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Stay Green Traits and Its Utilization in Heat Stress Management

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Importance of wheat as staple food is well known as being life line of 35% of the world population. But in past two-three decades, unpredictable climatic conditions have resulted in stagnation in production. Average temperature has risen significantly enforcing us to develop climate resilient high yielding varieties. To develop climate resilient varieties, we need to develop better understanding of the traits which respond to climate changes i.e., elevated temperature, drought and excess rainfall. We further require understanding how tolerance against rising temperature can be improved by exploiting key traits (Halford, 2009). Temperatures above the optimum level have negative effect on crop growth and injure plant tissues, which we generally call 'heat stress' (Wahid *et al*, 2007). Heat stress (high ambient temperature) is a serious problem to crop production worldwide (Hall, 1992). High temperature at the time of grain filling is a major constraint for the successful wheat production in many parts of the world.

Senescence and stay green

The term 'stay green' (SG) is given to a variant in which senescence (loss of chlorophyll) is delayed compared to a standard reference genotype. It is considered an important trait that allows plants to retain their leaves in the active photosynthetic state even under stress conditions. Early onset of senescence affects assimilation and grain filling in crop plants. The rate of senescence determines the maintenance of chlorophyll and hence photosynthesis for sink formation. Therefore, any defense mechanism that postpones the onset of senescence and keeps leaves green (active photosynthetic state) is expected to give additional yield to crop plants.

What type of stay green is beneficial to plants?

Stay green is not always useful. Stay green is of two types;
(i) Functional stay green
(ii) Non functional/cosmetic stay green.

In case of functional stay green mutant, either the initiation of senescence is delayed (Type A) or senescence progression is slow (Type B). Thus functional stay green trait is of agronomic interest because photosynthetic activity is retained for more time as compared to standard genotype and it provides yield advantages under stress conditions. In nonfunctional/cosmetic stay green mutants, senescence occurs at normal rate and photosynthetic capacity is lost, but leaf colour is retained due to defects in chlorophyll degradation pathway (Thomas and Howarth, 2000).

How useful stay green can be to provide tolerance against heat stress?

Stay green is a useful trait having potential to significantly enhance the radiation use efficiency by improving the longevity of photosynthetic machinery of plants. Stay green promotes development of the economic product especially in crops where grain is the final yield. It provides additional yield (up to 20%) to the plants. Loss of chlorophyll during grain filling toll significant yield reduction as leaves-active photosynthetic part of the plant does not contribute their role in photosynthesis thus no food synthesis and no transmission of food from leaves to grains.

Usefulness of stay green trait in different crops

The usefulness of stay green trait in the genotypes is to maintain the green coloration even under high temperature (>30oC) and are assumed to maintain lower canopy temperatures, which might a desirable trait for developing heat tolerant wheat varieties (Kumari *et al.*, 2006). Stay green duration of flag leaves and harvest index showed positive correlation with water use efficiency during grain formation of wheat (Gorny and Garczynski, 2002). Stay green has been found useful in other cereal crops like sorghum, pearl millet, maize etc for heat stress tolerance. Under water limited conditions, stay-green genotypes in case of sorghum retain more green leaf are than do genotypes not possessing this trait, and they also continue to fill grain normally under abiotic stress conditions (Rosenow, 1983). Moreover, there is a positive association between stay-green and grain yield under water-limited environments (Borrell and Douglas, 1996). The beneficial effect of stay-green trait towards grain yield is also reported in soybean (Philips *et al.*, 1984), maize (Duvick, 1984; Russel, 1986; Ceppi *et al.*, 1987) and sunflower (Cuckadar-Olmedo and Miller, 1997). Stay-green trait is also known to reduce lodging (Duncan *et al.*, 1981) and there is good association with resistance to stem rots as well (Rosenow, 1983; Evangelista and Tangonan, 1990) suggesting that stay-green leaves remain photosynthetically active.

Stay green trait is considered a useful trait in many crops for stress tolerance and for achieving yield gains. Stay green has shown association with other desirable traits i.e., tolerance to abiotic (Kassahun *et al.*, 2010) and biotic (Joshi *et al.*, 2007) stresses, greater number of fertile tillers (Ahlawat *et al.*, 2008), higher number of grains per ear (Luche *et al.*, 2013), higher industrial quality (Silva *et al.*, 2004) have been observed. However, how useful it would be and maintenance of stay green during grain filling is more important and deciding factor.

Use of molecular markers

Due to importance of this trait in heat stress tolerance, more emphasis has been given in last two decades to dissect the mechanism of stay green at molecular level. The enhancement of stay green efficiency is expected to be much higher if information is generated about the presence of stay green genes/QTLs in the promising genotypes with the help of linked SSR markers. The inheritance of the stay-green character in populations derived from the combination of stay-green and synchronized senescence wheat lines were reported (Silva *et al.*, 2000). The trait is governed by a single gene having two alleles, which has a partially dominant gene action, with great participation of additivity. The stay-green character has high heritability values varying from 0.75 to 0.80, being controlled by four genes that are segregated independently, with strong contribution of additive effects (Joshi *et al.*, 2007). Quantitative trait loci studies show that functional stay-green is a valuable trait for improving crop stress tolerance in cereals. Two QTLs i.e., *Gwm1037* (*QSg.bhu-3B*) and *Gwm691* (*QSg.bhu-1A*) for stay green trait has been reported by Kumar *et al.* (2010).

Future prospects

The understanding of the physiological mechanisms associated with stay green habit and photosynthetic efficiency in several crops may be the key to break the plateau of productivity associated with adaptation to unfavorable environmental conditions particularly heat and drought stresses. There is need to explore this trait extensively in breeding programs in different crops to harness more advantages of this trait like genetic progress in grain yield, quality, disease resistance and tolerance to abiotic stresses.

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