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Different characteristics of nutrient absorption and utilization between inbred *japonica* super rice and inter-sub-specific hybrid super rice

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ABSTRACT

Although previous researchers have revealed that inter-sub-specific hybrid rice between *indica* and *japonica* has super-high yield potential, the mechanisms underlying nutrient absorption and utilization remain limited. The present study assessed nutrient accumulation and utilization, root morphology, and physiology of inter-sub-specific hybrid super rice cultivars (IHSRC) Yongyou 12 and Yongyou 15, using inbred *japonica* super rice cultivars (IJSRC) Nanjing 44 and Ningjing 3 as control. Total nitrogen (N), phosphorus (P), and potassium (K) accumulations in IHSRC were 12.53%, 20.81%, and 17.30% higher than those in IJSRC respectively. The larger amounts of accumulated nutrients in IHSRC were mainly attributable to the high rates of nutrients accumulation before elongating and the long growth duration without premature senescence after elongating. The apparent recovery efficiency of N fertilizers, agronomic N use efficiency, and the partial factor productivity of applied N in IHSRC were all higher than those in IJSRC, whereas the physiological N use efficiency and internal N, P, and K use efficiencies of IHSRC were similar to or lower than those of IJSRC. Compared with IJSRC, the root weights of IHSRC were heavier with greater length and bigger volume, the total and active absorption areas were also larger. In conclusion, with strong and active root systems, IHSRC are more efficient in nutrient absorption than utilization.

1. Introduction

Indica and *japonica* are the two subspecies of Asian cultivated rice (*Oryza sativa* L.) that exhibit distinct features such as plant and grain type, yield, quality, and stress resistance. Although the use of heterosis between *indica* and *japonica* has long been considered as an important way to improve rice yield, the sterility of hybrid offspring was the primary hurdle for widespread use of it until the discovery of wide compatibility varieties (WCV) (Qiu et al., 2005). WCV are rice varieties that can produce normal fertile hybrids when crossed with either *indica* or *japonica* varieties (Ikehashi and Araki, 1984; Ikehashi and Araki, 1986). Through the use of WCV, a series of inter-sub-specific hybrid varieties with stronger heterosis and normal seed setting rate have been successfully bred, such as Yongyou 6, Yongyou 12, Yongyou 15, Yongyou 538, Chunyou 84, Zheyou 18, and Yongyou 2640 and have been designated as super rice by the Chinese Ministry of Agriculture based on their super-high yield (Chinese Super Rice Varieties Database).

Compared with inbred *indica* or *japonica* super rice and hybrid *indica* or *japonica* super rice, respectively, the number of inter-sub-specific hybrid super rice varieties between *indica* and *japonica* is relatively small, only accounting for 5.38% of the total as of 2017. However, the grain yield of inter-sub-specific hybrid super rice, which could achieve more than 13.5 t ha^{-1} yield easily in field production (Chang et al., 2016; Wang et al., 2014), is superior to the other types of super rice. Researchers have previously revealed that the yield advantage of inter-sub-specific hybrid rice is mainly attributable to its superior plant height (Meng et al., 2016; Wei et al., 2014) coupled with improved lodging resistance (Jiang et al., 2014c), high sink capacity due to the big size of panicle (Jiang et al., 2014b), erect upper three leaves that efficiently serve as a canopy (Jiang et al., 2014a), large leaf area with high photosynthetic rate to increase biomass production, and delayed leaf and root senescence that in turn increase grain filling after heading (Wei et al., 2016a).

In addition to genetic factors, nutrient input, particularly nitrogen (N) fertilizers, play an important role in high yield in rice. Previous studies have shown that the applied N fertilizers exceeding 350 kg ha^{-1} onto inter-sub-specific hybrid super rice Yongyou 12 results in a record yield of more than 15 t ha^{-1} (Li et al., 2014a; Sun et al., 2013). It has

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also been confirmed by Wang (Wang et al., 2014) that, 330 kg ha^{-1}N fertilizer is required to achieve a super high yield greater than 13.5 t ha^{-1} in the field production of Yongyou 12.

Furthermore, compared with the other types of super rice, the higher grain yield of inter-sub-specific hybrid super rice is usually accompanied by higher rates of accumulation of total N, phosphorus (P), and potassium (K) (Wei et al., 2017). In general, it seems that to achieve super high yield, the inter-sub-specific hybrid super rice should be better adapted to high N levels. Therefore, it is essential to establish the mechanisms underlying nutrient absorption and utilization in inter-sub-specific hybrid super rice. The present study investigated two different types of super rice (namely, Nanjing 44 and Ningjing 3 as inbred *japonica* super rice cultivars and Yongyou 12 and Yongyou 15 as inter-sub-specific hybrid super rice cultivars), in terms of differences in N, P and K accumulation and utilization, root morphology, and physiology.

2. Materials and methods

2.1. Experimental site and weather conditions

Field experiments were conducted at the research farm of Yangzhou University in Jiangsu Province, China (32°30′N, 119°25′E, 21 m altitude) during the rice growing season from May to November 2012, which was then repeated in 2013. The soil of the field was sandy loam with 0.14% total N, 87.75 mg kg^{-1} alkali hydrolysable N, 33.2 mg kg^{-1} Olsen-P and 88.5 mg kg^{-1} exchangeable K. The daily mean temperature and precipitation during the rice growing season in 2012 and 2013 were measured at a weather station close to the experimental site (Fig. 1).

