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Rice Crop Responses to Global Warming: An Overview

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Abstract

The mean temperature might rise up to range of 2.0–4.5 °C worldwide by the end of this century. Beside from this, a prediction has been made that rise in minimum night temperature will be at a quicker rate as compare to the maximum day temperature. Rising temperatures not only affect the crop growth process, but also lead to direct changes in other environmental factors and pose indirect effect on yield and quality of rice has been observed, so at the present stage, it aroused public attention. Breeds, including through breeding and biotechnology to improve high temperature tolerance of rice help to mitigate the negative effects of high temperature, however, progress in this area have been slow. By adopting different methods like sowing, water and nutrient management can also to some extent mitigate the effects of high temperature on rice performance, but in most cases, these techniques are influenced by many factors, such as crop rotation, irrigation and other constraints like their applications are hard to applied to large area. Therefore, this chapter addresses (1) empirical reduction of rice yield (2) highlights the key significant mechanisms that influence main grain quality attributes under high temperature stress (3) inducing stress resistance and adopting mitigation strategies for high performance of rice.

Keywords: high temperature, rice, yield, area, production and grain quality

1. Introduction

1.1. Rice crop future

Rice (*Oryza sativa*) is one of the significant cereals grown world widely. Globally, it is consumed mostly as a staple food crop to feed greater portion of the world's human population,

particularly in Asia. According to FAOSTAT data [1], it ranks third world wide on production basis, after sugarcane and maize crops. Regarding to human nutrition and caloric intake, it is considered the most significant cereal crop supplying over one-fifth of the calories consumed by humans globally [2]. Though for many years used as a model plant, however, in the last decades, the unprecedented increase in temperature extremities exposed a wide series of variances related with heat stress. In different regions of the world, its harsh influences on different crops have been noticeably apparent. Currently, rice production is facing multiple challenges such as water stress, insect pest infestation, disease attack, which delay its planting and as a result barricade its sustainable production its sustainable production. Forthcoming major challenge will be heat stress and its consequences on grain development. An increase of 1.4–5.8°C in surface air temperature is estimated by the end of twenty-first century as a result of global climate change events [3]. Risk of variability to this mean temperature even poses more severe threats to rice grain development. Experimental evidences have repeatedly repressed that a short episode of high temperature (owing to climatic fluctuations) had greater negative impacts on grain than continuous mild stress [4]. A 25-year weather data report from International Rice Research Institute, Philippines has indicated greater increase in night time temperature (1.13°C) over day time temperature (0.35°C) [5].

Like most of the other regions of the world, high temperature stress has raised in majority parts of China particularly in the northern parts for the last 50 years or so. In most parts of China, especially Xinjiang and mid lower reaches of Yangtze River, both hot days and heat waves have augmented [6]. The main rice-growing area of China i.e., Yangtze River Valley (YRV) faced severe problem of heat stress, causing heavy loss of mid-season rice [7]. According to Tian et al. [7], the extended heat stress in heat vulnerable rice varieties and hybrids in the provinces of Hubei and Sichuan China, resulting in greater reduction in yield of rice because of poor seed set (up to 10% only). In most rice-growing areas, the existing temperatures are almost touching the range of optimum temperatures; if further increases in temperature occur, there will be a chance of finishing the rice crop in such areas. Hence, during sensitive stages, any supplementary raises in mean temperatures or occurrences of high temperatures for shorter time, may lead heavy losses in grain yield. Due to the disastrous heat stress episode of 2003 in China, enormous amount of 5.18 million tons losses in rice yield was accounted from an area of 3 million ha [7, 8]. Likewise, in South-East Asia, Lobell et al. [9] noted a reduction of 4–14% in rice yield because of 1°C enhance in temperature.

By the end of the twenty-first century, 41% of reductions have been estimated in rice yields [10]. There is enough confirmation that, rising nighttime temperature since in the middle of the twentieth century has been the major reason of enhances in worldwide mean temperatures and is thus the major aspect contributing to the yield decrease [11, 12]. At the vegetative stage, rice with comparatively higher tolerance is tremendously susceptible during their reproductive stage against high temperature, mainly at flowering [13–17]. From the *Rice almanac*, using cropping pattern data [18], spatial analysis demonstrated rice susceptible stages from flowering to early grain-filling stages matching with high temperature situations in Bangladesh, southern Myanmar, northern Thailand, and eastern India [19]. Rice, with its extensively miscellaneous genetic traits, flees the influence of higher temperature during the morning later hours because of its early morning flowering (EMF) [20], while through transpiration cooling, avoidance of

elevated temperature is better equipped to resist high day temperature, provided that adequate water is accessible [21]. Conversely, at night time, the limited stomatal activity makes rice enormously susceptible to promptly mounting night temperature. Taking into consideration, the present and envisaged speeds of enhance in night temperature, the harmful effect is likely to be considered on a much larger range on rice production, with major losses in yield.

