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Increased Growth Respiration and Panicle Cooling Contributes for stable Grain Weight in Rice under High Night Temperature

Sharma N.[1*] and Anand A.[2]
[1]Ph.D. Scholar, Department of Plant Physiology,
ICAR-Indian Agricultural Research Institute, New Delhi, India.
[2]Principal Scientist, Department of Plant Physiology,
ICAR-Indian Agricultural Research Institute, New Delhi, India.

(Corresponding author: Sharma N.)*
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ABSTRACT: Night-time warming poses a serious threat to rice production in terms of yield loss, especially during the reproductive phase. The current study examined the effects of high night temperatures (4°C above control) from anthesis to physiological maturity on two rice cultivars, Vandana and Nagina 22, which differ in their sensitivity to night-time temperatures. For the first 20 DAA, the relative growth rate declined by 31% in Vandana while it increased significantly in Nagina 22 indicating amplified growth respiration component. HNT inflicted no effect on the grain weight in Nagina 22 due to minor spikelet fertility changes (5%), consistent higher grain weight under HNT throughout the grain filling period and greater panicle cooling throughout the night. Thus, our study revealed that tolerant cultivars offset HNT damage by increasing relative growth rate, cooling its panicle throughout night and maintaining higher grain filling rate.

Keywords: Rice, High night temperature, Grain Weight, Panicle temperature, Thermal imaging.

INTRODUCTION

Global crop production is being negatively impacted by rising surface temperatures (Xu *et al.*, 2020). As global night-time temperatures are increasing at twice the rate of daytime temperatures, the diurnal temperature difference keeps getting smaller (Easterling *et al.*, 1997; Vose *et al.*, 2005; Wang *et al.*, 2017). Studies conducted under controlled and field conditions have found that night-time temperatures have a significant impact on rice yield worldwide with 10% yield reduction for every 1°C increase in night time temperatures (Nagarajan *et al.*, 2010; Peng *et al.*, 2004; Sharma *et al.*, 2017; Shi *et al.*, 2013). Yield penalty under HNT is explained by reduction in number of panicle per square meter (Peng *et al.*, 2004), grain weight reduction (Kanno*et al.*, 2009; Morita *et al.*, 2005), reducing grain filling rate during early and middle phase of grain filling (Sharma *et al.*, 2017), increased nocturnal respiratory losses, reducing carbon pool availability for grain filling (Peng *et al.*, 2004; Mohammed *et al.*, 2013; Peraudeau *et al.*, 2015). It is well established that reproductive stage is most sensitive to heat stress (Satake and Yoshida, 1978). Anthesis is especially vulnerable to HNT, resulting in spikelet sterility (Coast *et al.*, 2020). The temperature the previous night is inversely correlated with the time of peak anthesis (Julia and Dingkuhn 2012). Early morning high temperatures advance the start of anthesis and flower opening by 1-2 hours in some cultivars (Kobayasi *et al.*, 2009). Organ temperatures are correlated with extent of damage inflicted by heat stress in terms of spikelets sterility as well as grain weight (Fu *et al.*, 2016). Increased sterility under HNT is associated with reduced photoassimilates, inhibition of anther dehiscence, lower pollen viability and its germination (Fahad *et al.*, 2015; Mohammed and Tarpley 2010). Furthermore, HNT reduces grain weight by reducing endosperm cell size that lowers endosperm capacity to accumulate the seed reserves (Morita *et al.*, 2005), decreased activity of Q enzyme and IAA content under heat stress (Wang *et al.*, 2001). The objective of the investigation is to understand the differences in two contrasting HNT tolerance rice cultivars in order to understand the growth respiration component and the impact of panicle thermal profile on grain filling dynamics.

MATERIAL AND METHODS

Experimental set up and crop husbandry: The present experiment is done at the pot culture facility of Division of Plant Physiology, Indian Agricultural Research Institute, New Delhi. Seeds of two early maturing (95 days) with contrasting HNT sensitivity, Vandana (HNT senstitive) and Nagina 22 (HNT tolerant) were sown during kharif 2017-18. N:P: K was applied at the rate of 120:60:40 Kh ha^{-1}. Three week old seedling were transferred to pots and were maintained at three plants per pot. At anthesis, one set each comprising of ten pots were shifted to HNT chamber made up of PVC sheets fitted with ceramic heaters and blowers to increase the temperatures at night. The plant were exposed to HNT from anthesis till physiological maturity every day from 6 PM to 6 AM. The average temperature for control and HNT during the grain filling period in our experimental setup was 24.00°C and 28.00°C, respectively.

Relative growth rate: It is calculated using the following formula by recording leaf area as well as dry weight at 10, 20 and 25 DAA

$$RGR=\frac{1}{W}\frac{dw}{dt}=\frac{\ln W2-\ln W1}{t2-t1}$$

Where L1 and L2 are leaf area at time t1 and t2 respectively

Where W1 and W2 are total plant dry weight at time t1 and t2 respectively.

