Original Research Article

EFFECT OF TEMPERATURE ON GROWTH, QUALITY, YIELD ATTRIBUTING CHARACTERS AND YIELD OF RICE – A REVIEW.

ABSTRACT

Rice (*Oryza sativa L.*) is the second most important food grain after wheat in World. The most of the rice is currently cultivated in regions where temperatures are already above the optimal for growth (28 / 22 °C); therefore, any further increase in mean temperature or episodes of high temperatures during sensitive stages of the crop may adversely affect the growth and yield of rice. Yield decrease was about 7 to 8 % in rice for each 1 °C increase in day time maximum / night time minimum in temperature from 28ºC / 21°C to 34ºC / 27 °C. Moreover, benefits of projected rise in atmospheric CO_2 on rice plant is eliminated by the increase in temperature. The thermal stability of cell membrane is considered to be positively associated with yield performance. Temperature is a major factor for photosynthesis, but excessive temperature can result in a decline in foliar photosynthesis and also a decrease in allocation of dry matter to shoots and roots. The adverse effects of high air temperature are not limited to the aboveground portion of rice. As the temperature of floodwater and soil get altered due to high air temperature, the below-ground portion can be equally, if not more affected. Future increases in global surface temperature threaten those worldwide who depends on rice production for their livelihoods and food security. Past analyses of high-temperature stress on rice production have focused on paddy yield. This review highlights the global significance of rice, the effects of high temperature on growth, quality, yield and its attributing characters of rice and the need for future research studies.

Keywords: Rice, Temperature, Global warming, CO_2

INTRODUCTION

Rice is the most important and major source of energy which is extensively grown food crop in the world providing staple food to more than 60 per cent of the world population. Rice is mainly produced and consumed in the Asian region. India has the largest area under rice in the world and ranks second in the production after China. Rice occupies about 24 per cent of gross cropped area of the country and contributing 42 per cent to the total food grain production of the country.

Temperature is the most important factor as far as crop growth and development is concerned. There is now clear evidence for an observed increase in global average temperature and this has changed the rainfall rate during the 20th century. Overall, the temperature rise is likely to be much higher during the winter (rabi) rather than in the rainy season (kharif). It is projected that by the end of the 21st century, rainfall over India will increase by 10-12 per cent and the mean annual temperature by 3-5°C. The warming is more pronounced over land areas with a maximum increase over northern India. Now the question is: Is it possible to produce more to meet the growing demand of rice? Keeling *et al.*, (1989) reports shows that the global atmospheric carbon dioxide concentration (CO_2) is currently increasing at an increasing rate. As a result of this rise in CO_2 and other "greenhouse gasses", several atmospheric general circulation models have predicted significant increases in global air temperature was reported by Hansen *et al.*, (1988). Most published studies on CO_2 and temperature effects on plants have dealt mainly with temperate crop species while tropical plants have received less attention. Since both CO_2 and temperature can have large effects on plants, it is important to quantify the effects of these climate variables on food crops such as rice.

There is general agreement among climatic and atmospheric scientists that by the end of the 21st century the atmospheric CO_2 concentration could be between 510 and 760 μL, the temperature may be an average of 1.5 – 4.5 ºC higher than present and there may be more frequent occurrences of extreme climatic events such as heat waves and drought was suggested by Wigley and Raper (1992). For cereal growers this could be both good and bad news, because the high CO_2 concentrations may increase productivity and reduce soil water use, whereas the higher temperatures and periodic drought could reduce grain yield and quality. Agriculture is likely to be hit drastically by the rise in global mean temperature. Global and regional scale studies found to vary in India; however declines in yield were generally projected for wheat and rice. The unusual rise in atmospheric temperature during different growth phases differently affected the rice growth and productivity. The assessed impact of temperature on rice crop by scientists is summarized here with.

