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EFFECT OF HIGH TEMPERATURE STRESS AT POST ANTHESIS STAGE ON PHOTO SYSTEM II, SENESCENCE, YIELD AND YIELD ATTRIBUTES OF WHEAT GENOTYPES

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SUMMARY

Wheat [*Triticum aestivum* (L.) emend Fiori & Paol.], a major cereal of north India experiences high temperature during anthesis and grain development stages coupled with sharp irradiance, low humidity and moisture deficit, resulting in adverse effect on different vital activities and finally the yield and yield attributes of the crop. Wheat genotypes may have variable response to these stresses, so a field experiment was conducted, where six wheat cultivars (UP-2338, PBW-343, UP-2113, PBW-175, VL-616 and VL-421) were subjected to variable temperature conditions by sowing them timely and delayed by 20 days. Results revealed that delayed sowing negatively affected growth attributes viz. plant height and leaf area as compare to timely sown crops. The photosynthetic pigments (chl a+b) along with chl a/b ratio also recorded reduction under delayed sowing as compared to timely sown cultivars. Chlorophyll fluorescence variable yield (Fv/Fm), which indicates the functionality of PSII also got impaired under delayed sowing. The higher temperature under delayed sowing enhanced plant growth and hastened both flowering and maturity, resulting in marked reduction in number of days to booting, heading, anthesis and maturity of wheat. Significant interaction was recorded between the genotypes and time of sowing. The yield and yield attributes in terms of spike length plant^{-1}, 1000-grain weight, harvest index and finally seed yield ha^{-1} recorded marked reduction under delayed sowing. UP-2338 recorded the highest grain yield both under timely and late sown conditions closely followed by VL-616. Percent reduction in grain yield due to delayed sowing was lowest in UP-2113 and the highest in VL-421. In case of test weight, PBW-343 and VL-616 maintained its significant superiority. In overall, among all the genotypes, UP-2338 was found to be best performer, while VL-421 was the worst in coping with high temperature stress.

Key words: **Chlorophyll fluorescence, delayed sowing, grain filling stage, photosynthetic pigments, senescence, wheat genotypes**

INTRODUCTION

Amongst cereals, wheat (*Triticum aestivum* (L.) emend Fiori & Paol.) is the second most important crop after rice, and is a constituent of major cropping systems across the nation with 29.0 million hectare acreage. It has been envisaged that at least 110 million tons of wheat will be needed by 2020. Amongst several constraints which affects its productivity, delayed sowing ranks at the top as it exposes the crop to high temperature stress at anthesis/grain filling stage. The effective development of plant parts are pre-requisite for better expression of inherent potential and better utilization of environmental variables. Extensive studies have demonstrated that at

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post-anthesis temperature and water stress results in early senescence and more mobilization of pre-anthesis stored assimilates to grain in cereals (Yang *et al.* 2004). Growth of kernels is reduced depending upon the degree of stresses and thereby limiting final grain yield (Kobata *et al.* 1992, Nicolas and Turner 1992). The reduction was found to be more severe when the stress occurred suddenly rather than gradually and at early stages of grain filling than at later stages. Higher temperature enhances leaf senescence causing reduction in green leaf area during reproductive stages. The rapid leaf senescence ultimately resulted in less productive tillers per plant, which is one of the major causes of yield loss of wheat. However, crop response to high temperature varied with variation of temperature, duration of exposure, crop growth stages, and also due to the level of crop tolerance (Rahman *et al.* 2009, Saeedipour 2011). There are several major aspects of thermotolerance from the biochemical and metabolic levels, the relation to membrane stability, production of heat shock proteins, and productivity during high temperature stress.

Royo *et al.* (2000) reported that flowering-to-maturity drought stress is usually accompanied by high temperature, shortened grain filling period for triticale thus reducing 1000 grain weight. Debake *et al.* (1996) demonstrated that imposing stress, especially after anthesis stage, entailed a significant decrease in harvest index. Gupta *et al.* (2001) suggested that there was a direct positive relation between biological yield and grain yield. Harvest index is highly affected by environmental changes that its value increases under desirable climatic conditions and decreases under abiotic stress condition at final period of plant growth (Shamsi *et al.* 2011). There is a need to generate more information on this aspect particularly on behavior of genotypes under high temperature stress. In view of this background, present study was conducted to determine the sensitivity of wheat genotypes to high temperature stress experienced under delayed sowing.

