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GROWTH AND PHYSIOLOGICAL RESPONSES OF WHEAT CULTIVARS UNDER VARIOUS PLANTING WINDOWS

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ABSTRACT

The accumulated photothermal units, growth attributes and phenology of three wheat varieties (Chakwal-50, Wafaq-2001 and an advance line NR-268) were studied in four planting windows from 20th October-5th December at 15 days interval during 2008-09 in Randomized Complete Block Design with factorial arrangements. Delayed sowing puts adverse effects with respect to growth characteristics of tested varieties like Crop growth rate (CGR), Net assimilation rate (NAR), Leaf area index (LAI) and growing degree days and photothermal units but the intensity varied among varieties. The late sown conditions induced the maximum epicuticular wax deposition (0.0071 g cm^{-2}) and synthesis of proline contents (37.08 µg g^{-1}) in leaf tissues at flag leaf stage and it was typically related to Chakwal-50 (44.45 µg g^{-1}). The Wafaq-2001 did well with respect to stomatal conductance and photosynthetic rates over tested NR-268 even in delayed sowing. Sustaining the growth in late sown conditions of Wafaq-2001 was clear indication of its adoptability measures to terminal heat stress. On overall basis, the Chakwal-50 was the best performer and seeding at 5th November must be ensured to maintain desirable growth pattern. The growing degree days and Photothermal units were growth drivers and early sowing time might need to be changed based on concept for better understanding of phenophases and other growth aspects of crop in context of climate variability.

Key words: Phenology; Planting windows; Crop growth rate; Net assimilation rate; Leaf area index; Photothermal units.

INTRODUCTION

Wheat, being a major source of human food, it occupies a significant portion of cultivated area of globe mostly located in altitude from a few meters to more than 3,000 m above sea level. Its ranks second most important consumables human commodity in world food scenario following rice (Bakhsh *et al.,* 2003) and rainfed wheat accounts 20 % area in Pakistan (Ahmad *et al.,* 2006). In rainfed wheat, the planting windows start right from October to December. The early sown wheat although enjoys a full growing season but observed a severe weeds infestation, high temperature stress (at germination) and chance of running out from moisture stress at later growth stages, while late sowing threatens the wheat through chilling injury to developing seedlings, accumulation of less solar radiations, incident of high temperature along with limited moisture availability at reproductive development (Cao and Moss, 1994). The intensive heat waves at terminal growth period might induce certain physiological and biochemical changes in plants (Tashiro and Wardlaw, 1999; Slafer and Whitechurch, 2001). The biochemical changes include low fluxes of sodium ion and high of potassium ion, high potassium to sodium ratio in shoot, synthesis of proline and change in chlorophyll contents (Din *et al*., 2008). Since, earth temperature is increasing significantly because of extreme climatic events like El-Niño Sothern Oscillations (ENSO) cycle (Ahmed, 2010).

The yield reduction by late planting can be explained in term of photothermal quotient effect on grains number of wheat (Fischer, 1985). The existing cropping pattern, soil moisture level, inputs and agriculture machinery availability are basic determinants for seed plantation time. However, the optimum soil moisture is major concern for successful rainfed cultivation. Different varieties of crop respond to temperature, moisture stress and day length according to their genetic make up. The only choice for wheat grower to escape the climatic shortfalls is from suitable cultivars and adjustment of plating windows.

The uncertain variability in climatic factors in the form of prolonged drought periods and intensified heat waves are impairing the agriculture productivity (Rounsevell *et al*., 1999). However, the breeders are always paying attention for providing genetic diversity through incorporation of resistant genes against extreme climatic events and this option must be considered on priority basis along with agronomic management tools to sustain wheat production (Bedo *et al*., 2005). The cultivars which have early grains filling characters and agronomic tools which may help the crop to sustain its production in changing climatic scenario need to be identified.

The intensity of climatic variables can be assessed only by quantifying the impact of temperature and solar radiations on crop performance especially plant canopies having direct relations with yield. The temperature has significant impact on duration of phenophases and dynamics of leaf appearance (Tewari and Singh, 1993, Slafer and Rawson, 1994). By taking the contribution of crop canopy and vegetative growth period to final harvest, it can be assumed that temperature and solar radiations are thus driving force of agriculture production and their combined effects on plant growth could be described by photothermal quotient (PTQ). Therefore, it is important to understand physiological behavior of various wheat cultivars in relation to ambient factors especially temperature and solar radiation by manipulating the planting windows.

