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Optimum time for evaluation of heat and drought tolerance traits in bread wheat genotypes

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Abstract

To improve wheat's adaptation for heat and drought tolerance, increasing the effectiveness of important physiological traits and genetic diversity is needed. The difficulty of selecting for improved adaptation to abiotic stresses makes the use of indirect measures attractive to plant breeders. In this study, the measurements of canopy temperature and leaf chlorophyll content were performed three in times: before, during and post anthesis stages on fifty bread wheat genotypes at Gachsaran Agricultural Research Station in 2011-2012. Canopy temperature showed strong and reliable association with yield under drought and heat stress at three stages, particularly in grain filling stage (R2=0.645, P<0.001). High association of LCC was observed with grain yield during anthesis (R2=0.418, P<0.001), grain filling stages (R2=0.326, P<0.001), and moderate relationships before anthesis (R2=0.234, P<0.01). Maintaining of high thousand-kernel weight despite heat and drought stress was accompanied by a high level of grain yield and leaf chlorophyll content under cooler canopy temperature. These results can provide an estimate of difficult-to-measure traits such as soil moisture availability and may provide clues to help identify alternatives for breeders to further increase yield.

Keywords: Anthesis; canopy temperature; dryland; grain filling; leaf chlorophyll content.

Abbreviations: GY, grain yield, VIG, early growth vigour, T/M, the number of tillers per square meter, DHE, days to heading, GFP, grain filling period, DMA, days to maturity, PLH, plant height, TKW, thousand kernel weight, PLUMP plumpness

Introduction

As agriculture originated in the eastern Mediterranean region (the Fertile Crescent), cereal crops have, from the beginning, experienced drought as a main yield-limiting factor (Araus et al., 2002). Heat and drought stresses were determined as the main yield limiting priorities, for all major developing world wheat-growing regions which reflecting long-term recognition of the disastrous effects of these constraints (CIMMYT and ICARDA, 2011). The greatest abiotic stress factor that damages wheat yield worldwide is drought, although, heat stress has been affected more areas across the world (Kosina et al., 2007). So, develop cultivars tolerating both types of stresses is an effective and sustainable way to improve grain yields (Lobell et al. 2005; Trethowan and Mujeeb-Kazi 2008). Large works has displayed recently that exist new opportunities to improve the adaptation of wheat to heat and drought stressed environments (Trethowan and Mujeeb-Kazi 2008; Rebetzke et al. 2009; Reynolds et al. 2010).
A major challenge in traditional breeding for heat and drought tolerance is the identification of reliable screening methods and effective selection criteria to facilitate detection of heat-tolerant plants. Several screening methods and selection criteria have been developed/ proposed by different researchers (Araus et al., 2002; Condon et al., 2004; Richards, 2006; Ortiz et al. 2008; Acreche et al., 2008; Mohammadi and Karimizadeh, 2011; Rebetzke et al., 2013) and a great number of physiological traits have the potential to improve crop performance under abiotic stress A better understanding of the genetics and physiology of heat and drought tolerance as well as the use of the proper germplasm and selection methods will facilitate the development of heat and drought tolerant cultivars. Some physiological traits that are integrative either in time or at an organisational level (Araus et al., 2002) have acquired increased importance in breeding programmes in recent years mainly due to a greater understanding of their relative contribution to yield (Araus et al., 2002; Koohafkan and Stewart, 2008; Reynolds et al., 2009; Lobell et al., 2011; Rebetzke et al., 2013).
Less canopy temperature (CT) has been associated with increased wheat yield under irrigated, hot environments (Fischer et al., Reynolds et al., 2002; Kumar et al., 2012), and also, under dryland environments (Araus et al., 2002, Olivares-Villegas et al., 2007; Balota et al., 2007, Mohammadi et al. 2009; Karimizadeh and Mohammadi, 2011; lopes et al. 2014). Under favourable soil-water conditions, less CT and more yield have been attributed to increased stomatal conductance and crop water use (Fischer et al., 1998; Kumari et al., 2012). Since CT has been shown to be well associated with ability to extract water from depth (Reynolds et al., 2005; lopes et al. 2010), selection for CT is most probably increasing gene frequencies for root-related traits. Canopy temperature (CT) is now used in drought breeding at CIMMYT to select segregating populations with better access to water by roots (Trethowan and Reynolds 2006).