For C3 plants such as rice and wheat, the basis for the increased productivity at high CO_2 is thought to be higher leaf CO_2 assimilation rates. Changes in water relations, hormone levels and action, nutrient and carbon allocation may also contribute. These physiological and biochemical modifications may not only influence productivity, but also alter the rate of development and affect grain quality. Rawson (1992) reported that climatic changes such as a general warming and greater incidences of periodic high temperature and drought are also likely to influence growth and development, reduce grain yield and possibly quality. Rawson 1992 also reported that 2°C rise in temperature seems insignificant compared with sudden temperature increases of up to 30°C in a single day, the cumulative effect is likely to have a significant influence on yield. This cumulative temperature effect can, therefore, be considered as a temperature stress if yield is depressed. Crops growing in environments such as Australia and the United States, which are already marginal in terms of temperature and water availability, will be more vulnerable to climatic change. However, the physiological and biochemical modifications arising from higher CO_2 concentrations may ameliorate some of the effects of high temperature and water stress.

The physiological response of plants to temperature stress can be (i) tolerance which is due to mechanisms that maintain high metabolic activity under mild stress and reduced activity under severe stress and (ii) avoidance which involves a reduction of metabolic activity, resulting in a dormant state upon exposure to extreme stress. The latter is not relevant to rice production. Critical temperatures define the environmental conditions under which the life cycle of a rice plant can be completed. Generally, rice is adversely affected by high temperature in the lower elevations of the tropics and by lower temperature in the temperate regions. At different times during the life cycle, rice plant is differentially sensitive to temperature stress. Hence, the critically low and high temperatures, normally below 20 °C and above 30 °C, vary from one growth stage to another. This paper focuses on high CO_2 and temperature effects on growth, development and yield of rice, although reference is made to the response of other species. Apart from the work of Baker and Allen (1993) and Rawson (1992), there have been few long-term CO_2 enrichment studies where the interactive effects of high CO_2 and temperature have been investigated. Consequently, much of the discussion about combined CO_2 and temperature effects is speculative. Hence, with which we have tried to review the effect of temperature on various qualitative and quantitative parameters of rice.

1. Climate requirement

The temperature required for blooming was in the range from 26.5° C to 29.5°C and lower than 20°C might result in imperfect grains was reported by Nagoto and Kobayashi (1957). Ebata and Nagata (1967) found that the optimum night temperature required during the ripening period was 23°C. The optimum range of air temperature for floral initiation was 25° to 30°C by day and 20° to 25°C by night for successful anthesis, the optimum being at 30°C was reported by Owen, (2011). Depending on the varieties, rice crop required a mean temperature above 20°C and not less than 15°C during the entire growing period. Angus and Robertson, (1976) also found out that the optimum temperature required for plant height was 25°C and 30°C for rate of leaf emergence. The optimum temperature required for tillering was 25° C to 31°C, 30°C to 33°C for anthesis and for ripening 20° C to 25°C was suggested by Yoshida (1981). Jing et al., (2007) found out that the optimum diurnal air temperature for high seed setting rate, grain weight and for the good qualities of rice were 35°C and 30°C at the filling stage for two different varieties.

2. Germination

Rice is most sensitive to high temperature at heading followed by at about 9 days before heading; Yoshida (1981). It is reported that pollen viability and production of rice begins to decline as daytime maximum temperature exceeds 33 °C and reaches zero at maximum temperature of 40 °C. Temperature has a profound influence on germination. As early as 1933, Livingston and Haasis found out that an incubation of 6 days was required for 90% germination at 25 °C, 2 days at 31–36 °C, and an extended period at 0 to 5 °C. At low temperatures, germination proceeds very slowly and may take a month or longer. Takahashi (1961) examined the effects of temperature on germination using rice seeds of variety Ou-no 200, on three aspects such as temperature, time, and germination percentage. In 2 days, about 90–97% germination was attained under incubation at 27ºC – 37 °C. But, the germination percentage dropped sharply below or above this range. At temperatures between 15°C and 37 °C, the incubation time for a germination of 90% or higher was about 6 days. No germination occurred at 8 and 45 °C. The suppression of germination at supra optimal temperatures is called thermo-inhibition. The germinating seeds may experience a 25 °C fluctuation in temperature throughout the course of a day, from a minimum of 22 °C to a maximum of 47 °C over a 12 hour period, under upland (aerobic) conditions. Under irrigated conditions, this fluctuation in temperature in a day will be less. If seeds germinate erratically over a long time, seedling growth will not be uniform and plants will mature over a wider period. The freshly harvested seed of rice can have low germination caused by post-harvest dormancy, which is referred to as exhibiting “nondeep physiological dormancy” (Hartmann et al., 1997).