MATERIALS AND METHODS

The present study was planned to asses the impact of climatic factors in the form of temperature and solar radiations on two wheat cultivars Chakwal-50 (V1), Wafaq-2001 (V2) and an advance line NR-268 (V3) under a range of sowing dates in rainfed conditions. The healthy seed @ 100 kg ha^{-1} were drill sown in 25 cm apart rows at National Agriculture Research Center, Islamabad ($33^o42^/$N and longitude of $73^o10^/$E), Pakistan during 2008 -09. The crop was sown on 20^{th} October (SW1), 5^{th} November (SW2), 20^{th} November (SW3), and 5th December (SW4) to provide various climatic conditions. The land was crossed ploughed by soil inverting implement three weeks before sowing for efficient harvesting of rain water. It was followed by single cultivation and surface planking for good seed bed preparation. The nitrogen and phosphorus were supplied @ 100 kg ha^{-1} each in the form of urea and DAP along with seed bed preparation. The treatment variables were set in Randomized Complete Block Design with factorial arrangements in three repeats in plot measured a net size (10 × 4.5 m). All the plots were treated alike for inputs and agronomic practices except treatments. The climatic data was obtained from weather station at NARC. The growing degree days were calculated from mean daily temperature (ºC) and base temperature as

$GDD = [\{(T\ max + T\ min) / 2\} - Tb]$

(Where Tb=4.5 ºC)

PTQ was calculated following the algorithm described by Ortiz-Monasterio *et al.*, (1994). PTQ/day = Solar Radiation/ (T-4.5) (If T > 10 where T= daily mean temperature)

PTQ/day = 0; (If T< 4.5) and PTQ / day = Solar Radiation × [(T-4.5) / 5.5] / 5.5 (If 4.5 < T < 10)

The solar radiations were recorded by Angstrom protocol as $Rs= [\underline{a_s}+b_s n/N]\ Ra$. Where Rs=short wave radiations, n is actual duration of sunshine(hours), N= Possible duration of sunshine, n/N= Relative duration of sunshine, Ra= Extraterrestrial radiations, a_s is regression constant, a_s+b_s is fraction of extraterrestrial radiations reaching on earth on clear days and default values of a_s and b_s were 0.25 and 0.50, respectively. The developmental stages were differentiated by Zadok's scale (Zadoks *et al.*, 1974) by observing the ten random plants and achievement of 50 % or more level of sample for typical character was the criteria for commencement of next stage. The crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR), leaf area index and leaf area duration was estimated by formula described by Gardner *et al.*, (1985) and leaf area duration was expressed by procedure suggested by Power *et al.*, (1967).

Photosynthetic, transpiration rate and stomatal conductance (at flag leaf stage) were measured by Infrared Gas Analyzer (IRGA, LCA-4, ADC, Hoddesdon UK) and readings were recorded by procedure suggested by Long and Bernacchi, (2003). The relative water contents were recorded by equation proposed by Bars and Weatherley (1962).

$RWC (\%) = [(FW-DW) / (TW – DW)] \times 100$

Wax contents were expressed on basis of leaf area by procedures suggested by Silva Fernandes *et al.*, 1964. The chlorophyll content was measured by SPAD chlorophyll meter by taking three readings then average SPAD chlorophyll content was calculated. Proline was estimated spectrophotometerically following the ninhydrin method (Bates *et al.*, 1973). The allocation of dry matter to leaves; stem, roots at (three leaf, tillering and flag leaf stages) and leaves, stem, root and spikes at (anthesis, milky, dough and maturity stages) were based on random selection of three plants from individual plot. The dry matter (g m^{-2}) acquired by leaves, stem, roots and spike was expressed on over dry basis. The recorded data was analysed by using analysis of variance technique Steel *et al.*, (1997) in computer based statistical programme, STATISTIX 8.1. The means were compared at $p \leq 0.05$ by using LSD test.

