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POTENTIAL OF PHYSIOLOGICAL TRAITS FOR BREEDING STRATEGIES IN WHEAT UNDER HIGH TEMPERATURE ENVIRONMENTS — A REVIEW

D.C. Saxena, S.V. Sai Prasad, Amit Gautam, Renu Parashar, Iti Rathi, J.B. Singh, Divya Ambati and A.N. Mishra.

Indian Agricultural Research Institute, Regional Station, Indore-452001(M.P.)

Email: dcsaxena54@gmail.com

ABSTRACT

Wheat (*Triticum aestivum*) represents about 30% of the world's cereal area, with over 220 million ha cultivated worldwide, often under abiotic stress. Wheat genotypes can be impaired by heat stress at any development stage and modeling scenario predict even warmer temperature in the future. High temperature during crop duration has significant influence on physiology, growth and yield attributes of wheat. Hence, there is imperative to develop high temperature tolerant genotypes through breeding strategies. The morpho-physiological traits based breeding approaches has merit over empirical breeding for yield because it increases the probability of crosses resulting in additive gene action for stress adaptation. Morpho-physiological traits like canopy temperature depression, membrane thermo-stability, leaf chlorophyll, stomatal conductance, normalized difference vegetation index (NDVI), can be used in breeding strategies to evolve genotypes with high temperature/moisture stress tolerance. This review focuses on potential of these physiological traits for breeding programme under abiotic stress conditions.

Key words : *Abiotic stress, wheat, breeding, physiological traits, canopy temperature depression, membrane thermo-stability, leaf chlorophyll, stomatal conductance, normalized difference vegetation index (NDVI).*

Among cereals, wheat (*Triticum aestivum* L.) is the second most important crop after rice, and is a constituent of major cropping systems across the country with 29.0 million hectare acreage. It has been envisaged that at least 110 million tons of wheat will be needed by 2020. In the recent past, the minimum and average temperatures have been increasing significantly at the rate of 0.06 and 0.03°C per year respectively; and during the last 32 years, the minimum temperature has increased by 1.9°C (Pathak and Wassmann, 2009). The yield loss of wheat in India due to rising temperature has been projected as 4-5 million tons per year with every degree rise of temperature throughout the growing period even after considering the beneficial effects of carbon fertilization (Aggarwal, 2007). Heat stress is a major determinant of wheat development and growth decreasing yield by 3 to 5% per 1°C increase above normal conditions (Gibson and Paulsen, 1999). The late sown wheat crop get exposed to maximum temperature of above 35°C during grain growth period, which causes reduction of 270 Kg/ha/ degree rise in temperature (Nagarajan and Rane, 2002). High temperature after anthesis upto maturity adversely affects fertilization and grain development. Rise in temperature decreases grain size due to high respiration rate and decrease in rate of starch synthesis, which reduces grain weight because of forced grain development (Stone and Nicolas, 1984; Tarshiro and Wardlaw, 1990). High temperature has significant influence on physiology, growth and yield traits of wheat. High night temperature (>14°C) had affected negatively the photosynthesis, spikelets fertility, grains per spike, grain size; and grain filling duration by 3 to 7 days and grain yield (Prasad *et al.,* 2008). Growth of kernels is reduced depending upon the degree of stresses, and thereby limiting the 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. 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).

Physiological approaches in breeding strategies

One approach to search for traits that could be used in breeding strategies is to identify the physiological processes determining productivity. A crop yield potential can be divided into three major processes (Hay and Walker 1989). First the interception of incident solar radiation by the canopy; second the conversion of intercepted radiant energy to potential chemical energy (i.e. plant dry matter); and the third, the partitioning of dry matter between the harvested parts and rest of the plant, whereas, the first component depends on the canopy's and total photosynthetic area, the second relies on the crops overall photosynthic efficiency (i.e. total dry matter produced per unit of intercepted radiant energy); and the third is harvest index. Total biomass, which is the result of the first two components, can be physiologically defined as the results of canopy photosynthesis over time. The yield can be divided into several integrative components or traits. Yield itself is the most integrative, because it is influenced by all factors that determine productivity. However, there are many limitations in a purely empirical breeding approach based only on yield. Therefore, any breeding strategy based on a physiological approach should use screening tools or criteria to evaluate the integrative physiological parameters that determine harvest yield with single measurement.

