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# Analysis of yield attributes and crop physiological traits of Liangyoupeijiu, a hybrid rice recently bred in China

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**Abstract**

Crop physiological traits of Liangyoupeijiu, a ‘‘super’’ hybrid rice variety recently bred in China, were compared with those of Takanari and Nipponbare in 2003 and 2004 in Kyoto, Japan. Liangyoupeijiu showed a significantly higher grain yield than Nipponbare in both years, and achieved a grain yield of 11.8 t $ha^{-1}$ in 2004, which is the highest yield observed under environmental conditions in Kyoto. Liangyoupeijiu had longer growth duration and larger leaf area duration (LAD) before heading, causing larger biomass accumulation before heading than the other two varieties. Liangyoupeijiu had a large number of grains and translocated a large amount of carbohydrates from the vegetative organ to the panicle during the grain filling period. The three yield components measured were panicle weight at heading ($P_0$), the amount of carbohydrates translocated from the leaf and stem to the panicle during the grain filling period ($\Delta T$), and the newly assimilated carbohydrates during grain filling ($\Delta W$). It was found that the sum of $P_0$ and $\Delta T$ were strongly correlated with grain yield when all the data ($n = 8$) were combined ($r = 0.876$**). However, there was no significant difference in the radiation use efficiency (RUE) of the whole growth period between Liangyoupeijiu and Nipponbare for both years. Even though the growth duration was shorter, Takanari, an indica/japonica cross-bred variety, showed a similar yield to Liangyoupeijiu in both years. The mean RUE of the whole growth period was significantly higher in Takanari, 1.60 and 1.64 g $MJ^{-1}$ in 2003 and 2004, respectively, than in Liangyoupeijiu, which had a RUE of 1.46 and 1.52 g $MJ^{-1}$ in 2003 and 2004, respectively. The high grain yield of Takanari was mainly due to its high RUE compared with Liangyoupeijiu and its large $P_0$ and $\Delta T$. Our result showed that the high grain yield of Liangyoupeijiu was due to its large biomass accumulation before heading, which resulted from its large LAD rather than its RUE.


*Keywords:* Liangyoupeijiu; Hybrid rice; Yield potential; Radiation use efficiency (RUE); Rice

## 1. Introduction

World rice production dramatically increased from the mid 1960s to the mid 1980s. In particular, rice production in China showed a marked increase, mainly due to the spread of F1 hybrid varieties (Horie et al., 2005). Yuan (2001) reported that the yield of hybrid rice exceeded that of inbred varieties by 15% in tropical irrigated lowlands, and Peng et al. (1999) reported that hybrid rice has a 9% higher yield potential compared with the best inbred varieties in the irrigated lowlands. Because of its high grain yield, hybrid rice is widely used in China and accounts for more than 50% of the rice planted area in recent years (International Rice Research Institute, 2007).

However, rice yield increase eventually slowed in China as well as in other countries. The average yearly increase in yield dropped from 3.7% in 1980s to 0.9% in 1990s. In order to break the yield ceiling, China started a nationwide mega project for the development of ‘‘super’’ rice in 1996 (Cheng et al., 1998). This project aims to achieve a yield potential of 15 t $ha^{-1}$ by 2015 and raise the national average rice yield to 7.5 t $ha^{-1}$ by 2030 through the development of ‘‘super’’ rice varieties. In this project, the breeding strategy was focused on morphological traits such as erect, thick, V-shape leaves, moderate tillering capacity, medium plant height, heavy panicle, and so on (Yuan, 2001). Today, many ‘‘super’’ rice varieties have been released, and many wide area field experiments have achieved a grain yield of more than 12 t $ha^{-1}$ (Peng et al., 2004).

Many studies have been conducted on the mechanism of high grain yield in hybrid rice (Song et al., 1990a,b; Amano et al., 1993; Hasegawa et al., 1993; Khan et al., 1998; Cheng

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and Zhai, 2000; Wang et al., 2000, 2006; Ren et al., 2003; Jiang et al., 2005). Hybrid rice varieties have ideal canopy structure, thick stems, and a large leaf area; they also store a large amount of non-structural carbohydrates before heading (Song et al., 1990a,b). Cheng and Zhai (2000) reported that hybrid varieties have erect leaves and maintain root vigor and high net photosynthetic rate until the grain filling stage. Hybrid varieties are better protected from photoinhibition (Wang et al., 2000) and have high apparent quantum yield and carboxylation efficiency (Wang et al., 2006). Most studies, however, compared morphological and/or physiological traits of ''super'' hybrid rice varieties with traditional hybrid rice varieties or their low yield parent varieties. On the other hand, some researchers achieved a grain yield of over 12 t $ha^{-1}$ using inbred rice varieties (Horie et al., 1997, 2005; Ying et al., 1998). Hence, it is meaningful to compare the grain yield of recently bred hybrid varieties with ''high-yielding'' inbred varieties.