RESULTS AND DISCUSSION

Growth and physiological parameters

Crop growth rate (CGR): The influence of varieties and planting windows on CGR was presented in table 1. The CGR being controlled by canopy, photosynthesis and respiration, so, it is considered more meaningful function of crop growth. The varieties could not produce statistical different figures for crop growth rate both at tillering and anthesis stages. The SW1 appeared to be the best upto tillering, however, it could not maintained higher CGR till anthesis over SW2. Each successive delay in sowing reduced CGR value and hence, SW4 had the lowest value. The similar growth pattern of wheat varieties under various planting dates have been reported by Takashi and Nakahisho (1992). The comparatively higher CGR values at anthesis stage could be described by favourable temperature. The results were in line to the findings of Valero *et al.*, (2005) who reported that lowest CGR values were recorded during early vegetative growth stages. The interactive effects of varieties and planting time was found to be non significant at early and later growth stages.

Relative Growth Rate (RGR): Pattern of RGR for four sowing windows with reference to their particular developmental stage was presented in Fig. 1. The RGR differed significantly over the growth stages of wheat cultivars being optimum at tillering and declined with the advancement of growth, even having negative values at maturity. The given pattern of RGR can be described in term of juvenility of plants at earlier growth periods and shading effects of upper leaves on older ones at later growth stages. The results of studies conducted by Alam *et al.*, (2006) had also revealed negative values at the later stages of growth. The similar pattern of RGR at different phenological stages has also been confirmed by findings of Adebo (2010).

Net Assimilation Rate (NAR): The Fig. 2 showed that pattern of NAR was depended on the phenological stage at all sowing times, achieving maximum value at flag leaf stage and thereafter it declined sharply. Finally, it reached negative values at later growth stages except SW1. The maximum NAR figure at flag leaf can be attributed by higher leaf area. Similar results were reported by Yang *et al.,* (1990).

Leaf Area Index (LAI): LAI is an important crop growth variable as it links biosphere with atmosphere through photosynthesis, light and rain interception and evapotranspiration. The pattern of leaf area development was like sigmoid growth, attaining its maximum potential at flag leaf stage and continuously declined at later growth stages without any significant interference of sowing time (Fig. 3). The decline in LAI following the flag leaf stage might be ascribed by aging of leaves, leaf senescence and thermal stress at later growth stages (Dalirie *et al.,* 2010).

Transpiration Rate: The flag leaf stage is an important developmental stage for translocation of sources to sink and any abnormality at this stage can severely reduce the yield. To avoid the effects of unfavourable climatic variants, the adjustment in sowing time is much important. The transpiration rate differed significantly among sowing windows and varieties (Table 1). The maximum transpiration rate was recorded in wheat cultivars sown in SW2 closely followed by SW1 and SW3. Thus, it is evident that early sowing supported the leaf development and hence gave maximum transpiration rate. Each successive delay in sowing date, adversely affected the transpiration rate and seed sown in SW4 had the lowest transpiration. The results were similar to those findings of Kahlown *et al.* (2007) who accomplished positive relationship between transpiration and photosynthetic rate. For varieties, the Wafaq-2001 had the highest value which may probably due to its larger leaf area and Chakwal-50 had the minimum value. The different behaviour of wheat genotypes for transpiration has been revealed by Balota (1995). The variety × sowing date interaction was non-significant for transpiration rate at flag leaf stage.

Proline Content: The accumulation of proline contents at flag leaf stage differed significantly among varieties for various planting times (Table 2). The SW4 had accumulated the highest proline content which can be related to sharp rise in temperature at flag leaf stage. In this situation, plant accumulated the osmolytes such as proline that may lead towards the increase in proline content. The results were at par with the findings of Chandra *et al*, (2004) who reported higher proline under high temperature and water stress. The cv. Chakwal-50, being the drought tolerant variety obtained the maximum value for proline content followed by NR-268 while minimum value was observed in Wafaq-2001. Similar results were observed by Mostajeran and Eichi (2009) who concluded that drought/stress have significant correlation with solute accumulation like proline and varieties which accumulate high proline need to be considered in future context of climate variability.

