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Research article

A combined application of biochar and phosphorus alleviates heat-induced adversities on physiological, agronomical and quality attributes of rice

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ABSTRACT

Present study examined the influence of high-temperature stress and different biochar and phosphorus (P) fertilization treatments on the growth, grain yield and quality of two rice cultivars (IR-64 and Huanghuazhan). Plants were subjected to high day temperature-HDT (35 °C ± 2), high night temperature-HNT (32 °C ± 2), and control temperature-CT (28 °C ± 2) in controlled growth chambers. The different fertilization treatments were control, biochar alone, phosphorous (P) alone and biochar + P. High-temperature stress severely reduced the photosynthesis, stomatal conductance, water use efficiency, and increased the leaf water potential of both rice cultivars. Grain yield and its related attributes except for number of panicles, were reduced under high temperature. The HDT posed more negative effects on rice physiological attributes, while HNT was more destructive for grain yield. High temperature stress also hampered the grain appearance and milling quality traits in both rice cultivars. The Huanghuazhan performed better than IR-64 under high-temperature stress with better growth and higher grain yield. Different soil fertilization treatments were helpful in ameliorating the detrimental effects of high temperature. Addition of biochar alone improved some growth and yield parameters but such positive effects were lower when compared with the combined application of biochar and P. The biochar+P application recorded 7% higher grain yield (plant^{-1}) of rice compared with control averaged across different temperature treatments and cultivars. The highest grain production and better grain quality in biochar+P treatments might be due to enhanced photosynthesis, water use efficiency, and grain size, which compensated the adversities of high temperature stress.

Abbreviations: A, photosynthesis; AT, control temperature; Ci, intercellular CO_2 concentration; E, transpiration; gs, stomatal conductance; HDT, high day temperature; HNT, high night temperature; LWP, leaf water potential; P, phosphorous; ROS, reactive oxygen species; RWCL, relative water contents of leaves; RWCS, relative water contents of young spikes inside panicle; WUE, water use efficiency.

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1. Introduction

The increase in both frequency and intensity of high temperature, along with its large variability, is emerging as a potential menace to the crop productivity and sustainability. Current Intergovernmental Panel on Climate Change (IPCC) models project mean global surface temperature raises between 1.8 °C and 4 °C over the 21st century at a rate of 0.2 °C increase per decade (Christensen et al., 2007). Recent raises in night temperatures have been about three times that of the corresponding day temperatures on earth's surface (Karl et al., 1991). The differential increase in day and night temperatures associated with global warming demonstrated strong negative linear relationships with rice grain yield and biomass production (Peng et al., 2004).

High temperature stress stimulates morpho-physiological (Giaveno and Ferrero, 2003), anatomical (Zhang et al., 2005) as well as biochemical alterations in plants. It induces the changes in accumulation of compatible osmolytes (Sakamoto and Murata, 2002), water relations (Simoes-Araujo et al., 2003), decrease in photosynthesis and hormonal changes (Wise et al., 2004) and quick production of reactive oxygen species (ROS) (Almeselmani et al., 2006).

Rice yield and related traits are considerably influenced by the cultivation system and by environmental factors among which temperature is considered to be most important (Singla et al., 1997). Temperature stress reduced rice yield by reducing the performance of different rice growth and yield traits (e.g) according to Li et al. (2003) tiller production is a key agronomical trait in rice and is very sensitive to temperature. The grain weights for a rice cultivar are nearly stable in a stress-free environment (Mohammed and Tarpley, 2010). Under high night temperature (HNT) stress, the decrease in individual grain weight resulted in significant reduction in rice grain production per unit area (Counce et al., 2005; Shah et al., 2014). Previous studies also reported that increased vegetative rates of respiration (Frantz et al., 2004) and leaf membrane injury (Reynolds et al., 1994) as a result of heat stress, which may reduce the supply of assimilate to the spikelet (Hirai et al., 2003). Recent investigation highlighted that key constituents of rice quality such as its physical appearance, cooking quality, eating quality and nutritional quality are also of prime importance in sustainable rice production system (Zheng et al., 2008).