MATERIALS AND METHODS

A field experiment was conducted to study the effect of variable temperature stress at anthesis and grain development of wheat on photosynthesis, senescence, yield attributes and grain yield of wheat. Treatment comprise of 12 combinations of two dates of sowing i.e. timely (D1) and late sowing (D2) and six genotypes of wheat viz. UP-2338, PBW-343, UP-2113, PBW-175, VL-616,VL-421.Wheat genotypes selected have different characteristics in terms of duration, adaptation, input requirement and morphology. Two cultivars in pairs were taken having different characters, just to obtain more comparative and clear observations. Among them (UP-2338, PBW-343) were temperature sensitive, UP-2113 and PBW-175 recommended for cultivation in rainfed area and VL-421 and Vl-616 are suitable for hilly region. The aim to take two cultivars in a group was to observe their comparative sensitivity/resistance to high temperature stress. Experiment was replicated thrice in split plot design assigning dates in main plots and genotypes in the sub- plots. The soil was sandy loam in texture. Plant height and spike length was recorded after emergence of ear head. The leaf area was measured using leaf area meter (portable leaf area meter) at the time of full expansion (after anthesis) of leaves. Chlorophyll ‘a’ fluorescence emitted by green plants reflects photosynthetic ability of PSII. A handy plant efficiency analyzer (Handy PEA, Hansatech, UK) was used to monitor chlorophyll fluorescence variable yield (Fv/Fm). Measurements were taken at 0, 10, 20 and 30 days after anthesis using flag leaf. All the measurements were recorded in the forenoon hours (9-10 AM) to avoid photoinhibition. The chlorophyll content was estimated by harvesting flag leaf at 0, 10, 20, 30 days after anthesis by using dimethyl sulphoxide (DMSO) extraction procedure as described by Hiscox and Israelstam (1979). Random samples of the grains were drawn from each treatment to determine 1000- grain weight. Weight was taken after drying the grains at room temperature (30^0C) to minimize intrinsic moisture content uniformly. After threshing and winnowing, grain yield per net plot was recorded in kg/plot and finally expressed as tonnes/ha.

RESULTS AND DISCUSSION

Data pertaining to shoot length (Table 1) clearly revealed that shoots were taller in case of timely sown wheat (D1) as compare to delayed sown (D2). UP-2113 recorded maximum flag leaf area over the rest of the varieties. The minimum value of flag leaf area was noted in VL-421 followed by PBW-175. VL-421 (18.75%) and PBW-343 (18.4%) showed considerable reduction in their leaf area under delayed sowing as compare to PBW-175 (5%) and UP-2113 (7.6%) (Table 1).

The loss of chlorophyll is the most visible event during leaf senescence so, total chl (a+b) and chl a/b ratio was monitored after anthesis in timely and late sown genotypes (Table 2). The trend of loss in chlorophyll content and chl a/b ratio over the successive sampling stage was much sharp in late sown situation as compare to timely sown. Basal values of chlorophyll pigment and the chl a/b ratio of timely sown cultivars was higher compared to late sown cultivars. The highest values of chlorophyll (a+b) at anthesis stage was found (4.1 mg^{-1} g fw) in UP-2338 along with chl a/b ratio (3.8) under timely sown conditions (D1) which declined to 1.5 and 1.6 respectively, at 30 days after anthesis under late sown condition (Table 3 and 4). Among all the cultivars VL-

Table 1. Effect of sowing dates and genotypes on growth attributes and life span of wheat.