Chlorophyll maintenance is essential for photosynthesis under drought stress (Yang et al., 2002; Sibel and Birol, 2007; Mohammadi et al., 2009; Ali et al., 2010). A highly significant correlation was found between leaf chlorophyll content (LCC) in the screen house and in field trials, indicating the promise of using a screen house for cost effective evaluation of heat tolerance traits. Before these traits can even be characterized, individual traits must be conceptualized and defined in terms of (i) the stage of crop development at which they are pertinent; (ii) the specific attributes of the target environment for which they are adaptive; (iii) their potential contribution to yield over a range of crop cycles. The main objective of this study is to evaluate, under field conditions, the response of some wheat genotypes facing to drought and high temperatures by the measurement of canopy temperature and leaf chlorophyll content, before, during and after anthesis, in addition to find out sources of terminal heat and drought tolerance in bread wheat germplasm for utilization in the breeding program.

Table 1. Comparing of rainfall, maximum and minimum temperature during growth season and long-term data

		Year	November	December	January	February	March	April	May	Total
Rainfall		2011-12	92.1	61.1	54.3	120.7	47.5	44.8	0.1	420.6
		Long-term	32.5	92.1	114.5	77.1	53.2	44.3	13.7	431.0
Temperature	Max. Temp.	2011-12	26.1	20.2	18.7	16.5	19.5	26.1	35.9	
		Long-term	26.3	19.9	16.6	17.3	21.5	26.1	33.8	
	Min. Temp.	2011-12	11.1	4.3	5.1	4.9	4.6	9.7	16.5	
		Long-term	11.1	6.6	5.0	5.5	7.9	11.2	17.0	

Materials and Methods

Field experiment was conducted at the Gachsaran Dryland Agricultural Research Station (30°20'N, 50°50'E, 710 m above sea level) as a main station in Dryland Agricultural Research Institute (DARI) which covers the semi-warm dryland regions of Iran. The long-term annual precipitation of the site is 431 mm, which most of it falls in December, January and February. Terminal heat and drought stresses were occurred as usual. The soil type was a clay loam with a pH of 7.0 and 1 % organic matter. This study was done using 50 bread wheat genotypes in 2011-12. They were planted in alpha-lattice design with two replications under dryland conditions.

Appropriate fertilization and weed control, were implemented to avoid more yield limitations and in-uniformity. Plants were sown in 7m long and 1.05m wide plots (17.5 cm between rows) at seed rates of 300 seed per square meter. Canopy temperature was measured about two weak before anthesis (Zadoks 46-47), during anthesis (Zadoks 53-55), and two weak after anthesis (Zadoks 73-75). Measurements were taken with the infrared thermometer (Model LT-300, Sixth sense) held 0.5-1 m from the edge of the plot and approximately 50 cm above the canopy at a 30° angle from the horizon on cloudless days with low wind between 12 and 14 h. Chlorophyll relative content of flag leaves was determined using a portable chlorophyll meter (SPAD 502-Minolta Co. Japan) at three abovementioned stages. The measurements were performed on 10 flag leaves were chosen randomly and the SPAD value recorded for each plot.

Results and Discussion

In Climate comparing during crop growth season with long-term average showed that maximum and minimum temperature was largely consistent. During grain filling period, maximum temperature has increased to 40.8 °C. It has strengthened the impact of the drought stress that has occurred from mid-April to mid-May.

Canopy temperature differences among genotypes have been significantly in each three stages and it consistently showed negative phenotypic correlations with yield under dryland conditions, across different phenological stages (Fig. 1). However, CT measured before anthesis was not as strongly associated with yield either in anthesis or post anthesis with CT measured under more heat and drought stress (Fig. 1). Canopy temperature showed a most highly significant association with yield when measured during grain filling period. During anthesis, CT also showed a good association with final yield.

