51**		**75.84**	**69.85**		**67.89**	**59.60**	

	At 50 % anthesis S.Em.±	At 50 % anthesis LSD @ 0.05	15 DAA S.Em.±	15 DAA LSD @ 0.05	30 DAA S.Em.±	30 DAA LSD @ 0.05
Temperature regimes	1.18	3.40	1.43	4.11	1.67	4.80
Genotypes	0.56	1.60	0.67	1.94	0.79	2.26
Interaction	1.67	4.81	2.02	5.81	2.36	6.78

Note:- DAA- Days after anthesis, D_1- Early sown (Low temperature regime), D_2- Late sown (High temperature regime)
DMRT- Values in the column followed by the same letters do not differ significantly.

grain yield and all the yield attributing characters decreased significantly under D2 temperature regime as compared to D1 temperature regime. Among the genotypes HW-1098 maintained highest yield in both the temperature regimes and the per cent yield reduction was less in HW-1098 (24.79) as compared to all other genotypes. The reason might be the prevailing of favorable temperature required for wheat crop for higher photosynthate accumulation consequently resulting in higher yield parameters in timely sown crop (Parwaiz *et al*., 2013). Similar results were obtained by Sharma *et al*. (2008), Yin *et al*. (2009), Talukder *et al*. (2014), Upadhyay *et al*. (2015). The yield decrease was due to reduction in the number of seeds per spike and also due

Table 4 : Effect of temperature regimes on yield and yield attributes in wheat genotypes.

Genotypes	Yield (kg ha^{-1})			1000 grain weight (g)			HI			No of spikes (hill^{-1})		
	Temperature regimes											
	D_1	D_2	Mean	D_1	D_2	Mean	D_1	D_2	Mean	D_1	D_2	Mean
UAS-304	6552^{b-d}	3929^{gh}	5240^{bc}	39.89^{b-e}	33.53^{f}	36.71	0.45^{ab}	0.39^{c-e}	0.42^{ab}	4.33^{d-f}	3.33^{fg}	3.83^{cd}
NIAW-34	5517^{d-f}	3612^{h}	4564^{c}	44.56^{ab}	36.98^{-c-e}	40.77	0.42^{a-d}	0.32^{f}	0.37^{bc}	4.33^{d-f}	2.67^{g}	3.50^{d}
HD-3090	7156^{ab}	4622^{f-h}	5889^{b}	39.77^{b-e}	35.55^{ef}	37.66	0.47^{a}	0.39^{c-e}	0.43^{a}	5.00^{b-d}	3.67^{e-g}	4.33^{b-d}
UAS-415	6403^{b-d}	4767^{fg}	5585^{bc}	45.95^{a}	36.64^{c-e}	41.29	0.43^{a-c}	0.41^{b-d}	0.42^{ab}	5.00^{b-d}	3.67^{e-g}	4.33^{b-d}
UAS-458	6019^{c-e}	4469^{f-h}	5244^{bc}	44.47^{ab}	36.59^{c-f}	40.53	0.39^{c-e}	0.35^{ef}	0.37^{bc}	5.33^{b-d}	4.33^{d-f}	4.83^{bc}
UAS-459	6824^{bc}	5065^{ef}	5944^{b}	44.44^{ab}	35.78^{ef}	40.11	0.42^{a-d}	0.41^{b-d}	0.41^{ab}	5.67^{bc}	4.67^{c-e}	5.17^{b}
HW-1098	8102^{a}	6093^{b-e}	7098^{a}	41.50^{a-c}	40.84^{b-d}	41.17	0.46^{ab}	0.42^{a-d}	0.44^{a}	7.67^{a}	6.00^{b}	6.83^{a}
DDK-1045	6304^{b-d}	4499^{f-h}	5402^{bc}	41.60^{a-c}	37.71^{c-f}	39.65	0.35^{ef}	0.33^{f}	0.34^{c}	8.00^{a}	6.00^{b}	7.00^{a}
DDK-1046	6254^{b-d}	4619^{f-h}	5437^{bc}	39.77^{-b-e}	35.93^{d-f}	37.85	0.45^{ab}	0.37^{d-f}	0.41^{ab}	8.00^{a}	6.00^{b}	7.00^{a}
Mean	**6570**	**4631**		**42.44**	**36.62**		**0.43**	**0.38**		**5.93**	**4.48**	

	S.Em.±	LSD @ 0.05	S.Em.±	LSD @ 0.05	S.Em.±	LSD @ 0.05	S.Em.±	LSD @ 0.05
Temperature regimes	235	676	1.06	3.04	0.01	0.03	0.28	0.82
Genotypes	111	319	0.50	NS	0.01	0.02	0.13	0.38
Interaction	333	956	1.49	4.29	0.02	0.05	0.40	1.15

Note :- NS- Non-significant, HI- Harvest index, D_1- Early sown (Low temperature regime), D_2- Late sown (High temperature regime), DMRT- Values in the column followed by the same letters do not differ significantly.

to reduction in seed size as well as 1000- grain weight. Among the genotypes, the maximum reduction in the yield was recorded in UAS-304 (40.03%), HD-3090 (35.40%) and NIAW-34 (34.53%). Reduction in yield due to high temperature was mainly attributed to the significant reduction in 1000-grain weight, harvest index and number of spikes per hill.

