Journal of Integrative Agriculture 2017, 16(7): 1467–1473

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RESEARCH ARTICLE

Erect panicle super rice varieties enhance yield by harvest index advantages in high nitrogen and density conditions

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Abstract

The erect panicle (Ep) type is an important characteristic for *japonica* super rice in Northeast China and plays a significant role in enhancing yield. The Ep type is considered to be a genetic ideotype resource to the *japonica* super rice group by virtue of its agronomic advantages such as grain number per panicle and biomass. This study addresses the effects of nitrogen and planting density conditions on yielding performance regarding panicle type (PT) using the recombinant inbred line (RIL) population derived from the cross between an Ep variety Liaogeng 5 and non-Ep variety Wanlun 422. The genetics underlying the Ep type proved to be robust not only for panicle-type optimization but also plant height, panicle length, flag leaf length and seed density. We also found that regardless of nitrogen and density, correlation between harvest index (HI) and plant height was not significant in Ep type whatever the nitrogen and density. The application of Ep type provides a potential strategy for yield improvement by increasing biomass through HI maintainable in rice.

Keywords: super rice, erect panicle, harvest index, nitrogen, planting density

1. Introduction

Agricultural concerns, especially food availability issues, are always a top priority in developing countries. Rice is a staple food source that is heavily relied upon in Asia (Cheng 2009). With growing populations, rice production is continuously strained to increase yields and feed the continent. The 'Green Revolution', cause from the application of dwarf and semi-dwarf traits in agriculture, has allowed for more plantings increased harvest index (HI) (Chen and Xu 2007). This excessive pursuit of increasing HI has instead led reduced biomasses and yields. Blindly pursuing high biomass without ensuring suitable HI has resulted in over-consumption, lodging and inefficiency (Klaus *et al*. 2014). In some cases, the yield increase in hybrid rice yield as a function of increasing biomass can only be achieved by over-fertilization of the crop. After the promising introduction of dwarfing and hybrid rice breeding, rice yield improvement entered a periods of stagnation. A wide mega project entitled 'Breeding and Cultivation System of Super Rice' brought

Received 24 January, 2017 Accepted 24 May, 2017
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doi: 10.1016/S2095-3119(17)61667-8

another breakthrough of rice yield in the early 1980s in China (Virmani *et al*. 1982). After nearly 30-years endeavor, breeders have exploited a new germplasm resource named Ep type. The first famous erect panicle (Ep) type variety, Liaogeng 5, was developed in 1976 in Liaoning Province, and then widely introduced into cultivation. It displayed high yield potential and was novel for many traits, including panicle and leaf erectness (Wang *et al*. 2009). Since then, an increasing number of Ep type varieties have been bred and released. Currently, it has been successfully bred into new high-yield varieties and commercially planted in Northeast China. The gene regarding to erect panicle was also map-base cloned in the Ep type rice, Liaogeng 5 and Qianchongliang 2, respectively (Huang *et al*. 2009; Wang *et al*. 2009). The Ep type was caused from a gain-of-function mutation for the *DEP1* (*EP*/*qPE9-1*) gene, resulting a truncation of phosphatidylethanolamine-binding protein-like domain protein and significantly enhancing meristematic activity, resulting in a reduced length of the inflorescence internode, an increased grain number per panicle and a consequent increase in yield (Huang *et al*. 2009). Although some Ep type varieties show a high-yield performance, there is a lack of experimental evidence that this ideotype truly results in higher yields when bred into non-Ep lines. Here, we tested how nitrogen and planting density affect the first generation rice recombinant inbred lines derived from the cross between the Ep type, Liaogeng 5, and the non-Ep type Wanlun 422. Phenotypic traits of Ep and non-Ep offspring were measured in high or low nitrogen and density treatments to show the effect, if any, on the performance of this genetic ideotype rice.

2. Materials and methods

2.1. Plant materials and treatments

The 171 recombinant inbred lines (RILs) population used in these experiments were derived from the cross between typical Ep variety Liaogeng 5 (LG5) and non-Ep type variety Wanlun 422 (WL422). The RILs were transplanted into the paddy field of Kyoto University in Kyoto, Japan, with one seedling per hill, 30 days after sowing. Sowing was conducted on 13 May for two consecutive years. In 2012, fertilizers were applied at 60, 90 and 90 kg ha^{-1} for N, P_2O_5 and K_2O, respectively. Plants were spaced at a low nitrogen and density (LND) setting at 15 cm×30 cm apart. In 2013, fertilizers were applied at 120, 90 and 90 kg ha^{-1} for N, P_2O_5 and K_2O, respectively. During this second year, plants were spaced at a high nitrogen and density (HND) manner at 10 cm×30 cm. Water management was carried out according to the popular cultural practices followed in Kyoto. In 2014, 20 Ep varieties (Shennong 265, Shennong 606, Shennong 9816, Shennong 9903, Liaogeng 5, Liaogeng 9, Liaogeng 287, Liaogeng 294, Liaogeng 326, Liaogeng 454, Liaoxing 1, Liaoxing 16, Liaoxing 17, Shendao 29, Shendao 3, Shendao 6, Shendao 9, Yanfeng 47, Yangeng 68, Yangeng 218) and 20 non-Ep varieties (Sasanishiki, Ou392, Chuyucan, Hatsuhoshi, Shunyo, Toyonishiki, Wanlun 422, Fukuhibiki, Sekkanmuri, Kinuhata, Rika, Tachiminori, Miyamanishiki, Norinmochi 12, Akitakomachi, Chiyounishiki, Dennishikimochi, Iwatedente, Hitomebore, Tadamitsu) that are commonly cultivated were planted into the paddy field of Shenyang Agricultural University, fertilizers and water management were carried out according to the popular cultural practices followed in Shenyang.

All panicles and plant types were measured during the maturation stage, and simple sequence repeat molecular marker-assisted detection was used for *DEP*1 gene detection. Fifteen representative plants from each plot were sampled to measure the flag leaf length (FLL), plant height (PH), panicle length (PL), and panicle number (PN). For grain number per panicle (GNPP), seed set rate (SSR) and 1 000-grain weight (TGW) measurements, at least eight representative plants from each RIL were sampled from the middle of each plot. Whole plants were dried naturally after harvesting and stored at the greenhouse for at least 1 mon before testing. Fully filled and unfilled grains were separated using sterile water.

2.2. Statistical analysis

The data were processed using Microsoft Excel software. Analysis of variance (ANOVA) on agronomic characters of Ep type, non-Ep type, LND and HND with *post hoc* Duncan's multiple range test (DMRT) was applied for mean separation using the SAS software package.

3. Results

3.1. Analysis of agronomic characters for the two types rice under LND and HND

Analysis of the *cv*. LG5, *cv*. WL422 and RIL population revealed that both progenitors were high yield varieties with different yield component strategies. In the HND conditions, typical Ep LG5 is multi-panicle type while non-Ep WL422 is heavy panicle type. The yield of parents was higher and the difference was not significant. Compared with non-Ep type WL422, PN and HI of Ep type LG5 had some significant advantages (14.6 and 16.9%), but in terms of GNPP and TGW, WL422 were 34.2 and 27.8% higher than LG5. The average RIL yield increased in the HND treatment by 35.6%. PN, TGW, and total dry weight increased by 54.9, 21.5, and 32.1% and played a significant role in increasing yield in the HND conditions. However, GNPP, SSR, FLL,