Epicuticular Wax (g cm^{-2}): The late sown varieties had produced higher epicuticular contents over the early sown (Table 3). The intense temperature stress to late sown wheat provided the drought conditions to crop through higher rate of evapotranspiration. The crop response to reduce the evapotranspiration appeared in the form of accumulation of epicuticular wax and hence biosynthesis of wax was indirectly controlled by temperature and moisture stress. The similar results reported by Zhang *et al*., (2005) who concluded that cuticular wax accumulation enhanced the drought tolerance in plants. The cv. Chakwal-50 attained the highest figure and Wafaq-2001 had accumulated the lowest epicuticular wax. The presence of more epicuticular contents on leaves surface is desirable character for rainfed cultivation (Nizamuddin and Marshall, 1988), therefore, cv. Chakwal-50 seems to be drought tolerant. The interaction between varieties and sowing dates appeared to be significant for epicuticular wax at flag leaf stage. The cv. Chakwal-50 produced the maximum value for epicuticular wax when sown at SW2 but the performance of Wafaq-2001 was much poor at same sowing time.

Photosynthesis Rate and Stomatal Conductance: The stomatal conductance is actually the rate at which water moves to atmosphere through small leaf aperture (stomata). The range of net photosynthesis and stomatal conductance was recorded against planting window and SW2 was the optimum time over the other sowing dates. Their lower values in case of late sowing is mainly attributed to adverse effects of sharp rise of temperature and unfavorable light interception on leaf area development. Xu *et al*, (2009) confirmed that leaf blade mainly functions as the main plant part for photosynthesis. Both the processes of stomatal conductance and photosynthetic rate showed a similar trend for varieties and sowing dates (Fig. 4 and 5) and their positive association has also been confirmed by Chaves *et al*., (2002). The tested varieties behaved differentially for photosynthetic rate (Fig. 4) and stomatal conductance (Fig. 5) and Wafaq-2001 was the superior for the said traits. The confirmation of photosynthetic patterns and stomatal conductance has been made by Meir *et al.* (2002) and Siddique *et al.,* (1990), respectively.

Chlorophyll Content and Relative Water Contents: The data for Chlorophyll and relative water contents showed wide differences among varieties sown on various dates (Fig. 6 and 7). While comparing the planting windows, the suitable time of seed planting was SW2 with respect to chlorophyll contents and relative water contents (Fig. 6 and 7). The relative water content controls the leaf tissue turgor pressure which ultimately maintains the activities of leaf resulting to high rate of photosynthesis. Similarly, high chlorophyll contents might also contribute to higher photosynthetic rate and significant positive correlation between chlorophyll content and photosynthesis rate was reported in earlier findings (Thomas *et al.*, 2005). The Wafaq-2001 attained maximum chlorophyll contents along with relative water contents and Chakwal-50 did not performed well. Pande and Verma (2011) have also documented the adverse effects of delayed sowing and wide variations among genotypes for chlorophyll contents.

AGRO-CLIMATOLOGICAL PARAMETERS

Growing Degree Days for Maturity: The early sown wheat has availed the longest period for completion of phenological stages and thus attained maximum values for GDD and it appeared to be reduced with subsequent delayed sowing (Table 4). The highest GDD for maturity (1715) were recorded for Chakwal-50 and lowest (1432) for NR-268. The results were similar to those of Pal *et al.,* (1996) who reported that GDD requirement were dependent on genetic constitution. The results were contradictory to the findings of Phadnawis and Saini (1992), they observed independence of accumulation of growing degree days to sowing dates but cultivars might modify it. The interaction between sowing date and cultivars found significant. The variety chakwal-50, when early sown accumulated the highest GDD (1994) for maturity. The lowest GDD for maturity (1306) were utilized by NR-268 when sown on Dec.5 because it matures in the shortest period.

Table 1. Crop growth rate (g m^{-2} day $^{-1}$) at tillering and flag leaf stage as influenced by sowing dates and cultivars

Sowing Windows	CGR (g m^{-2} day $^{-1}$) at Tillering Stage				CGR (g m^{-2} day $^{-1}$) at Flag leaf Stage			
	Chakwal-50	NR-268	Wafaq-2001	Means	Chakwal-50	NR-268	Wafaq-2001	Means
SW1	1.72 NS	1.88	2.13	1.91 a	4.46 NS	6.77	6.2	5.81 b
SW2	1.2	1.55	2.02	1.59 ab	8.29	9.33	11.12	9.58 a
SW3	1.03	1.78	1.49	1.43 ab	8.18	6.36	5.29	6.61 b
SW4	0.9	1.11	1.21	1.07 b	5.35	7.06	4.74	5.72 b
Means	1.21 a	1.58 a	1.71 a		6.57 a	7.38 a	6.84 a	