3. Seedling growth

A temperature of 22 °C or below is considered subnormal for seedling growth. The seedling growth may be reasonably good up to 35 °C, above which it declines sharply. The seedlings will die above 40 °C. Nishiyama (1977) reported that the critical minimum temperature for shoot elongation ranged from 7°C to 16 °C and that for root elongation from 12°C to 16 °C. The critical minimum for elongation of both shoot and root is, hence, about 10 °C.

4. Plant height

High day and night temperature have enhanced plant growth and internodes elongation of stem by way of increasing the cell elongation in the internodal region in conformity with the study reported by Singh (2000). Osada *et al.,* (1973) and Oh-e *et al.,* (2007) also reported that plant height of rice increased with the rise of temperature within range of 30°C -35ºC. Kondo and Okamura (1931) suggested that the optimum temperature for dry-matter production was lower than or equal to that for stem elongation. In a recent study, Oh-e *et al.,* (2007) reported that the increase in plant height was steeper under high temperature than under ambient temperature condition.

5. Leaf area and development

Sharma and Singh (1999) observed that increase in size of leaves causes increase in total leaf area per shoot and per plant. That increase in total leaf area per plant was caused mainly by increasing the size of the successive leaves. Hong *et al.,* (1999) observed that green leaf area index was found greater with the plants grown at higher temperature. Plants in high night temperature had an increase of leaf area and tiller number as reported by Kanno et al., (2009)

Leaf appearance for the four fluctuating temperature treatments could be accurately predicted by Yin *et al.,* (1996) on the basis of these relations in each cultivar. This indicated that there were no specific effects of day and night temperature on leaf appearance in rice, in contrast with phenological development to flowering. The optimum temperature for leaf development was found to be substantially higher than for development to flowering. The final main stem leaf number differed with diurnal temperature conditions. When a diurnal temperature delayed flowering, it increased the leaf number as well. This might explain why day and night had a different effect on development to flowering but not on leaf development. The greatest drop in amylose content of milled rice (from 21.6% to 15.5%) was due to an increase in day temperature. On a starch basis, this corresponded to an actual drop in amylose content of from 24.9% to 18.4%. A moderate increase in temperature speeds up leaf emergence, and temperature is a principal environmental determinant of leaf appearance in rice was reported by Gao, et al., (1992). The phyllochron concept, which is defined as the time interval between the appearances of successive leaf tips by Klepper et al., (1982), is used to predict the appearance of individual leaves, expressed in thermal time, with units of degree days. The leaf appearance rate (LAR) is not constant with time when rice plants are grown at constant temperature (Yin et al., 1996), suggesting an effect of age. . Leaf appearance rate increases with temperature from a T base of 8 ℃, until reaching 36ºC – 40°C, the thermal threshold of survival (Baker *et al.,* 1995) with biomass increasing up to 33°C (Matsushima *et al.,* 1964).

6. Biomass

Kima *et al.,* (2011) reported that, high temperature increased the rate of grain filling and leaf senescence while it reduced the duration of them. However, grain filling was terminated earlier than complete leaf senescence, the time gap being greater at higher temperature. In addition, the fraction of dry matter partitioning to the leaf sheath + culm resumed to increase following the termination of grain filling under high temperature.