2.2. Plant materials and growth conditions

Two different types of super rice cultivars, namely, Nanjing 44 and Ningjing 3 as inbred *japonica* super rice cultivars (IJSRC) and Yongyou 12 and Yongyou 15 as inter-sub-specific hybrid rice cultivars (IHSRC), were adopted as experimental materials. Seedlings were raised in the seedbed with a sowing date of May 17, and transplanted on June 7. The duration of each growth stage and grain yield of the different types of super rice are shown in Table 1.

Hill spacing was 13.1 cm × 30 cm with two seedlings per hill for the IJSRC and 14.6 cm × 30 cm with one seedling per hill for the IHSRC, respectively. The experiments followed a complete randomized block design consisting of three replicates. The plot area of each treatment was 15 m^2 (3 m × 5 m). Nutrient input included N, P, and K fertilizers with no N fertilizer treatment in the control (CK). 300 kg ha^{-1} N was applied as urea in 4 splits: 90 kg ha^{-1} N before transplanting and at 7 days after transplanting, 60 kg ha^{-1} N at 65 days and 78 days after transplanting for the IJSRC, and 90 kg ha^{-1} N before transplanting and at 7 days after transplanting, 60 kg ha^{-1} N at 80 days and 96 days after transplanting for the IHSRC. In addition, 150 kg ha^{-1} P (as superphosphate) and 150 kg ha^{-1} K (as KCl) were also applied and incorporated before transplanting. The plots were separated by a ridge that was wrapped with plastic film, and each plot was irrigated or drained independently.

Table 1
The duration of each growth stage and grain yield of different types of super rice.

Year	Cultivar	Days from sowing to elongating (d)	Days from elongating to heading (d)	Days from heading to maturity (d)	Grain yield (t ha^{-1})
2012	Nanjing 44	66 a	28 b	61 b	10.85 b
	Ningjing 3	66 a	29 b	60 b	10.61 b
	Yongyou 12	63 a	50 a	71 a	12.37 a
	Yongyou 15	63 a	47 a	70 a	12.63 a
2013	Nanjing 44	66 a	28 b	62 b	10.97 b
	Ningjing 3	66 a	29 b	60 b	10.85 b
	Yongyou 12	63 a	50 a	72 a	12.41 a
	Yongyou 15	64 a	48 a	70 a	12.53 a

2.3. Sampling and measurements

5 hills of plants were collected from each plot at elongating, heading, and maturity stages (days of each growth stage are presented in Table 1). The shoots and roots were detached from their nodal bases. The samples were oven-dried at 70 °C to a constant weight to calculate the ratio of root to shoot. Then, the shoots were processed for the determination of N, P and K concentrations. N concentrations were determined by semi-micro-Kjeldahl digestion and distillation (Nelson and Sommers, 1980). P concentrations were determined by the vanado-molybdate yellow method (Jackson, 1958). K concentrations were measured using a flame spectrophotometer.

N, P and K accumulation in the plant was calculated by multiplying the N, P and K concentration (%) by the plant total biomass respectively. The indexes of nutrient use efficiencies were calculated and expressed as follows.

The apparent recovery efficiency of N fertilizer = [N accumulation in N application plots-N accumulation in N omission plots (kg)]/the amount of applied N fertilizer (kg) × 100.

Agronomic N use efficiency = [grain yield in N application plots-grain yield in N omission plots (kg)]/the amount of applied N fertilizer (kg).

Physiological N use efficiency = [grain yield in N application plots-grain yield in N omission plots (kg)]/[N accumulation in N application plots-N accumulation in N omission plots (kg)].

Partial factor productivity of applied N = grain yield in N application plots (kg)/the amount of applied N fertilizer (kg).

Internal N use efficiency = grain yield (kg)/N accumulation in plant (kg).

Internal P use efficiency = grain yield (kg)/P accumulation in plant (kg)

Internal K use efficiency = grain yield (kg)/K accumulation in plant

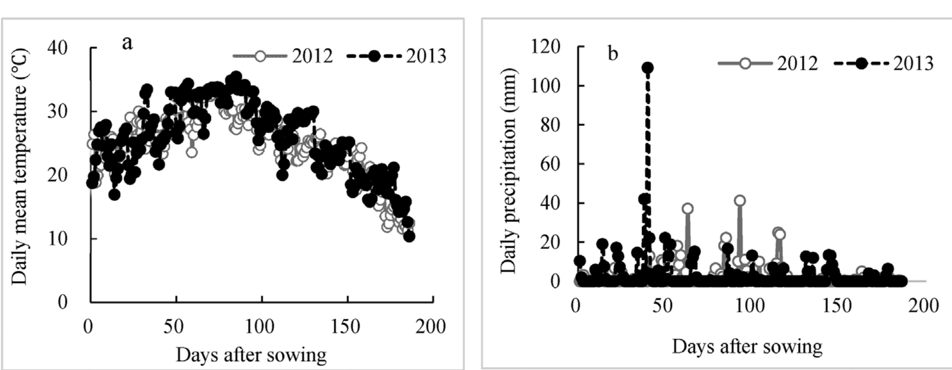

Fig. 1. Daily mean temperature (a) and precipitation (b) during the rice growing season of 2012 and 2013.

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