Most rice is currently grown in such regions where current temperatures are already near to optimum for rice production. Therefore, any further raises in mean temperatures or of short episodes of high temperatures during sensitive phases may be supra-optimal and reduce grain yield (Fahad et al., 2014; 2015a,b). The role of agriculture in mitigating climate change through options such as carbon sequestration in stable forms of soil organic matter is gaining attention universally (Stavi and Lal, 2013). Application of biochar is being considered as a means to sequester carbon (C) while concurrently improving plant performances. Presently, in modern agriculture biochar application is hardly utilized, and its agronomic value in terms of crop response and soil health benefits has yet to be quantified (Fahad et al., 2015a). Experimental evidence so far demonstrates that (a) biochar addition frequently encourages plant growth, in particular combined with N or P types fertilizer addition in poor soils (Blackwell et al., 2009; Major et al., 2010), (b) it decreases nutrient leaching (Laird et al., 2009). Furthermore it could be shown (c) that the soils cation exchange capacity (CEC) raises with biochar addition (Liang et al., 2006), in particular over time as the functional groups are oxidized (Cheng et al., 2006). Besides these positive effects, different studies have reported growth stimulatory effects of biochar soil amendment on field crops grown under greenhouse conditions. For instance, shoot and root biomass of birch and pine were found larger in charcoal-amended soil (Wardle et al., 1998). An increase in maize yield by 28–140% was observed with the single application of 20 t/ha biochar in Columbian savanna soil as compared with the un-amended control in the 2nd to 4th years after application (Major et al., 2010). Kammann et al. (2010) found that plant water status with biochar application was improved because it increased the osmotic values of the leaves and reduced transpiration indicating a higher tolerance to potential water stress conditions (Gonzalez et al., 2009; Kammann et al. 2010). These amendments could be more effective if supplied with major nutrients such as nitrogen (N), phosphorus (P) or potassium (K). In recent years, exogenous applications of protectants like P and K have been found effective in mitigating heat stress-induced damage in plants (Hasanuzzaman et al., 2013). Under drought conditions, the positive effects of P on plant growth have been attributed to an increase in water-use efficiency, stomatal conductance (Brück et al., 2000), and photosynthesis (Ackerson, 1985), to higher cell-membrane stability, and to effects on water relations (Sawwan et al., 2000).

Until now, few investigations have been performed to study the effects of biochar and P on plants under different stress conditions but unfortunately no study is available related to high day and high night temperature, leaving a significant gap in the literature on this crucial topic. It was hypothesized that the application of Biochar and P may alleviate the negative effects of high temperature on growth and yield of rice. Therefore, the present study was carried out, for the first time in order to; (a) to evaluate the response of rice growth, yield and quality of different rice cultivars to high day and high-night-temperature stresses, and (b) to examine the influence of different biochar and P fertilization treatments on rice performance under high-temperature stress.

2. Materials and methods

2.1. Experimentation

Experiments were conducted during 2014 growing season in the greenhouse at the Huazhong Agricultural University, Wuhan, China (30° 47′ N, 114° 35′ E). Two *indica* rice cultivars, IR-64 and Huanghuazhan, were used. Rice plants were sown during the rice growing season (15 May to 25 September) under natural conditions. To facilitate germination, seeds of both cultivars were kept in a wet towel for 2 days. After germination, the seeds were planted in different seedling trays (1 seeds per cell). Three weeks after sowing, three seedlings were transplanted to plastic pot. After transplantation, plants were grown in plastic pots (21.6 cm lower inside diameter, 27.2 cm upper inside diameter, 27.2 cm height and 0.15 cm thickness) filled with 12 kg of air-dried soil. Soil was silt loam composed of 32% sand, 54% silt and 14% clay. The soil pH, organic carbon, available phosphorus (P), available potassium (K) and total nitrogen (N) content were 5.22, 22.85 g kg^{-1}, 8.36 mg kg^{-1}, 81.13 mg kg^{-1} and 0.15%, respectively. N and K were applied at recommended doses to all pots. Standard practices suitable for pot experiments were followed, and no pest or disease problems were found during the experimental period.

2.2. Treatments

For temperature treatments, three indoor controlled growth chambers (Climatrons, Southeast Ningbo Instruments Ltd, Zhejiang, China) already set at three different temperatures treatment i.e. HDT (high day temperature of 35 °C ± 2), HNT (high night temperature of 32 °C ± 2) and CT (control temperature of 28 °C ± 2 throughout the day) were provided. Separate sets of rice seedlings