Journal of Integrative Agriculture 2018, 17(4): 726–738

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REVIEW

Mechanisms and molecular approaches for heat tolerance in rice (*Oryza sativa* L.) under climate change scenario

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Abstract

Rice, a staple cereal crop in many parts of the world, has been confronted with multiple environmental stresses including high temperature, negatively impacts the booting as well as anthesis growth stages. The situation is further complicated by the changing climatic conditions, resulting in gradual escalation of temperature as well as changing the rainfall pattern and frequency, thus raising a concern of food security worldwide. The situation can be combat by developing rice varieties with excellent genetics with improved morpho-physiological, biochemical, and molecular mechanisms, together can minimize the adverse effects of heat stress. Here, several strategies (encompassing genetic and genomic, and mechanisms involved) for mitigating the impact of high temperature on rice have been discussed. Finally, the utilization of genomic knowledge in augmenting the conventional breeding approaches have been comprehensively elaborated to develop heat tolerant germplasm.

Keywords: heat stress, rice, climate change, molecular markers, heat stress responses

1. Introduction

Rice (*Oryza sativa* L.) is grown on around one 10th of the arable land (Wang and Peng 2017), and sustains the lives of three billion people (Krishnan *et al*. 2011). Major share of the rice production and consumption is centered in Asia (growing on ~90% acreage) (Kloti and Potrykus 1999; Datta 2004; Suh 2015). Rice is also a source of protein (~14%) and fat (2%) (Kennedy and Burlingame 2003). Rice is an

Received 6 April, 2017 Accepted 9 September, 2017
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doi: 10.1016/S2095-3119(17)61718-0

attractive model plant species due to its small genome size (~440 Mb) (Bennetzen 2002), suitability for doing efficient transformation and genetic analysis (Hiei *et al*. 1994), availability of genome sequence of both *indica* and *japonica* subspecies and close genetic relationship with other cereals (Buell 2002). All these features made rice to be first choice for exploring its potential to the fluctuating climates (Jwa *et al*. 2006).

1.1. Climate change scenario

Climate change adversely impacts our agriculture and other resources including water, bio-diversity, etc. (Rasul et al. 2012; Afzal *et al*. 2015; Bakhtavar *et al*. 2015; Zafar *et al*. 2015; Fiaz *et al*. 2016; Waqas *et al*. 2017). Escalating temperature (predicted to increase by 0.2°C per decade) would add 1.8 to 4°C at the end of this century (IPCC 2007). Most developing nations would be the major victim of emerging scenario largely because of lack of resources (Noor 2017) and information to the resource poor farming communities (Ahmad *et al*. 2016; Fiaz *et al*. 2016). Thus it would be catastrophic to the low income farmers than that of the progressive growers.

Major source of changing the climate is the emission of greenhouse gases, result in increase in atmospheric temperature. Episodes of excessive heat occurred in the past and are estimated to recur more frequently at the fall of the 21st century (Semenov and Halford 2009). Climate change will suppress yields by 15–35% especially in Africa (Parry *et al*. 2007) and Asia, and 25–35% in middle East by the increment of 3–4°C (Ortiz *et al*. 2008). Currently, most of the rice is grown in regions with prevailing optimum temperature (28/22°C), and any further change in average temperature will drastically impact the yield (Krishnan *et al*. 2011).

1.2. Heat stress in rice

Heat stress (excessive heat) can cause irreversible damage (Wahid *et al*. 2007) by retarding the plant growth, metabolic activities, and pollen fertility and seed setting (Jagadish *et al*. 2007; Xiao *et al*. 2011), thus reducing the rice production (Wahid *et al*. 2007; Hasanuzzaman *et al*. 2013; Zafar *et al*. 2017). In another report, it has been shown that excessive heat accelerates reduction in rate of photosynthesis, leaf area, reduces shoot and grain mass as well as seed weight, and water-use efficiency (Shah and Paulsen 2003). High temperature may impede the vegetative as well as reproductive stages (from emergence till maturity, Katiyar-Agarwal *et al*. 2003). However, booting and flowering are the most critical stages which may lead to complete sterility in rice (Shah *et al*. 2011).

2. Mechanisms of heat tolerance in rice

Heat tolerance is usually coined with plants which can minimize the stress effects and produce acceptable economic yields at high temperature (Wahid *et al*. 2007). Like many other crop species, there is substantial genetic variations in rice germplasm exist which can thrive better under the prevailing high temperature environments (Shah *et al*. 2011). The tolerance is addressed by making adjustments in various morphological, physiological, and biochemical traits in rice plant. Heat stress triggers the expression of certain genes and metabolites production — both together enhance the heat tolerance in plant (Hasanuzzaman *et al*. 2013). Plants have evolved multiple mechanisms including escape, avoidance, or survival under high temperatures. These mechanisms impart short term avoidance or long term resisting adjustments. At cell level, tolerance processes including ion transporters, LEA proteins, factors participating in signaling cascades, osmolytes, antioxidant defense, and transcriptional control are essentially required to neutralize the stress effects (Rodríguez *et al*. 2005). Reduction in yield by inducing early maturity in hot environment is a part of an avoidance strategy under high temperature (Adams *et al*. 2001).

2.1. Morphological adaptations

Modifications in plant architecture contribute significantly in heat stress avoidance. For instance, the cultivars with covered panicles are better tolerant to high temperature because of their ability to reduce the evaporation rate from anthers — reduced the spikelet sterility. Reduced evaporation rate results in swelling of pollens which is a crucial mechanism of anther dehiscence (Shah *et al*. 2011). In addition, the genotypes in which flowers open early in the morning have better heat tolerance utilizing the avoidance mechanism (Ishimaru *et al*. 2015; Bheemanahalli *et al*. 2017). Hence, the genetic variability for tolerance to heat in rice can be used as germplasm screening criteria (Ishimaru *et al*. 2015).

2.2. Physiological adaptations

Temperature stress may significantly suppress the photosynthetic rate, hormone levels, membrane stability, respiration, the primary and secondary metabolites, etc. (Wahid *et al*. 2007; Bakhtavar *et al*. 2015; Ahmad *et al*. 2016; Waqas *et al*. 2017). For responding sudden heat shock, leaf position, cooling effect of transpiration and alteration in lipid constituents of membrane are more vital for plant survival (Rodriguez *et al*. 2005). A number of ionic and osmotic processes trigger the stress related signals which help