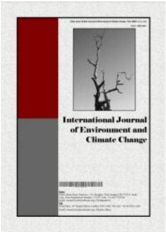

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Evaluation of Wheat Varieties for Terminal Heat Stress under Varying Environments

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Climate change and global warming have increasingly become relevant factors in recent years in determining the success of wheat production under heat stress conditions. Throughout its growth period wheat crop requires varying degrees of temperature to achieve ideal growth. Any variation from optimal temperature adversely affects plant growth and development. Many places where wheat is grown have high temperatures at the time of grain filling which is a major constraint on yield potential. A field experiment was conducted during the Rabi season of 2020-21 at Student's Instructional Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh to evaluate the performance of wheat varieties under heat stress conditions. The treatment for the experiment consisted of sowing on three different dates i.e. D_1 (30^{th} November), D_2 (15^{th} December), D_3 (30^{th} December). It was observed that time of sowing decreased substantially almost all the yield components measured *viz*; number of ear bearing tillers per plant, number of grains per ear, ear length (cm), grain yield per plant (g), biological yield per plant (g), which caused severe reduction of yield in V_1 (PBW-343) and V_2 (HD-2967). This

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reduction was caused due to onset of high temperature during crop growth and particularly grain filling. Variety V_3 (Halna) reduced the detrimental effect of heat stress by improving physiological traits which ultimately helped in obtaining higher yield.

Keywords: Wheat; heat stress; tillers; ear number; grain yield; biological yield.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the major cereal crops on which one third of the world population relies for its staple diet after rice. In India it is the second most cultivated crop. India is the second largest producer of wheat with around 31.45 million-hectare area under the crop giving 107.59 million tonnes production and 3421 kg/ha productivity [1]. Wheat kernel consist of four main parts; seed coat (10% of the kernel weight), aleurone layer (6%), starchy middle i.e. the endosperm (81%), and germ (3%). Consumption of wheat is popular throughout the world due to its unique viscoelastic and adhesive properties of gluten protein. This property facilitates the production of processed foods.

Climate change and geological stress can be attributed to high temperatures, droughts, salinity, waterlogging, and mineral toxicity on agricultural productivity due to rise in global temperatures. Heat stress can be defined as the rise in temperature for a period and beyond the point that results in an irreversible damage to the plant growth and development [2]. Heat stress caused by high temperatures is when the air temperature rises above threshold level for an extended period causing injury to crop plants or irreversible damage [3]. Production of wheat has been curtailed by a number of factors, the major one being increased temperatures which effect production and reduces nutritional value of wheat. More than 7 million hectares of wheat grown in around 50 countries are continuously harmed by the effect of high temperatures [4]. Plants show decreased nutrient uptake and photosynthetic efficiency at temperature above the ideal and length of time for organ growth (leaf, tiller, spike) shortens in various stages of wheat crop development. Many places where wheat is grown have high temperatures at the time of grain filling period, which is a major constraint on yield potential. Heat stress considerably decreases the number of leaves, the area of leaves and wheat grows vegetatively for a longer time. It has also been shown that heat stress during wheat reproductive growth is detrimental to chloroplast activity, minimizing the activity of wheat's source organs and reducing its sink capacity. This results in lower production and leaf senescence, resulting in reduction of green leaf area during the reproductive process. Wheat yield loss is caused in part by the rapid leaf senescence resulting in fewer productive tillers on plant. Wheat growth and development are affected by temperatures above 32℃ which is considered as a major obstacle to grain weight and yield during grain filling stage, decreasing yield by 3-5 percent for every 1℃ rise in temperature above 15℃ [5]. A terminal heat stress, which delays maturity and substantially reduces grain size, weight, and production, occur at anthesis stage and during grain filling stage [6]. Thus keeping in mind the detrimental effect of high temperature on the yield components and yield potential of wheat crop it is important to develop varieties which can withstand this effect without the yield being compromised. The present study was conducted keeping in view the effect of elevated temperature on wheat to screen wheat variety that can perform better even under terminal heat stress.

