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The Bases of Decrease in Rice Productivity due to Global Warming

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CONCLUSIONS

Decreased rice yield due to

1. **Increased respiration rates, but no effect on photosynthesis**
2. **Increased injury to the membrane**
3. **Decreased crop duration**
4. **Decreased spikelet fertility**
5. **Decreased pollen germination**
6. **Decreased grain length and grain width**

Salicylic acid and glycine betaine show promise for protecting the rice plants from high night temperatures

Above mentioned parameters can be used as screening tools to identify heat stress tolerant rice cultivar

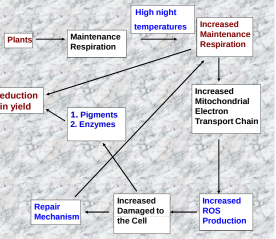
ABSTRACT

The presence of seasonally high nighttime temperatures (HNT) along the Gulf Coast, occurring during the critical stages of development, could reduce rice yield and quality. The objective of this study was to determine the effects of HNT and plant growth regulators (vitamin E, glycine betaine [GB], salicylic acid [SA]) on growth, development and physiology of rice plants. Plants were grown under ambient nighttime temperature (ANT) (27 ºC) and HNT (32 ºC) in the greenhouse. They were subjected to a HNT through use of continuously controlled infrared heaters. Nighttime temperatures were imposed from 2000h until 0600h. The results indicated no effects of HNT on photosynthesis; however, HNT increased respiration rates, decreased membrane stability, pollen germination, spikelet fertility, grain length, width, and weight. In addition, HNT hastened the crop development rate, as indicated by the dates of panicle emergence. All the above parameters contributed towards decreased rice yields under HNT. Rice plants treated with GB or SA showed an increase in yield compared to untreated plants, when grown under ANT and HNT.

INTRODUCTION

- High temperatures are a major constraint to crop productivity (McWilliam, 1980)
- Most heat stress studies on crop growth and grain yield are based on mean day temperature (Peng et al., 2004)
- Year-to-year variation in rice (*Oryza sativa* L.) yield was attributed to night temperature (NT) (Peng et al., 2004)
- Rice yields decreased with increase in NT (Peng et al., 2004)
- Plant pre-treated with SA (Larkindale and Knight, 2002), GB (Diaz-Zorita et al., 2001) and vitamin E (Fryer, 1992) showed induced thermo-tolerance and protection against oxidative damage as a result of high temperatures.

HYPOTHESIS


Plants
Maintenance Respiration
High night temperatures
Increased Maintenance Respiration
Reduction in yield
1. Pigments
2. Enzymes
Increased Mitochondrial Electron Transport Chain
Repair Mechanism
Increased Damaged to the Cell
Increased ROS Production

OBJECTIVES

To investigate the effects of high night temperature on rice morphology, phenology and physiology

To develop PGR (chemical) treatments to prevent or remediate the heat damage

MATERIALS AND METHODS

Plant culture:
Plants were grown in the pots.
Cultivar: Cocodrie
PGR (Chemical) treatments: 20 DAE; **Number of applications:** 3(on same day); **Rate:** 100 µl
Salicylic acid (SA) : 0.3 µmole / plant
Glycine betaine (GB): 90 µmole / plant
Vitamin E : 0.014 µmole / plant
Heat Treatments: Using continuously controlled infrared heaters, starting 20 DAE (2000 to 0600 h).
Ambient night temperature (ANT): 27 ºC
High night temperature (HNT): 32 ºC.