7. Tillers and panicles

Lalitha *et al.,* (1999) reported that increase in temperature during the active tillering period from 24.1ºC to 27.4°C did increase the tiller production from 453 to 689 tillers m^2. Yoshida (1973) observed that the increased temperature affected the early growth stages as the temperature rose from 22ºC to 31°C, the growth rate found decreased with time. Tillering was more vigorous at high temperature than at low temperature. The optimum temperature for tillering is 25 °C at day and 20 °C at night is reported by Sato, (1972). Tillering increases with rising temperature in the range of 15ºC to 33 °C. Chaudhary and Ghildyal (1970) found that temperatures above 33 °C were unfavourable for tillering. Oh-e *et al*., (2007) observed that the number of tillers per square meter during the early growth period was generally larger under high temperature and the maximum tillering stage was earlier than under normal temperature conditions Panicle differentiation occurs generally at temperatures between 18 and 30 °C. During tillering stage, the number of panicles will increase if the air temperature is lower than 20 °C; Yamamoto *et al.,* (1985). After the active-tillering stage, high temperatures decrease the number of panicles, especially at maturity.

8. Spiklet sterility

Bhattacharya (1970) found out that high temperature at ripening resulted in premature, mainly due to inability of spikelet to serve as a sink, since the opening of the spikelet was already closed. Yoshida and Parao (1976) suggested that Spikelet sterility induced by higher temperature, which became very severe near 40ºC and resulted in complete loss of crop production. Spikelets at anthesis exposed to temperature more than 35ºC for about 5 days during the flowering period resulted in sterile spikelet and no seed set was found which is given by Satake and Yoshida (1978). Fu *et al.,* (1999) indicated that, spikelet sterility was positively correlated with the average daily temperature and the maximum daily temperature, with the coefficients of 0.8604 and 0.9850 ($P < 0.05$) respectively and the injury in seed setting was found with high average daily temperature during the grain filling stage. Chakrabarti *et al.,* (2010) reported that crop exposed to high temperature during anthesis (most sensitive stage) in rice might cause a reduction in floral reproduction. Temperature above 33°C during anthesis gradually increased pollen sterility and reduced germination of pollen grains on the stigma and this resulted in limited rice yield by affecting pollen germination and grain formation. The increase in spikelet sterility under high night temperature was associated with decreased pollen germination (36%) and increased respiration rates (28%) and relative membrane injury (86%), but not with photosynthesis (production) was reported by Mohammed and Tarpley (2009 and 2010).

9. Grain filling

High temperatures at flowering and during grain filling phase reduce yield by causing spikelet sterility and shortening the duration of grain filling phase was shown by Tian et al., (2007) and Xie *et al.,* (2009). Yoshida and Hara (1977) and Oh-e *et al.,* (2007) observed that the rate of grain growth was faster and the grain filling period was shorter at higher temperatures. High temperatures above 30 °C are generally not favourable for ripening was suggested by Osada *et al.,* (1973). Morita *et al.,* (2005) reported that high night temperatures (22ºC / 34 °C, day / night) were more harmful to grain weight in rice than high day temperatures (34ºC / 22 °C) and control conditions (22ºC / 22 °C) at optimum temperature. Song *et al.,* (2013) result indicated that the high night temperature had distinct effect on the grain-filling rate of 1 to 10 days after anthesis and the rate was 9.89–40.45 per cent and decreased accumulation of grain-filling matter, resulting in inferior appearance and poor milling qualities (e.g., brown rice rate, milled rice rate, head rice rate, imperfect rice rate, chalky rice rate, and chalkiness degree). At above 22°C, an increase in mean temperature corresponded to an increase in protein content of both varieties. Therefore temperature during ripening could be considered another factor that affects protein content. This indicates that temperature is less affected in protein accumulation than total dry matter accumulation. Hence, temperature affected the accumulation of non-protein constituents, particularly starch, more than accumulation of protein.