The values of CT have been changed between 16.4 and 22.1°C before anthesis, 20.4 to 26.1oC at anthesis and 24.3 to 30.9oC after anthesis. Canopy temperature average values were respectively 19.4, 23.1, and 27.4oC before anthesis, at anthesis and grain filling periods. Leaf chlorophyll content differences between genotypes have been significantly at three times measurements. At the stage of Zadoks: 46-47, LCC values changed between 43.4 and 63.2. On the second measurement (Zadoks 53-55), LCC values ranging from 37.7 to 56.8. This trait showed 30.4 to 48.7 values at grain filling period (Zadoks 73-75).

The repeatable relationship between CT and grain yield in across diverse environments has agree with the results of previous studies on the robustness of the association between this physiological character and grain yield (Balota et al., 2007; Olivares- Villegas et al., 2007; Mart´ınez-Ballesta, 2009; Mohammadi et al. 2009; Reynolds et al., 2009; Lopes et al., 2010; Karimizadeh and Mohammadi, 2011; Rebetzke et al., 2013; Lopes et al., 2014). The more grain yield at grain filling period may be contributed to more water absorption through aerial roots which reach to the most growth at this time.

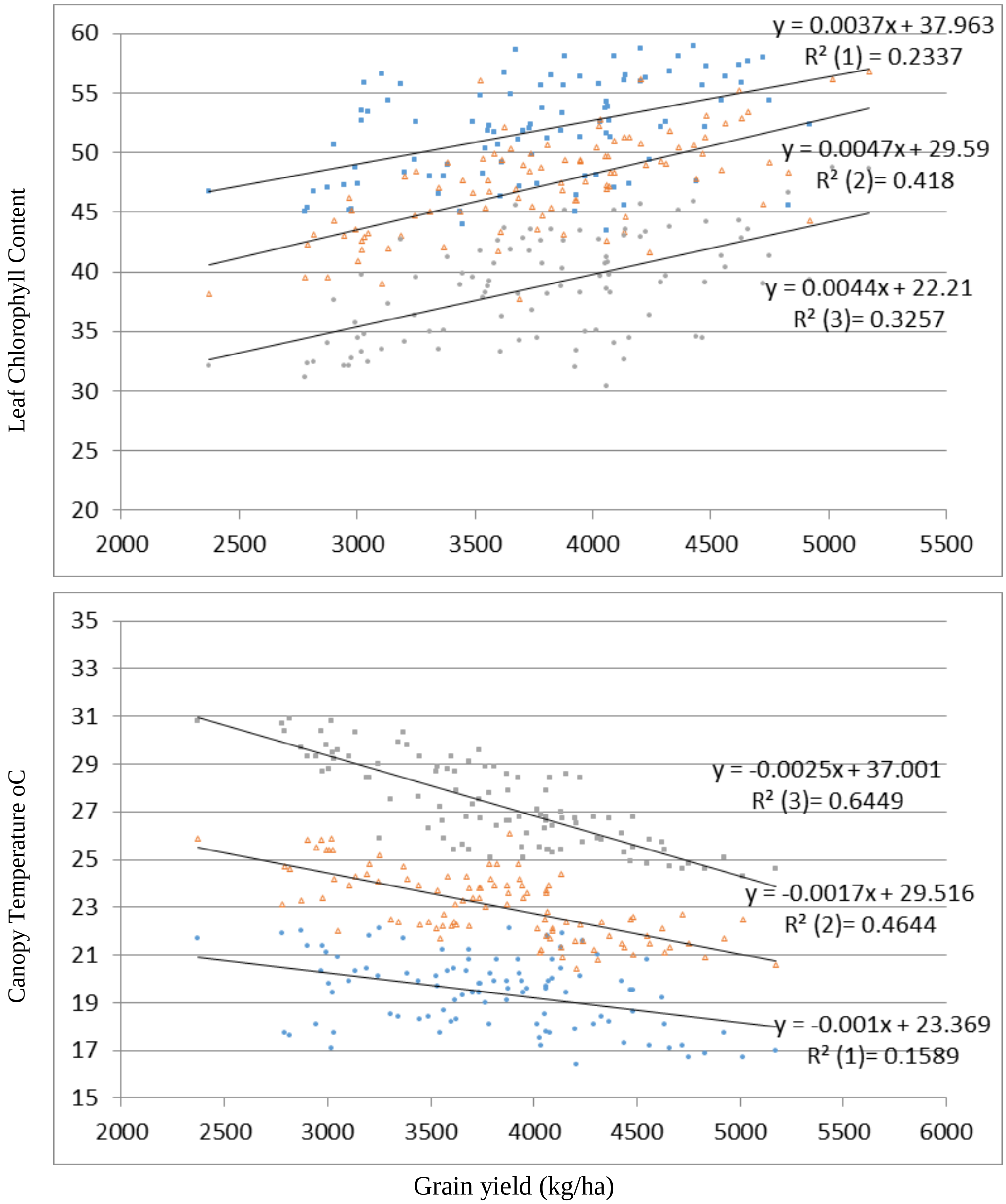

Figure 1. The relationship of grain yield to canopy temperature and leaf chlorophyll content at three stages: before anthesis (1), during anthesis (2) and after anthesis (3).

In spite of high importance of root characteristics in drought tolerance, root traits are difficult to measure in realistic field situations. In the other hand, CT has been shown to be well associated with ability to extract water from depth (Mart´ınez-Ballesta, 2009; Lopes et al., 2010). Therefore, selection for CT may increase gene frequencies for root-related traits. Moreover, CT has the following applications in breeding for drought: early generation selection to enrich populations for generally better drought-adapted characteristics and screening of genetic resources for use in wide crossing (Reynolds et. al., 2009). Lopes et al., (2010) suggest cooler canopy temperature as a surrogate indicating a genotypes ability to maintain transpiration through access of roots to water deep in the soil profile. They used grain filling time (Zadocks 70-85) as optimum time for CT evaluation.