DAA → Genotypes ↓	Plant height (cm)*			Total leaf area plant^{-1} (cm^2)*			Days to anthesis			Grain filling duration (days)		
	D1	D2	M	D1	D2	M	D1	D2	M	D1	D2	M
UP-2338	83	75	79	48	41	44	93	87	90	33	21	27
PBW-343	70	69	70	38	31	34	95	89	92	28	21	24
UP-2113	78	70	74	52	48	50	94	87	91	46	30	38
PBW-175	77	70	73	33	28	30	84	79	82	23	11	17
VL-616	82	75	79	46	40	43	100	91	95	27	19	23
VL-421	66	62	64	32	26	29	87	79	83	26	21	24
Mean	76	70		42	36					31	21	
CD(P=0.05)												
Genotypes		1.44			0.8			2.4			1.1	
Date of sowing		0.8			0.3			1.2			0.9	
GxD		3			0.8			NS			2.3	

* DAA- 30 Days after anthesis; D1 = Timely sown; D2 = Late sown

Table 2. Effect of sowing dates and genotypes on yield attributes of wheat.

DAA → Genotypes ↓	Spike length (cm)*			1000-grain weight (g)			Grain yield (tonne ha^{-1})			Harvest index (%)		
	D1	D2	M	D1	D2	M	D1	D2	M	D1	D2	M
UP-2338	13	12	13	37	35	36	3.7	2.5	3.1	36	23	30
PBW-343	9	8	9	46	40	43	3.7	2.3	3.0	36	20	28
UP-2113	12	11	12	34	32	33	3.4	2.3	2.9	34	23	29
PBW-175	11	10	11	30	26	28	3.5	2.3	2.9	34	19	27
VL-616	11	10	11	40	35	37	3.7	2.5	3.1	37	21	29
VL-421	10	10	10	29	23	26	3.0	1.8	2.4	32	21	27
Mean	11	10		36	32		3.5	2.3		35	21	
CD (P=0.05)												
Genotypes		0.11			1.4			0.06			0.4	
Date of sowing		0.06			0.7			0.04			0.3	
GxD		NS			1.8			0.09			0.8	

*DAA- 30 Days after anthesis

421, was very poor in chlorophyll pigment retention both in timely and delayed sown condition. It recorded the lowest values across the sampling stages both under timely and late sown condition. The photosynthetic efficiency of flag leaf in all wheat genotypes has been monitored using plant efficiency analyzer (Handy PEA). The higher Fv/Fm values just after anthesis shows better performance of PSII, which starts getting down regulated on maturity. Under delayed sowing, photosynthetic efficiency get adversely affected. The trend was quite similar in all the cultivars. Among the cultivars, UP-2113 recorded the lowest percent of flag leaf senescence. Amongst cultivars UP-2338 was superior to all other, while PBW-175 and VL-421 were more vulnerable to high temperature stress with respect to PSII (Fig. 1a and 1b). Data pertaining to days to anthesis after sowing and days to grain filling after anthesis has been presented in Table 1. The total life span of a plant depends upon two phases i.e. vegetative followed by reproductive. Both the phases are important to determine several physiological characteristics of a plant. On the basis of normal and abnormal life span shown of wheat cultivars, one can easily correlate or predict about the resistance and sensitiveness of a plant getting experienced by either favorable or adverse environmental variables. Delayed sowing reduced the mean duration of reproductive phase from 31 to 21 days. Amongst cultivars UP-2113 had the longest reproductive phase of 46 days under timely sown and 30 days under late sown condition followed by UP-2338. PBW-175 recorded the shortest reproductive phase both under normal and late sown condition. Contrary to reproductive phase duration VL-616 experienced the

Table 3. Effect of sowing schedules (timely and delayed sown) on total chlorophyll content (mg g^{-1} fw) of flag leaf in different wheat cultivars (DAA-days after anthesis)