10. Chalkiness

The chalkiness is one of the key factors in determining rice quality and price. Yoshioka et al., (2007) found out that In Japan, chalky grains are conventionally classified into different categories such as milky white rice, white-core rice, white-belly rice, white-based rice, and white-back rice. Wakamatsu *et al.,* (2007) observed that the incidences of white-back kernel and white-based kernel were high when an average temperature during the 20-day period after heading was 27 °C or higher. Below that temperature, no such incidence was apparent. Yamakawa *et al.,* (2007) reported that expose of high temperature on ripened grains consists decreased amylose content and increased long chain amylopectin. Severely chalky grain contained amylopectin enriched particularly with long chains compared to slightly chalky grains, suggesting that such alterations of amylopectin structure might be involved in grain chalkiness. Cooper *et al.,* (2008) reported that head rice yield, grain dimensions and amylase content got decreased and the number of chalky kernels found increased as night time temperature increased, while total brown rice, lipid and protein contents did not vary. She *et al.,* (2010) observed that seeds developed under high-temperature condition, had chalky or white core endosperm. According to Lanning *et al.,* (2011) the elevated night time air temperature had contributed to higher chalk formation and reduced milling quality in rice. Yonemaru and Morita (2012) found that high temperature during ripening of rice caused the conditions namely “immature thin grain” and “chalky grain” and in turn reduced the yield and did lower milling quality. Das *et al.,* (2010) reported that high temperature of 30 - 36°C during grain filling led to significant increase in chalk percentage and reduction in head rice recovery percentage and amylase accumulation in almost all varieties.

11. Heat tolerance

Matsui and Omasa (2002) reported the relationship between morphological characteristics of anther and fertility in japonica rice cultivars subjected to high temperature (37.5 and 26 °C for day and night respectively); fertility percentage was negatively correlated with the number of cell layers that separated the anther locule from the lacuna that formed between the septum and the stomium. They conclude that the tight closure of the locule by the cell layers locule opening and decreased fertility at high temperature. Prasad *et al.,* (2006) evaluated fourteen rice cultivars of different species (*Oryza sativa and Oryza glaberrima*), and ecotypes (indica and japonica) exposed to ambient and high temperature (ambient +50 C) at Gainesville, Florida. High temperature significantly decreased spikelet fertility across all cultivars. Chakrabarti *et al.,* (2010) studied the effect of high temperature on pollen as well as spikelet sterility in Basmati and Non-Basmati rice. Rise in temperature increased pollen sterility and reduced germination of pollen grains on the stigma. At 35.5° C, variety Pusa Sugandh 2 (Basmati) recorded a pollen sterility of 17% and 26% reduction in pollen germination. Increased temperature during the grain filling period also increased spikelet sterility in rice variety. Non-Basmati rice varieties were less affected by increased temperature than Basmati types. Shah *et al.,* (2011) studied impact of high temperature stress on rice plant and its traits related to tolerance. Booting and flowering stages were most sensitive to high temperature, which lead to complete sterility. Significant variation was found among rice germplasm in response to temperature stress. Flowering at cooler times of day, more pollen viability, larger anthers, longer basal dehiscence and presence of long basal pore are some of the phenotypic markers for high temperature tolerance. Jagdish *et al.,* (2011) studied that rice crops will be frequently exposed to water deficit and heat stress at the most sensitive flowering stage, causing spikelet sterility and yield losses. Water deficit alone and in combination with heat stress significantly reduced peduncle elongation, trapping 32% and 55% of spikelets within the leaf sheath respectively. Trapped spikelets had lower spikelet fertility (66% in control) than those exserted normally (>93%). Average weighted fertility of exserted spikelets was honest with head stress (35%) but higher with combined stress (44%), suggesting acquired thermo tolerance when preceded by water deficit stress. Pale *et al.,* (2012) evaluated a total of 600 rice germplasm from the North-Eastern hills of India for their tolerance to high temperature. A total of 78 genotype s showed more than 80% germination at 40° C, while only 27 genotypes showed 60% or more germination at 45° C. After heat treatment of the latter 27 genotypes at 40° C and 45° C at the seedling stage, 18 genotypes successfully recovered from the 40° C treatment, while only 9 recovered after exposure at 45° C. These 9 genotypes were found to contain 30 – 60% relative water content under 22 days of drought stress. Jagadish *et al.,* (2012) reported that high temperature stress negatively affects rice production, especially in vulnerable regions in South and South East Asia. Hemantaranjan *et al.,* (2014) reported that high temperature during seed germination may slow down or totally inhibit germination, depending on plant species and the intensity of the stress. At later stage, high temperature may adversely affect the vital physiological processes like photosynthesis, respiration, water relations and membrane stability and also modulate levels of hormones and primary and secondary metabolites. Kumar *et al.,* (1999) noted significantly variation for plant height, number of tiller per plant, flag leaf area, number of panicle per plant, number of spikelets per plant, yield per plant and test weight. Foolad (2005) reported that growth chamber and greenhouse studies suggest that high temperature is most deleterious when flowers are first visible and sensitivity continues for 10-15 days. Reproductive phases which is most sensitive to high temperature are gametogenesis (8-9 days before anthesis) and fertilization (1-3 days after anthesis) in various plants. A major influence of temperature is the acceleration of development. In both rice and wheat, leaf appearance rates are faster and time to flowering is shortened by increases in temperature. It is showed that low temperature had significant effect in level of one percent on all characters, such as the number of panicles, the length of panicle, and the number of full, empty, and total grains;

