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Impact of Temperature Variations on Rice Production

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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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. Climatic variables affect the growth and development of the crop differently at different growth stages. The rate of development of a crop depends on the climate. Temperature is the primary factor that influences the growth and productivity of crops. Higher or lower temperatures than the optimum lead to improper crop development and affect rice's phenological stages. Extreme temperature may lead to early maturity of the crop and lower temperature lead to prolonged maturity of the crop which in both cases leads to a decrease in yield. A moderate increase in temperature will not have severe implications, but an increase in average temperature by 2^0 C will likely have strong negative effects on rice crop production. In several studies, it has been reported that high night temperature decreases the yield potential of rice. Whereas, respiratory losses have been shown to increase due to higher day temperature, leaf conductance and net assimilation rates during the day were reported to be higher.

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1. INTRODUCTION

"Rice plays an important role in food security of many countries as it is the staple food for more than half of the world's population. It is the staple food for over 65 per cent population in India" [1]. "Globally rice is cultivated in an area of 167.13 million hectares with a production of 782 million tonnes and with a productivity of 4,679 kg ha^{-1}" [2]. "In India, rice is grown in an area of 44.15 m ha with 116.4 million tonnes of production and 2,638 kg ha^{-1} productivity" [3]. "90 per cent of the world's rice comes from Asia of which 85 per cent of production is used for human consumption and it deserves a special status among cereals as the world's most important wetland crop" [4]. "Regarding human nutrition and caloric intake, it is considered to be the most significant cereal crop supplying over one-fifth of the calories consumed by humans globally" [5]. 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 to 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, and disease attack, which delay its planting and as a result, barricade its sustainable production. Future crop yields will be influenced by complex interactions between the effects of increases in atmospheric concentrations of CO2 [6] and trace gases such as ozone [7] as well as the effects of temperature increases brought about by climate change [8]. "Global mean surface air temperature increased by nearly 0.5°C in the 20th century and is projected to further increase by 1.5 to 4.5°C in this century" [9]. "In the past century, the daily minimum nighttime temperature increased at a faster rate than the daily maximum temperature in association with a steady increase in atmospheric greenhouse gas concentrations" [10,11]. "Experimental evidence has repeatedly repressed that a short period of high temperature (owing to climatic fluctuations) had greater negative impacts on grain than continuous mild stress" [12]. "A 25-year weather data report from the International Rice Research Institute, Philippines has indicated a greater increase in night time temperature (1.13°C) over daytime temperature (0.35°C)" [13]. "World rice production must increase by 1 per cent annually to meet the growing demand for food that will result from population growth and economic development" [14]. "Most of this increase must come from greater yields on existing cropland to avoid environmental degradation, destruction of natural ecosystems, and loss of biodiversity" [15,16]. "Achieving greater yields depends on increasing total crop biomass because there is little scope to further increase the proportion of that biomass allocated to grain" [17]. "Total crop biomass is determined mainly by crop photosynthesis and respiration losses, both of which are sensitive to temperature" [18].

"The growth and grain yield of rice depend on the combined effect of the genetic characteristics of the variety and environmental conditions of the area where the variety is grown" [19]. "Among all the environment factors, temperature plays a major role in rice yield. The optimum temperature for the normal development of rice plants ranges from 27^{0}C to 32^{0}C" [20]. "High temperature affects almost all the growth stages of rice which includes from emergence to ripening and harvesting" [21,18,22,23]. "However, flowering (anthesis and fertilization) and booting (microsporogenesis) are considered to be the most susceptible stages to temperature in rice" [22,24]. "Temperatures higher than the optimum induce floret sterility and thus decrease rice yield" [25]. "Spikelet sterility is greatly increased at temperatures higher than 35^{0}C which is the critical maximum temperature in rice" [22,26]. "A night temperature of less than 19^{0} C is the critical low temperature for inducing grain sterility in rice" [27]. "The unimpeded growth of greenhouse gas emissions is raising the earth's temperature. The consequences include melting glaciers, more precipitation, more and more extreme weather events, and shifting seasons. The accelerating pace of climate change, combined with global population and income growth, threatens food security everywhere. Agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce the yield of desirable crops while encouraging weed and pest proliferation. Adaptation forecasts that by 2050 rice prices will increase between 32 and 37 per cent as a result of climate change. They also show that rice productivity will reduce by 14 per cent in South Asia, 10 per cent in East Asia and the Pacific, and 15 per cent in Sub-Saharan Africa" [28]. "The increased global temperature leads to rainfall deviations which can produce even more devastating results in crop growth" [29,30,31,32].

