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# Cultivar differences in the grain protein accumulation ability in rice (*Oryza sativa* L.)

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ABSTRACT

The demand for rice grain protein content (GPC) differs in different regions of the world. Despite large differences in GPC among cultivars, evaluation of the effects of genotype on GPC is difficult because GPC is influenced not only by cultivar traits (such as nitrogen uptake ability, sink size and heading date) but also by the environment. We hypothesized that grain protein accumulation ability (GPA) also affects GPC. The objective of this study was to clarify the differences in GPA among six lodging-tolerant, high-yielding Japanese cultivars: Bekoaoba, Habataki, Takanari, Hokuriku193, Momiroman, and Akenohoshi. To produce a wide variation in nitrogen availability per unit sink capacity (Nav), we used nitrogen topdressing at heading and spikelet-thinning treatment. In each cultivar, we found a logarithmic relation between GPC and Nav: $GPC = A \times \mathrm{Ln}(Nav) + B$, where A is the regression coefficient and B is a constant. A highly significant difference in regression coefficients among cultivars was found ($P < 0.01$). The regression coefficient was considered to be a measure of GPA; it varied from 0.969 in Bekoaoba to 1.820 in Takanari. This relation suggests that GPC is determined by Nav and GPA and that the environment affects GPC through Nav. GPA is a good criterion for evaluation of the effects of genotype on GPC. Nitrogen harvest index was highly significantly explained by multiple regression with GPA and the ratio of sink capacity to total dry matter production as independent variables, suggesting the influence of GPA on plant nitrogen dynamics during the grain-filling period. Therefore, it would be useful to determine the cultivars' GPA values for optimizing nitrogen management.



## 1. Introduction

Rice is the staple food for nearly half of the world's population, primarily in Asia (Mohanty, 2013), including many developing countries. Rice is an important source of proteins and calories. Although nitrogen fertilization may increase rice grain protein content (GPC), development of high- GPC cultivars is expected to ensure consistently high GPC (Hillerislambers et al., 1973; Gomez and De Datta, 1975). However, protein content affects the texture of cooked rice, increases hardness, and reduces stickiness (Hamaker and Griffin, 1990; Martin and Fitzgerald, 2002). In Japan, where sticky and tender cooked rice is favored, high GPC is considered to negatively affect rice eating quality (Matsue et al., 2001) and is not desirable. Thus, there are diverse demands in terms of rice GPC in different regions of the world.

Different cultivars differ in GPC (Perez et al., 1996; Tirol-Padre et al., 1996; Singh et al., 1998; Koutroubas and Ntanos, 2003). GPC is also affected by the nitrogen application rate, nitrogen application method, and other cultivation practices, such as planting density and weed control (De Datta et al., 1972; Gomez and De Datta, 1975). GPC in rice is correlated with plant nitrogen concentration at various growth stages (Mori et al., 2010). There are genotypic differences in the responses of GPC to nitrogen levels (Perez et al., 1996). Highly significant effects of interactions between genotype and environment or management on GPC have been reported (Perez et al., 1996; Tirol-Padre et al., 1996; Singh et al., 1998; Koutroubas and Ntanos, 2003). GPC may be affected by genotypic differences in nitrogen uptake ability at a given soil nitrogen availability, and by the ability to incorporate the absorbed nitrogen and accumulate storage protein in seeds. The grain protein accumulation ability (GPA) is a characteristic independent of plant nitrogen status and thus can be a stable criterion for the evaluation of the effects of genotype on GPC. However, to the best of our knowledge, no evaluation of the effects of genotype on GPA has been reported.

GPA is important for determination of grain quality and grain yield. The potential capacity of the sink to accumulate assimilates

*Abbreviations:* GPC, grain protein content; GPA, grain protein accumulation ability; Nav, nitrogen availability per unit sink capacity.

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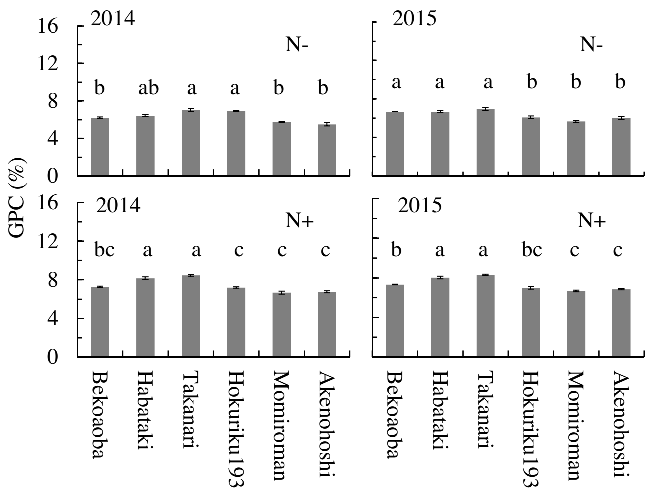


**Fig. 1.** Grain protein content (GPC) of intact plants with (N+) or without (N−) nitrogen topdressing at heading in 2014 and 2015. Data are means ± standard error (n = 3). Bars with the same letters are not significantly different at the 0.05 probability level by Tukey's test.