as a result, yield had caused significant reduction. Low temperature in the range of 15ºC to 19°C during the reproductive stage impairs microspore development and causes the production of sterile pollen grains, resulting in poor grain filling and high spikelet sterility and reducing spikelet fertility and affecting grain quality.

12. Crop duration

High temperature boosted the plant growth rate and could reduce growth duration leading to a shorter grain filling period which varied from 25 days in the tropics to 35 days in the temperate zone was reported by Swaminathan (1984). Sinha and Swaminathan (1991) suggested that the increase in winter temperature by 0.5°C would reduce crop duration by seven days and yield by 0.45 t ha^{-1}. Ziska *et al.,* (1997) found that an increase in temperature by 4°C during the growing season resulted in earlier maturation of the crop by five and six days for wet and dry seasons respectively. Lalitha *et al.,* (1999) stated that daily mean temperature exceeding 26°C restricted the duration of the tillering period to five weeks after planting. Venkatramanan and Singh (2009) found that plants grown under high day and night temperatures showed reduction in the days to flowering and maturity. The crop duration was reduced under elevated temperature. The 4°C treatment had a duration of 96 days (12 days earlier than ambient temperature), whereas 2°C had 102 days (6 days earlier than ambient temperature) compared to that of ambient which had a duration of 108 days. Rani and Maragatham (2013) during Kharif 2012 reported that under temperature control chamber in which temperature is elevated from the ambient level (2°C and 4°C) for the entire crop growth period. The results showed that the days taken to attain maturity was less under elevated temperature of 4°C (96 days) and 2°C (102 days) when compared to the ambient temperature (108 days). The accumulated growing degree days were higher under elevated temperature of 4°C and nearer value for 2°C viz., 1641 and 1583 respectively from that of ambient.

13. Grain quality

Grain quality owing to high temperatures during the ripening period, abnormal morphology and coloration occur in rice, probably due to reduced enzymatic activity related to grain filling, respiratory consumption of assimilation products and decreased sink activity was reported by Inaba and Sato (1976) and Tsukaguchi and Iida (2008). Xun *et al.,* (2005) observed that the high temperature at the grain filling stage did increase protein content, and decreased amylose content and taste meter value of rice, inferior grain quality. Varieties showed a greater magnitude of the increase or decrease than the superior ones.

