Differences in Protein Content, Amylose Content and Palatability in Relation to Location of Grains within Rice Panicle

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Abstract: The protein and amylose content of milled rice grains collected from the top and base rachis branches at different positions on the panicle were measured. The palatability of the grains on primary and secondary rachis branches were also investigated. Grains on upper rachis branches had a lower protein content than those on lower rachis branches with a gradual change from the base to the top of both primary and secondary rachis branches. Grains on primary rachis branches also had lower protein content than those on secondary rachis branches at any position within the panicle. Conversely, amylose content on upper rachis branches was higher than that on lower rachis branches, and that on primary rachis branches was higher than that on secondary rachis branches. Protein content and amylose content varied widely within the panicle with 1.2% and 3.3%, respectively, range at maximum. Grain weight was negatively correlated with protein content and positively correlated with amylose content. Grains which originated from early flowering spikelets generally had low protein content and high amylose content. The palatability of the grains on primary rachis branches was superior to grains on secondary rachis branches, both in Koshikikari and Nippomare. It was concluded that the variations in protein content and amylose content, and differences in palatability within a rice panicle were caused by the differences in the extent of grain filling, which was closely related to the flowering order of spikelets. This leads us to suppose the varieties with high and stable palatability in any growth environment could be raised from genetic resources which have more grains on primary rachis branches in the ear or on the secondary rachis branches in the upper position of the ear.

Keywords: Amylose content, Flowering order, Grain weight, Palatability, Protein content, Rice grain, Rice panicle, Rachis branch.

The flowering period of spikelets within the rice panicle is long and the flowering date of an individual spikelet is dependent on its location on the panicle. It results in differences in growth, weight, maturity, grain-filling ability and quality among rice grains within the panicle. Oota et al. reported that seed-setting rate and 1000-grain weight on secondary rachis branches was inferior to that on primary rachis branches. Kambayashi et al. reported that number of grains on the secondary rachis branches was greatly influenced by environment. Kawatake, and Caudhry and Nagato reported that the development and function of primary rachis branch vascu-
lar bundles was superior to that of secondary rachis branch vascular bundles. Matsumoto and Yoshida\(^6\) reported the differences in grain appearance in primary and secondary rachis branches. These reports suggest that there are differences in physicochemical properties among grains. Horiuchi\(^6\) reported a wide amylose content variation among individual grains in a single panicle. It is also expected that palatability may differ among grains in a panicle. Therefore, more detailed analysis is needed to clarify the relationships and variation in palatability and physicochemical components among grains in a panicle.

In the present study, the variation in protein content and amylose content within the rice panicle was studied by separating rachis branches into primary and secondary branches. In addition, a sensory test was conducted to ascertain the palatability differences between the grains on primary and secondary rachis branches.

**Materials and Methods**

Two Japanese rice cultivars with varying palatability; Koshihikari (a highly palatable cultivar) and Nipponbare (a moderately palatable cultivar), were used. These cultivars were grown at the experimental field of the Buzen Branch of Fukuoka Agricultural Research Center in 1991 and 1992. Seedlings of each cultivar were transplanted in the paddy field on June 15, with a planting space of 15 cm × 30 cm (four plants per hill). The total amount of nitrogen fertilizer application for Koshihikari and Nipponbare was 8.5 kg and 9.5 kg per 10 a, respectively. Koshihikari plants matured in late September and Nipponbare plants matured in early October. After harvesting, plants were solar-dried.

Preliminary observations showed that the most frequent number of primary rachis branches from the main stem was 10 for both cultivars. Therefore, about 80 ears with 10 primary rachis branches from the main stem were harvested in 1991 for each cultivar. The number of secondary rachis branches of Koshihikari and Nipponbare were about 17 and 14 per panicle, respectively. As indicated in Fig. 1, rachis branches were designated as I (panicle base) to X (top), and each rachis branch was separated into primary and secondary branches. Grains were collected from the primary branch and secondary branch at different positions on the panicle. Rice grains from the separated samples were hulled and milled at a 90% milling rate before analysis.