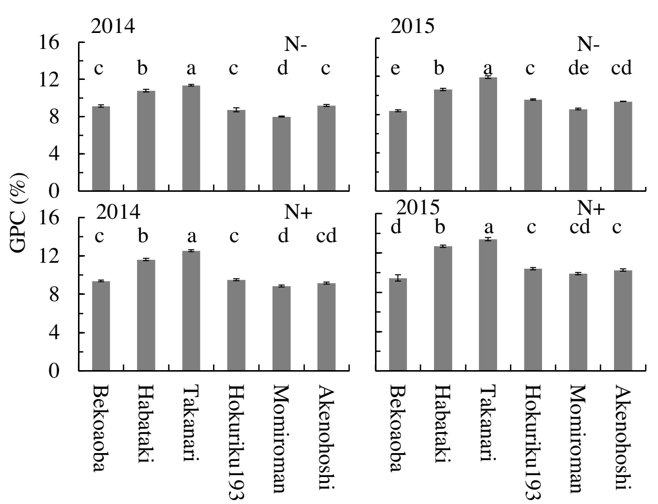


**Fig. 2.** Grain protein content (GPC) of spikelet-thinned plants with (N+) or without (N−) nitrogen topdressing at heading in 2014 and 2015. Data are means ± standard error (n = 3). Bars with the same letters are not significantly different at the 0.05 probability level by Tukey's test.

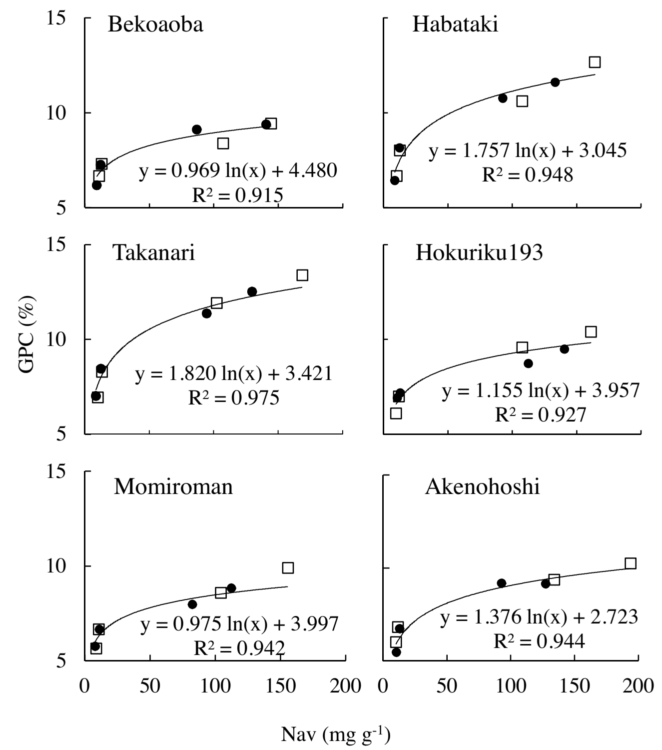


**Fig. 3.** The relation between nitrogen availability per unit sink capacity (Nav) and grain protein content (GPC). Solid circles, 2014; open squares, 2015.

is suggested to be a measure of sink strength (Marcelis, 1996); therefore, GPA can be a good measure of sink strength for nitrogen. GPA may affect nitrogen dynamics during the grain-filling period and remobilization of nitrogen from leaves, which reduces photosynthetic ability. Therefore, characterization of genotypes with different GPA may be useful for optimum nitrogen management for each cultivar.

In this study, we hypothesized that GPC is determined by GPA and the amount of nitrogen available for developing grain per unit sink capacity (Nav) and GPA was defined as the regression coefficient between GPC and logarithm of Nav. The total amount of nitrogen available for grain is the sum of the amount of new uptake during the grain-filling period and the amount which can be remobilized from leaves (Yoshida et al., 2016). Sink capacity affects nitrogen dynamics during the grain- filling period (Wada and Wada, 1991; Ida et al., 2009). The objective of this study was to determine and compare GPA among six high-yielding, lodging-tolerant cultivars with different GPC. To produce a wide variation in Nav, nitrogen topdressing at heading and spikelet thinning were conducted.

## 2. Materials and methods

### 2.1. Plant materials

Field experiments were conducted at Ishikawa Prefectural University, Nonoichi, Japan (36°02′N, 140°04′E) in 2014 and 2015, in Gray Lowland soil. Six Japanese rice (*Oryza sativa* L.) cultivars with different genetic backgrounds – Bekoaoba, Habataki, Takanari, Hokuriku193, Momiroman, and Akenohoshi – were grown under irrigation. These are high-yielding lodging-tolerant multipurpose cultivars that have been bred by crossing *japonica* and *indica* cultivars. Bekoaoba, Momiroman, and Akenohoshi are *japonica*-dominant, whereas Habataki, Takanari, and Hokuriku193 are *indica*-dominant (Yamamoto et al., 2010).

Seeds were sown in a seedling nursery box. In 2014, 21-day-old seedlings of Bekoaoba, Habataki, and Takanari (early cultivars) and 35-day-old seedlings of Hokuriku193, Momiroman, and Akenohoshi (late cultivars) were transplanted on 23 May. In 2015, 25-day-old seedlings of early cultivars and 35-day-old seedlings of late cultivars were transplanted on 22 May. One seedling per hill was transplanted (22.2 hills $m^{-2}$; 15 cm between hills; 30 cm between rows). Late cultivars were sown earlier to ensure harvesting before rainy and cold weather starts. All cultivars received a total of 8 g N $m^{-2}$ (4 g $m^{-2}$ as basal dressing at puddling and 4 g $m^{-2}$ as topdressing at panicle formation stage, 18–20 days before heading). At heading, half of each plot received 4 g N $m^{-2}$ as topdressing (N+) while the other half did not (N−). Nitrogen was applied as ammonium sulfate. Phosphorus (10 g $m^{-2}$ as calcium superphosphate) and potassium (10 g $m^{-2}$ as potassium chloride) were also applied to all plots as basal fertilizers. Weeds, insects, and diseases were controlled with standard chemicals as necessary. The experimental plots (18 $m^2$) were arranged in a split-plot design (main plots and subplots were cultivar and nitrogen topdressing, respectively) with three replicates.