14. Yield and its components

Yoshida (1983) found out that the number of panicles is closely associated with grain yield, but there is often a negative correlation between the number of panicles per unit land area and spikelets per panicle and between spikelets per unit land area and filled grain percentage or 1000 grain weight. It is seen that high temperature (40 / 33 / 37°C, daytime dry bulb air temperature / night-time dry bulb air temperature / paddy water temperatures) during stem elongation led to death of rice plants while CO_2 enrichment (660 mmol CO_2 mol^{1} air) helped plants to survive, but with sterile panicles. As a result of high temperature, the extent of sterility can vary from a few empty glumes to the entire panicle having unfilled grains. Temperatures below 20 °C or above 35 °C and radiation lower than 200 cal cm^{2} day^{1} at anthesis can result in up to 40–60% sterility. Lin et al., (1997) reported that seed set and panicle weight of rice plants grown at higher temperatures (ambient 4 °C) are significantly reduced while green leaf area increased, relative to those plants grown at ambient temperatures. Generally, the rice cultivars with high yield potential have grain weights in the range of 20–30 g and grain weight generally follows the order of maturity within a panicle, the first maturing grain being the heaviest. High temperature can increase the grain growth rate, but decrease the grain-filling period was found out by Akita (1989). The rice yield in the temperate or high altitude subtropical or tropical environments shows plasticity in the yield components and there are strong compensation mechanisms, particularly, for panicle and spikelet number in crops under tropical conditions. In subtropical rice - growing regions, occurrence of seasonal high night temperature (HNT) during the critical stages of development reduced rice yield and its quality. High night temperatures decreased the yield by 90 per cent, spikelet sterility with 61 per cent and grain length of 2 per cent, width 2 per cent and weight. High night temperature increased grain nitrogen concentration (44%), which was inversely related to grain weight. The average milling recovery decreased from 67.88 per cent in crop plants exposed to 30°C (minimum temperature) to 56.49 per cent in plants that experienced 36°C (maximum temperature). The HRR per cent was drastically reduced from 55.08 per cent at 30°C to 30.79 per cent at 36°C. The amylose content also got varied with lowest (24.33%) at 36°C and highest (28.80%) at 30°C. High temperature resulted in increased gelatinization temperature values. The average protein content found decreased from 9.12 per cent at 30°C to 7. 38 per cent at 36°C. Islam (2011) studied the impact of high temperature of 34°C at booting stage and at the grain filling stage and found that photosynthetic rate, grain yield and harvest index did decrease, but leaf conductance and transpiration rate got increased. Total dry matter per plant was the lowest with the temperature of 34°C at booting stage, but plant height and number of panicles/plant was not affected by the temperature stress. Basak *et al.,* (2014) studied that the impact of climate change on rice yields depend on actual patterns of climatic factors change in rice growing regions. Both higher maximum and minimum temperature reduce rice yields due to spikelet sterility and higher respiration losses. At the same time, rice production may be threatened in vulnerable regions. Overall, much uncertainty still exists about the true direction of the impacts of CO2 and temperature.

15. Yield

The optimum temperature for grain yield is generally 5 to 10°C lower than that for photosynthesis. Increasing temperature treatment above 28°/21°/25°C resulted in decreased grain yield due largely to a decline in the number of filled grain panicle. The various phenological stages like active tillering, panicle initiation, 50 percent flowering and harvest for the crops raised under elevated temperature (4°C and 2°C) was found to be shorter than ambient temperature. Under elevated temperature of 4°C and 2°C, the grain yield was 23 and 13.3 percent less from the ambient. The highest grain yield is from the treatment under ambient temperature with 6.2 t ha^{-1} followed by 5.3 t ha^{-1} under 2°C level and 4.7 t ha^{-1} at 4°C level. The yield loss under elevated temperature is due to the sterile florets and lesser crop duration. Matsui et al., (2000) reported that the mean optimum temperature for ripening of japonica rice in Japan was about 20–22°C. Although temperature during ripening affects the weight per grain, the 1000-grain weight of a particular cultivar is considered to be almost constant under different environments and cultural practices. However, Murata (1976) observed that the 1000-grain weight of the same variety varied from about 24 g at a mean temperature of 22 °C in the 3-week period after heading to 21 g at a mean temperature of 28 °C in Kyushu, southern Japan. Peng *et al.*, (2004) reported that grain yield found to decline by 10 per cent for each 1°C increase in growing season minimum temperature in the dry season, whereas the effect of maximum temperature on crop yield was insignificant. This report provided a direct evidence of decreased rice yields from increased night time temperature associated with global warming. While, Baker and Allen (1993) and Peng *et al.*, (2004) found that rice grain yield is reduced about 10% per 1°C temperature increase above 25 °C, until reaching zero yield at 35–36 °C mean temperature, using a 7 °C day and night temperature differential. However, the optimum temperature for grain formation and yield is lower (25°C) (Baker *et al.*, 1995).

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