2. MATERIALS AND METHODS

The field study was conducted at Student's Instructional Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh during the Rabi season of 2020-21. Geographically the experimental site is situated 42km away from Ayodhya on Ayodhya- Raibarielly road between latitude of 26.47^{0} North and longitude of 81.12^{0} East on an elevation of 113 meters in the gangetic alluvium of eastern Uttar Pradesh. Climate of district Ayodhya falls under semi-arid zone, receiving a mean annual rainfall of 1100 mm, of which about 80% occurs during monsoon season (November to April) with few showers in winter. Meteorological data i.e. temperature, rainfall, relative humidity and sunshine hours of experimental site were collected from meteorological observatory situated at Kumarganj, the main campus of University. The experiment was conducted in field containing silt loam soil with three varieties PBW-343, HD-2967 and Halna. PBW-343 and HD-2967 wheat varieties, are popular high yielding wheat varieties in the North Eastern Plain Zone (NEPZ) for timely sown conditions but they are susceptible to temperature stress but Halna is a popular late sown high yielding variety which is tolerant to high temperature stress. The whole experiment was planned under split plot design with three replications along with three treatments. The treatment given were namely; D_1 (30th November), D_2 (15th December), D_3 (30th December). The three dates were selected based on the optimum dates of sowing for timely sown and late sown varieties of wheat so that due to rise in temperature in later developmental stages heat stress may be experienced by the varieties. In case of timely sown varieties, the optimum time of sowing is mid-November and for late sown varieties it is first fortnight of December. A total of 27 plots were taken under observation during the study with the plot size of 5m*4m and spacing of 20 cm * 10 cm. a total of five plants were taken from each plot as sample for recording the observations. Tillers were recorded at maximum tillering stage and effective tillers were observed at physiological maturity of different wheat varieties. Dry matter of plant was recorded by oven drying the plant sample at 80℃ for 24hours. Relative Water Content (RWC) of plant was measured based on fresh weight, dry weight and turgid weight of plant by method described by Turner and Beg (1981). Yield attributes such as, ear bearing tillers per plant, number of grains per ear, ear length and number of grains per plant was recorded a few days before harvesting. The grain yield and biological yield was observed after harvesting. Harvest index was calculated using formula: Harvest Index (%) = (Economic Yield/Biological Yield) * 100. Test weight was recorded by taking 1000 well filled grains having moisture content 12-15% from the samples of each treatment and measuring their weight. The data recorded on various growth and yield attributes was subjected to statistical analysis by Fisher method of analysis of variance. Significance of various treatments was judged by comparing calculated, F value with Fisher's F value at 5 percent level.

3. RESULTS

Wheat crop is generally grown during Rabi season and has a wide range of adaptability. It can be grown in tropical and subtropical zones as well as in temperate zone and cold tracts of north. Climatic conditions most suitable for wheat crop cultivation include cool and moist weather at the time of vegetative period followed by dry and warm weather during grain filling to maturity and ripening. Temperature requirements at various growth stages of wheat are represented in Table 1. However, temperature may vary from one variety to another the critical minimum temperature for wheat crop is from 3.5℃-5.5℃, optimum 20℃-25℃ and maximum temperature is around 35℃. If the temperature at the time of maturity is more than 30℃ then it leads to forced maturity and yield loss.

The meteorological data on weather conditions prevailing during Rabi season of year 2020-21 has been illustrated in Fig. 1.