Correlation studies

Under D1 temperature regime grain yield exhibited a positive correlation harvest index, number of spike/hill. Under D2 temperature regime grain yield exhibited a positive correlation with cell membrane thermostability index (CMS), canopy temperature depression (CTD), chlorophyll stability index (CSI). Fokar *et al*. (1998) reported that there was a strong positive association across cultivars between grain weight per ear and cell membrane stability as a measure of heat tolerance. Membrane stability of flag leaf at the early milk stage was significantly correlated with grain yield (Yildirim *et al*., 2013).

References

Almeselmani, M. and P. S. Deshmukh (2012). Effect of high temperature stress on physiological and yield parameters of some wheat genotypes recommended for irrigated and rainfed condition. *Jordan J. Agric. Sci*., **8(1)** : 66-78.

Anonymous (2014). *Agriculture Statistics at a Glance*, Dept. Agriculture and co- operation, Publ. Oxford Univ. Press, New Delhi.

Araus, J. L. (2003). Breeding cereals for Mediterranean conditions: eco-physiological clues for biotechnology applications. *Ann. Appl. Biol*., **142** : 129-141.

Balota, M., W. A. Payne, S. R. Evett and T. R. Peters (2008). Morphological and physiological traits associated with canopy temperature depression in three closely related wheat lines. *Crop Sci*., **48** : 1897-1910.

Donald, C. M. (1962). In search of yield. *J. Australian Inst. Agric. Sci*., **28** : 1971-1978.

Fischer, R. A., D. Rees, K. D. Sayre, Z. M. Lu, G. A. Condon and V. Larque-Saavedra (1998). Wheat yield progress associated with higher stomatal conductance and photosynthetic rate and cooler canopies. *Crop Sci*., **38** : 1467-1475.

Fokar, M., A. Blum and H. T. Nguyen (1998). Heat tolerance in spring wheat. II. grain filling. *Euphytica*, **104** : 9-15.

Md. Parwaiz, A., Satyender Kumar, Naiyar Ali, M. Ram Prasad, K. Nargis, K. L. Rajni and I. Tajwar (2013). Performance of wheat varieties under different sowing dates in Jharkhand. *J. Wheat Res*., **5(2)** : 61-64.

Ray, J. and J. U. Ahmed (2015). Canopy temperature effects on yield and grain growth of different wheat genotypes. *J. Agric. Vet. Sci*., **8(7)** : 48- 55.

Reena, M., M. Shashi, M. Renu, C. Shilpa, D. Yogita and A. Vinita (2011). Changes in protein profile, ascorbic acid and chlorophyll stability index of wheat (*Triticum aestivum* L.) seedlings under heat stress and revival conditions. *J. Wheat Res*., **3(2)** : 18-25.

Reynolds, M. P. (2002). Physiological approaches to wheat breeding. In: Curtis, B. C., S. Rajaram and H. Gomez Macpherson (eds.). *Bread Wheat Improvement and Production. FAO Plant Production and Protection Series No. 30.* Food and Agricultural Organization (FAO) of the United Nations, Rome, Italy, pp. 119-140.

Reynolds, M. P., J. L. Ortiz-Monasterio and A. McNab (2001). *Application of Physiology in Wheat Breeding*, CIMMYT, Mexico, D. F.

Sairam, R. K. and D. C. Saxena (2000). Oxidative stress and antioxidants in wheat genotypes: possible mechanism of water stress tolerance. *J. Agron. Crop Sci*., **42** : 18: 55-61.

Sharma, R. C., A. K. Tiwary and F. Ortiz (2008). Reduction in kernel weight as a potential indirect selection criterian for wheat grain yield under terminal heat stress. *Pl. Breed*., **127 (3)** : 241-248.

Talukder, A. S. M. H. M., K. Glenn, McDonald and S. G. Gurjeet (2014). Effect of short- term heat stress prior to flowering and early grain set on the grain yield of wheat. *Field Crops Res*., **160** : 54–63.

Upadhyay, R. G., R. Rajeev and P. S. Negi (2015). Influence of sowing dates and varieties on productivity of wheat under mid Himalayan region of Uttarakhand. *Int. J. Trop. Agric*., **33(2)** : 98-115.

Yildirim, M., K. Mujde, A. Cuma and B. Celaleddin (2013). Variations in morphological and physiological traits of bread wheat diallel crosses under timely and late sowing conditions. *Field Crops Res*., **140** : 9–17.

Yin, X., W. Guo and J. H. Spiertz (2009). A quantitative approach to characterize sink source relationships during grain filling in contrasting wheat genotypes. *Field Crops Res*., **114** : 119–126.