Any two means not sharing a common letter in a column or row differ significantly at 5% probability level

Table 2. Transpiration rate (mmol m^{-2} s^{-1}) as influenced by sowing dates and cultivars

Sowing windows	Transpiration rate at flag leaf stage (mmol m^{-2} s^{-1})				Proline content at flag leaf stage (µg g^{-1})			
	Chakwal-50	NR-268	Wafaq-2001	Means	Chakwal-50	NR-268	Wafaq-2001	Means
SW1	8.07 NS	9.00	9.52	8.86 a	41.75 NS	31.03	30.39	34.39 b
SW2	7.50	9.99	10.06	9.18 a	45.88	33.78	27.17	35.61ab
SW3	7.80	8.49	9.59	8.64 a	43.54	32.99	27.19	34.57 b
SW4	5.30	7.56	7.91	6.92 b	46.65	34.69	29.90	37.08 a
Means	7.17 b	8.76 a	9.27 a		44.45 a	33.12 b	28.66 c	

Any two means not sharing a common letter in a column or row differ significantly at 5% probability level

Photothermal Units for Maturity: Altering the growth periods of wheat varieties by modifying the sowing times significantly had accumulated a range of photothermal units for both at anthesis and maturity (Table 5). The early sown wheat had maximum sunshine hours, which in turn provided optimum photothermal units for anthesis and heading stage. The wheat varieties consumed 97.53 to 107.72 and 85.02 to 96.82 °C days to attain anthesis and heading stage, respectively over four sowing dates. While focusing the varietals response for photothermal units, it was realized that Chakwal-50 was the most promising closely followed by Wafaq-2000. The similar results were reported by Pal *et al.*, (1996) who had noted various photothermal units requirement among cultivars. No significant interaction was found for given parameters.

Table 3. Epicuticular wax (g cm^{-2}) as influenced by sowing dates and cultivars

Sowing windows	Wheat cultivars			
	Chakwal-50	NR-268	Wafaq-2001	Means
SW1	0.0061 ^{bc}	0.0053 ^{cd}	0.0058 ^{cd}	0.0057 ^{b}
SW2	0.0098 ^{a}	0.0064 ^{bc}	0.0042 ^{d}	0.0068 ^{a}
SW3	0.0076 ^{b}	0.0049 ^{cd}	0.0061 ^{bc}	0.0062 ^{ab}
SW4	0.009 ^{a}	0.0062 ^{bc}	0.0051 ^{cd}	0.0071 ^{a}
Means	0.0082 ^{a}	0.0058 ^{b}	0.0054 ^{b}	

Any two means not sharing a common letter in a column or row differ significantly at 5% probability level

Table 4. Growing degree days for maturity of different wheat cultivars as influenced by sowing dates and cultivars.

Sowing windows	Wheat cultivars			
	Chakwal-50	NR-268	Wafaq-2001	Means
SW1	1994 ^{a}	1582 ^{cd}	1749 ^{b}	1775 ^{A}
SW2	1782 ^{b}	1441 ^{ef}	1601 ^{c}	1608 ^{B}
SW3	1599 ^{c}	1400 ^{f}	1506 ^{de}	1501 ^{C}
SW4	1487 ^{e}	1306 ^{g}	1429 ^{ef}	1407 ^{D}
Means	1715 ^{A}	1432 ^{C}	1571 ^{B}	

Any two means not sharing a common letter in a column or row differ significantly at 5% probability level

Table 5. Photothermal units for anthesis and heading stage of wheat cultivars as influenced by sowing dates and cultivars.