3.1 Growth and Phenological Parameters

The data regarding number of tillers per plant, dry matter of plant and Relative Water Content as effected by different time of sowing was recorded at 60, 75, 90 DAS and is represented in Table 2. In general, it was observed that at D_1 maximum number of tillers per plant, dry matter of plant and RWC was obtained in V_2. At D_2 maximum number of tillers per plant, dry matter of plant and RWC was obtained in V_2 and at D_3 maximum number of tillers per plant, dry matter of plant and RWC was obtained in V_3. Minimum number of tillers per plant, dry matter of plant and RWC was obtained in V_3 at D_1 and D_2. It was observed that late variety V_3 when sown early i.e. D_1 showed a significant decrease in number of tillers while when early variety V_1 and V_2 were sown late then also number of tillers significantly decreased due to onset of unfavorable environmental conditions for crop. The data also showed significant variation with regard to dry matter per plant. Varieties sown early i.e. D_1 showed significantly high dry matter per plant as compared to D_2 and D_3. It was evident from the data that date of sowing D_1 reduced the RWC of late variety V_3 as compared to V_1 and V_2 at all stages of observation. Similarly, late sowing i.e. D_3 caused reduction in RWC of varieties V_1 and V_2 at all stages of observation compared to V_3. It is evident from the meteorological data that temperature at the time of active growth was fairly high i.e. 28℃-32℃ then that optimal for the crop growth thereby causing significant reduction in the tiller number, dry weight as well as RWC. However, in case of V_3 the temperature was optimal so no significant effect was observed.

3.2 Components of Yield

Effect of different time of sowing on the three main components of yield ear length, ear bearing tillers per plant and number of grains per ear was observed and is represented in Table 3. It was observed that at D_1 and D_2 maximum ear length, number of ear bearing tillers per plant and number of grains per ear was observed in V_2 and at D_3 maximum ear length, number of ear bearing tillers per plant and number of grains per ear was observed in V_3. Minimum ear length, number of ear bearing tillers per plant and number of grains per ear was observed in V_3 irrespective of their time of sowing. Data pertaining to ear length indicated that delayed sowing of early variety V_1 and V_2 significantly reduced the ear length with a maximum reduction of 10.12% recorded for V_2 also it is observed that ear length was increased in V_3 at D_3 (late sown) as compared to D_1 and D_2 by about 9.25 percent. In case of number of ear bearing tillers per plant it was evident from pooled data that early sowing i.e. D_1 and D_2 reduced significantly ear bearing tillers of late variety V_3 as compared to late sown i.e. D_3. It was also evident from the data that early sowing i.e. D_1 and D_2 scaled down the grain number per ear of the late variety V_3 as compared to D_3. This was so because the temperature at the time of grain filling was ranging between 35℃-38℃ and this is considered as damaging to the crop leading to poor grain filling and forced maturity in the wheat crop. However, V_3 being high temperature stress tolerant showed no significant effect.

3.3 Yield

Effect of different time of sowing on grain yield per plant, biological yield per plant and test weight was observed and is represented in Table 4. It was observed that at D_1 and D_2 maximum grain yield per plant, biological yield per plant and test weight was observed in V_2 and at D_3 maximum grain yield per plant, biological yield per plant and test weight was observed in V_3. Minimum grain yield per plant, biological yield per plant and test weight was observed in V_3 for D_1 and D_2. Data pertaining to grain yield indicted that delayed sowing of early variety V_1 and V_2 significantly reduced the grain yield. In case of biological yield, it was evident from pooled data that time of sowing significantly affected the biological yield per plant of all the varieties. It was also evident from the data that delayed sowing of early varieties V_1 and V_2 significantly scaled down the test weight however maximum reduction in test weight was observed for late sown variety V_3 under early sowing condition i.e. D_1.

Table 1. Temperature requirement at different growth stages of wheat crop

S. No.	Growth Stages	Temperature Requirements
1	Germination	20℃-25℃ mean daily
2	Accelerated growth	20℃-23℃ mean daily
3	Proper grain filling	23℃-25℃ mean daily