Measurements:
Grain dry weight was measured at the end of the experiment.
Photosynthesis (P_n) and Respiration: Using LI-6400 portable photosynthesis system (LI-COR Inc, Lincoln, Nebraska, USA) .
Grain dimensions: Winseedle (Regent Instruments, Inc. Quebec, Canada)
Grain nitrogen: FP-528 Nitrogen/Protein analyzer (LECO Corporation, St. Joseph, Michigan, USA)
Procedures:
Membrane stability: Martineau et al., 1979
Pollen germination: Mohammed and Tarpley, 2009
Spikelet fertility: Prasad et al., 2006
Antioxidant capacity: Goffman and Bergman, 2004

RESULTS & DISCUSSION

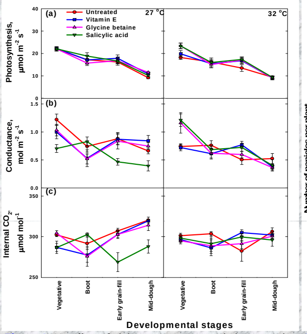


Figure 1: No effect of night temperatures and plant growth regulators on photosynthetic parameters.

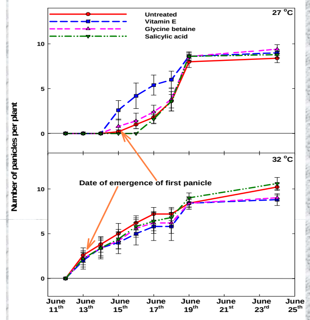


Figure 4: Crop duration decreased by 2 d under high night temperature as indicated by date of panicle emergence.

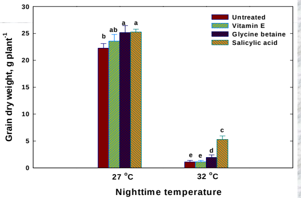


Figure 6: On average, plants grown under **high night temperature (HNT) showed a 90% decrease in yield** compared to plants grown under ambient night temperature (ANT). Plant treated with vitamin E, glycine betaine and salicylic acid showed 18%, 21% and 24% and 5%, 77% and 5-fold increase in yield at ANT and HNT respectively, compared to untreated plants.

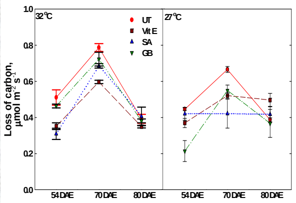


Figure 2: Leaf respiration rate, expressed as loss of carbon, was greater (27 %) in plants grown under high night temperature compared to plants grown under ambient night temperature at early grain-fill stage. Plant treated with plant growth regulators fared better than the untreated plants.

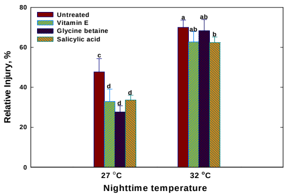
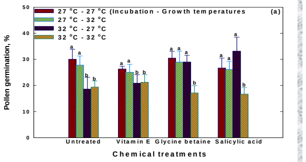


Figure 3: Plants grown under high night temperature showed a 60% increase in electrolytic leakage compared to plants grown under ambient night temperature (ANT). Application of vitamin E, glycine betaine and salicylic acid decreased electrolytic leakage by 31%, 42% and 30%, respectively, compared to untreated plants grown under ANT.



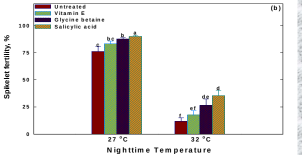


Figure 5a: Pollen incubated at higher temperature (32 ºC) showed 20% decrease in percent pollen germination (PPG) compared to pollen incubated at lower temperature (27 ºC). Plants treated with plant growth regulators showed increased PPG under high night temperature.
Figure 5b: Spikelet fertility (SF) defined as the ratio between filled grain to total number of grains, showed 72% decrease in plants grown under high night temperature (HNT), compared to plants grown under ambient night temperature (ANT). Plants treated with vitamin E, glycine betaine and salicylic acid showed 9%, 15% and 18% and 47%, 120% and 195% increase in SF, at ANT and HNT respectively, compared to untreated plants.

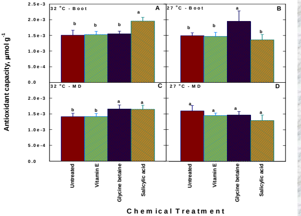


Figure 7: Plants grown under high night temperature (HNT) and treated with salicylic acid showed increases of 30% and 16.7% in total antioxidant capacity at boot and mid-dough stages, respectively, and plants treated with glycine betaine grown under HNT showed a 17% increase in total antioxidant capacity at mid-dough stage.

