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RESEARCH ARTICLE

Morphological and physiological traits of large-panicle rice varieties with high filled-grain percentage

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Abstract

Understanding the morphological and physiological traits associated with improved filling efficiency in large-panicle rice varieties is critical to devise strategies for breeding programs and cultivation management practices. Information on such traits, however, remains limited. Two large-panicle varieties with high filled-grain percentage (HF) and two check large-panicle varieties with low filled-grain percentage (LF) were field-grown in 2012 and 2013. The number of spikelets per panicle of HF and LF both exceeded 300, and the filled-grain percentage (%) of HF was approximately 90, while that of LF was approximately 75 over the two years. The results showed that when the values were averaged across two years, HF yielded 12.9 t ha^{-1}, while LF yielded 11.0 t ha^{-1}. HF had a greater leaf area duration, biomass accumulation and transport of carbohydrates stored in the culm to the grains from heading to maturity compared with LF. HF exhibited a higher leaf photosynthetic rate, more green leaves on the culm, and higher root activity during filling phase, especially during the middle and late filling phases, in relative to LF. The length of HF for upper three leaves was significantly higher than that of LF, while the angle of upper three leaves on the main culm was less in both years. Meanwhile, specific leaf weight of HF was significantly higher when compared with LF. In addition, the grain filling characteristics of HF and LF were investigated in our study. Our results suggested that a higher leaf photosynthetic rate and root activity during filling phase, greater biomass accumulation and assimilate transport after heading, and longer, thicker and more erect upper three leaves were important morphological and physiological traits of HF, and these traits could be considered as selection criterion to develop large-panicle varieties with high filled-grain percentage.

Keywords: large-panicle varieties, improved filling efficiency, morphological and physiological traits, grain filling characteristics

1. Introduction

Expanding the sink size through increase in spikelets per panicle has been proven as an effective approach to increase rice yield in China (Li *et al*. 2012; Zhang H *et al*. 2013). In recent years, rice varieties with large panicles (with numerous spikelets per panicle), e.g., *japonica*/*indica* hybrids and 'super' rice, have become available in production (Cheng *et al*. 2007). These large-panicle varieties often show larger sink sizes and higher yield potential over

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conventional varieties (Laza *et al*. 2004; Jiang *et al*. 2014). However, majority of these large-panicle varieties have always failed to achieve the expected yield performance in production, mainly due to poor grain filling (Zhang *et al*. 2012; Li *et al*. 2013). Many physiological causes that are responsible for grain filling problem of large-panicle varieties have been proposed, such as source limitation (Shi *et al*. 1995; Yuan 1997), assimilates transport obstacles to grains (Yang *et al*. 2002), slow endosperm cell division rate (Li *et al*. 2013), and unbalanced plant hormone concentrations (Yang *et al*. 2000, 2003; Zhang *et al*. 2009a; Zhang *et al*. 2012).

Some studies have been conducted to determine the physiological traits associated with improved filling efficiency of rice, such as enhanced root activity and leaf photosynthesis during grain filling (Zhang H *et al*. 2009b, 2013), increased pre-anthesis nonstructural carbohydrate reserves in the culm (Fu *et al*. 2011; Li *et al*. 2012). Besides, some cultivation practices aimed to improve the filling efficiency of large-panicle varieties have also been proposed, e.g., moderate soil drying during the ripening phase (Yang and Zhang 2010) and spraying abscisic acid (ABA) during the early filling phase (Xu *et al*. 2007). In recent years, a few studies have focused on large-panicle varieties with high filled-grain percentage, such as Nanjing 11, an *indica* variety developed in China (Kato *et al*. 2007, 2010). To date, however, very few studies have focused on the morphological and physiological traits of large-panicle varieties with high filled-grain percentage. Understanding these traits is of great importance to devise strategies for breeding programs and cultivation management practices.

Recently, the Ningbo Academy of Agricultural Sciences, Zhejiang Province in China released two new large-panicle varieties, Yongyou 1540 and Yongyou 4540. In our field experiment during two continuous cropping seasons, both Yongyou 1540 and Yongyou 4540 exhibited approximately 350 spikelets per panicle, and had a filled-grain percentage (%) of nearly 90, respectively, indicating that Yongyou 1540 and Yongyou 4540 are large-panicle varieties with high filled-grain percentage.

The primary objective of this study was to identify the morphological and physiological traits underlying the improved filling efficiency of Yongyou 1540 and Yongyou 4540. Yongyou 1540, Yongyou 4540 and two check large-panicle varieties with low filled-grain percentage were grown in the field. We believe that this study will provide useful information to breeders to develop large-panicle varieties with high filled-grain percentage.

2. Materials and methods

2.1. Locations and weather conditions

Field experiments were conducted at Bailiangqiao village, Ningbo City, Zhejiang Province, China (121.31°E, 29.45°N) in 2012 and 2013. The soil was blue purple clay with organic matter (g kg^{-1}) 26.8, total N (g kg^{-1}) 1.7, available P (mg kg^{-1}) 19.8, and available K (mg kg^{-1}) 75.9. Meteorological data, including mean temperature, number of sunshine hours and precipitation from May to November (rice growing periods) of 2012 and 2013, are shown in Fig. 1.

2.2. Plant materials and cultivation management

Two large-panicle varieties with high filled-grain percentage (HF) and two check large-panicle varieties with low filled-grain percentage (LF) were field-grown. The two HF varieties were Yongyou 1540 and Yongyou 4540, and the two LF varieties were Yongyou 240 and Yongyou 7177. Details on these varieties are shown in Table 1. The seeds of the four varieties were kindly provided by the Ningbo Seed Company (Ningbo, Zhejiang, China).

The experiment was arranged in a complete randomized block design with three replications. The plot covered 40 m^2 (8 m×5 m) in both years. Pre-germinated seeds were sown in seedbeds on 18 May 2012 and 19 May 2013. 20-d-old seedlings of the four varieties were transplanted into open fields with two seedlings per hill. The hill spacing was 30 cm row spacing and 13.2 cm plant spacing. The N, P and K application rates were identical in all plots. N application rate was 270 kg ha^{-1} in total, equally applied 1 d before transplanting, mid-tillering, panicle initiation, and the 2nd leaf from top stretching. 1 d before transplanting, 150 kg ha^{-1} P_2O_5 and 100 kg ha^{-1} K_2O were applied to all plots. Other cultivation practices, such as the control of insects and diseases, were performed following local recommendations. The heading date (50% plants) of the four varieties was 26–29 August in both years.

2.3. Sampling and measurements

Twenty representative plants with average number of panicles from each plot were collected at the stem elongation, heading and maturity stages to determine aboveground biomass and leaf area index. Average number of panicles in each plot were determined from 100 hills from five different locations 1 d before each sampling stage. Leaf area duration (LAD) was calculated with the following formula: LAD (m^2 m^{-2} d)=$\frac{1}{2}(L_1+L_2)\times(t_2-t_1)$, where, L_1 and L_2 are the 1st and 2nd measurements of leaf area (m^2 m^{-2}), respectively, and t_1 and t_2 represent the 1st and 2nd times (d) of the measurement.

Six representative plants with average number of panicles in each plot were collected at heading stage, 10, 20, 30, 40, 50, 60 days after heading (DAH), and maturity stage. These plants were divided into green leaves, panicles, stems (culm and sheath), and dead parts. These organs were dried at 75°C for 80 h to a constant weight to determine the dry