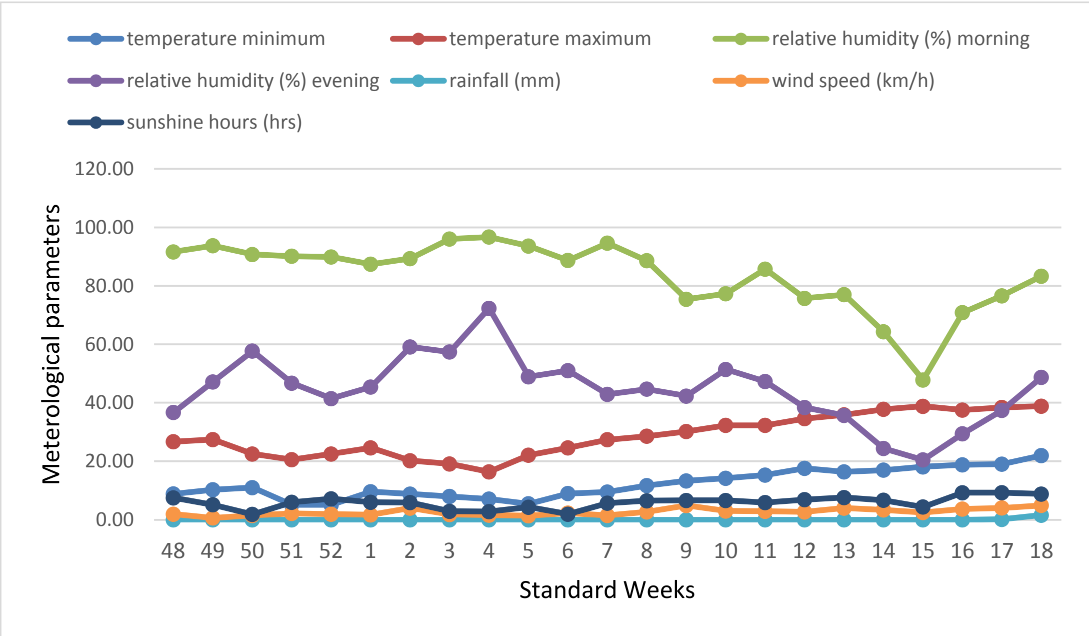

Fig. 1. Meteorological data during the crop season 2020-21

Table 2. Effect of different time of sowing on number of tillers per plant, dry matter of plant and relative water content recorded at 60, 75, 90 days after sowing (DAS) on different wheat varieties

	Number of tillers per plant									**Dry weight per plant (g)**									**Relative Water Content (%)**								
Treatments	**60DAS**			**75 DAS**			**90DAS**			**60DAS**			**75 DAS**			**90DAS**			**60DAS**			**75 DAS**			**90DAS**		
	V_1	**V_2**	**V_3**	**V_1**	**V_2**	**V_3**	**V_1**	**V_2**	**V_3**	**V_1**	**V_2**	**V_3**	**V_1**	**V_2**	**V_3**	**V_1**	**V_2**	**V_3**	**V_1**	**V_2**	**V_3**	**V_1**	**V_2**	**V_3**	**V_1**	**V_2**	**V_3**
D_1	4.5	4.7	3.4	5.5	5.7	4.3	4.4	4.7	3.5	23.9	25.7	21.9	27.5	28.9	24.1	33.2	34.1	30.5	77.1	78.8	70.5	74.1	75.7	68.5	71.1	72.7	66.1
D_2	4.4	4.5	3.9	5.4	5.6	4.4	4.4	4.6	3.6	23.3	24.3	22.7	27.0	28.1	25.4	32.3	33.1	32.6	76.9	77.8	71.0	74.0	74.8	69.0	70.6	71.4	66.4
D_3	4.5	4.7	3.9	4.4	4.3	5.3	3.4	3.5	4.4	21.7	22.5	23.9	24.0	25.2	27.2	29.3	30.8	34.1	71.4	71.9	76.2	69.3	69.3	73.2	67.2	68.1	70.2
	S.Em±	**CD at 5%**		**S.Em±**	**CD at 5%**		**S.Em±**	**CD at 5%**		**S.Em±**	**CD at 5%**		**S.Em±**	**CD at 5%**		**S.Em ±**	**CD at 5%**		**S.Em±**	**CD at 5%**		**S.Em±**	**CD at 5%**		**S.Em±**	**CD at 5%**	
Variety	0.13	0.39		0.07	0.21		0.05	0.16		0.71	2.18		0.47	1.43		0.43	1.31		0.84	2.58		0.83	2.55		0.84	2.58	
Treatment	0.05	0.20		0.05	0.20		0.05	0.20		0.47	1.85		0.35	1.36		0.67	2.65		0.52	2.06		0.50	1.98		0.43	1.69	
V*T	0.12	0.36		0.12	0.36		0.09	0.27		1.22	3.77		0.81	2.49		0.74	2.28		1.45	4.48		1.43	4.41		1.45	4.47	