Thermal profiling of panicles: Thermographic camera (Model: TESTO 890-2- Thermal Imager) having 42° wide angle lens was used to capture panicle temperatures at 10 and 20 DAA at 11 PM and 6 AM with black background to minimize interference. Thermal images so generated was analysed using test to IR software version 4.8. Background temperature was subtracted from panicle temperature to compute panicle temperature depression.

Panicle temperature depression = $T_{environment} - T_{spikelet}$

Panicle sterility and grain weight: Panicle sterility was calculated as proportion of grains that remain unfilled in comparison to total number of filled grains and expressed in terms of percentage. Panicles were marked at 50% exsertion and grains were obtained 5 days after anthesis for each cultivar (Yamakawa *et al.,* 2007). Fifty grains per replicate were weighed for fresh weight.

Statistical analysis: Duncan's multiple range test was carried out with the IBM SPSS statistics 26 software to assess statistically significant differences between treatments at the 0.05 level.

RESULTS AND DISCUSSION

The majority of studies, both controlled and field, used night temperatures above 27°C. The average temperature for control and HNT during the grain filling period in our experimental setup was 24.00°C and 28.00°C, respectively, which is higher than the optimum night temperature of 22°C for grain filling in rice (Nagarajan *et al.,* 2010; Peng *et al.,* 2004). In annual and perennial crops, 30-60% of the carbon assimilated during the day by photosynthesis is lost through the process of respiration (Thornley and Cannell 2000). In rice leaves, respiration rates are positively correlated with temperature within the physiological temperature range of 0 to 38°C (Li *et al.,* 2021). Increase in night temperatures are associated with increased respiration rates that creates carbohydrate deficit (Sharma *et al.,* 2017; Tombesi *et al.,* 2019). Further, relative growth rate during the active grain filling period from 10 to 20 DAA (Fig. 1), significantly decreased in Vandana pointing out increased respiration is less partitioned towards growth while in Nagina 22, plant growth rate increased to compensate for decreased crop growth duration as duration of growing period decreases with increase in temperatures.

Further, the imposition of HNT at anthesis stage, resulted in significant decreased panicle fertility in Vandana from 91 to 79% (Fig. 2).

In contrast, panicle fertility in Nagina 22 ranged from 89 to 94%, which is consistent with studies in which temperatures up to 35°C caused the least changes in Nagina 22 among the genotypes tested (Coast *et al.,* 2015).

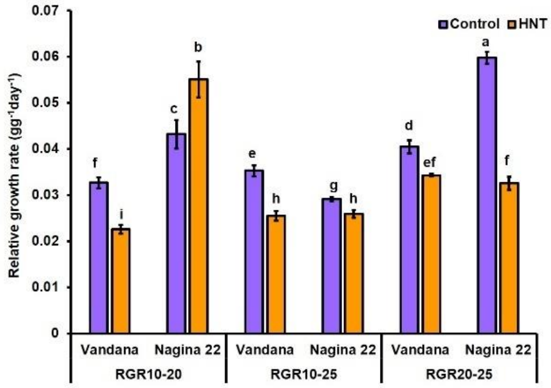


Fig. 1. Effect of HNT on relative growth rate in Vandana and Nagina 22 under control and HNT conditions at 10, 20 and 25 DAA. Values are mean of three replications. Duncan's multiple range test was used to compare mean at 5% and means with same letter are not significantly different.

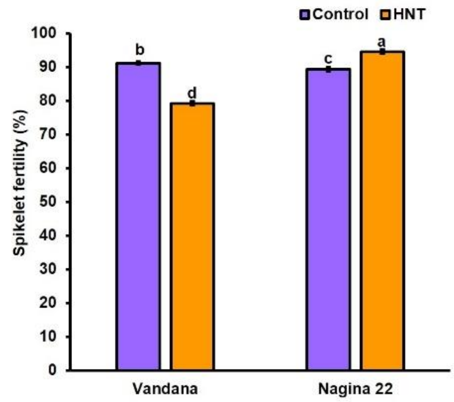
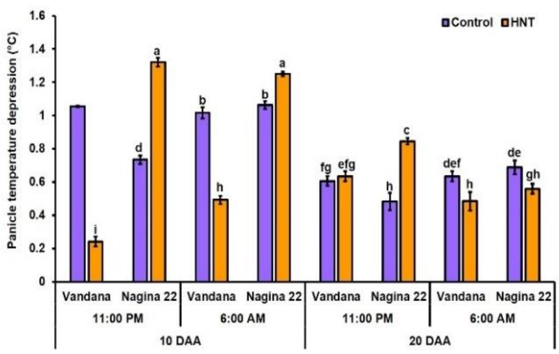
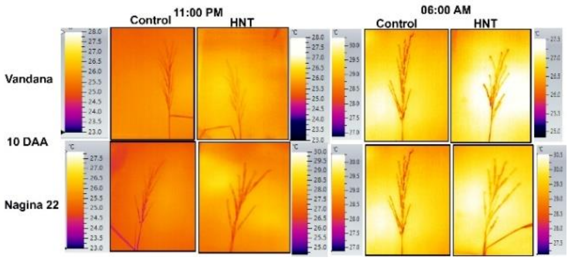