Sowing windows	Photothermal units for anthesis stage				Photothermal units for heading stage			
	Chakwal-50	NR-268	Wafaq-2001	Means	Chakwal-50	NR-268	Wafaq-2001	Means
SW1	123.90 ^{NS}	88.02	111.23	107.72 ^{a}	117.27 ^{NS}	77.99	95.2	96.82 ^{a}
SW2	118.52	85.62	107.5	103.88 ^{ab}	108.56	76.7	87.91	91.05 ^{b}
SW3	116.44	83.6	101.77	100.61 ^{b}	103.08	75.15	86.56	88.26^{bc}
SW4	115.45	80.66	96.48	97.53 ^{b}	99.99	74.04	81.05	85.02 ^{c}
Means	118.58 ^{a}	84.48 c	104.24 ^{b}		107.23 ^{a}	75.97 ^{c}	87.68 ^{b}	

Any two means not sharing a common letter in a column or row differ significantly at 5% probability level

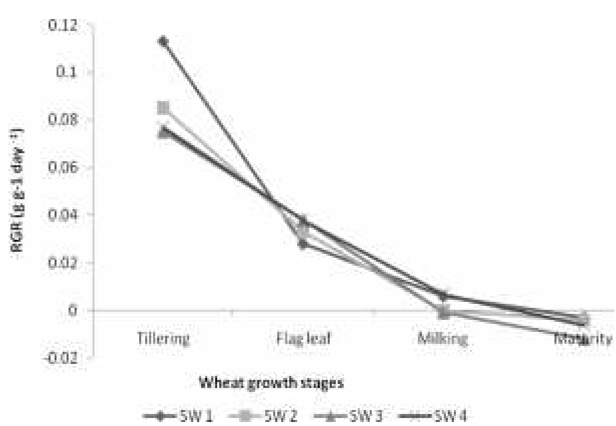

Fig. 1. Pattern of relative growth rate at all four sowing windows with reference to their phenological stages

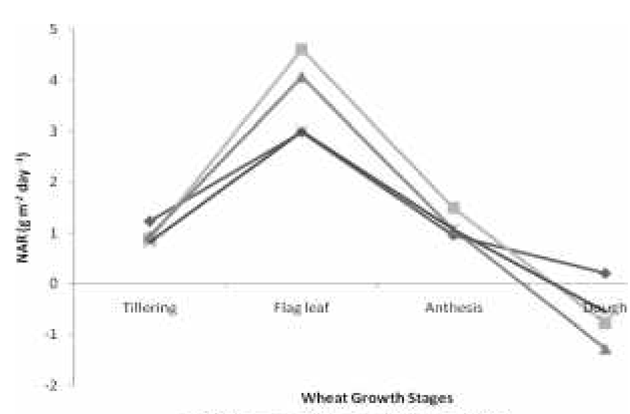

Fig. 2. Pattern of net assimilation rate (NAR) at all four sowing windows with reference to their phenological stages

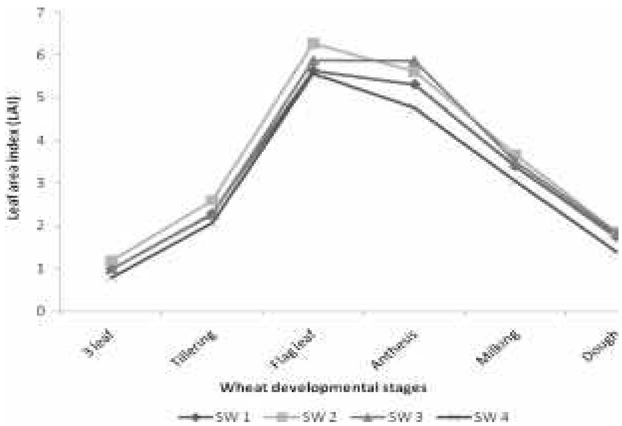

Fig. 3. Pattern of leaf area index (LAI) for all four sowing windows with reference to their phenological stages

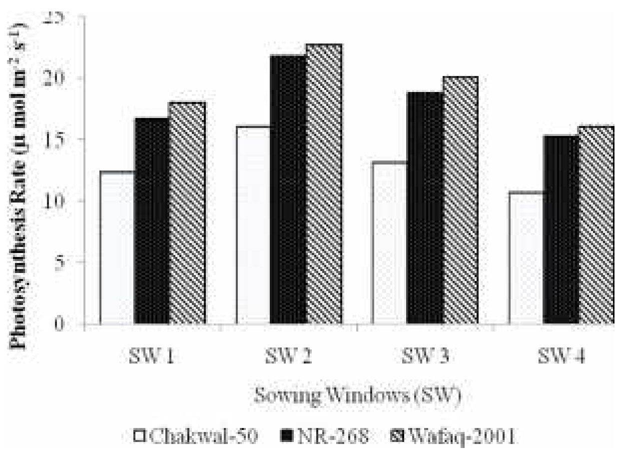

Fig. 4. Photosynthesis rate among the sowing dates and wheat cultivars at flag leaf stage.