Protein and amylose analysis was carried in January, 1992, using rice grains harvested in 1991. Methods of protein and amylose analysis were described in the previous paper\(^5\).

Flowering order of spikelets on main stem was observed in August, 1992. The observation of anthesis was conducted from 9 a.m. to 3 p.m., during the flowering period. Three ears per cultivar were observed and averaged. Flowering order of spikelets was expressed with sequence numbers of date of anthesis by counting the first date of anthesis as 1. Sensory tests on cooked rice were conducted in February 1993 for Koshihikari and Nipponbare harvested in 1992. Milled grains on primary and secondary rachis branches were tested. Grain thickness of the brown rice used in this sensory test was over 1.8 mm. The reference cultivar for the sensory test was Nipponbare, mixing the grains from primary and secondary rachis branches. The following four sensory attributes were evaluated by 15 panel members for overall eating quality, stickiness, appearance and taste of cooked rice. Other details of the evaluation were described in the previous paper\(^5\).

**Results and Discussion**

1. **Protein content in different positions on a panicle.**

Protein content differed among their positions on a panicle. In both Koshihikari and Nipponbare, the protein content of upper rachis branches was lower than that of lower rachis branches (Fig. 1) and for primary rachis branches, it was lower than that for secondary rachis branches.

In Koshihikari, protein content in primary and secondary rachis branches ranged from 6.1% to 6.8%, and from 6.3% to 7.1%, respectively. In Nipponbare, it ranged from 6.8% to 7.4%, and from 6.9% to 8.0%, respectively. In any position, the protein content of the high palatability cultivar, Koshihikari, was lower than that of the moderate palatability cultivar, Nipponbare. This indicates that not only the total amount of protein accumulation, but also the protein content of each rachis branch within a panicle, were dependent on the
cultivars.

In Koshihikari, 1000-grain weight in primary and secondary rachis branches ranged from 20.5 g to 21.8 g, and from 16.9 g to 19.7 g, respectively. In Nipponbare, it ranged from 22.0 g to 22.8 g, and from 19.1 g to 21.1 g, respectively. In any position, 1000-grain weight of Koshihikari was lower than that of Nipponbare.

Protein content of milled grains from primary and secondary rachis branches showed a significant (p<0.01) negative correlation with 1000-grain weight (Fig. 2) and a positive correlation with flowering order (Fig. 3). In Koshihikari, flowering order in primary and secondary rachis branches ranged from 4.1 to 1.8, and from 6.0 to 2.6. In Nipponbare, it ranged from 4.8 to 1.8, and from 7.0 to 2.6, respectively. In any position, flowering period of Koshihikari was shorter than that of Nipponbare.

The upper position of the rachis branches flowered earlier than the lower position of the rachis branches. This trend on flowering order was approximately similar to that in other studies. The result suggests that the early flowering spikelets had the advantage in competing for starch distribution.

2. Amylose content in different positions on a panicle

Amylose content of milled grains from primary and secondary rachis branches differed among their positions on a panicle and showed an opposite tendency to protein content. In both Koshihikari and Nipponbare, amylose content of milled grains from upper rachis branches was higher than for lower rachis branches (Fig. 4). Between primary and secondary rachis branches, amylose content of primary rachis branches was higher than that of secondary rachis branches.

In Koshihikari, amylose content in primary and secondary rachis branches ranged from 16.0% to 18.4%, and from 15.1% to 16.8%, respectively. In Nipponbare, it ranged from 19.4% to 20.9%, and from 17.6% to 20.5%, respectively. In any position, the amylose content of the high palatability cultivar, Koshihikari, was lower than that of the moderate palatability cultivar, Nipponbare. This indicates that not only total the amount of amylose accumulation but also the amylose content of each rachis branch within a panicle was dependent on cultivars.

Amylose content of milled grains between primary and secondary rachis branches showed a significant (p<0.01) positive correlation with 1000-grain weight (Fig. 5) and a negative correlation with flowering order (Fig. 6). Kamata and Matsushima reported that amylose content of thick grain was higher than that of thin grain. These results suggest that grains that originate from early flowering spikelets have the advantage in competition for amylose synthesis. In addition, it is estimated that differences in amylose content in relation to the location of grains within a panicle are due to the difference in activity of starch synthesizing enzymes for amylose synthesis, which vary with different rachis branch positions in a panicle, as reported by Umemoto.