Traits associated with heat stress tolerance

The morpho-physiological traits based breeding approach has merit over empirical breeding for yield because it increases the probability of crosses resulting in additive given action for stress adaptation. Direct physiological interventions in breeding include (i) characterization of potentials parents for strategic crossing (ii) early generation selection and (iii) evaluation of promising genetic resources in breeding (Saxena *et al.,* 2012).

Different physiological mechanisms may contribute to heat tolerance in the field for example heat tolerant metabolism as indicated by higher photosynthetic rate, stay green, membranes thermo-stability or heat avoidance and canopy temperature depression. Several physiological and morphological traits have been evaluated for heat tolerance viz. canopy temperature depression, leaf chlorophyll /stay green, stomatal conductance, NDVI.

Canopy temperature depression (CTD)

CTD has shown clear association with grain yield and heat stress tolerance in warm environments. CTD shows high positive genetic correlation with grain yield and high values of proportion of direct response to selection (Reynolds *et al.,* 1998) indicating that the triat is heritable and therefore amenable to early generation selection since an integrated CTD value can be measured almost instantaneously on scores of plants in a small breeding plot (thus reducing error normally associated with traits measured on individual plants). Work has been conducted to evaluate its potential as an indirect selection criterion for genetic gain in yield. CTD is directly or indirectly affected by a number of physiological processes, hence it is a good indicator of a genotype's fitness in a given environment. CTD also seems to be affected by the ability of a genotype to partition assimilates to yield, indicated by the fact that CTD frequently shows a better association with grain yield and grain number than it does with total above ground biomass (Gautam *et al.,* 2013). For a given genotype, CTD is a function of a number of environmental factors, principally soil water status, air temperature, relative humidity and incident radiation. CTD is best expressed at high vapors pressure deficit conditions associated with low relative humidity and warm air temperature (Amani *et al.,* 1996).

The effect of canopy temperature on grain yield and its components in durum and bread wheat were studied and found that durum wheat was cooler than bread wheat in high temperature conditions (Bilge *et al.,* (2008); Rosyara *et al.,* (2008)). In addition CTD was positively correlated with grain yield and grain number per spike. Overall CTD has played an important role to search physiological basis of grain yield of wheat and can be used successfully as a selection criterion in breeding programmes. These results were substantiated by the findings of Kumari *et al.,* 2007; Karimizadeh and Mohammadi, 2011 and Sai Prasad *et al.,* 2012. Saxena *et al.,* 2014 evaluated forty wheat genotypes to know the relationship between grain yield and root characteristics along with canopy temperature depression and flag leaf drying under early and late sown conditions, and suggested to select wheat varieties with high root density and more root length in the lower depths of the soil for rainfed/restricted irrigation conditions to mitigate the early heat effects; and varieties having high root density and more root length in the upper layers of the soil for late sown conditions to mitigate the late or terminal heat. It was also found that high CTD scores at vegetative and post flowering were important selection parameters to reduce the evapo-transpiration and increase 1000 grain weight under early sown conditions, whereas, CTD at flowering stage contributed mostly to maintain stay green trait for longer period and in-turn increased the grain yield under late sown conditions.

Membrane thermo-stability

Although resistance to high temperatures involves several complex tolerance and avoidance mechanisms, the membrane is thought to be a site of primary physiological injury by heat (Blum, 1988), and measurement of solute leakage from tissue can be used to estimate damage to membrane (Foker *et al.,* 1998) and shows high genetic correlation with yield with potential application in breeding.

Shanahan *et al.,* (1990) obtained significant increase in yield of spring wheat in hot locations by selection of membrane thermo-stable lines, as determined by measurement on flag leaves at anthesis. By applying the membrane thermo-stability test on winter wheat seedlings, Saadalla *et al.,* (1990) found a high correlation in membrane thermo-stability between seedlings and flag leaves at anthesis for genotypes grown under controlled environmental conditions. Measurement of membrane thermo-stability of 16-spring wheat cultivars were compared with performance at several heat stress locations. Variation in membrane thermo-stability of both field acclimated flag leaves and seedlings grown in controlled conditions were associated with heat tolerance in warm wheat growing regions (Reynolds *et al.,* 1994). Other studies have confirmed genetic variation of these materials and indicated high heritability for the trait like membrane thermo-stability (Fokar *et al.,* 1998).