Note: the values were analyzed with analysis of variance (ANOVA); S.Em± represents standard error of mean; CD represent the critical difference value to test the level of significance between means (P>0.05)

Table 3. Effect of different time of sowing on ear length, ear bearing tillers per plant and number of grains per ear on different wheat varieties

Treatments	Ear length (cm)			Ear bearing tillers per plant			Number of grains per ear		
	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3
D_1	9.24	9.38	8.24	4.80	5.04	3.99	41.05	41.72	35.39
D_2	9.04	9.16	8.63	4.64	4.72	4.08	40.69	41.51	36.11
D_3	8.32	8.43	9.08	4.14	4.22	4.54	35.38	36.16	40.29
	S.Em±	**CD at 5%**		**S.Em±**	**CD at 5%**		**S.Em±**	**CD at 5%**	
Variety	0.16	0.50		0.13	0.41		0.36	1.11	
Treatment	0.14	0.53		0.13	050		0.26	1.00	
V*T	0.28	0.87		0.23	0.70		0.62	1.93	

Note: the values were analyzed with analysis of variance (ANOVA); S.Em± represents standard error of mean; CD represent the critical difference value to test the level of significance between means (P>0.05)

Table 4. Effect of different time of sowing on grain yield per plant, biological yield per plant and test weight on different wheat varieties

	Grain yield per plot (kg/m^2)			Biological yield per plot (kg/m^2)			Test weight (g)		
Treatments									
	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3
D_1	1281	1452	1038	1874	20.88	17.54	41.44	41.84	38.42
D_2	1246	1406	1092	1867	20.53	17.81	39.08	39.58	38.51
D_3	1072	1096	1156	1761	17.93	19.68	36.47	36.74	40.21
	S.Em±	**CD at 5%**		**S.Em±**	**CD at 5%**		**S.Em±**	**CD at 5%**	
Variety	0.33	1.03		0.31	0.97		0.25	0.77	
Treatment	0.23	0.90		0.29	1.15		0.32	1.24	
V*T	0.58	1.78		0.55	1.68		0.43	1.34	

Note: the values were analyzed with analysis of variance (ANOVA); S.Em± represents standard error of mean; CD represent the critical difference value to test the level of significance between means (P>0.05)

4. DISCUSSION AND CONCLUSION

The present study indicated that heat stress is one of the major abiotic stresses impairing the growth of wheat crop at any developmental stage [7,8,9]. Heat stress severely effects the grain filling due to a marked reduction in flag leaf and ear photosynthesis at high temperatures [10]. Several studies reporting variation in the tolerance to high-temperature stress among genotypes of wheat have been conducted [11,12,13] indicating that heat-susceptible wheat genotypes show reduced photosynthesis and premature senescence under heat stress during reproductive development. This leads to reduced yields due to pollen sterility and seed abortion, and subsequently lowers seed weight, grain yield and dough quality.

In the present study it was observed that when late sown variety i.e. V_3 was sown early D_1 it showed a significant decrease in the number of tillers similarly when the early varieties V_1 and V_2 were sown late tiller number was reduced and this was due to onset of unfavorable environmental conditions. A similar result of tillering was observed by Donaldson et al., [14]. Time of sowing also significantly reduced the Relative Water Content (RWC) and dry matter content of the plants with Halna showing the most depression under early sowing condition as it is a late sown variety. These observations are supported by the work of Ahmad et al., [15] and Shahzad et al., [16].