The yield determining period of rice growth is a controversial topic; some researchers indicate the importance of dry matter production after heading for high yield rice (Jiang et al., 1988; Saitoh et al., 1993; Murchie et al., 2002), while others cite the importance of dry matter accumulation before heading (Horie et al., 2003; Takai et al., 2006). However, the recently bred hybrid rice varieties have not been evaluated from this point of view.

In this study, field experiments were conducted for 2 years in the temperate environment of Kyoto, Japan. The following three rice varieties were used: Liangyoupeijiu, which is recently bred and one of the most popular ''super'' hybrid rice variety in China, Takanari, an inbred variety with high yield potential, and Nipponbare, a typical commercial variety used as a control. The objective of this study was to evaluate the grain yield of Liangyoupeijiu, a recently bred ''super'' hybrid rice variety, in order to identify the crop physiological factors resulting in high grain yield and examine the possibility of further higher grain yield rice.

## 2. Materials and methods

Three rice (*Oryza sativa* L.) varieties, Liangyoupeijiu (which is a two line hybrid variety of Peiai 64S × 9311 (both indica, Zou et al., 2003)), Takanari (bred in 1990 from the cross Milyang 42 × Milyang 25 (both indica-japonica cross-bred)) and Nipponbare (bred in 1963 from the cross Sachikaze × Yamabiko (both japonica)) were used in the following experiments in the temperate environment of Kyoto University Farm, Kyoto, Japan (35°02′N, 135°47′E, 60 m altitude) in 2003 and 2004. The seeds of Liangyoupeijiu originated from a seed lot for farmers in the Lijiang region of Yunnan, China. Chemical fertilizers were applied as follows: 14 g $P_2O_5$ and 7 g $K_2O$ $m^{-2}$ as basal dressing, 3 g N $m^{-2}$ 7 days after transplanting, 7 g $K_2O$ and 4 g N $m^{-2}$ at panicle initiation, 4 g N $m^{-2}$ 2 weeks before heading, and 3 g N $m^{-2}$ at heading as top dressing. The total N application was 14 g $m^{-2}$. Rice varieties were arranged in a completely randomized block design with three replications each. The size of each block was 21.6 $m^2$ (3.0 m × 7.2 m) in 2003 and 32.0 $m^2$ (3.2 m × 10 m) in 2004. Twenty-one-day-old seedlings were transplanted on 22 May, and harvested on 3 October, 27 September, and 28 September for Liangyoupeijiu, Takanari, and Nipponbare, respectively in 2003. Twenty-three-day-old seedlings were transplanted on 26 May, and harvested on 25 September, 15 September, and 16 September for Liangyoupeijiu, Takanari, and Nipponbare, respectively, in 2004. The planting density was 22.2 plants per $m^2$ (0.3 m × 0.15 m) with two seedlings per hill. The grain yield was adjusted to a moisture content of 14%. Water, weeds, insects, and diseases were controlled as required to avoid yield loss.

In 2003, plant materials were initially harvested from twenty plants at transplanting and later from eight hills 20 days after transplanting, at panicle initiation, 2 weeks before heading, full heading, 2 weeks after heading, and finally at maturity. In 2004 plant materials were harvested from eight hills 3 weeks before heading, 1 week before heading, 1 week after heading, and 3 weeks after heading, in addition to the same respective times as in 2003. The leaf area index (LAI) as well as the dry leaf, stem (culm and leaf sheath), panicle, and dead foliage weights were measured for each rice sample. The nitrogen concentration of each tissue was determined by the Kjeldahl method. Twenty-four hills were harvested from each replicate to measure the yield and yield components at maturity.

Grain yield ($Y$) can be expressed as follows:

$$Y = P_0 + \Delta T + \Delta W \quad (1)$$

$P_0$ is the panicle weight at heading; $\Delta T$ is the amount of carbohydrates translocated from the leaf and stem to the panicle during grain filling, and $\Delta W$ is the newly assimilated carbohydrates during grain filling. We assumed here that $\Delta T$ is equal to the difference between the maximum and minimum value of total dry weight of the leaf, stem and dead foliage during grain filling; we likewise assumed $\Delta W$ to be equal to the difference between $Y$ and the sum of $\Delta T$ and $P_0$.

The stratified clipping method was employed to measure the light extinction coefficient ($K$) and distribution pattern of the leaf area for the 2003 plant samples. After measurement of the relative light intensity for each layer (20 cm intervals) by a photosynthetically active radiation (PAR) meter (AccuPAR, Decagon, USA), the leaf area for each layer was measured 2 weeks before and 2 weeks after heading using nine plants from each variety.

Radiation use efficiency (RUE) was calculated using $K$, the LAI, and crop growth rate (CGR) using the following equation (Monteith, 1977).

$$\mathrm{RUE} = \frac{\mathrm{CGR}}{S_0[1 - \exp(-K \cdot \mathrm{LAI})]} \quad (2)$$

where $S_0$ is amount of solar radiation (MJ $m^{-2}$ $day^{-1}$). The daily LAI was calculated by interpolating data from two samplings. Daily solar radiation was measured using a pyranometer (2103A, Thermic, Eto Denki Co., Japan). Statistical analysis of variance was made by IRRISTAT (International Rice Research Institute, 2006).