Food Sci. Technol. Res., **6** (4), 252–256, 2000

Effects of Early Harvesting of Grains on Taste Characteristics of Cooked Rice

Eiko ARAI[1] and Tomio ITANI[2]

[1] *Faculty of Education, Shizuoka University, Shizuoka, 422-8529, Japan*
[2] *School of Bioresources, Hiroshima Prefectural University, Shobara, Hiroshima, 727-0023, Japan*

Received December 24, 1999; Accepted July 17, 2000

In order to clarify the effects of early harvesting of rice grains on the taste characteristics of cooked rice, especially on the taste items of "sweetness" and "deliciousness," we compared "early-harvest" rice which was harvested 10 days before the ordinary harvest time and "ordinary-harvest" rice which was harvested at the usual time. From the results of sensory tests, the cooked early-harvest rice was evaluated as being sweeter and more delicious than the cooked ordinary-harvest rice. The greater sweetness in the former rice was primarily due to the formation of glucose, maltose and maltoligosaccharides from starch, probably by starch degradation enzymes during soaking and/or cooking. The cooked early-harvest rice also contained more L-glutamic acid than the cooked ordinary-harvest rice. From these results, it was concluded that when rice is harvested 10 days before the ordinary time of harvesting, the cooked rice will be sweeter and more delicious.

Keywords: early harvesting, cooked rice, sweetness, maltoligosaccharides, starch degradation enzyme

The time of harvesting rice grains has conventionally been determined from the standpoints of attaining a good external appearance, getting sufficient yield and making the harvesting work easier, without taking the eating quality of the harvested grains into account. On the other hand, when the harvesting time of rice has been extremely retarded or advanced the taste of cooked rice has been reduced; suggesting that the time of harvest of the grains can have a critical influence on the quality of cooked rice. To identify an optimum harvesting time to assure rice of good eating quality, many studies have examined factors related to taste such as the contents of amylose and protein in milled rice (Taira *et al*., 1978; Asaoka *et al*., 1985; Tamaki *et al*., 1989a; Matsue *et al*. 1991; Takebe *et al*., 1994) and the texture parameters of cooked rice (Ebata *et al*., 1982; Tamaki *et al*., 1989a) in relation to the time of harvesting. It has been asserted in these studies that an adequate period of time for harvesting rice grains to obtain cooked rice of good quality is about 40 days after heading (Ebata *et al*., 1982).

More, recent reports showed that in addition to such taste components as amylose and protein, other characteristics of sweetness and deliciousness greatly contribute to the quality of cooked rice (Tamaki *et al*., 1989b; Matsuzaki *et al*., 1992; Sugiyama *et al*., 1995; Arai *et al*., 1997). However, the optimum time for harvesting grains with special reference to the taste characteristics of cooked rice has scarcely been examined to date.

The objective of the present study was thus to clarify the effects, which the harvest time, especially early harvest, has on these previously unevaluated taste characteristics of cooked rice, as well as on taste characters, which have already been subjected to research.

Materials and Methods

Plant materials Rice plants (*Oryza sativa* L. cv. Koshihikari) grown at Nita-cho in Shimane Prefecture in 1997 were used. Developing grains were sampled at 32 and 42 days after heading. These two kinds of harvested grains are hereafter referred to as "early-harvest" and "ordinary-harvest" grains, respectively. All of the early-harvest and ordinary-harvest rice grains were immediately dried after harvest until the water content reached 15%, then dehulled and milled to a milling yield of 90±1%.

Protein and amylose contents of milled rice The nitrogen content of milled rice was determined by the semi-micro Kjeldahl method. The protein content of milled rice was obtained from the nitrogen content by multiplying it by a factor 5.95. Amylose content of the milled rice was estimated by the iodine colorimetric method of Juliano (Juliano, 1971). Three independent measurements were made of each sample and the result was expressed as an average±standard error.

