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Impact of high temperature stress on Rice and its mitigation strategies

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Abstract
Rice (*Oryza sativa* L.) is a central to the lives of billions of people around the world. Most of the world's populations carbohydrate requirement is fulfilled with rice. The population of world goes on increasing at an alarming rate. It is estimated that the world's population become 10 billion by 2050. The demand for rice increases and cultivated area under rice decreases day by day. On the other hand various abiotic and biotic stresses like heat, moisture, nutrients, chemical insect, pest etc also vigoursley reduces and hampered the growth and yield of rice. Among the different abiotic stress high temperature stress have negative impact on growth, development and yield of rice. It is a time of question that how we can stabilize the yield of rice under high temperature environment through different management practices? Therefore this review tried to cover the answer for this question, Developing high temperature tolerance rice along with genetical, biotechnological and physiological approaches to solve the problem of high temperature stress. Various agronomical practices adopted to overcome the high temperature stress are early sowing of rice, early maturing variety of rice during the grain filling stages etc. In this review, the effects of high temperature stress on rice growth, yield and quality characters, including different morphological, physiological and biochemical mechanisms along with use of convectional and molecular breeding methods and techniques are discussed. The production of heat shock proteins (HSPs), reactive oxygen species (ROS) that helps in high temperature tolerance mechanisms in plants also covered.

Keywords: Rice, Stress, temperature, heat shock protein, reactive oxygen species

1. Introduction

Rice is an important cereal crop, which fulfil the calorific need of millions of people of the world. Rice has a wide range of adaptability and it is grown even 3m below sea level in Kerala in India and also cultivated an altitude of more than 3000m in Bhutan and Nepal. More than 2/3rd population of India depends on rice as a staple food. Globally rice is grown in more than 114 countries over 161 million hectares to produce more than 650 million tons (FAO, 2012) [16]. India produces 99.15 million tonnes of rice (Anonymous, 2009) [6], while China ranks first in worlds rice production (Anonymous, 2007) [5]. However, there is rapid increase in populations, rice production has to enhance about 120 million tons by 2020 (Survey of Indian Agriculture, 2005). There is a big challenge among scientists to achieve this much of target from the limited available land and water resources, deteriorating environment and climate change. Worldwide, the rice area has increased from 120.1 million ha in 1960 to 155.7 million ha in 2008 (Childs and Baldwin 2010) [13]. During "Green Revolution" hazardous application of inorganic fertilizers, and other agrochemicals and use of high-yielding rice cultivars has doubled rice yield from 1.84 to 4.25 Mg ha^{-1}. The various activities including human interventions, industrialisation, urbanisation and deforestation, which causes green house effect on earth and increase the surface temperature both in terms of intensity and magnitude of high temperature increase gradually (Peterson *et al*. 2012) [32] reducing the rice yields. Under changing climate scenario effects on rice production have estimated the impact of high temperatures on paddy (rough) rice yield (Welch *et al*. 2010; Peng *et al*. 2004) [50, 31] and milling quality. Recently, the researcher has shown that increases in 1^0C daily maximum and minimum temperatures the paddy yields decrease by 10% (Welch *et al*. 2010; Peng *et al*. 2004) [50, 31]. The IPCC projected that the heat stress is responsible for yield reduction of rice both in temperate and tropical regions (IPCC, 2014). Arise in temperature beyond a critical threshold for a period of time sufficient to cause irreversible damage to plant growth and development is defined as high temperature stress (Krishnan *et al*., 2011) [24]. All the crop plants required optimum temperature to perform the different physiological, biochemical function such as growth, development, reproduction, protein synthesis etc. Temperature below or above that range causes adverse effect on crop yield. The yield contributing parameter such as number of productive tillers, spikelet sterility and test weight are affected (Sheehy *et al*. 2001) [38] by cultivation practices and by environmental factors among which temperature is considered to be agronomically important (Singla *et al*. 1997) [41]. The spikelet sterility in rice is sensitive to high temperature but, the degree of sensitivity depends upon developmental stages of the spikelet (Zakaria *et al*. 2002) [56]. Earlier studies have emphasize on the effects of heat stress on long period of reproductive stage but, now major emphasis given on short-term heat stress on rice. Anthesis and grain filling are critical reproductive stages for determining rice grain yield, and both are sensitive to temperature (Jagadish *et al*. 2007; Prasad *et al*. 2008) [20, 33]. There is a decreased in accumulation of photosynthates in grains and poor grain yield due to high temperature stress (Morita *et al*. 2005) [28]. But the response of plants to temperature stress depends on duration, intensity, period of its occurrence (day or night), and rate of temperature change.