Chlorophyll content showed a moderate phenotypic association with yield at pre-anthesis stage ($R2=0.234$, $P<0.001$). The trait was correlated with yield with increasing the intensity of heat and drought stresses at anthesis and post anthesis stages (Fig. 1). It has been understood that in the latest two measurement dates, LCC val¬ues of bread wheat showed stronger positive correlations with grain yield. When comparing chlorophyll content between two last stages, the association was partially high ($r=0.65$, $P<0.001$).

Among the genotypes, the average decrease in chlorophyll content ranged from no loss to 8 and 10% loss of chlorophyll as severity of heat and drought stresses increased at anthesis and post anthesis stages respectively.

Higher chlorophyll content and lower percent decrease in drought tolerance genotypes of wheat have been reported by Sibel and Birol (2007). Moreover, Rong-hua et al. (2006)

reported that the values of chlorophyll content were significantly higher in tolerant genotype of barley than in drought sensitive genotypes under drought stress.

Chlorophyll content which was correlated with grain yield, CT and thousand kernel weight (TKW) in this research, is positively correlated with the photosynthesis rate (Yadava, 1986; Yang et al. 2002) and it is suggested as an indicator of early senescence, (Rharrabti et al., 2001; Ristic et al., 2007; Talebi,2011). Studies have shown that the ability of plants to maintain leaf chlorophyll content under high temperatures stress is associated with GY and yield components (Ali et al., 2010; Yang et al., 2002). The chlorophyll content which was measured by SPAD 502 is also correlated to the photosynthesis of leaves (R2=0.77, P<0.001) (Mamnoui et al., 2006). A significant correlation between the SPAD reading and spectrophotometric method of chlorophyll determination (R2=0.95, P<0.001) was also reported and SPAD units are linearly related to chlorophyll concentration (Yadava, 1986; Fischer et al., 1998). Thus, SPAD measurements can routinely use in breeding program.