Free sugar content of milled rice grains Milled rice grains were pulverized with a test mill (TM-05, Satake Co., Hiroshima) into an outer part (the surface of a brown rice grain, from 10% to 22% of the whole grain) and an inner part (the remaining central portion) and then sieved through a 100-mesh sieve. The pulverized milled rice flour (10 g) was mixed with water (50 ml) and stirred at under 25°C for 3 h. The mixture was centrifuged (19,000×*g*, 20 min) and the supernatant was subjected to high performance liquid chromatography (HPLC). Instead of water, 10 mM mercuric chloride as an inhibitor of starch degradation enzymes was used for extraction. The conditions of HPLC were as follows: apparatus, PU-980; column, Finepak SIL NH_2-5 (both from Japan Spectroscopic Co., Tokyo); solvent, acetonitrile/water (7/3); flow rate, 1 ml/min; column temperature, 40°C; and detector, reflection indicator, 830-RI (also from Japan Spectroscopic Co.). Three independent measurements were made of each sample and the result was expressed as an average.

Rice cooking For each sample of milled rice, 145 g of the early-harvest or ordinary-harvest was washed three times with

E-mail: ejearai@ipc.shizuoka.ac.jp

water (200 ml each) and soaked in water of up to 1.5 times the weight of the grains at 25°C for 60 min. The samples were cooked in an electric rice cooker (SR-30F, Matsushita Electronic Co., Osaka) for 18 min, then kept warm ("murashi") for 12 min.

Sensory test of cooked rice The evaluation was carried out by panels composed of 20 male and female students (20–23 years old) at Shimane University. The sensory test of cooked rice prepared with both early- and ordinary-harvest grains was done according to the standard Japanese method for cooked rice evaluation (National Food Research Institute of Japan, 1961). Seven factors of the cooked rice samples (color, brightness, hardness, stickiness, sweetness, deliciousness and overall judgment) were evaluated using a seven-grade rating scale from +3 (positive) to −3 (negative). The cooked rice made from ordinary-harvest rice grains was used as a reference (zero value) for this sensory evaluation.

Instrumental measurement of color of cooked rice The color of the cooked rice was measured with a color difference meter (CR-300, Minolta Co., Osaka), based on the L^*, a^*, and b^* values in the CIE 1976 (L^*, a^*, b^*)-Space (JIS Z 8729). The color difference (ΔE^*ab) between the early-harvest and the ordinary-harvest rice grains was then calculated using the following formula:

$$\Delta E^*ab=[(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}.$$

Ten independent measurements were made of each sample and the result was expressed as an average±standard error.

Degree of gelatinization of cooked rice A portion taken from the center of the rice cooker was collected immediately after "murashi" and finely ground in cold ethanol and cold acetone with a mortar and pestle to obtain a dehydrated powder sample. The degree of gelatinization of the resulting samples was estimated by the β-amylase-pullulanase method (Kainuma *et al.* 1981). Three independent measurements were made of each sample and the result was expressed as an average±standard error.

Amount of hot-water extractable starch liberated from cooked rice Hot-water extractable starch was prepared from the cooked rice (10 g) by extraction with boiling water (100 ml) under gentle stirring (3 min). The mixture was filtered through a glass filter (11G-P100, Shibata Science Co., Tokyo) to separate the glutinous substance (containing the hot-water extractable starch) from the residue of cooked rice grains. The total reducing sugar content of the glutinous substance was measured by the Somogyi-Nelson method (Nelson, 1944; Somogyi, 1952). After hydrolysis of the glutinous substance with 2 N trifluoroacetic acid at 100°C for 4 h, the sugar content of the hydrolysate was measured as above. The hot-water extractable starch was calculated from the difference between the sugar content before and after hydrolysis by the method of Fraser and Hoodless (1963). Five independent measurements were made of each sample and the result was expressed as an average±standard error.

Measurement of texture of cooked rice The hardness and stickiness of cooked rice grains were measured with a Texturometer (GTX-2, General Foods-Zenken Co, Tokyo) by the three-grain method (Okabe, 1979). The conditions for the measurement were as follows: sample size, 3 grains; plunger, Lucite (18 mm in diameter); clearance, 0.2 mm; bite speed, 6 times/min; and sample temperature at the time of measurement, 25°C. The most important parameter, the stickiness/hardness ratio proposed by Okabe (1979), was also determined. Ten independent measurements were made of each sample and the result was expressed as an average±standard error.

