Physico-ecological Studies on Quality Formation of Rice Kernel

II. Changes in quality of rice kernel during grain development*

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Abstract : Changes in the quality of nonwaxy and waxy rice during grain development were investigated, laying emphases on the texture of cooked rice and protein, amylose and fat-by-hydrolysis contents. In terms of textural features, chewiness value decreased with maturity, but stickiness and the textural palatability index values increased. The trends of decrease or increase became constant after 30-40 days after heading. There were no clear differences in the formation mechanism of texture during maturation between nonwaxy and waxy rice. Changes in the contents of protein, amylose and fat-by-hydrolysis with maturity were similar to those in chewiness. At the early maturing stage, the protein content of the rice kernels was very high. Protein seemed to restrict starch swelling, so that cooked rice from immature kernels were thought to be harder and less sticky. Amylose was considered to be a dominant factor in determining texture during ripening. The texture of waxy rice also changed although amylose was not detected throughout the ripening period. Hence, amylose could not be the only factor that might control textural changes. Since fat-by-hydrolysis was relatively abundant at the early stage of ripening, it was thought to make cooked rice harder and less sticky by limiting starch swelling. For the reasons mentioned above, protein, especially water-insoluble protein, amylose and fat-by-hydrolysis were found to play an important role in restricting the expansion of starch.

Key words : Amylose, Eating quality, Fat-by-hydrolysis, Grain development, Protein, Rice, Texture.

米の品質形成に関する生理・生態学的研究 第2報 登熟にともなう米質の変化：玉置雅彦・江幡守衛・田代 亨・石川雅士（名古屋大学農学部）

要 旨：うるち米，もち米における登熟にともなう米質の変化を，米質のテクスチャー，タンパク質，アミロース，結合脂質 (fat-by-hydrolysis) 含有率の点から検討した。登熟にともないテクスチャーのそしゃく性値は減少し，粘着性および食味指数値は増加し，出穂後 30—40 日目以降一定となった。登熟過程におけるテクスチャーの形成機構には，うるち米ともち米の間に明らかな差異は認められなかった。登熟にともないタンパク質，アミロース，結合脂質含有率は，そしゃく性の変化と同様に变化した。登熟初期は，米粒中のタンパク質含有率は大変高いことから，タンパク質によりデンプンの膨潤が阻害され，未熟粒の米飯は硬く粘りがないものになると考えられた。アミロースも，登熟にともなうテクスチャーの変化要因として考えられた。しかしもち米では，登熟中アミロースは認められないにもかかわらず，テクスチャーは変化することから，アミロースはテクスチャーの変化を支配する唯一の要因ではなかった。未熟期には結合脂質含有率が高いことから，結合脂質もデンプンの膨潤を妨げて米飯を硬く粘りがないものにすると考えられた。以上から，タンパク質，とくに難溶性タンパク質，アミロースおよび結合脂質がデンプンの膨潤を阻害する上で，重要な役割を果たしているものと思われた。

キーワード：アミロース，結合脂質 (fat-by-hydrolysis)，米，食味的品質，タンパク質，テクスチャー，登熟。

Much work has been done on eating quality of rice, but there were only few studies on its changes during grain development⁵⁾. Since eating quality changes with ripening, its formation mechanism needs studying. Hence, this study was conducted to make clear the

changes of eating quality of rice during grain development, with special emphases on the texture of cooked rice and protein, amylose and fat-by-hydrolysis contents.

Materials and Methods

Nonwaxy rice plants (*Oryza sativa* L.), cvs. Sasanishiki and Nipponbare, were grown both in 1984 and 1987, and waxy rice plants, cvs.

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Koganemochi and Iwaimochi, were grown in 1987 at the experimental field of Nagoya University.

Developing nonwaxy grains were sampled every ten days from 15 to 45 days after heading (DAH) in 1984, and they were used for texture and protein analysis. Developing waxy and nonwaxy grains were sampled every five days from 15 to 30 and 40, 50 DAH in 1987. Waxy grains were used for texture, protein, amylose and fat-by-hydrolysis, and nonwaxy grains for amylose and fat-by-hydrolysis analysis. All the samples were dehulled and milled at a milling rate of about 91% with a small test mill (Kett Pālest). Poorly ripened and checked kernels were taken out from the test samples. Only superior spikelets kernels were used for the samples at 15 and 20 DAH, and the embryos were discarded with a pincette after removing bran with a test mill. The measurement method used to determine the texture of the cooked rice, and the analytical methods used for protein, amylose and fat-by-hydrolysis determinations were the same as described in the previous paper¹³⁾. The contents of protein and amylose were shown as average of two duplications, and the fat-by-hydrolysis content was shown as mean values of three duplications.