Fig. 2. Effect of HNT on spikelet fertility (%) in Vandana and Nagina 22 under control and HNT conditions. Values are mean of three replications. Duncan's multiple range test was used to compare mean at 5% and means with same letter are not significantly different.

A lack of panicle cooling was also recorded in Vandana where at 10 DAA, panicle cooling decreased by 71% and 51% at 11 PM and 6 AM, respectively. Nagina 22, on the other hand recorded increased panicle cooling under HNT by 79% and 17% at 11 PM and 6 AM, respectively (Fig. 3A, B).



(A)



(B)

Fig. 3. Effect of HNT on panicle temperature depression (A) and thermal images (B) in Vandana and Nagina 22 under control and HNT conditions at 10 and 20 DAA at 11 PM and 6 AM. Values are mean of three replications. Duncan's multiple range test was used to compare mean at 5% and means with same letter are not significantly different.

However, at 20 DAA, at 11 PM a consistent on par cooling was recorded in Vandana while a much cooler panicle was observed in Vandana. In addition, a lack of panicle cooling during the day and night increases the severity of damage in terms of increased panicle respiration. Grain dry weight in Vandana was consistently reduced by 10%, 18%, 10%, 8%, and 7% at 5, 10, 15, 20, and 25 DAA (Fig. 4).

Nagina 22, on the other hand, maintained on par dry weight throughout the grain filling period, resulting in a grain with a on par final dry weight (Fig. 5).

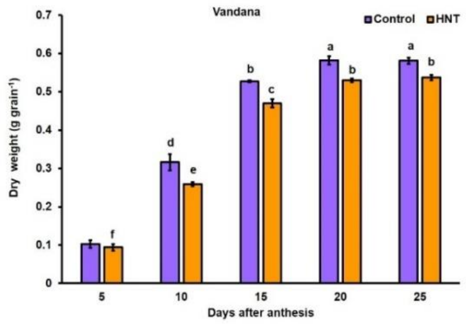


Fig. 4. Effect of HNT on grain dry weight in Vandana under control and HNT conditions at 5 days interval from anthesis. Values are mean of three replications. Duncan's multiple range test was used to compare mean at 5% and means with same letter are not significantly different.

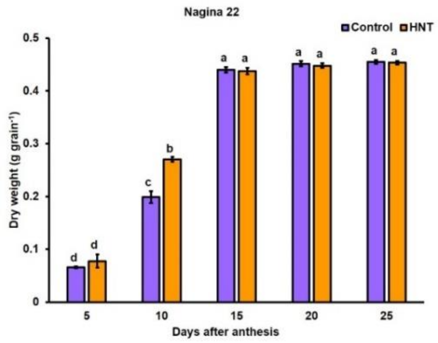


Fig. 5. Effect of HNT on grain dry weight in Nagina 22 under control and HNT conditions at 5 days interval from anthesis. Values are mean of three replications. Duncan's multiple range test was used to compare mean at 5% and means with same letter are not significantly different.

In the early and middle stages, HNT is especially sensitive to grain filling because it reduces cell enlargement in areas where cells enlarge during these stages (Morita *et al.*, 2005; Sharma *et al.*, 2017). Grain weight is reduced under HNT because of an increase in energy consumption to meet the seeds' respiratory demand or a decrease in endosperm cell size during the early stages of grain development (Morita *et al*., 2005). Furthermore, a lack of panicle cooling during the day and night increases the severity of damage due to increased panicle respiration. A decreased carbon pool under increased panicle temperature, rather than a decrease in grain filling period duration, which decreases with increase in average daily temperature regardless of period of high temperature (day or night), results in a decreased final dry weight of the grain. Further studies on panicle cooling by transpiration is required to get a deeper insight of temporal variation observed.

CONCLUSIONS

Nagina 22 showed increased relative growth rate during the first 20 DAA which is the active grain filling period. Grain weight is consistently higher during the entire grain filling period and cooler panicle throughout the night under HNT indicates Nagina 22 is able to offset adverse effect of HNT while Vandana is unable to tolerate HNT and grain weight is throughout lower during the entire grain filling period and decreased panicle temperature depression.

FUTURE SCOPE

Panicle temperature depression can be used as selection parameter for screening rice genotypes for high night temperature sensitivity.

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Conflict of interest. None.

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