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Yield and quality responses of two *indica* rice hybrids to post-anthesis asymmetric day and night open-field warming in lower reaches of Yangtze River delta

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ABSTRACT

Rice production is challenged by asymmetric rise in day and night temperatures. Efforts are required to improve our understanding about the impact of climate change induced asymmetrical fluctuations in temperature extremes. This paper presents first effort to investigate effect of post-anthesis asymmetric daytime, nighttime and diel warming, as predicted under low emission scenario (B1) of Intergovernmental Panel on Climate Change (IPCC), on yield and milling quality of two *indica* rice hybrids, Teyou-559 (susceptible) and Shanyou-63 (resistant), differing in response to temperature. Four canopy warming regimes, ambient reference (AT), daytime warming (HDT, +1.3 °C), nighttime warming (HNT, +2.7 °C), and diel warming (HDNT, +1.3/2.7 °C), were imposed through free-air temperature enhancement (FATE) facility using infrared heaters. Both hybrids responded differentially to daytime, nighttime and diel warming and shortened grain filling duration (1–2 days), reduced grain yield and 1000-grain weight were determined. Nighttime warming caused more deleterious impact than daytime or diel warming. These results indicate that the daytime (−4%), nighttime (−7%) and diel (−6%) warming under low emission scenario will have differential effects on rice production. This reduction is mainly due to differential decrease in grain weight. Resistant Shanyou-63 proved to be more susceptible to daytime warming, while susceptible Teyou-559 was affected more by nighttime and diel warming. Diel warming had significantly negative influence on head rice recovery of both cultivars, with slight inter-annual variation, followed by nighttime and daytime warming. Reduction in head rice recovery indicated the breakage of rice kernels. Daytime warming had greater effect on grain yield 1000-grain weight than nighttime warming considering per 1 °C warming. Effect of warming on yield and quality can be attributed to reduction in translocation of photosynthates during grain filling, resulting in reduced grain filling, grain weight and development of chalky kernels. Further studies are required to elucidate mechanism underlying differential response to asymmetric warming and to suggest appropriate management practices to minimize yield loses.

1. Introduction

Rice (*Oryza sativa* L.) is primary source of food and nutrition for major component of human population and cultivated on an area of about 29.9 million ha. Demand of rice will grow faster as expected population will reach 9.15 billion by 2050, mainly in Asian countries (UNFPA, 2010). Increasing instability in rice yield due to weather conditions and monsoon anomalies is of great concerns for global food security (Krishnan et al., 2011). Anthropogenic climate change in the presence of increasing global population is widening the gap between supply and demand of rice (Fischer, 1998). Global mean temperature is expected to be 1.1–6.4 °C higher by 2100, (IPCC, 2007), with faster rise in nighttime temperature (daily minima) than daytime temperature (daily maxima), ultimately with decreased diurnal temperature range (Easterling et al., 1997). Projected warming under low emission growth scenario (B1) is 1.8 °C with likely range of 1.1–2.9 °C by 2100 (IPCC, 2007). Predicted anomalies in temperature have serious implications for crop production, food security and human survival (Wassmann et al., 2009). Plant growth and development are strictly controlled by the surrounding environment (Franklin, 2009) and are more vulnerable

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to temperature extremes, especially at their susceptible stages i.e., flowering and early grain filling (Peng et al., 2004; Welch et al., 2010).

Rice can avoid high day temperature through transpirational cooling under conditions of lower relative humidity (Yan et al., 2010) and ample water supply. Significant decrease in rice yield due to rise is night temperature is reported and predicted (Peng et al., 2004; Welch et al., 2010). Yield reduction during grain filling under high temperature has been attributed to lower grain weight (Morita et al., 2005), and which are partially explain by increased rate of respiration (Mohammed and Tarpley, 2009b), slow grain filling as result of reduction in translocation of nitrogen and nonstructural carbohydrates (Shi et al., 2013).

Economic value of rice is directly depends on the head rice yield. Due to increased chalkiness, a strong negative correlation exists between head rice yield and high temperature, especially nighttime temperature at grain filling stage (Counce et al., 2000; Ambardekar et al., 2011). Advances in technology and development of high yielding varieties have contributed significantly to increase crop yield, however, regional weather and climate remain the major uncontrolled driving forces in crop production (Liu et al., 2013).

Experiments aimed to simulate the impact of warming on crop/plant growth and yield are mostly based on mean air temperature, without considering differential influence of day and night temperatures (Peng et al., 2004). Recent increasing trend of experiments focusing asymmetric rise of day and night temperature has been observed in literature (Morita et al., 2005; Mohammed and Tarpley, 2011). Warming studies conducted under controlled environmental conditions provided by indoor or glasshouse facilities, require extreme care to reduce possible artifacts from limited soil volumes and unnatural crop microclimate. Such unnatural conditions can limit their use in climate change research (White et al., 2011).