Results

1. Changes in the texture of cooked rice during grain development

Textural parameters of cooked rice are shown in Fig. 1 and Fig. 2. Hard features are shown inclusively by a parameter "chewiness" and sticky features by another parameter "stickiness". The textural palatability index (TPI), which is the value product of chewiness and stickiness⁴⁾, has been used as a general index of eating quality in nonwaxy rice^{4,5,13)}. Since generally waxy rice is eaten differently from nonwaxy rice, TPI value was not shown. Chewiness value was very high at the early stage of ripening, but it decreased rapidly with ripening and became constant afterward in nonwaxy rice. On the contrary, both stickiness and TPI values increased during maturation up to 35 DAH and decreased slightly thereafter. These trends agreed with the result of Ebata et al.⁵⁾ In waxy rice, chewiness value decreased with ripening but it became constant after 30-40 DAH. On the

Fig. 1. Changes in chewiness, stickiness and the textural palatability index during grain development of nonwaxy rice.

○, △, □, Sasanishiki; ●, ▲, ■, Nipponbare.
 --- : chewiness, — : stickiness, : textural palatability index.

Fig. 2. Changes in chewiness and stickiness during grain development of waxy rice.

○, □, Koganemochi; ●, ■, Iwaimochi.
 --- : chewiness, — : stickiness.

other hand, stickiness value kept increasing during maturation until after 30 DAH and reached a plateau afterwards. These trends of waxy rice were the same as those of nonwaxy rice and there were no differences in the formation mechanism of texture during ripening between nonwaxy and waxy rice. However, chewiness value of waxy rice was much lower than that of nonwaxy rice throughout the ripening stage, but stickiness value of the former was much higher than that of the latter. Varietal differences in the texture of waxy rice were rather smaller as compared with nonwaxy rice.

2. Changes in the protein content during grain development

Changes in the total protein (water-

Fig. 3. Changes in the total protein content of milled rice during grain development.
■, Sasanishiki; ▲, Nipponbare; □, Koganemochi; △, Iwaimochi

Fig. 5. Changes in the amylose content in rice starch during grain development.
Symbols are the same as those in Fig. 3.

soluble+water-insoluble) content of milled rice during ripening are illustrated in Fig. 3. Total protein content was high at 15 DAH, but it decreased with maturity up to 30-35 DAH. The decrease in protein content was caused mainly by the decrease in water-insoluble protein which comprised most of rice kernel protein (Fig. 4).

3. Changes in the amylose content during grain development

Changes in the amylose content in rice starch are shown in Fig. 5. The figure shows that the amylose content was high at the early developmental stage, but it decreased with the progress of maturation and became constant after 30 DAH in nonwaxy rice. In waxy rice,

Fig. 4. Changes in the water-insoluble and water-soluble protein contents of milled rice during grain development.

— : water-insoluble protein,
--- : water-soluble protein.

Symbols are the same as those in Fig. 3.

Fig. 6. Changes in the fat-by-hydrolysis content in rice starch during grain development.

Symbols are the same as those in Fig. 3.

however, amylose was not detected throughout ripening. Many researchers reported that the amylose content in nonwaxy rice starch increased during maturation^{1,2,12)}. However, all of these works were undertaken from around 5 days after flowering. Asaoka et al.¹⁾ reported that the amylose content in nonwaxy rice starch increased from 5 to 17 days after flowering, but it decreased slightly afterwards. In this study the determination of amylose was

Table 1. Correlations between textural parameters and water-insoluble protein,

	Sasanishiki			Nipponbare			Koganemo	
	WIPC	AC	FBHC	WIPC	AC	FBHC	WIPC	AC
chewiness	0.976	0.998**	0.993**	0.987*	0.972	0.952	0.938**	—
stickiness	-0.932	-0.901	-0.913	-0.977	-0.947	-0.925	-0.994***	—
TPI	-0.862	-0.823	-0.831	-0.889	-0.925	-0.839	—	—

1) WIPC ; water-insoluble protein content, AC ; amylose content, FBHC ; fat-by-hydrolysis content, TPI ; textural palatability index.

2) n=4 (Sasanishiki, Nipponbare), n=6 (Koganemochi, Iwaimochi).