2. Effect of high temperature on rice

2.1 Growth and development

Temperature is the main abiotic component for crop development. The optimum temperature range for better development of rice is 27 to 32 °C (Yin *et al*. 1996). The heat stress affects all the phonological stages of rice, starting from emergence to harvesting (Table 1). High-temperature stress is one of the major factor affecting the rate of plant development, which is considered to increase to a certain limit and then decrease afterward. The succession of rice developmental stages (phenology) depends on air, water temperature and on photoperiod (day-length). Thus, the changes in phenology in response to heat stress can reflect the interactions between stress environment and plants. The translocation of dry matter during the vegetative stage decreased with increasing temperature and heat stress duration and there is also reduction in dry matter translocation in stem following heat stress at anthesis (Shi *et al*. 2016) [39]. Temperature affects the growth duration of the rice crop to a great extent. Upon exposure of rice to high air temperatures causes reduction in plant height, tiller number and dry weight. The leaf area index (LAI), leaf nitrogen (N) concentration and flag leaf net photosynthetic rate (Pn) of rice leaves exposed to heat stress at 12 days after anthesis gradually decreased with increasing temperature level and duration throughout the entire grain filling process (Shi *et al*. 2016) [39]. The effects of high temperature causes delayed in germination, seedling emerengece and seedling establishment. The quantitative traits such as germination rate, germination percentage, root length, shoot length, seed vigour, seed viability also affected due to high temperature stress. (Cao and Zhao 2008) [9].

Under high-temperature stress conditions, there is a tendency for reduced cell size, closure of stomata and curtailed water loss (usually not observed in high light conditions, until there has been a temperature more than 35^{0}C), increased stomatal and trichomatous densities, and greater xylem vessel numbers of both root and shoot.

Table 1: Symptoms of heat stress on rice plants

Growth stage	Threshold Temperature(^{0}C)	Symptoms	References
Emergence	40	Delay and decrease in Emergence	Yoshida (1978), Akman (2009)
Seedling	35	Poor growth of the Seedling	Yoshida (1981)
Tillering	32	Reduced tillering and height	Yoshida (1978)
Booting	-	Decreased number of Pollen grains	Shimazaki *et al*. (1964)
Anthesis	33·7	Poor anther dehiscence and sterility	Jagadish *et al*. (2007) [20]
Flowering	35	Floret sterility	Satake &Yoshida (1978)
Grain formation	34	Yield reduction	Morita *et al*. (2004)
Grain ripening	29	Reduced grain filling	Yoshida (1981)

2.2 Pollination

The production and productivity of crop also determines by the production of pollen, germination, viability and reception of pollen grain. The development of pollen occours within the anthers of an flower. There is a formation of tetrads after pollen mother cell entering to meiosis division. This process of cell divison known as microsporogenesis. Wassmann *et al*. 2009 [49] reported in rice crop that male reproductive development process is more sensitive to high temperature stress. High temperature also have adverse effect during flowering stage of rice which ultimately affect production of pollen and shedding of pollen, pollen germination (Prasad *et al*. 2006) [33]. The reason behind the decreased in pollen production germination and shedding in rice may be swelling of pollen grains, improper development of anthers, less release of pollen grains (Matsui *et al*. 2000) [26] and that why less no of pollen grains is available for fertilizing the stigma. The required amount of pollen production is decreased when the plant growing under high temperature environment, that might be due to improper cell division of microspore mother cells. The high temperature also have negative impacts on pollen tube growth, pollen germination, reduced anther dehiscence at anthesis stage or soon after anthesis. Song *et al*. 2001 [42] reported that in rice crop exposure to high temperature at the pollination periods causes loss of pollen viability within 10 minutes and it was essential that more than 10 pollen grains should germinated on stigma of floret to ensure the successful fertilisation of flower. The yield loss occours when rice plant upon exposure to high temperature for a few hours that may be due to reduce pollen viability (Wassmann and Dobermann 2007) [48]. Temperature more than 35/25 ^{0}C there is a significant decrease in length of pollen tubes observed. Das *et al*. 2014 found on his research work that high temperature stress on rice decrease the pollen diameter by 3.15% per degree celcius and also pollen tube by 12.36% per degree celcius. Under high temperature stress there is change of biochemical characteristics of pollen like protein concentration affected, sugar content increases, membrane stability index (MSI) were found to decreases with increase in temperature (Das *et al*. 2014) [14].