Renu *et al.,* (2004) studied the membrane thermo-stability as an indicator of heat tolerance at seedling stage in bread wheat and reported that genotypes WH 730, AP1074 and HD 2285 appeared to be heat tolerant in terms of their minimum injury to the plasma membrane and low reduction in grain yield. Grain yield under normal conditions did not show any correlation, but under heat stressed conditions the genotypes having higher yields had higher heat response index. Cultivars HD2285, AP1074 and WH730 had a combination of all the three traits as these had significantly higher membrane thermo-tolerance, higher yields under heat stress conditions.

Ud-Din *et al.,* (2006) studied the contribution of pre-anthesis reserves of wheat cultivars differing in membrane thermo-stability under heat stressed environment; and showed that “Kanchan” was considered as relatively heat tolerant cultivar and Sonora as heat sensitive cultivar. The heat tolerance of “Kanchan” was attributed to longer time of reaching 50% membrane leakage and less dependence on pre-anthesis reserves, therefore, membrane thermo-stability and less dependence on pre-anthesis reserve could be used to determine the relative heat tolerance of wheat under heat-stressed environment .

Kushwaha *et al.,* (2011) studied twenty four wheat genotypes under normal and late sown irrigated conditions and observed that membrane stability index at seed development stage showed positive association with biomass and seed yield. The linear relationship of MSI with seed yield and biological yield showed dependences of seed yield and biomass on membrane stability index. The presence of both additive and dominant gene action has been reported for membrane thermo-stability in wheat (Dhanda and Munjal, 2012).

Stay green/leaf chlorophyll

Stay green traits indicated continuous presence of chlorophyll in the leaf tissues for relatively long duration. This characteristic reflects delayed senescence which is crucial under heat and moistures stress, as the stress induced accelerated leaf senescence reduces leaf viability and photosynthetic activity. Hence, stay green trait is considered to play an important role in the grain development by regulating the source- sink ratio (Saxena *et. al.,* 2012). Stay green has been widely used in breeding for heat tolerance. Physiological evidence indicates that loss of chlorophyll is associated with reduced yield in the field (Reynolds *et. al.,* 1994). Studies in controlled environments have revealed genetic variability in photosynthetic rate among wheat cultivars when exposed to high temperatures (Wardlaw *et. al.,* 1980; Blum, 1986). Such differences in photosynthesis under heat stress have been shown to be associated with loss of chlorophyll and a change in the a: b chlorophyll ratio due to premature leaf senescence (Al-khatib and Paulsen, 1984; Harding *et. al.,* 1990).

Ristic *et. al.,* (2007) studied the correlation between heat stability of thylakoid membranes and loss of chlorophyll in winter wheat under heat stress to investigate the relationship between the heat stability of thylakoid and loss of chlorophyll in winter wheat (*Triticum aestivum L.*) and suggested that heat induced damage to thylakiod and chlorophyll loss are closely associated in winter wheat. Measurement of chlorophyll content could be useful for screening for heat tolerance in wheat.

Srivastava *et. al.,* (2012) studied the effect of high temperature on chlorophyll content in wheat and observed that loss of chlorophyll content and chl *a*/b ratio was much sharp in late sown conditions as compare to timely sown. Basal values of chlorophyll pigment and chl a/b ratio of timely sown cultivars were higher compare to late sown cultivars. Water deficit at higher temperature particularly at post-anthesis stage leads to an increased depletion of chlorophyll and a decreased concentration of chlorophyll (Almeselmani *et. al.,* 2012).