"Rice phenology is strongly influenced by the environmental conditions in a certain range, an increase in temperature leads to a decrease in the vegetative phase. Low thermal stress occurs in seedling and heading-flowering stages, whereas high thermal stress during the end of the growing season causes the sterility of seeds. On the other hand, the risk of cold stress during the rice growth leads to a reduction in yield" [33]. "With increasing temperature, the maturity stage will decline" [6]. "Increasing seasonal temperatures, will cause an increased risk of drought and the speed of photosynthesis will be limited" [34]. Roberts [35] suggested that "the temperature during the night rather than the day largely determines the response of plants to temperature". "Climate models foresee that a relatively greater increase in nighttime temperatures than daytime temperatures will occur because of less radiant heat loss due to increased cloudiness" [36]. "Over the past century, the increases in global daily minimum temperatures were more than twice that of daily maximum temperatures" [37]. Evidence of historical yields of rice (Peng et al. 2004), [38] and wheat (Lobell et al., 2005), [39] shows that "cereal yield was strongly correlated with minimum nighttime temperatures rather than daytime maximum temperatures" [40].

"Temperature is considered to be the most critical yield determinant of rice and high temperatures in the lower elevation of the tropics and lower temperatures in the temperate regions adversely affect the crop" [41]. Moderate warming in the coming decades, will possibly imply a net negative impact on the yield of rice [40,42] and productivity may decrease by 4.17 per cent [43]. "The rise in atmospheric temperature causes detrimental effects on the growth, yield, and quality of the rice crop by affecting its phenology, physiology, and yield components" [44,45]. "It can affect the crop at all stages of development, particularly during flowering when it causes spikelet sterility. It increases plant respiration, affects photosynthesis and shortens the grain filling period, all of which leads to lower productivity" [38]. "On the other hand, relatively low temperatures and high solar radiation during the reproductive stage had remarkable effects on increasing spikelet number and hence grain yield" [46]. "The rise in the night temperature is another reason for the decline in historical rice yield in addition to the observed changes in the climatic conditions, particularly during the ripening phase of the crop". [47] "Night-time warming at the end of the growing season had a greater impact on yield than the increase in the maximum temperature and changes in rainfall characteristics" [48,49].

"Although an increase in global temperature has been well documented, a greater increase in night-time compared with day-time temperatures has been highlighted recently" [50]. "This differential increase in day and night temperature will result in a reduced diurnal temperature range, which has been shown to affect crop growth and development" [20,38,51].

2. IMPACT OF TEMPERATURE VARIATIONS

2.1 Impact of Day and Night Temperature Variations on Rice Phenology

"In a study conducted at IRRI, Philippines, it was noticed that an increase in early night temperature from 24 to 30 or to 35 °C advanced the start of anthesis by 2 or 2.5 hours respectively in cultivar WAB56-104, but no effect was detected in the other two cultivars. Late high night temperature advanced the start of anthesis in cultivar N22 by 30 min at both 30 and 35 °C, while a delay and advance in flowering by 30 min at 30 and 35 °C, respectively, was recorded in WAB56-104, with no change in CG14. CG14 opened its first flower before 0530 hours consistently and because observations started at 0500 h and every 30 min 23 thereafter no high night temperature effect could be detected" [52]. "High-day temperature damage leaf gas exchange properties during the vegetative stage and even a short period of heat stress can cause significant increases in the abortion of floral buds and opened flowers during the reproductive stage" [53]. "Increased night temperatures significantly increased the rate of senescence and maturity was achieved in those plants exposed to high night temperature 15 days earlier than in the normal temperature chamber. The effects of high minimum temperatures increased the rate of senescence and decreased the ability of the plant to efficiently produce grain" [54,55]. "In all genotypes tested (Nagina 22 (N22; heat tolerant), IR64 (heat susceptible), heat tolerant IR64 near-isogenic line (HT NIL), and two hybrids, H2 (private company hybrid) and H5 (International Rice Research Institute hybrid breeding program)), the maximum (Cm) and mean (C) grain-filling rates were higher with high night temperature than for the control, whereas the time taken to reach the maximum grain-filling rate (tm) and total grain-filling duration (te) were shortened by HNT compared with the control" [56]. "Results of a study conducted at IRRI, Philippines indicated that night temperature promoted flowering more efficiently than day temperature in three cultivars only, whereas the opposite effect was found in most other cultivars" [20].