DAA → Genotypes ↓	Timely sown				Late sown			
	0 DAA	10 DAA	20 DAA	30 DAA	0 DAA	10 DAA	20 DAA	30 DAA
UP-2338	4.1±0.23	3.8±0.31	3.4±0.36	2.8±0.26	3.5±0.20	3.1±0.33	2.8±0.20	1.5±0.26
PBW-343	4.0±0.25	3.8±0.33	3.2±0.20	2.3±0.25	3.3±0.28	2.8±0.35	2.5±0.28	1.2±0.31
UP-2113	4.1±0.42	3.6±0.23	3.4±0.30	2.7±0.36	3.1±0.24	2.9±0.30	2.5±0.32	1.2±0.20
PBW-175	3.7±0.25	3.6±0.32	2.8±0.22	2.3±0.32	2.8±0.06	2.6±0.08	2.4±0.32	1.4±0.15
VL-616	3.7±0.42	3.5±0.23	3.2±0.31	2.5±0.36	3.2±0.20	2.6±0.33	2.5±0.22	1.6±0.31
VL-421	3.2±0.45	2.6±0.26	1.8±0.31	0.8±0.15	2.8±0.22	1.8±0.28	1.32±0.31	0.5±0.22

The values are mean of 5 replicates ± SE

Table 4. Effect of sowing schedules (timely and delayed sown) on chlorophyll a/b ratio of flag leaf in different wheat cultivars (DAA-days after anthesis)

DAA → Genotypes ↓	Timely sown				Late sown			
	0 DAA	10 DAA	20 DAA	30 DAA	0 DAA	10 DAA	20 DAA	30 DAA
UP-2338	3.8±0.14	3.4±0.09	2.8±0.06	2.5±0.08	3.1±0.06	2.8±0.23	2.1±0.15	1.6±0.20
PBW-343	3.7±0.15	3.5±0.20	3.2±0.14	2.0±0.08	3.1±0.13	2.8±0.22	2.0±0.32	1.2±0.32
UP-2113	3.7±0.16	3.5±0.08	3.2±0.06	2.7±0.05	2.8±0.06	2.7±0.08	2.1±0.32	1.5±0.15
PBW-175	3.5±0.16	3.1±0.12	2.8±0.22	2.3±0.25	3.1±0.16	2.8±0.05	2.4±0.08	1±0.15
VL-616	3.6±0.13	3.20±0.09	2.88±0.04	2.0±0.05	2.8±0.06	2.3±0.32	2.1±0.15	1.1±0.12
VL-421	2.8±0.12	2.2±0.22	1.5±0.28	0.6±0.15	2.0±0.08	1.7±0.25	0.8±0.15	0.4±0.22

The values are mean of 5 replicates ± SE

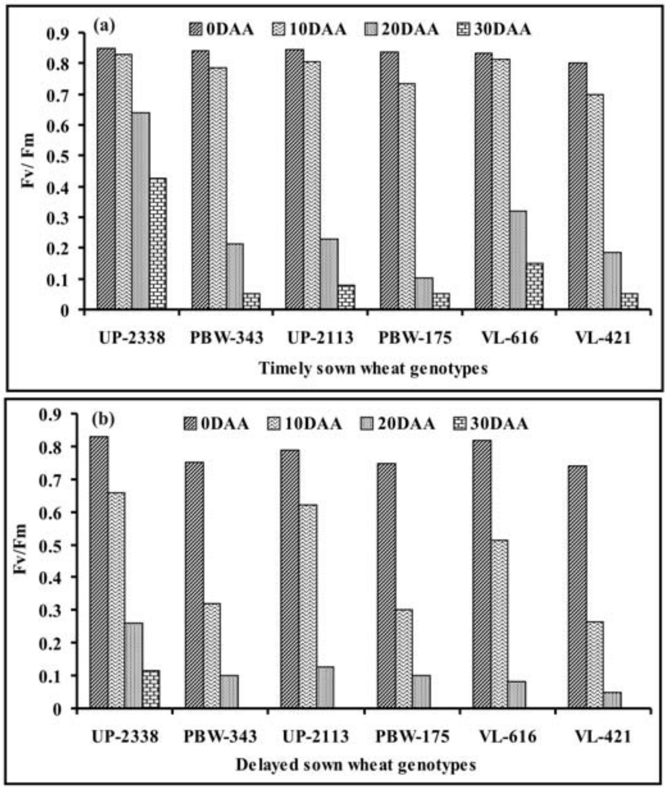

Fig. 1. Chlorophyll fluorescence variable yield (Fv/Fm) in different wheat genotypes under (a) timely and (b) late sown conditions. (DAA- Days after anthesis)