According to Mohammed and Tarpley [22], enhanced respiration rates are generally related with high night temperatures (HNTs), resulting to a lessening in yield. However, in response to both high day and night temperature, connection of physiological processes up to some extent (e.g., effect of the pollination process, reduced germinated pollen number on the stigma, and augmented spikelet sterility) has been recognized [17, 23]. According to Nakagawa et al. [24], High temperatures induced floret sterility and therefore, decreased rice yield and therefore, decreased rice yield. In response to a temperature more than 35°C, spikelet sterility was significantly augmented [25, 26]. Jagadish et al. [15] conducted an experiment in greenhouse condition using both genotypes (*Indica* and *Japonica*), observed that plants exposure to temperatures above 33.7°C for less than 1 h was enough to induce sterility. This problem may further aggravate by enhanced levels of CO₂, probably because of decreased transpirational cooling [26–29].

1.2. Global warming influences rice crop production

Rice production significantly gets affected by diurnal temperature changes. Beyond the critical level, day temperatures can severely affect the activity of photosynthesis, by altering the thylakoids structural organization and upsetting the photosynthetic system II [30, 31]. As a result of this modification, it will enhance the production of reactive oxygen species (ROS) and thus cause damage to integrity of cell membrane, cell content leakage, and eventually decease of cells [32]. Recently, high night temperature (HNT) stress has gained the attention in rice examine region. In the region of tropics and subtropics, critical ranges of an extremely narrow 2–3°C have caused severe reduction in grain yield [11, 33]. Although the reduced yield caused by HNT may be attributed to higher respiration rates [23], the percentage yield decline was much higher than the percentage increase in respiration rate [11]. Comprehensive attempts are needed to facilitate rice plants to survive under high temperature stress, just by utilizing the present existing variation of the accessible genetic resources; rice plants can target by researchers with increased tolerance to high temperature stress. Besides, to avoid these losses of crop production by the imminent global warming, researches relating to physiological outcomes of high temperature on grain-filling stage are also highly critical [34]. Time of cultivation and their adjustment, for instance flowering and booting stages, which are the most vulnerable stages, do not hit the highest point of temperature stress is a valuable approach for crop management; therefore, this approach will assist the plants to flee the adverse effect of heat stress [35].

1.3. Rising temperature influences rice grain quality attributes

During kernel development, environmental temperature plays a fundamental part in producing the observed, impenetrable variations in the quality of rice grain [36]. Rice quality traits encompass milling, physical manifestation, cooking, and sensory characteristics and also

their eating and nutritional worth [37]. The assessment criteria for milling quality generally include percentage of brown rice, milled rice, and head rice, which reflect the ratio of entire kernels (head rice or head milled rice) and broken kernels produced throughout the milling of rough rice. According to Koutroubas et al. [38] observed that with the market demand, the above mentioned criteria are intimately related because broken milled rice is less than half of the price of head milled rice. Quality of appearance is mostly decided by grain size, translucency, chalky grain percentage, chalky area, and chalky degree. An opaque mark has present in the endosperm of chalky grains that range in size, either found on the grain dorsal side (white belly) or in the middle (white center) [39]. Contents of amylase, gelatinization temperature, and also gel consistency of the grain starch determine the cooking and eating characteristics of rice [40].

Fahad et al. [28] observed that at a period of kernel development, a relationship of decrease in yield of head rice with enhance in nighttime temperature. Likewise, chalkiness formation in grain, small amount of amylose content, and reduction in grain size are assisted by high temperature stress during grain ripening phase [34, 36, 41]. Moreover, during grain-filling stage, high temperatures can vary physico-chemical characteristics, breeding, and flour qualities of grain crops [42], together with alterations in flour protein contents [43]. Proficient utilization of the already accessible genotypic deviation in rice [44] and use of different chemical application can alleviate the pessimistic influence of high temperatures on yield of crops. However the potential role of these two approaches concerning on the qualitative features of rice there is a literature scarcity which limits our understanding. Furthermore, in the view of the predicted global warming, understanding the molecular basis of these traits is essential to allow breeders to develop new genotypes, which can withstand across a wide range of environmental conditions and locations.

