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A better root morpho-physiology after heading contributing to yield superiority of *japonica/indica* hybrid rice

Tianyao Meng, Huanhe Wei, Xiaoyun Li, Qigen Dai, Zhongyang Huo*

Co-innovation Center of Modern Production Technology of Grain Crops/Jiangsu Key Lab of Crop Genetics & Physiology/Research Institute of Rice Industrial Engineering Technology, Yangzhou University, Yangzhou 225009, China

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ABSTRACT

Grain yield superiority of *japonica/indica* hybrid rice (JIHR) over *japonica* inbred rice (JIR) and *indica* hybrid rice (IHR) was reported, and some shoot traits underlying high yield of JIHR were identified, like shoot stay-green traits after heading. To date, little information has focused on root trait differences among JIHR, JIR and IHR. Besides, improved shoot stay-green traits after heading of JIHR might indicate better root morpho-physiological traits after heading compared with JIR and IHR, considering the interdependent relationship between root and shoot. In this study, two JIHR, two JIR, and two IHR were planted in 2014 and 2015 at Ningbo, and in 2015 and 2016 at Yangzhou, China. JIHR showed longer total growth period especially the period from heading to maturity and higher grain yield per day, and 5.6–19.8% higher grain yield compared with JIR and IHR across two years at two sites. JIHR had consistently higher root and shoot biomass at heading and maturity at two sites compared with JIR and IHR. Higher root length and root volume, and more roots in the 11–30 cm soil depth at heading and maturity of JIHR over JIR and IHR were observed across years and sites. JIHR had not only higher leaf SPAD value and leaf photosynthetic rate, but also higher root bleeding rate and root oxidation activity during grain filling, compared with JIR and IHR. JIHR had lower reduction rate of root biomass, length, volume, bleeding rate, and oxidation activity from heading to maturity than JIR and IHR at two sites. Root length and root volume were correlated positively ($P < 0.01$) to shoot biomass at heading and maturity and rice grain yield. Root bleeding rate and root oxidation activity were correlated positively ($P < 0.01$) to leaf SPAD value and leaf photosynthetic rate during grain filling and rice grain yield. Our results suggested that better root morpho-physiological traits (showing as longer, larger, deeper, and more active roots) after heading of JIHR could contribute to the shoot stay-green traits, higher biomass accumulation, and finally yield superiority over JIR and IHR.

1. Introduction

Rice is one of the most important staples in the world (Khush, 2005). In the face of the growing population and reduced arable land resources, one of the effective ways to increase continuously rice production is to breed high-yielding rice cultivars (Mae, 2011; Hayashi et al., 2012). Specific selection criterion such as 100 kg ha^{-1} d^{-1} grain yield per day (Yuan, 1997), and 22 t ha^{-1} aboveground biomass and 0.5 harvest index (Peng and Khush, 2003) were suggested in high-yielding rice breeding program. Utilization of heterosis from crossing *japonica* and *indica* is recognized as a promising approach to improve rice grain yield (Mi et al., 2016; Yuan, 2017). However, poor grain-filling barrier which was a common phenomenon in the crossbreds of previous *japonica/indica* hybrids often limited the realization of their high yield potential (Zhang et al., 1997; Singh et al., 2006). Great progress was achieved to solve this barrier recently, and some *japonica/indica* hybrid rice (JIHR) varieties with strong heterosis were bred successfully and released for production in China (Wei et al., 2016a, 2016b; Gui et al., 2016).

Nowadays, these JIHR were grown widely in East and South China, and shown a 5–20% increase in grain yield compared with *japonica* inbred rice (JIR) and *indica* hybrid rice (IHR) (Wei et al., 2017, 2018a; Xing et al., 2017). Some studies identified morphological and physiological traits underlying yield superiority of JIHR over JIR and IHR, e.g. larger sink capacity (Jiang et al., 2014a; Wei et al., 2018a), greater leaf area and higher leaf chlorophyII content after heading (Jiang et al., 2015), and higher nutrient uptake (Wei et al., 2017, 2018b). These studies focused mostly on comparisons of shoot traits among JIHR, JIR

* Corresponding author.
E-mail addresses: 516060030@qq.com (T. Meng), huozy69@163.com (Z. Huo).