longest vegetative phase of 101 days under timely sown and 91 days under late sown condition. VL-421 recorded the shortest vegetative phase followed by PBW -175 (Table 1). The data shown in Table 1 indicates that the length of spike was found to be longer in case of timely sown wheat over delayed sown. UP-2338 recorded maximum spike length and it was significantly higher from rest of the genotypes. Minimum percent reduction of spike length was observed in UP-2113 (7.40%), VL-421 (7.8%) and UP-2338 (8.09%), while rest of the genotypes viz., PBW-343 (12.9%), PBW-175 (10.30%) and VL-616 (10.2%) have shown higher values for the reduction in their spike length. After the completion of life span/maturity, plants were harvested and their yield attributes were recorded in terms of 1000-grain weight, grain yield and harvest index in both delayed and timely sown condition. On an average delayed sown caused 32% reduction in test weight. In the genotypes, maximum reduction in test weight 19.23 (%) due to delayed sown was recorded in VL-421 and minimum in UP-2338 (5.8%). 1000 grain weight was found maximum in PBW-343 (46.5 g), while minimum in VL-421 (28.6 g). Across the varieties, 23% reduction in grain yield was recorded due to late sown condition. Among the genotypes VL-421 registered maximum reduction (39%) in grain yield due to delayed sowing while PBW-175 was found less sensitive to delayed sowing as it recorded the lowest reduction (32%) in grain yield. UP-2338 showed maximum grain yield up to 3.7 followed by PBW-343 and VL-616 (3.6 tonne/ha), while VL-421 produced the lowest grain yield (3.0 tonne/ha) (Table 2). Under late sown, UP-2338 recorded maximum grain yield (2.5 tonne/ha) followed by VL-616 (2.5 tonne/ha). There was not much difference in harvest index (%), amongst cultivars though the maximum HI was found in UP-2338 (37%) (Table 2 and Fig. 2).

Plants are often exposed to high temperature and irradiance stress under field condition, which usually create water deficit in plant tissue. The consequences of these factors have already been studied in ecophysiology and cell metabolism (Shinozaki and Yamaguci 1997, Dekov *et al.* 2000). Indeed, the importance of changes due to these stress characteristics depend on the plant capacity and sensitivity, as well as on the intensity and duration of the stress, either applied alone or in combination. The negative effect of high temperature is likely to occur more in those crops which are adopted to temperate climate such as wheat, barley, cauliflower etc as thermal requirement for optimum growth and productivity is less as compared to other

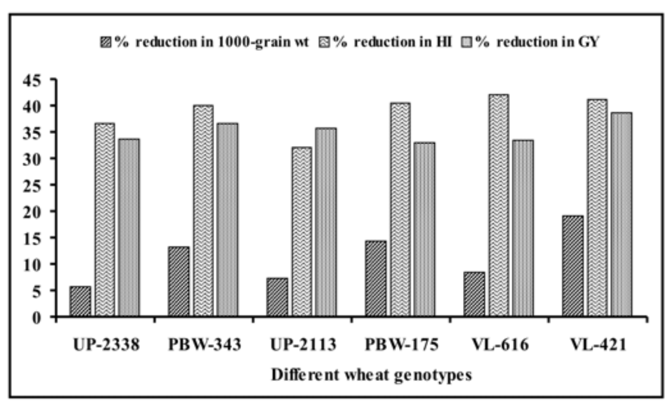

Fig. 2. Effect of delayed sowing on percent reduction in 1000-grain weight, grain yield and harvest index in different wheat genotypes.