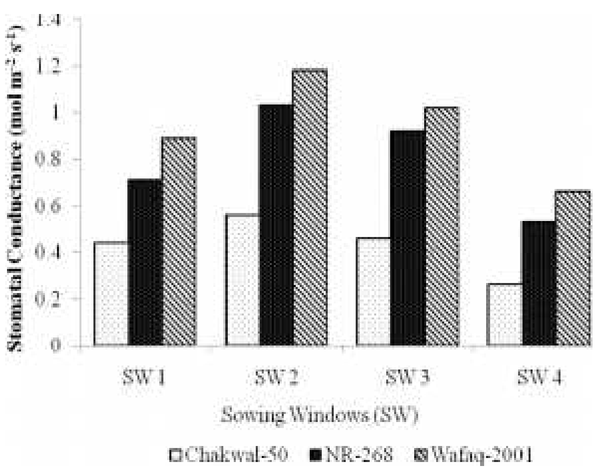

Fig. 5. Stomatal conductance among the sowing dates and wheat cultivars at flag leaf stage

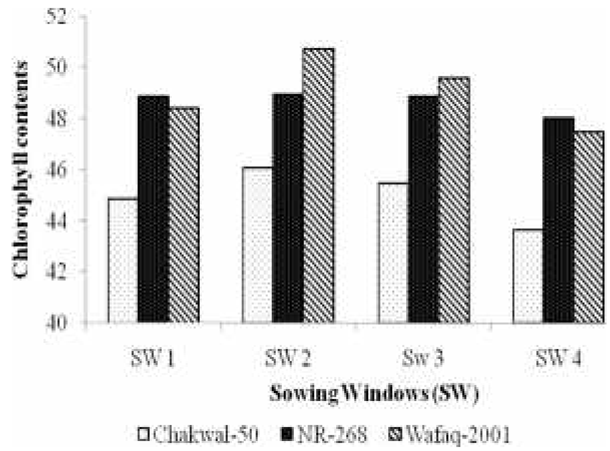

Fig. 6. Chlorophyll content (SPAD) among the sowing dates and wheat cultivars at flag leaf stage.

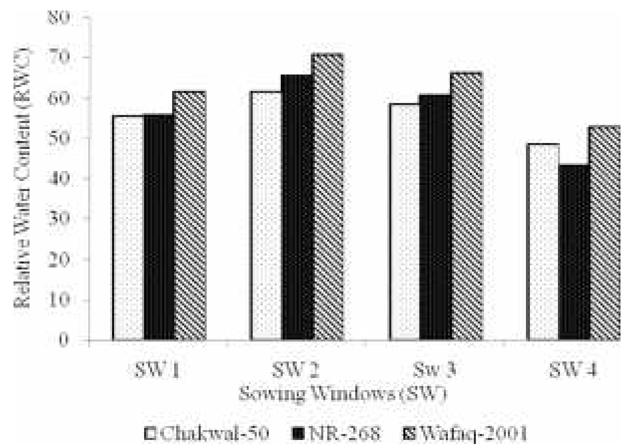

Fig. 7. Relative water content (RWC) among the sowing dates and wheat cultivars at flag leaf stage

Conclusion: The tested varieties showed a range of responses for physiological and agrometrological parameters over the planting windows. Most of the growth and physiological parameters was reduced by delaying the planting which might be ascribed by exposure to higher temperature. However, increased accumulation of proline due to stress in Chakwal-50 might recommend this genotype for the stress environments. On overall basis, it can be concluded that use of growing degree days as a prominent parameter to recommend crop genotypes and sowing time might be useful for addressing climatic variability. Similarly, to design a long term strategy for addressing climatic variability it is essential to build growing degree day model which might give options about sowing time and genotypes selection. Since in future there is one to three degree rise in temperature therefore, change in the sowing time with appropriate genotype plantation according to changing climate variability is need of time.

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