Characterization of Yield Production and Grain Quality of Erect Panicle Rice (*Oryza sativa* L.) under Varied Nitrogen Fertilizer Application

(異なる窒素施肥下における直立穂イネ品種の収量生産ならびに子実品質特性)

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Rice (*Oryza sativa* L.) is an essential crop to feed the world's growing population in Asia and Africa. In the year 2050, most of the world population will be domiciled in these respective continents. Successful breeding programs have resulted in introducing a group of high-yielding rice varieties, known as dense and erect panicle (EP) genotype conferred by *dep1*. This type of rice serves as a germplasm resource for developing new rice types with EP phenotype in China. The EP genotype had been reported to be higher yielding than the non-EP (NEP) genotype, and they had been released in commercial quantities in China. However, the yield advantage of the EP varieties as compared to NEP varieties was not consistent at different locations. The efficient utilization of applied nitrogen (N) fertilizer was not consistent in different studies. Depending on the source and sink formation affected by N fertilization and panicle types, a reduced source-to-sink ratio (available carbohydrate per spikelet; ACPS) would lead to poor grain filling and reducing grain carbohydrate accumulation causing chalky grain, particularly under high temperatures. The advantage of EP genotype would be better evaluated using near isogenic lines (NILs) regarding the *dep1* under varied culture conditions. This study was conducted to characterize the EP genotype in grain yield and quality. First, the study was conducted to understand the interaction of EP genotype and environment on yield. Then, the utilization of applied N fertilizer was examined in reference to productivity. Finally, the effect of N fertilizer on ACPS and chalkiness for improving grain quality was studied.

To evaluate the effect of EP genotype and environment interaction on yield and its components, I grew two sets of NILs of EP and NEP genotypes with Liaojing 5 (LG5) and Akitakomachi (AKI) backgrounds. The study was conducted as a joint field experiment in 2016 and 2017 in Shenyang, China, and Kyoto, Japan. In 2018, these sets were grown only in Kyoto, Japan. I grew the four NILs with 15 × 30 cm spacing (22.2 pl·m^{-2}), and we applied nitrogen fertilizer of 6 g m^{-2} as a coated urea, along with P_2O_5 (6 g m^{-2}) and K_2O (10 g m^{-2}). The average yields of EP and NEP genotypes were 6.67 and 6.13 t ha^{-1} for the AKI background and 6.66 and 6.58 t ha^{-1} for the LG 5 background, respectively. EP genotype positively affected panicle number (PN) and grain number per square meter (GNPM), mostly resulting in a positive effect on harvest index (HI). In contrast, the EP genotype negatively affected thousand-grain weight (1000GW). The ratio of the performance of the EP genotype relative to the NEP genotype in terms of yield and total biomass tended to correlate positively with mean daily solar radiation during 40 days around heading. Therefore, the advantage of the EP genotype depends on the availability of a high-radiation environment, and its effect is consistently positive for sink formation, conditional in terms of source capacity.

Secondly, to achieve the second objective, the utilization efficiency of applied N was examined in reference to productivity, using the same sets of NILs of EP and NEP genotypes with LG5 and AKI backgrounds in 2016 and 2017 in the field at Kyoto, Japan. Under N fertilization (0, 6, 20 N gm^{-2}), the effect of the EP genotype was positive on the yield and HI, but it was neutral on biomass at maturity. The effect of the EP genotype was positive also on yield, harvest index, and sink size but negative on ACPS due to reduction of nonstructural carbohydrates (NSC) at the heading stage. The biomass produced after the heading stage was not consistently affected by genotype. Its components, cumulative intercepted solar radiation (IR) and radiation use efficiency (RUE), compensated for each other's reduction or increase. The agronomic efficiency of N fertilizer (AE) and the uptake efficiency (amount of N in plants per applied N) as a component of AE, were not affected by genotype. At the same time, the biomass at maturity per N in plants [physiological efficiency for biomass; PE(Biomass)] was lower in the EP genotype than in the NEP genotype. In contrast, the yield at maturity per N in plants [physiological efficiency for yield; PE(yield)] was higher in the EP genotype than in the NEP genotype. These findings indicated that EP genotypes have a lower source-sink ratio; regardless of the N supply conditions and that the EP genotype does not affect AE. The two genetic backgrounds differed in the genotype effect on PE(yield), presumably due to plant height differences.

Thirdly, the effect of erect panicle genotype and nitrogen fertilizer application on grain chalkiness was studied for two consecutive years (2020 and 2021). Rice grain chalkiness is expected to be a severe challenge due to global warming. Chalky grains have loosely packed and unfilled starch granules in amyloplast. N fertilization is known to increase transpiration and photosynthesis and decrease chalkiness. This chapter examined the relationship between chalkiness, EP, and NEP genotypes with varied ACPS and amyloplast molecular chaperon under different levels of temperature and N treatments. The EP and NEP genotypes of LG5 were used along with Japanese japonica cultivars Nipponbare, Kinmaze, and the conditional chalky mutant *flo11-2,* which is highly sensitive to HT, as pot and field experiments in Kyoto, Japan. The chalky ratio was the highest in *flo11-2* and increased with the average daily maximum temperature (Tmax) for 20 d after flowering while decreasing with N fertilization in all cultivars. The chalky ratio was marginally higher in LG5-EP than that in LG5-NEP, possibly because of lower ACPS. Although the grain projection area, related to ACPS, was negatively correlated with the relative chalky ratio for the LG5-NEP, the correlation was positive for Japanese japonica cultivars at high temperatures. The genotypically different responses of grain projection area to N fertilization, along with a negative correlation between ACPS and N dosage in NILs of LG5, suggest that ACPS is insubstantial for chalkiness. Meanwhile, N fertilization increased the grain nitrogen concentration and accumulation of the amyloplast molecular chaperon cpHSP70-2, suggesting the involvement of cpHSP70-2 in lowering chalkiness under N fertilization.

In general, the results revealed the yield of the EP genotype was affected by background, owing partly to phenological differences and plant statures, and the yield advantage of the EP genotype tended to depend on the solar radiation environment. The sink size and HI were consistently greater with the EP genotype regardless of the environmental variation. The EP genotype reduced the ACPS due to the larger sink size and an indistinct effect on source size despite N fertilization. However, the EP genotype did not affect AE or the uptake efficiency of applied N fertilizer. But PE(yield) of the EP genotype was greater than the NEP genotype when the plant height is low, being associated with high HI. In this aspect, the EP genotype utilized nitrogen better for grain yield. In addition, N fertilization decreased grain chalkiness. However, N fertilization also decreases rice grain's eating and cooking quality. Because cpHSP70-2 assists correct folding of amyloplast-localizing enzymes such as granule bound starch synthase I, a high accumulation of cpHSP70-2 induced genetically or agronomically without N fertilization would help reduce chalkiness and deterioration of eating and cooking quality simultaneously.

The conclusions are as follows. The yield advantage of the EP genotype is dependable on the solar radiation environment, but it positive effect on the sink size and HI were not affected by the environment. The advantage of the EP genotype in HI was reduced as plant height increased, which suggests maintaining a moderate N application is necessary for greater yield advantage, as PE(yield) was greater for the EP genotype with smaller plant height. A large sink size causes a reduced ACPS because of lower NSC with smaller 1000GW and higher chalky grain than the NEP genotype, though ACPS is insubstantial for chalkiness. N fertilization reduces chalkiness, possibly owing to the increase of amyloplast molecular chaperon (cpHSP70-2).