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Elevated CO_2 and heat stress interactions affect grain yield, quality and mineral nutrient composition in rice under field conditions

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ABSTRACT

Heat stress is a major constrain to sustain rice production and grain quality. Rising atmospheric [CO_2] is predicted to increase photosynthesis resulting in higher biomass and yield. Conversely, both elevated (e[CO_2]) and heat stress (HT) are documented to deteriorate grain quality traits in rice. However, interactive effect of e[CO_2] + HT on rice grain yield, quality traits and particularly mineral composition under natural field condition in tropical environments are limited. Independent field experiments were conducted to assess the potential impact of e[CO_2] alone and in combination with HT on grain yield, quality traits and mineral composition of two rice cultivars Nerica-L-44 (heat tolerant) and Indian basmati rice variety Pusa 1121, using field based open top chamber (OTC) facility. Elevated [CO_2] significantly influenced grain quality traits by increasing chalkiness (69–83%), amylose content (18–37%), decreasing protein content by 4% and altering grain mineral nutrient composition across the cultivars. Proportion of chalky grains was further increased in Nerica-L-44 and Pusa 1121 under e[CO_2] + HT interaction. Correlation analysis revealed negative relationship of grain minerals with chalkiness and amylose content. In summary, independent exposure of rice to e[CO_2] reduced grain quality and e[CO_2] + HT further increased the negative effects on grain nutrient and quality.

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1. Introduction

Carbon assimilation by plants is a fundamental route to providing fuel, fiber and food for human consumption, thereby supplying energy to terrestrial ecosystems and regulating ambient atmospheric CO_2 (a[CO_2]) level (Shimono et al., 2013). Global climate change models predict increase in atmospheric [CO_2] concentration to 700 ppm by 2100 and temperature by up to 2.6° and 4.8°C by 2065 and end of twenty-first century, respectively (IPCC, 2013). The greater certainty among recent global climate models indicate increasing global temperature leading to increased frequency of heat stress episodes (Battisti and Naylor, 2009). Rice is sensitive to heat stress (Jagadish et al., 2010) and the predicted changes in current and future climate would negatively affect global rice production (Teixeira et al., 2013) and grain quality (Lin et al., 2010) reducing both its economic (Lyman et al., 2013) and nutritional benefits (Wang et al., 2011). Being a C3 crop, elevated CO_2 (e[CO_2]) exposure is documented to increase rice yield (Shimono et al., 2009). Studies using indica, japonica and rice hybrids have documented increased yield (24–34%) with e[CO_2] of about 580 ppm, keeping all the other climatic factors (temperature and irrigation) optimal (Liu et al., 2008; Yang et al., 2009). However, it has also been reported that the beneficial responses of e[CO_2] in rice were negated significantly under heat stress coinciding with reproductive stage (Prasad et al., 2005; Kadam et al., 2014; Madan et al., 2012). Environmental and climatic factors such as [CO_2] and ambient temperature may vary dynamically and interact under realistic field conditions affecting different growth and developmental stages of crops (Mittler and Blumwald, 2010; Jagadish et al., 2016).

It is documented that e[CO_2] deteriorates rice milling percentage and head rice recovery due to increased chalkiness (Yang et al., 2007). Previous studies have also provided a strong link between e[CO_2] and reduced grain protein content and also altering grain