Grain yield was positively correlated with thousand kernel weight (TKW) (r=0.57, P<0.01), in addition to grain per unit area(r=0.34, P<0.05) (Fig. 2), which indicates that TKW influenced grain yield more than the other yield components. Significant correlations was also found between LCC and TKW (r=0.29, P<0.5). Similarly, there were significant associations between CT and flag leaf chlorophyll content at most optimum time (r=-0.52, P<0.001) under heat and drought stresses, suggesting that chlorophyll loss might have been a symptom of inability to access water.

Moderately correlation coefficient between TKW and grain yield was observed as well as between TKW with LCC and CT. Obtained results showed that TKW influence grain yield strongly in the presence of heat and drought stress. This finding is in agreement with the previous reports from the studies conducted in South and east Asia (Tyagi et al. 2003, Singha et al. 2006; Mohammadi, 2012) and other parts of the world (Lopes et al. 2012; Griffiths et al., 2015). Thus, wheats with high thousand-kernel weight despite heat and drought stresses may possess a high level of heat and drought tolerance. Previous finding from the Eastern Gangetic plains showed that one gram increment in TKW produced 110 kg/ha increase in wheat grain yield (Sharma et al. 2007). Hede et al. (1999) is also found that leaf chlorophyll content was correlated with 1000-kernel weight.

The two main yield components are the number of grains per unit land area and the averaged individual grain weight. Historically, wheat grain yield has been increased by genetic improvement and management progress, mainly by augmenting grain number (Shearman et al. 2005; Royo et al., 2007; Bustos et al. 2013; García et al. 2013). However, many studies have reported a trade-off between grain weight and grain number (Peltonen-Sainio et al. 2007; Sadras 2007). Grain weight was been recently recognized as a key trait for yield improvement (Kesavan et al., 2012) and also for seed and grain quality (Marshall et al. 1986; Wiersma et al. 2001; Richards and Lukacs 2002).

To date, doubled haploid (DH) and RIL populations have been developed that show variation for both grain number and grain weight components (e.g. Breseghello and Sorrels 2007; Dreccer et al. 2009; Bustos et al. 2013). However, cultivars showing high grain number and high grain weight in the same genotype have scarcely been released, emphasizing the need to further improve our knowledge of grain weight determination and the causes affecting the trade-off between grain weight and grain number.

These findings highlight the need to increase grain weight to avoid compensations between the two main yield components, which negatively affect the efficiency of wheat yield improvement. Some of the genotypes such as: ATTILA/BAV92//PASTOR/3/ATTILA*2/PBW65 and PASTOR*2/BAV92/5/FRET2*2/4/SNI/TRAP#1/3/ KAUZ*2/ TRAP// KAUZ, had high grain yield and also, optimum values for these three important traits, although, this was not a general trend and there was much exceptions.

Selection of adapted genotypes based on empirical selection for yields per se is limited by the low heritability of yield and a large genotype × environment interaction (Trethowan et al. 2002). In addition, yield per plant may not be related to crop yield in early generations. Therefore, Progress through plant breeding has been achieved by using effective physiological traits in the selection process in optimum time to complement conventional breeding for yield that is supported by many research results (Condon et al., 2002; Richards et al., 2002; Reynolds et al., 2009; Rebetzke et al., 2013; Lopes et al., 2014; Griffiths et al., 2015; Rauf et al., 2015; Sharma et al. 2015).

Conclusion

It was concluded that screening for CT and LCC is rapid, accurate, easy to operate, non-destructive and with reasonable repeatability. The best time for CT and LCC measurement is under grain filling period and anthesis respectively. Obtained results highlight the optimum time for measuring canopy temperature and leaf chlorophyll content as powerful physiological selection tools, which, can accurately provide an estimate of potentials that are directly related to difficult-to-measure traits with remarkable reduction in time and costs. Early-generation progeny can be screened for integrative traits such as canopy temperature in relevant environments; families with warm canopies, compared with checks, are mainly discarded. It seems more adapted genotypes with higher TKW extract more water from deep layers of soil which leads to avoiding of early senescence and cooler canopy temperature. Some of the bread wheat genotypes in this study can be utilized in breeding programs for development of wheat varieties having heat and drought tolerance at terminal growth stage.

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