PGR treatments	Grain length (mm)	Grain Width (mm)	Nitrogen (mg g-1)	Grain dry weight (g plant-1)
27ºC-Untreated	7.51 ± 0.04 a	2.18 ± 0.01 a	11.00 ± 0.20 c	22.25 ± 0.86 b
27ºC-Vitamin E	7.36 ± 0.03 bc	2.20 ± 0.01 a	10.50 ± 0.20 d	23.56 ± 1.24 ab
27ºC-GB	7.29 ± 0.07 c	2.20 ± 0.01 a	10.80 ± 0.20 cd	25.14 ± 1.30 a
27ºC-SA	7.34 ± 0.03 c	2.21 ± 0.01 a	11.00 ± 0.20 c	25.26 ± 0.53 a
Mean	**7.37 ± 0.01**	**2.20 ± 0.01**	**10.90 ± 0.10**	**24.05 ± 0.53**
32ºC-Untreated	6.86 ± 0.07 d	2.19 ± 0.01 a	16.00 ± 0.40 a	1.09 ± 0.30 e
32ºC-Vitamin E	7.26 ± 0.05 c	2.15 ± 0.01 b	16.30 ± 0.30 a	1.15 ± 0.25 e
32ºC-GB	7.30 ± 0.05 c	2.10 ± 0.01 c	16.00 ± 0.60 a	1.94 ± 0.45 d
32ºC-SA	7.42 ± 0.04 b	2.18 ± 0.01 a	14.60 ± 0.40 b	5.28 ± 0.68 c
Mean	**7.25 ± 0.03**	**2.15 ± 0.01**	**15.70 ± 0.20**	**2.37 ± 0.35**
Difference between group means	*	*	*	*

Table 1: High night temperature decreased grain length and grain width by 2%, compared to ambient night temperature. Plant growth regulator application yielded a mixed response with respect to grain length and width.

In the present study, high night temperature (HNT) did not affect the following daytime's P_n at any particular developmental stage. This differs from the findings of Turnbull et al. (2002), which stated that HNT can increase the following daytime's P_n by reducing carbohydrate-induced inhibition of photosynthesis. However, respiration rates increased during EGF and declined as the plants matured. Similar trends were seen in wheat (*Triticum durum* L.) and sorghum (*Sorghum bicolor* L. Moench.), where the respiration rates peaked at grain filling stage (Albrizio and Steduto, 2003) then declined. Our results also indicated decreased membrane stability in plants grown under HNT, indicating that high temperatures of the range used in the present study lead to leaky membranes. Previous studies reported increased electrolytic leakage as a result of increased temperature in cowpea (*Vigna unguiculata* L.) (Ismail and Hall, 1999; Ibrahim and Quick, 2001).

The HNT decreased duration from emergence to appearance of first panicle by 2 d on average across all chemical treatments. Similar results of decrease in developmental period with increase in temperatures were seen in rice (Prasad et al., 2006). In addition to a decrease in crop duration, there were also decreases in percent pollen germination (PPG) and spikelet fertility (SF). In many crops, PPG decreased with increase in temperature (Hall, 1992; Matsui et al., 2001). In the present study, decrease in SF was partially due to decrease in PPG.

The HNT decreased grain length and width, thereby decreasing plant grain yield. Previous studies reported a decrease in grain yield due to decreased grain widths as a result of HNT (Counce et al., 2005; Morita et al., 2005). The decreases in rice grain length and width might be associated with a reduction in average endosperm cell area observed under HNT (Morita et al., 2005). Moreover, it is known that the capacity of endosperm to accumulate dry matter is determined by endosperm cell number (Bingham, 1969), which is affected by high temperature (Communi and Jones, 1999).

Application of glycine betaine or salicylic acid increased antioxidant capacity, thereby limiting the heat induced ROS-damage to the membrane, thus protecting cellular integrity, including the enzymes involved in translocation of photosynthates, thereby increasing spikelet fertility, hence plant grain yield.

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