2.2 Impact of Day and Night Temperature Variations on Growth Parameters

"Three cultivars of rice (BR 3, BR 6 and BR 8) were studied in Bangladesh, under natural day length with normal night temperature, short day (10 hours) and low night temperature (16^{0}C), and long day (16 hours) and high night temperature (35^{0}C). The growth parameters like crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR), and leaf area index (LAI) increased in BR 8 while only LAI increased in BR 3 and both RGR and LAI were found to be increased in BR 6 under a long day with high night temperature. The plant height and panicle length Were found to be reduced under long days with high night temperatures in all cultivars" [57]. "In a study conducted in China, it was found that plant height, leaf area, and shoot dry weight were greater in high night temperature (HNT-27^{0}C) than in control (CK) (22^{0}C)" [40]. "In a study conducted in Germany, a large variation in leaf area was observed, but it was not significant in relation to day temperature (DT), night temperature (NT), or their combined effects, represented by the temperature treatments (TR). The marginal means according to NT were in the range of 436.16 ± 55.93 cm2 at 25^{0}C, and 454.75 ± 61.96 cm2 at 30^{0}C. The magnitude between DT and NT was not significant, though the highest LA was in TR D30 C/N20 C. Rice plant height, tiller number, dry mass, and all of its constituents (leaf, sheath, and root mass) were unaffected by DT, NT or by TR" [58]. "With high day temperature, the shoot mass fraction increased, whereas the root mass fraction decreased. Specific leaf area increased at high night temperatures and led, along with the high leaf mass fraction at high night humidities, to higher growth rates. The results showed the importance of considering relative air humidity when focusing on plant responses to temperature, and strongly suggest that under asymmetric day and night temperature increases in the future, biomass partitioning rather than biomass itself will be affected" [59]. "Plant leaf growth was increased by high night temperature as well as leaf area ratio (LAR) and specific leaf area (SLA), while the effect on organ weight and total dry matter was less clear, and varied between plant functional groups. As a result, it was concluded that complexities and challenges remain when seeking general patterns of plant growth in response to high night temperatures" [60]. Zhang et al. [56],[61] found that "the plant height of rice was significantly increased by high night temperature in all four experiments except one season (2011 DS) which might be due to the reason that elongated rice stems retained more photosynthate than the ears did under high night temperature (HNT)" [57,62]. "Panicle number was not significantly affected between high night temperature and low night temperature (LNT). Biomass in HNT decreased by 9.2 per cent, 5.3 per cent, 5.5 per cent and 4.1 per cent than LNT in the four consecutive seasons, because HNT received lower biomass due to its lower CGR. Rice biomass production was determined by the balance between net photosynthesis rate and night respiration" [63]. "Total dry weight is significantly greater in the HNT-grown plants than in the LNT-grown plants, because plants in HNT had an increase of leaf area and tiller number" [64].