Infrared heaters (IRH) are widely gaining ground in climate manipulation studies, since their first application in the mid-1990s (Harte and Shaw, 1995) and their use in ecosystem warming experiment is rapidly increasing with a wide range of crops (Kimball et al., 2008; Aronson and McNulty, 2009; Kimball, 2011). These IRH artificially shed IR flux on vegetation, similar to the solar radiating, and directly elevate its temperature without altering air temperature. Increased canopy temperature through IRH can mimic global warming, though difference in its physical mechanism, as global warming will increase plant temperature through warmer air (Amthor et al., 2010; Kimball, 2011). Effect of IRH on wind profile and solar radiation in the plant canopy is negligible (Kimball et al., 2008). However, high energy requirement along with structural modification required for safe and effective use in the paddy fields (Krishnan et al., 2011), which were reduced through proper installation and modifications in the IRH design to provide stable infrastructure, safe use and uniform distribution of warming in the canopy (Rehmani et al., 2011). Artificial IR flux can induce mild water stress symptoms in wheat crop, and increased warming under water stress is not expected for rice crop under flooded condition (Kimball, 2011).

Two-year field experiment was conducted to impose different warming regimes, at rice grain filling stage. Our goals were to assess genotypic variation in grain yield and quality response to differential daytime, nighttime or diel warming as expected by 2100, during temperature sensitive grain filling stage. To date, there is no report of manipulating differential daytime and nighttime warming in the open paddy fields, following the IPCC scenario B1. Thus results from open-field simulation of predicted warming would help us to understand expected vulnerability of rice crop to global warming and will provide guideline for food security in the region.

2. Materials and methods

2.1. Crop culture and experiment site

A two-year experiment was conducted (during summers of 2009–2010) at Danyang Free-air Temperature Enhancement (FATE) facility, Danyang, Jiangsu, China (119°27′E, 31°54′N) with split-plot combinations of two contrasting *indica* hybrids, Shanyou-63 (high temperature resistant) and Teyou-559 (high temperature susceptible during reproductive growth stage) (Tang et al., 2008) and four warming (described below) regimes with three replications each (Table 1). The soil of FATE site was clayey, containing fair amount of total nitrogen (1.10 g kg^{-1}), available phosphorus (12.23 mg kg^{-1}), and exchangeable potassium (119.41 mg kg^{-1}). Danyang FATE facility was established before rice transplantation in 2009 (Rehmani et al., 2011).

Certified seeds of abovementioned rice hybrids were sown in raised bed (25th May, 2009) and plastic trays (27th May, 2010) and two seedlings per hill (with hill and row spacing of 13 cm × 30 cm) were manually transplanted (34 d and 27 d old seedling in 2009 and 2010, respectively) in three blocks (serve as replications, 50 m × 70 m), each with four plots (9.5 m × 9.5 m) including 6 m × 6 m useable plot with infrared heater array. Each array was separated by alleyways (0.5 m) plus buffer strips (5 m), similarly each plot was also separated by alleyways (0.5 m) and buffer strips (5 m). Experimental plots were divided into two equal halves (3 m × 6 m) in the exact center of array, two hybrids were collocated in each array while no additional space was kept between two halves except 13 cm hill to hill distance and central post of FATE array was used to separate both subplots. Nitrogen as urea (240 kg N ha^{-1} in 2009 and 250 kg N ha^{-1} in 2010), P as single super phosphate (120 kg P ha^{-1}) and potassium (KCl, 180 kg K ha^{-1}) were applied to the crop. Total N and K were applied in three and two split doses, respectively. One day before transplantation total P and half of the N and K were incorporated into the soil. Rest of N was equally top dressed at 72 and 85 days after transplantation (DAT), while remaining 50% K was top dressed at 72 DAT. Local recommendations of irrigation, insect, pest and disease control were followed to avoid any stress except warming.

Historical averages (1953–2010) of meteorological data including daily maximum (T_{max}) and minimum temperatures (T_{min}), RH and precipitation during rice growing season were obtained from nearest possible weather station (119°48′E, 31°43′N) (NOAA, 2011). Data was further grouped to obtain averages during vegetative, reproductive and grain filling stages of rice in the area (Fig. S1). Meteorological conditions of the FATE site including T_{max} (31.98 °C, 33.0 °C and 27.2 °C), T_{min} (25.27 °C and 25.1 °C and 19.2 °C) air temperatures, RH (83%, 82% and 84%) and wind speed (1.32, 0.7 and 0.9 m s^{-1}) for July, August and grain filling (1 September–15 October) were calculated from weather station installed near the FATE site in 2010 (8 July-harvest) (Fig. 2) and were used to calculate daytime and nighttime averages during rice grain filling stage. During warming period, wind speed was higher during daytime (1.24 m s^{-1}) than during nighttime (0.37 m s^{-1}), while RH was higher (93.5%) than during daytime (76.4%).

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fcr.2013.09.019.

2.2. Infrared warming system

Detailed description of Danyang FATE (Free-air Temperature Enhancement) Facility is described earlier (Rehmani et al., 2011). Total 12 FATE arrays (hence called array), 3-m diameter hexagonal in shape, equipped with six IRH, (Model FTE-1000) fitted in reflector housing Model ALEX-F (Mor Electric Heating Association Inc. MI, USA). IRH were deployed at 120 cm above the rice canopy.