Grain yield being a multifactorial trait is determined by several components like tillers per plant, ear length, ear bearing tillers per plant and number of grains per ear, biological yield, 1000 grain weight of plant (test weight). Delay in sowing of wheat than normal date of sowing decreased substantially almost all the yield components and thereby yield in turn. Reduction percentage was more in case of PBW-343 and HD-2967 compared to Halna due to it performing better under high temperature conditions. Data pertaining to ear length indicated that delayed sowing of early varieties V_1 and V_2 significantly reduced the ear length with a maximum reduction of 10.12% for V_2. However, an increase in ear length 9.25% was observed for late variety Halna under late sown condition D_3 when compared to D_1 and D_2. These findings were in accordance to the work conducted by Praveen et *al.* [17]. The ear length was significantly reduced by date of sowing due to unfavorable environmental conditions like high temperature along with wind velocity and low water content at crop growth stage. The current study also suggested that early sowing i.e. D_1 and D_2 reduced the number of ear bearing tillers plant^{-1} of late variety Halna. However, perusal of data revealed that late planting of early varieties V_1 and V_2 resulted in smaller number of ear bearing tillers plant^{-1}. These results are in agreement with those of Simons and Hunt (1983). The results thus suggested that a high number of tillers in late April and early May is important for high yields. It was also concluded that the number of fall produced tillers was important in determining yields. When tillering occurs mainly in spring, spike numbers are restricted by low tiller production and greater tiller death [18,19].

It is also evident from the study that less number of grains per ear at late sowing of V_1 and V_2 was due to less production of photosynthates due to shorter growing period. These results are in line with those of Shahzad et al. [20]. The early sowing resulted in better development of grains due to longer growing period available. The data also clearly indicates that the three dates of sowing D_1, D_2, D_3 significantly affect the grain yield plant^{-1} and biological yield plant^{-1} of all the varieties V_1, V_2 and V_3. Lower grain yield at early sowing of V_3 was mainly due to smaller number of tillers and smaller number of grains per spike. Decrease in biological yield under high temperature stress has been advocated by Singh et al. (2001) [21]. Grain yield is the product of number of grains per plant, ear length, individual grain weight and biological yield and hence a reduction in all these components under late sowing condition accounted for greater decrease in grain yield. The crop sown early showed highest biological yield as compared to late sown in case of V_1 and V_2, while V_3 (late sown variety) showed minimum biological yield at early sowing as compared to late sown condition. This result is in line with Jat et al. [22]. Time of sowing significantly suppressed the test weight of all varieties. Delayed sowing of early varieties V_1 and V_2 significantly reduced the test weight with a maximum reduction of 12.18% recorded for V_2 at D_3. This result is in accordance with the findings of Akhtar et al. [23]. This is because delayed sowing shortens the duration of developmental stages thereby ultimately reducing grain filling period resulting in lower grain weight [24]. Smith and Humphreys [25] reported that at high temperature the duration of grain filling period is reduced with a net effect of low kernel weight. High temperature coupled with desiccating winds during the month of March-April leads to forced maturity late sown wheat and results in reduction of test weight (Singh and Dhaliwal, 2000).

The present investigation makes it explicit that growth and phenological parameters like tillers per plant, dry weight per plant and Relative Water Content (RWC) of V_1, V_2 and V_3 was found maximum in D_1, D_1 and D_3, respectively at 60, 75 and 90 days after sowing. Yield and yield contributing factors like ear bearing tillers per plant, number of grains per plant, ear length, grain yield per plant, biological yield per plant and test weight for V_1, V_2 and V_3 was found maximum in D_1, D_1 and D_3, respectively. Maximum grain yield was recorded from crop sown on D_1 and this is because yield attributes were adversely affected by delayed sowing which led to forced maturity due to high temperature. V_3 is not affected by delayed sowing because Halna is a heat tolerant variety and thus is less affected by delayed sowing and thereby heat stress on the other hand V_1 and V_2 being timely sown varieties showed a substantial decrease in the yield due to heat stress attributed to delayed sowing. Based on the observations it can be suggested that V1 and V2 should be sown till mid-November any time later than this will cause a reduction in the yield due to the crop facing heat stress. In areas where high temperature is a common problem being faced V3 can be recommended for cultivation as it can be sown till 30th December and it withstands high temperature stress.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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