3) *, **, *** indicate significant differences at 5%, 1%, 0.1% level, respectively.

conducted on the rice samples at 15 DAH and thereafter. The findings were the same as the result of Asaoka et al.¹⁾.

4. Changes in the fat-by-hydrolysis content during grain development

Changes in the fat-by-hydrolysis content in rice starch during ripening are shown in Fig. 6. The contents both in nonwaxy and waxy rice were considerably high at 15 DAH, but decreased with maturation and became constant after 30 DAH. This result showed a quite similar trend to that of bound lipid in developing wheat¹⁰⁾. Choudhury and Juliano³⁾, however, reported that the proportion of fat-by-hydrolysis in brown rice increased in the developing grain. The fat-by-hydrolysis content of nonwaxy rice was much higher than that of waxy rice, and the degree of decrease in the former was larger than that in the latter.

5. Correlations between textural parameters and water-insoluble protein, amylose, fat-by-hydrolysis contents

In nonwaxy rice, chewiness was positively correlated to water-insoluble protein, amylose and fat-by-hydrolysis contents. On the other hand, stickiness and TPI were negatively correlated with them. In waxy rice, it was found out that there were high positive correlations between chewiness, water-insoluble protein and fat-by-hydrolysis contents. However, negative correlations were revealed between stickiness, water-insoluble protein and fat-by-hydrolysis contents (Table 1).

Discussion

In both nonwaxy and waxy rice, chewiness value was high, but stickiness value was low at the early stage of ripening. However, the former decreased and the latter increased with maturation, and the curve trends became a

plateau after 35 DAH in nonwaxy rice and 30-40 DAH in waxy rice. Changes in the contents of protein, amylose and fat-by-hydrolysis were similar to those in chewiness during ripening. Changes in the protein content were mainly due to those in water-insoluble protein. Protein is thought to restrict starch expansion by encircling starch granules and disturbing the water penetration¹¹⁾. Hence, when the protein content of the rice kernel was high at the early stage of ripening, cooked rice was hard and less sticky. As its content decreased with maturity, chewiness value decreased and stickiness value went up. This was thought to be due to the relative decline of a starch-swelling-restrictive mechanism of protein. A previous paper¹³⁾ showed that the texture of high protein rice was undesirable. In this report, protein, especially water-insoluble protein, was suggested to adversely affect the texture of cooked rice.

The amylose content has been regarded as a general index for eating quality of cooked rice^{8,9)}. In this research, it was found out that cooked rice of Nipponbare, whose amylose content was higher than that of Sasanishiki, was harder and less sticky than the latter. In addition, cooked rice was harder and less sticky at the early maturing stage when the amylose content was high. The varietal differences in the texture were very small in the case of waxy rice whose starch was made up of amylopectin alone. Although amylose was not detected at any stage of maturation in waxy rice, cooked waxy rice was also hard and less sticky at the early developing stage ; moreover its chewiness value decreased and stickiness value increased with maturity. Hence, in this case, amylose could not be an influential factor of texture formation.

amylose, fat-by-hydrolysis contents.

chi	Iwaimochi		
FBHC	WIPC	AC	FBHC
0.944**	0.993***	—	0.985***
−0.976**	−0.978***	—	−0.928**
—	—	—	—

Fat-by-hydrolysis, starch-bound fatty acids, means fatty acids derived from starch lipids (bound lipids) released by hydrolysis. Fat-by-hydrolysis is considered to complex with amylose in starch and to inhibit starch swelling by disturbing water absorption⁷⁾. When the fat-by-hydrolysis content was high at the early stage of ripening, cooked rice became hard and less sticky. When its content decreased with maturation, chewiness value decreased and stickiness value increased. This was due to the relative decline of a starch-swelling-restrictive mechanism of fat-by-hydrolysis. Although much work has been done on the relationship between amylose content and eating quality of cooked rice, fat-by-hydrolysis content should be considered in future. However, it is thought that more detailed study should be done to discuss the effect of the difference in fat-by-hydrolysis content on the texture of cooked rice in this study. A small amount of fat-by-hydrolysis was found in waxy rice starch, although no amylose was detected. Fujino and Miyazawa⁶⁾ reported that not only amylose but also amylopectin could combine with fatty acids. Therefore, it was thought possibly that fat-by-hydrolysis might combine with the long-chain-parts of amylopectin molecule forming a micelle structure as well as amylose.

From the reasons discussed above, water-insoluble protein, amylose and fat-by-hydrolysis were found to play an important role in restricting the expansion of cooked starch.

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