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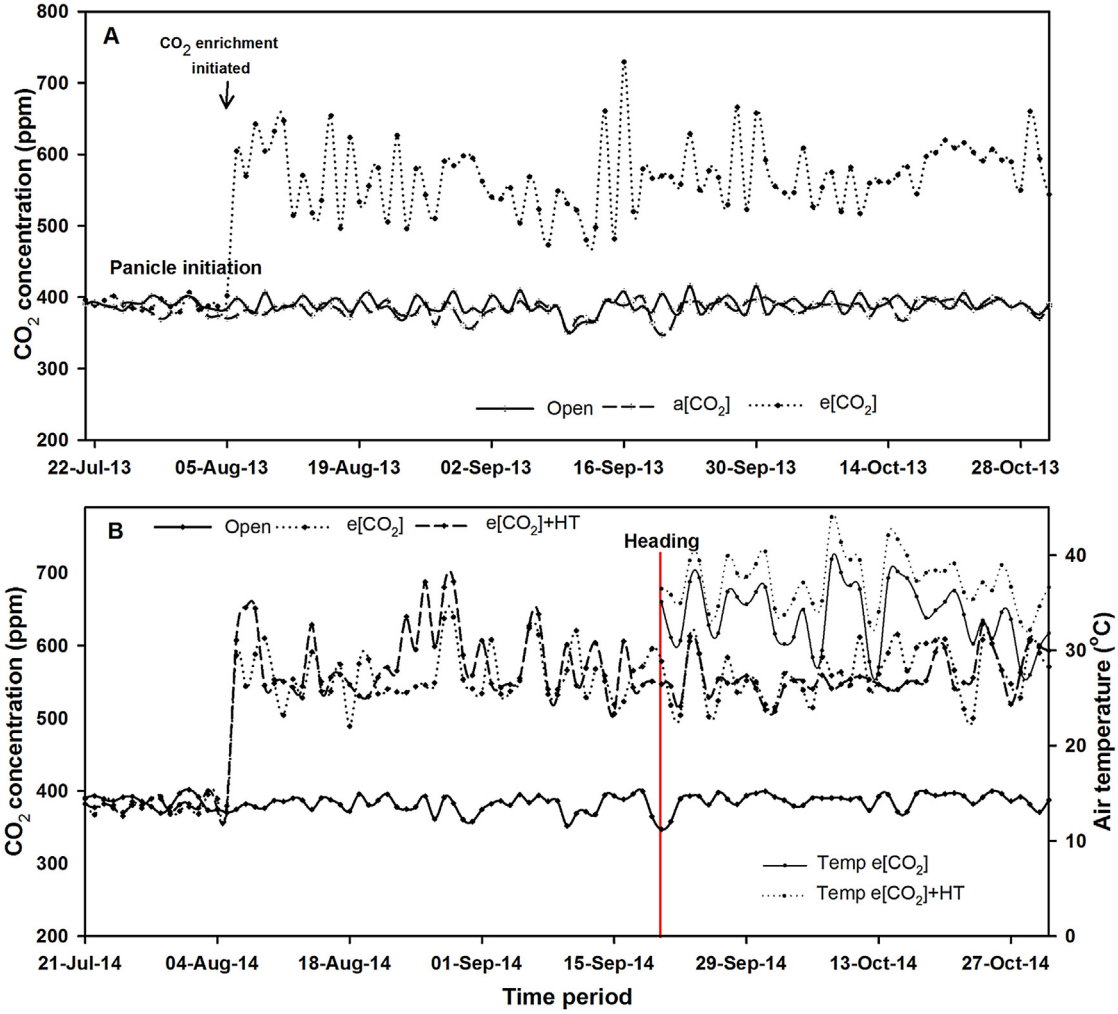

Fig. 1. Environmental conditions in different experiments during 2013 and 2014. [A] Daily [CO_2] concentration in open field and inside open top chambers during 2013 experiment, [B] Daily [CO_2] concentration in open field and inside open top chambers during 2014 experiment. Elevated [CO_2] exposure in during both year experiments was initiated at panicle initiation and continued till physiological maturity. Vertical red line denotes onset of high temperature exposure at heading till crop maturity. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

minerals composition (Taub et al., 2008; Wang et al., 2011; Myers et al., 2014). Studies conducted under e[CO_2] involving rice and wheat, revealed an overall decrease in grain nutrient concentration (Taub et al., 2008; DaMatta et al., 2010; Wang et al., 2011; Myers et al., 2014). Heat stress occurring at reproductive or grain filling stages is reported to reduce grain yield and quality in rice (Lin et al., 2010; Usui et al., 2014; Bahuguna et al., 2015). Independent reports are available on the quality of the rice under e[CO_2] and HT (Terao et al., 2005; Madan et al., 2012; Kadam et al., 2014) but interactive effect of e[CO_2] + HT on grain quality and particularly mineral nutrients composition under realistic field condition in tropical environments is largely unknown. A complex correlation of grain minerals with different quality traits such as amylose content, protein content, gel consistency, gelatinization temperature has been documented in rice (Zeng et al., 2005a; Jiang et al., 2007; Gu et al., 2015). Recently, Lin et al. (2016) reported synergistic or antagonistic effect of chalkiness on the accumulation of different macro and micronutrients providing useful clues on the relationship between chalkiness and grain mineral content. However, this relationship has not been explored under heat and other abiotic stress conditions. Thus, experiments were conducted to explore the effect of e[CO_2] and e[CO_2] + HT interaction on key grain quality traits and mineral composition using Indian basmati rice variety (Pusa 1121) and a newly identified heat tolerant cultivar Nerica-L-44 (Bahuguna et al., 2015), using field based OTC facility.

The major objectives of the studies were to explore (i) interactive effect of e[CO_2] + HT on rice grain yield, quality and mineral nutrient composition (ii) association between grain quality traits and mineral composition exposed to e[CO_2] and e[CO_2] + HT under field conditions.

2. Materials and methods

2.1. Crop management

Field experiments were conducted during July–October in 2013 and 2014 using OTC facilities at Indian Agricultural Research Institute (IARI), New Delhi, India (28°35′N latitude, 77°12′E longitude). Indian popular basmati variety Pusa 1121 and Nerica L-44 a high temperature tolerant cultivar (Bahuguna et al., 2015) were used to test the objectives.

2.2. Experimental setup

Two experiments were conducted in field based OTCs to investigate the effect of e[CO_2] from panicle initiation till maturity (2013)