![Fig. 1. Protein content of milled grains in primary and secondary rachis branches at different positions on a panicle.](image)

Roman numerals: order of the rachis branch from top (X) to base (I), within a rachis. The upper Arabic numerals: Koshihikari, The lower Arabic numerals: Nipponbare. * : materials from I and II were, ** : materials from IX and X were mixed.
Fig. 2. Relationship between protein content and 1000-grain weight in the rachis branches at different positions on a panicle.
- ○: Koshihikari, primary rachis branch,
- △: Koshihikari, secondary rachis branch,
- ●: Nipponbare, primary rachis branch,
- ▲: Nipponbare, secondary rachis branch,
- *, **: 5%, 1% level of significance.

Fig. 3. Relationship between protein content and flowering order in the rachis branches at different positions on a panicle.
Symbols are the same as those in Fig. 2. **: 1% level of significance.

Fig. 4. Amylose content of milled grains in primary and secondary rachis branches at different positions on a panicle. Symbols are the same as those in Fig. 1.

In this report, well-developed grains had a high amylose content within a cultivar, though a cultivar with a relatively low amylose content is considered to have high palatability compared with other cultivars. Baun et al. reported that activation of starch synthase during the ripening stages was proportional to the amylose content. This suggests that the amylose content of seeds is dominated by the activation of starch synthase. It is estimated that the high amylose content of well-developed grains is due to the high activity of starch synthase in rice endosperm.

3. Palatability of grains from primary and secondary rachis branches

In Koshihikari, the values of overall eating quality, appearance, taste and stickiness for the grains on primary rachis branches were positive as compared with the reference cultivar (table I). The values for the grains from secondary rachis branches, however, were minus. In Nipponbare, the values for the grains from primary rachis branches were near to zero, or minus, and the values for the
secondary rachis branches were significantly low.

Generally speaking, the sensory attributes (overall eating quality, stickiness, appearance and taste of cooked rice) of grains from primary rachis branches were superior to the those of grains from secondary rachis branches in both Koshihikari and Nipponbare.

These results indicate that the poor palatability of the grains on secondary rachis branches could lower the overall palatability of the whole ear. Palatability of the whole ear could be influenced by the ratio of the number of grains from primary and secondary rachis branches.

The deterioration of palatability on secondary rachis branches could be due to the increase of protein content and the remarkable decrease of amylose content. This suggests that amylose content must be within a optimum range.

Locational differences in the protein content and amylose content of milled rice grains on primary and secondary rachis branches were dependent upon the difference of maturity of individual grain, which was related to the flowering order of spikelets. This information
would be very useful for accurate measurement of protein content and amyllose content of milled rice. The materials should be collected and adjusted uniformly.

It is evident that the palatability and quality (appearance of grains) are significantly affected by difference in maturity between grains due to locational distribution of spikelets within an ear.

Sasahara et al.\textsuperscript{23} described differences in increasing rate of ear dry weight between different rice ecotypes resulted from differences in the structure of the ear, and Indica varieties, which showed a higher increasing rate of ear dry weight than Japonica ones and had abundant secondary rachis branches at the upper position of the ear. Nagato et al.\textsuperscript{19} reported that spikelets on secondary rachis branches in the upper position of the ear were dominant spikelets. These results may suggest that a) cultivars with a larger number of spikelets on the primary rachis branches than those on the secondary rachis branches or b) cultivars with a large number of spikelets on secondary rachis branches at the upper rachis nodes, but with a few spikelets on the lower rachis node, have advantages in faster development or weight heavier. Hence, The varieties with high and stable palatability in any growth environment could be raised from genetic resources which have more grains on primary rachis branches in the ear, or on the secondary rachis branches in the upper position of the ear.

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* In Japanese.
** In Japanese with English summary.
*** In Japanese with English abstract.
**** Translated from Japanese by the present authors.