2. Inducing stress resistance and mitigation strategies

For the study of heat tolerance, rice is considered an excellent model plant among all cereal crops because of the accessibility of high-density genetic and physical maps, expressed sequence tags (ESTs), genomic sequences, and mutant stocks such as T-DNA insertional mutants [45]. Due to the greater level of synteny and homology within the Poaceae family will help to recognize perfect QTLs and transfer of candidate genes from rice to other cereals [46]. Various approaches that may enable rice plant to perform better against coming threats of changing climate are outlined below.

2.1. Breeding strategy

Because of the accessibility to the full rice genome sequence [47] and rigorous QTL mapping efforts for a greater range of traits [48], breeders have achieved a lot of success in rice-breeding program to combat the high temperature. Therefore, various options of the breeding program,

if we utilized, will assist to alleviate the issue of mounting temperature to large extents. Some of the approaches are briefly summarized below.

During the reproductive stage, spikelets fertility is considered an important trait for rice yield and it can be utilized as a screening tool for high temperature tolerance. Plant selection should be done for heat tolerance from those breeding materials, which can perform well even at temperatures more than 38°C [49]. While some cultivars such as N22 have already been well known for their tolerance to comparatively higher temperatures, they should be used as “genetic donors” in the case of breeding for high temperature stress. Visible markers are needed of the high temperature tolerance for the effective assortment in a breeding program. Especially in flowering time (mainly the wild type), investigating the existing genotypic alteration assists as an important alleviation choice for mounting temperature as it is a comparatively simple attribute that needs to be a focal point in breeding programs. According to Ishimaru et al. [50], positive influence has been recorded on reducing the spikelet fertility by the introgression of the early morning flowering gene from *Oryza officinalis* into *Oryza sativa*. QTL mapping, together with allied genetic studies concentrating on the association between the phenotypic quality and its genetic markers, would afford an opportunity to relate specific alleles to trait variant and consequently to recognize candidate genes [51].

Investigating the alteration in both genotypic and morphological attributes, future studies should be focused at identification and breeding of heat tolerant germplasms. Numerous strategies should be vigorously identified in order to enhance tolerance in existing cultivars against heat stress, comprising discovery and utilization of novel genes and alleles, enhanced breeding efficacy, marker-assisted selection and genetic variation.

2.2. Agronomic strategy

In the present, rice genetic reserve existence of large unpredictability exists against temperature. To achieve high production of rice globally, sensitive cultivars should be replaced with tolerant ones in the fields. Timely sowing of varieties is also very critical to avoid peak stress periods from the management point of view. And for this determination, varieties development along with appropriate growth periods and tolerance of altered sowing times can perform a key part. To cope with the climatic severities that vary within the region, adjustments of site specific in cropping systems may be required. Therefore, aerobic and flooded rice systems may be relatively helpful for this targeted adaptation. Likewise, in nearby future shifting from flooded to aerobic rice is expected in the cropping pattern. According to Yu et al. [52], maintain the field wet but not flooded along with the addition of organic matter decreases the global warming potential from rice fields without any reduction in the yield. So, management approaches such as saturated soil culture (SSC), alternate wetting and drying (AWD), and aerobic rice cultivation under drought stress, while cultivating advanced varieties comprising the sub1 gene in flooded soils, provide certain adaptive choices for the indirect stresses connected to high temperature. Alternate wetting and drying strategy in the irrigated rice fields may also assist indirectly, as it decreases methane emission (an important contributor to global warming).

3. Conclusion

For attaining high yield production under more imperfect circumstances is one of the main challenges of this century. It is now clear that the emphasis on stress tolerance in plants has to be readdressed from the vegetative to reproductive stages because of greater sensitivity to environmental variations and also their direct connection with fruit and seed production. Current constraints caused by high temperature related to yield losses and to overcome these issues have gained much attention among the researchers, though investigating the multifaceted concerns connecting with grain quality losses continue to be a main task. Further challenges that might arise with the shift from entirely flooded rice conditions to water-saving technologies require more concentration to confirm that the benefit attained under fully flooded situations assists the alteration with lowest harm under a future warmer and drier climate.

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