crops (Singh and Singh 2001, Tas and Tas 2007). The sowing schedule has affected shoot length and spike length. Indeed, delayed sown cultivars minimized their shoot length and spike length due to imposition of adverse environmental variables i.e. high temperature, dry air coupled with sharp irradiance and loss in humidity. Efficient translocation of photoassimilates to growing seeds is one of the key factor to increase seed production (Aldesuquy 2000). The main source of carbon for grain filling in wheat is that produced by current photosynthesis through flag leaf. The importance of leaf area in controlling plant growth and productivity was confirmed by Potter and Jones (1977) who concluded that the rate of leaf area expansion have a greater influence on dry matter production. Thus, the flag leaf in cereal plants is a powerful source of assimilates translocated to developing grains. The increase in flag leaf area in the first phase of development is attributed to expansion through water uptake as confirmed by the strong correlation between area and fresh matter. Chloroplasts are one of the first organelles to be targeted by senescence, while nuclei and mitochondria maintain their integrity until the late stages of senescence. Thus, functionality of the chloroplast has been evaluated through chlorophyll fluorescence variable yield based on the potential contribution of PSII. Chlorophyll fluorescence variable yield (Fv/Fm) of photosystem II was monitored with the view to access contribution of PSII present in all green leaves individually. Fv/Fm was consistent with normal chlorophyll content prior senescence while it started declining during the development of senescence. The down regulation of PSII photochemical efficiency and photon energy transport efficiency may be one of the intrinsic physiological features of flag leaf during senescence. The trend of senescence was similar in case of earhead, though it started earlier contrary to flag leaf senescence. Senescence is an essential developmental process associated with plants which eventually leads to either whole plant or its parts viz. organ, tissue etc. followed by cell death through highly regulated genetically controlled processes. Leaf senescence is a key developmental state in the life of plant, and is characterized by cell death through highly regulated, genetically controlled processes (Chandlee 2001). Leaf senescence is a key developmental state in the life of a plant, and is characterized by specific cell ultrastructral changes (Buchanan *et al*. 2003) and by chlorophyll loss, oxidative stress (Upadhayaya *et al*. 2008, Haque *et al.* 2010) and decrease in photosynthesis (El-Shintinaway *et al.* 2004). The profile of percentage senescence of flag leaf and whole plant indicate that delayed sowing may induce senescence quicker than the normal sown conditions, may be due to imposition of adverse environmental variables over late sown cultivars, which resulted in dwarfness of plant height, reduction in internodal distance, spike length and also hastens the maturation period to avoid the effect of adverse environmental variables. In terms of different yield attributes, high temperature which hastened spike initiation, reduction in internodal length and induction of early flowering in wheat cultivars might have decreased the number of spikes and grains mainly by shorting the vegetative growth phase, while prevailing high temperature during grain filling might have impaired 1000-grain weight. Abrol and Ingram (1996) have also reported that warmer temperature hastens the development and shortens the growth period. High temperature accelerates respiratory processes and inhibits dry matter accumulation in sink (Yang *et al.* 2004, Bogard *et al.* 2011). A reduction in grain yield due to a premature cessation of sucrose activity and a reduction in post anthesis photosynthesis and the amount of remobilizable assimilate (Kobata *et al.* 1992) has been suggested to be the main cause under water stress conditions. The reduction in economic and biological productivity of wheat crop under thermal stress may perhaps be due to reduction in vegetative and reproductive growth phases. Apart from this, it eventually declined the partitioning of biomass from vegetative to reproductive organs as clearly evident from the results of reduced harvest index and grain spike ratio under high temperature condition. The sudden rise in temperature enhances forced maturity/senescence because it hastens the phenological development of the crop which reduces the grain filling period, eventually reducing grain yield. The number of days taken from emergence to booting, heading and physiological maturity was significantly reduced when sowing was delayed. An adequately long vegetative stage is required to establish the normal root-shoot system and leaf canopy needed for better crop growth (Spano *et al*. 2003)

In the present investigation, the rapid onset of senescence of flag leaf was the result of higher chlorophyll decreasing due to delayed sowing. Photosynthetic activity was also ceased earlier if sowing is delayed. It was concluded that crop growth, growing periods, grain yield and all the yield components of wheat genotypes were affected by high temperature under delayed sowing. Maintenance of higher total plant dry matter and current photosynthesis throughout the crop season may be considered as one of the major contributors towards realization of higher grain yield in wheat.

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