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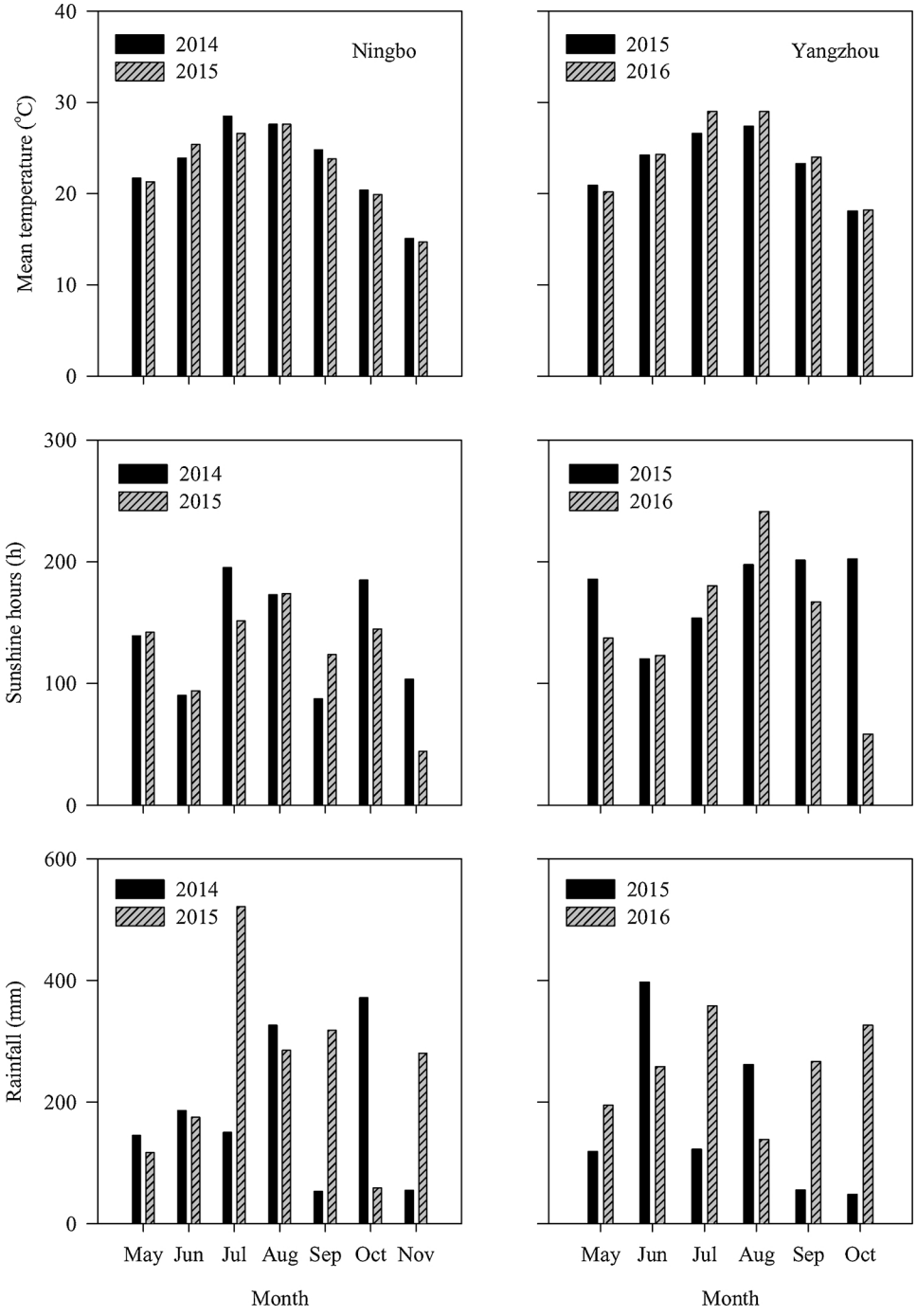

Fig. 1. Mean temperature, sunshine hours, and rainfall per month during rice growing periods in 2014 and 2015 at Ningbo (left parts) and in 2015 and 2016 at Yangzhou (right parts).

and IHR. However, little information is available on root trait differences among JIHR, JIR and IHR.

Root is a crucial plant organ involved in the process of crop yield formation (Costa et al., 2002; Rich et al., 2016). The improved root morpho-physiological traits were related closely with increased shoot biomass accumulation (Kano-Nakata et al., 2013; Narayanan and Prasad, 2014), higher nutrient utilization efficiency and water productivity (Chu et al., 2014; Kijoji et al., 2014; Manschadi et al., 2014), and stronger plant lodging-resistance in crops (Berry et al., 2003; Pinera-Chavez et al., 2016). For instance, a higher root biomass, root length density, and root oxidation activity contributed to higher grain yield and water productivity of water-saving and drought-resistant rice (Chu et al., 2014). Compared with JIR and IHR, JIHR exhibited improved shoot growth especially during grain filling, such as greater shoot biomass accumulation (Wei et al., 2017, 2018a), enhanced stem lodging-resistance (Jiang et al., 2014b), and shoot stay-green traits during grain filling (Jiang et al., 2015), which in turn might indicate JIHR has better root morpho-physiological traits after heading. However, few studies were conducted to confirm such hypothesis. In addition, it is also interesting to clarify the main root traits underlying yield superiority of JIHR over JIR and IHR.

The main objectives of this study were to: (1) compare root trait differences among JIHR, JIR, and IHR, three main rice varietal groups in China, (2) confirm the hypothesis that JIHR showed better root morpho-physiology during grain-filling phase compared with JIR and IHR, (3) identify the main root traits underlying high grain yield of JIHR.