Stomatal conductance

Canopy temperature depression is highly suitable for selecting physiologically superior lines in warm low relative humidity environments, where high evaporative demands leads to leaf cooling of upto 10°C below ambient temperatures. This permit differences among genotypes to be detected relatively easily using infrared thermometry. However, such differences cannot be detected in high relative humidity environments because the effect of evaporative cooling of leaves is negligible. Nonetheless, leaves maintain their stomata open to permit the uptake of CO_2 and differences in the rate of CO_2 fixation may lead to differences in leaf conductance that can be measured using a porometer. Porometry can be used to screen individual plants. The heritability of stomatal conductance is reasonably high, with reported values typically in the range of 0.5 to 0.8. Porometer can give a relative measure of stomatal condition in a few seconds, making it possible to identify physiologically superior genotypes from within bulks (Reynolds *et. al.,* 2001).

Normalized Difference Vegetation Index (NDVI)

NDVI or Vegetation indices (VI) estimate parameters related to the photosynthetic size of a canopy based on the reflectances in the red and near infrared regions. Green biomass, Leaf area index, Green Area Index, Green Leaf Area Index, Photosynthetic Active Radiation etc., can be estimated through their positive correlation with vegetation indices (Wiegand and Richardson, 1990 a, b: Barret and Gujot, 1991; Prince and Baush, 1995). Measuring vegetation indices periodically during the crop growing cycle allows the estimation of Leaf Area Duration (which can be used as an indicator of environmental stress tolerance) and the total PAR absorbed by the canopy, which is one of the most important factors for predicting yield (Wiegand and Richardson, 1990).

A practical use of vegetation indices is for making yield predictions. Yield can be predicted from successive vegetation indices measurements taken during the growing season based on the following assumptions (Wiegand et. al. 1991) : (1) plant stands integrate the growing conditions experienced and express net assimilation achieved through the canopy; (2) stresses severe enough to affect economic yield will be detectable through their affects on crop development and the persistence of photosynthetically active tissues in the canopy; (3) high economic yields cannot be achieved unless plant canopies fully utilize available solar radiation as the plant enter the reproductive stage; and (4) vegetation indices calculated from remote observation in appropriate wavelengths effectively measure the photosynthetic size of the canopy.

Normalized Difference Vegetation Index (NDVI) showed significant association with grain yield under heat stress in two large mapping populations, making it a reliable tool for large scale screening and gene discovery work (Lopes and Reynolds, 2012). Although the Normalized Difference Vegetation Index, which is a reliable indicator of greenness integrating all chlorophyll is associated with heat tolerance, whereas, studies in other species suggest that chlorophyll '*a*' degrades sooner than chlorophyll '*b*' (Keskitalo *et. al.,* 2005).

Future strategies of utilizing physiological traits in plant breeding in wheat under climate change scenario

Climate change may bring an increased intensity and frequency of storms, drought and flooding, weather extremes, altered hydrological cycles, and precipitation. Such climate vulnerability will threaten the sustainability of farming systems, particularly in the developing world. Stress tolerant wheat germplasm coupled with sustainable crop and natural resource managements will provide means for farmers to cope with climate change and benefit consumers worldwide. The improvement in traits such as heat tolerance, water productivity, and better use of nutrients will enhance crop adaptation to the changing climate. Under high temperatures, the wheat genotypes should have higher relative water content, better osmotic adjustment, increased photosynthesis rates, lower percentage of ion leakage, less lipid membrane per-oxidation, and higher grain yield. Physiological traits like chlorophyll content, stomatal conductance, leaf temperature, reduced wilting, and maintenance of photosynthesis under limiting water and high temperatures will contribute to grain yield. Improved reproductive process also includes better partitioning of assimilates to developing grains, which is associated with the plant's ability to store reserves in some organs (stem and roots) and to mobilize them for grain production, a response well documented in cereal crop plants (Bruce *et al,* 2002). Delayed senescence in genotypes may be desirable where yield is source limited, and stem reserve storage and use is insufficient to support grain formation under stress. Partial plant dormancy to survive the high temperature period is another tolerance strategy by repression of genes encoding photosynthetic proteins and activation of genes in recovery of suitable environmental conditions. Stomatal closure along with leaf growth inhibition is the traits, which are important to protect the plants from excessive water loss during high temperatures. Therefore, physiological traits viz., canopy temperature, membrane thermo-stability, stay green nature, delayed senescence, high chlorophyll content, deep root system and more root weight should be given due emphasis during breeding programmes to enhance the productivity of the crop plants.

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