2.3 Impact of Day and Night Temperature Variations on Yield and Yield Parameters

"Fertile tillers, fertile grains, and 1000-grain weight of three cultivars of rice (BR 3, BR 6 and BR 8) were found to be increased under long days with high night temperatures as compared to other treatments" [57]. "In an experiment conducted at Tamil Nadu, India, empirically it was observed from the differences between the two seasons (*Kharif* and Summer) that on an average 1.2^{o}C increase in night temperature had reduced the head rice recovery by 24.9 per cent whereas 4.4 ^{o}C increase in day temperature is required to produce the same effect on head rice recovery as that of night temperature. Hence it was concluded that a very small magnitude increase in night temperature affects the head rice recovery negatively" [65]. "In a study conducted in Bangladesh, it was revealed that maximum temperature is statistically significant and negatively affects the yield of all three rice crops (*Aus, Aman,* and *Boro*). In contrast, minimum temperature is highly significant and has a positive impact on the yield of *Boro* rice only" [66]. "High night temperatures (22/34^{o}C, day/night) were more harmful to grain weight in rice than high day temperatures (34/22°C) and control conditions (22/22°C) at optimum temperature" [67]. "From the report of a study conducted at Jharkhand, India, it was found that minimum temperature during the vegetative stage in variety Vandana and flowering stage in rice varieties BVD-109 and BVD111 had a negative correlation with rice yield" [68]. "In a field experiment carried out in China, from rice heading stage to maturity (6 August to 19 September 2006 and 7 August to 20 September 2007), mean air temperatures of daytime (from 07:00 to 19:00 h) and nighttime (from 19:00 to 07:00 h) under high air temperature (HAT) were approximately 2.0 and 0.3 °C higher than those under natural air temperature (NAT). HAT treatment was conducted from the rice heading stage, hence significant difference was not observed in effective panicles per m^2 between NAT and HAT. When compared to NAT, significant decreases in the number of filled grains per panicle (25.70 %), seed-setting rate (22.09 %), 1000-grain weight 5.17 (%), and grain yield (31.24 %) under HAT were observed" [69]. "The night temperature (NT) did not affect number of productive tillers, main-stem panicle length or a number of primary branches per panicle. The decreased plant grain yield under high night temperatures was due to increased spikelet sterility and decreased grain length and width" [70]. "Night temperatures greater than 29° C can increase spikelet sterility in rice with a subsequent reduction in seed-set and grain yield" [22,71,72]. "From the results of an experiment conducted at IRRI, Philippines, it was observed that there was a strong negative linear relationship between above-ground total biomass (grain and straw) at maturity and minimum temperature over a very narrow range of minimum temperature (<2°C) in the dry season. Biomass production decreased by ≈10 per cent for each 1°C increase in minimum temperature. There was no significant relationship between crop growth duration and minimum temperature. Therefore, the reduction in biomass production with warm nights was not associated with a decrease in growth duration. There was a tight negative linear relationship between spikelets per m^2 and minimum temperature in the dry season. Panicles per m^2 were negatively related to minimum temperature but not to radiation or maximum temperature. Other yield components such as spikelets per panicle, grain-filling percentage, and grain weight were not related to minimum or maximum temperature or radiation. There was a significant negative relationship between minimum temperature and harvest index in the dry season. Therefore, grain yield decreased by at least 10 per cent for each 1°C increase in growing-season minimum temperature. Because the increase in mean minimum temperature was >3-fold greater than the increase in mean maximum temperature, it was concluded that rice grain yield declined by ≈15 per cent for each 1°C increase in growing-season mean temperature" [38]. "Besides reducing carbon availability and its rate of translocation to seeds, increases in night temperature-induced yield losses through direct impacts on complex reproductive and seed maturity processes, resulting in not only quantitative grain losses but also effects on grain quality and composition. One mechanism that enables yield penalties through high night temperatures operates by lowering seed sets as a result of poor pollination" [73]. This effect is mediated by increased accumulation of reactive oxygen species (ROS) leading to increased membrane damage, ultimately leading to lower pollen viability [74,75]. Exposure to increasing temperatures under high day time temperatures, high night time temperatures or combined high day and night temperatures under a chamber [76,77] or field [78,79,80] conditions during grain filling impairs grain growth, leading to poor seed-set and reduced single-grain weight. The high night temperature was strongly and negatively correlated with grain yield in all four experiments. Grain yields in HNT decreased by 16.7 per cent, 9.1 per cent, 9.6 per cent and 8.0 per cent than LNT in the four seasons. Among the yield components, significant differences were observed in both grain weight and harvest index in the four experiments [81]. Seshu and Cady (1984) [82] predicted that rice yield would decrease by 41 g m^{-2} when the average minimum temperature raised from 22 to 23°C.

3. CONCLUSION

Production and productivity of rice depend on agrometeorological parameters. By exploring the rice-temperature relation, it can be concluded that optimum day and night temperatures are required for better growth and productivity of crops. From the above reviews, it can be concluded that cool night temperature causes spikelet sterility and hence reduces the yield. Rice crop might get benefit from day and night temperature variations (high or low) during the vegetative growth stages whereas it is not the same during the reproductive stages. Day temperature independently or in combination with high night temperature alters the plant processes and hence decreases the grain yield and quality.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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