2.3 Spikelet sterility

At flowering stage spikelet fertility affects negatively upon exposure to high temperature (Yan *et al*. 2010) [51]. Spikelet sterility happened due to improper dehiscence of anther, poor production pollen which leads to develop less quantity of germinating pollen grains on the stigma of flower (Prasad *et al*. 2006) [33]. There is also observed that high temperature shows genotypic variation in spikelet sterility under different temperature treatment (Nakagawa *et al*. 2002) [29]. In rice plant high temperature exposure there is a decrease in fertility of spikelet and this is taken as a phenotypic character but decrease the activity and germination of pollen grain consider as a physiological factor responsible for this (Tang *et al*. 2008). There is complete grain sterility in rice plant observed at the heading stage upon exposure to day/night temperature at $35/30^0$C and relative humidity (RH) of 85-90% (Abeysiriwardena *et al*. 2002) [1]. At temperature more than 35^0C there is a maximum spikelet sterility in rice. Jagadish *et al*. (2007) [20] conducted an experiment on both indica and japonica genotypes of rice under green house conduction and resulted that upon exposure to an temperature more than 33.7^0C for less than one hours was enough to develope sterility.

2.4 Anthesis and grain filling stages

The heat stress is most adversely affected at anthesis stage of rice. At anthesis stage, under heat stress causes limited grain growth this happen may be due to inhibiting translocation of dry matter rather than decrasing photosynthetic production. The effects of high temperature stress causes decrasing in spikelet fertility, less weight of grain and photosynthesis capacity of leaf and leaf area also decresed, which helps in supply of nutrient for growth of grain (Shi *et al*. 2016) [39]. The duration of rice grain filling is decreases at anthesis stages under heat stress condition. The portioning of dry matter to panicle and timing for grain filling rate also decreased with increase in heat stress duration and temperature, but grain growth increased with increasing temperature and duration. From this result it is indicated that heat stress enhanced the growth rate of grain and shorten the grain filling duration (Shi *et al*. 2016) [39]. The reason of decreased grain weight is mainly due to the failure of increased grain filling rate to compensate for the reduced grain filling duration, so sufficient assimilation supply do not get to fulfil daily demand for grain growth (Kim *et al*. 2011, Kobata and Uemuki 2004) [22, 23]. There are some sensitive events of Anthesis under high temperature environment are pollination, germination of pollen, development of pollen tube, dehiscence of anther are severely affected within 45 minutes of spikelet opening (Prasad *et al*. 2006) [33]. Heat stress just before/ after Anthesis in rice results poor seed setting (Prasad *et al*. 2008) [34]. Heat stress also reduces the transport of assimilates during grain filling period (Farooq *et al*. 2011) [17]. under heat stress environment in temperate rice cultivars causes the reduction of grain filling duration it may due to premature senescence of leaves (Kim *et al*. 2011) [22].

2.5 Grain yield

The yield attributing components in rice are no. of panicle per unit area, no of spikelet per panicle, the spikelet fertility percentage and test weight determine the grain yield. The no of panicle per unit area is an important component that contributing the grain yields. Under high temperature stress reduces the transport of carbohydrate to spikelet of rice (Cao *et al*. 2008) [9]. Heat stress reduces the grain yield due to spikelet sterility and a shorter duration for grain filling period at the stages of flowering and grain filling periods of rice respectively.

3. Mitigation strategies against thermal stress

Most of the people belongs to Asian continent, there is a maximum demand for rice as their staple food as daily diet. It is an issue that how rice yield can be stabilize under changing climate scenario. Heat stress is an important abiotic stress which affect the rice yield, quality and acceptability. To mitigate the heat stress some strategies must be followed to avoid the effect of heat stress.

3.1 Agronomic strategy

Globally to achieve the target yield there should be replacement of heat sensitive cultivars with tolerant one in the field. The agronomic practices like time of sowing is an important operation to avoid the peak periods heat stress from the management point of view.

I. The field should be maintained wet but not flooded and addition of organic matter decreases the global warming potential from rice fields without reduction in yield.
II. Appropriate choice of varieties that have appropriate growth under heat stress and can perform better in different sowing time.
III. Climate changes differs in regions wise accordingly select the appropriate site specific cropping systems to overcome the problem.
IV. Some of growth regulators like salicylic acid and Glycine betaine (increase percentage of pollen germination and spikelet fertility) will helpful for mitigating heat stress.
V. Soil should be cover with crop residues that act as a insulating material and alter the heat transfer form soils.
VI. Practicing of diversified crop rotations.
VII. Under unfavourable condition of high temperature planting a late/early maturing cultivar or shifting the crop season (Ohe *et al*. 2007).

3.2 Breeding strategies

The full rice genome sequence and quantitative trait loci (QTL) mapping efforts for a greater range of trait, breeder have achieved a lot of success in rice breeding programme to mitigate high temperature.

I. In the reproductive stage of rice, spikelet fertility is consider as an important character for rice yield. The spikelet fertility can be utilized as a screening tool for high temperature tolerance.
II. Developing high- temperature -tolerant transgenic rice.

The recombinant DNA technologies is one of the best option for developing high temperature tolerant transgenic rice (Katiyar –Agarwal *et al*. 2003). It can be done by altering levels of HSPs levels either directly or through regulatory circuits that govern HSPs levels (Katiyar –Agarwal *et al*. 2003).

3.3 Biotechnological strategies

Among the different strategies biotechnological strategies is one of the important strategies for tackle the problem of high temperature stress in rice. There are so many marker identified that are associated with high temperature tolerance. These markers can be used in future rice breeding programme to develope heat tolerance cultivars. The different type of markers are molecular, biochemical, morphological and physiological which are used in rice breeding programme.

3.3.1 Morphological markers
There are so many morphological markers have been identified for high temperature tolerance in rice such as more fertile pollen, long anthers, large basal dehiscence of pollen. These markers are used for screening of rice germplasm aganist high temperature (Shah *et al*. 2011) [37]. The other morphological marker like number of spikelets per panicle, test weight, percentage of seed filling, grain yield are also used for rice germplasam aganist high temperature stress. It was reported that there is reduction in these trait after exposure to high temperature (Cao *et al*. 2008) [9]. In the early morning opening of spikelet is an important criteria for heat tolerant rice plants (Bheemanahalli *et al*. 2017) [8].

3.3.2 Physiological markers
In a research the amount of chlorophyll content in the leaves where as the leakage of electrolyte both from root and leaf increases under high temperature environment (Liu and huang 2000) [25] and this is used for physiological markers for heat tolerance. Wahid *et al*. 2007 [46] reported that membrane stability, levels of hormones, respiration, water relationship are some physiological parameters used for screening of rice germplasm to high temperature stress. Similarly positions of leaf, transpiration and composition of lipid in the membrane (Rodriguez *et al*. 2005) [25] are some other physiological parameter responsible for high temperature tolerance.

3.3.3 Biochemical markers
Antioxidants: These includes super oxide dismutase (SOD), catalase (CAT), Ascorbate peroxidise (APX) used as a biochemical markers for screening of rice genotypes aganist high tempearature stress (Almeselmani *et al*. 2006, Wahid *et al*. 2007. Hasanuzzaman *et al*. 2013) [3, 46, 18]. The antioxidants which are non-enzymatic also play an important role in heat tolerance. These are help in protecting the cell organell from ROS (Chen *et al*. 2010) [12].

3.4 Heat shock protein (HSPs)
These proteins have important role in protecting plant cell from high temperature injury (Chang *et al*. 2007) [11]. These HSPs are divided in to 5 unlike families in plants are HSP 20 (or small HSP, s HSP), HSP 60 (or GroE), HSP70 (or Dnak), HSP90 and HSP100 (or ClpB) (Swindell *et al*. 2007) [44]. A HSP plays as molecular chaperons which help in both repair of damaged cell and protests cell from stresses (Wang *et al*. 2004) [47].

3.5 Malondialdehyde (MDA)
The levels of Malondialdehyde in cell membrane indicate the lipid peroxidation in plant cells upon the exposure to high temperature stress (Anjum *et al*. 2016) [4]. There is positive correlation between levels of MDA and membrane damage. Low content of MDA in plant cell is a desirable traits for heat tolerance and is used as a biochemical marker in rice genotype for high temperature tolerance (Cao *et al*. 2008, Zafar *et al*. 2017) [9].

4. Conclusion
Most of the Asian countries depends on rice as a staple food. Still continuing struggles for rice cultivation to obtain higher productivity in most of the countries. Due to various abiotic stresses specially high temperature stress affect the rice production and becomes a greatest challenges in future. So, there is our basic need to be understood the growth and development of rice under high temperature stress condition. For this selection, identification and development of suitable varieties, various agronomical measures, biotechnological tools, marphological, physiological and biochemical markers becomes a potent tool to mitigating adverse effect of high temperature and sustain the rice production. There is also so many other technological option like GIS, climatological tools become available to solve the problem of high temperature stress.

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