Free sugar content of cooked rice The glutinous substance obtained by the above extraction process was centrifuged (19,000×*g*, 20 min) and the supernatant was concentrated ten-fold by evaporation *in vacuo*. The concentrated sample was tested by the same HPLC as above. The residual cooked rice grains separated from the glutinous substance (5 g) were mixed with water (25 ml) and then homogenized (10,000 rpm, 5 min) with a homogenizer (500 AC-2, Sakuma Co., Tokyo). The homogenate was centrifuged (19,000×*g*, 20 min) and the supernatant was concentrated to ten-fold by evaporation *in vacuo*. The concentrated sample was also tested by HPLC. Three independent measurements were made of each sample and the result was expressed as an average.

Content of L-glutamic acid of cooked rice The amount of L-glutamic acid contained in the glutinous substance and in the residual grains of cooked rice obtained by this extraction method were measured with an F-kit for L-glutamic acid (Boehringer Mannheim, Tokyo). Five independent measurements were made of each sample and the result was expressed as an average±standard error.

Statistical analysis Comparison of the two means were made by Student's *t*-test (Fisher, 1958).

Results and Discussion

Rice grain characteristics of the early-harvest rice The rice grain characteristics of early-harvest rice, which would affect the texture of cooked rice, were identified using 1000-kernel weights of the brown rice and milled rice and the amylose and protein contents of milled rice (Table 1).

The 1000-kernel weight of the early-harvest brown rice was significantly less than that of the ordinary-harvest brown rice, but in the milled rice, no significant difference was noted between them. While the amylose content has been reported to increase at the initial stage of ripening and to decrease slightly in the full-ripe stage (Matsue *et al*., 1991), the present experiment showed no significant difference in amylose content between the ordinary-harvest and the early-harvest rice (harvested 10 days earlier). The protein content likewise has been reported to be high in the initial stage of ripening and then to decrease in the full-ripe stage (Matsue *et al*., 1991), but again no significant difference was noted between the two groups in the present study.

Sensory test and related sensory characters of the cooked early-harvest rice Table 2 shows the sensory scores of the

Table 1. Characteristics of the early-harvest and ordinary-harvest rice grains.

Characteristic	Early-harvest	Ordinary-harvest
	av.±s.e.	av.±s.e.
1000-kernel weight		
Brown rice (g)	22.79±0.02[a)]	23.74±0.08
Milled rice (g)	20.56±0.24	20.25±0.12
Content of milled rice		
Protein (%)	5.70±0.12	5.69±0.03
Amylose (%)	19.22±0.13	18.94±0.21

[a)]indicates significant difference at the 0.1% level between the two types of rice.

Table. 2. Sensory scores of the cooked early-harvest rice compared with the ordinary-harvest rice (zero value).

Item	Score
	av.±s.e.
Color[a)]	0.03±0.34
Brightness[b)]	0.64±0.27
Hardness[c)]	0.30±0.45
Stickiness[d)]	0.33±0.37
Sweetness[e)]	1.30±0.18
Deliciousness[f)]	0.76±0.31
Overall judgement[g)]	1.33±0.34

[a)] 3, very white; −3, not white. [b)] 3, very bright; −3, not bright. [c)] 3, very soft; −3, very hard. [d)] 3, very sticky; −3, not sticky. [e)] 3, very sweet; −3, not sweet. [f)] 3, very delicious, −3, not delicious. [g)] 3, very good; −3, very bad.

Table 3. Characteristics of the cooked early-harvest and ordinary-harvest rice.

Characteristic	Early-harvest	Ordinary-harvest
	av.±s.e.	av.±s.e.
Color index		
L^*	76.4±0.7	77.6±0.5
a^*	−2.15±0.03[b)]	−1.96±0.03
b^*	+18.2±0.16	+16.3±0.11
ΔE^*ab	2.52±0.30	0
Degree of gelatinization (%)	95.0±0.2	93.2±0.2
Amount of hot-water extractable starch (mg/100 g)	3.22±0.06[a)]	2.85±0.07
Texturometric		
Hardness (kgf)	2.05±0.02[a)]	2.14±0.03
Stickiness (kgf)	0.46±0.01[a)]	0.42±0.01
Stickiness/hardness	0.22±0.01	0.20±0.01

[a)] and [b)] indicate significant difference at 5% and 0.1% levels, respectively, between the two types of rice.

cooked early-harvest rice compared with those of the cooked ordinary-harvest rice. All the scores were positive values, and most were larger than zero, indicating that the early harvesting of rice resulted in higher sensorial characteristics than those found in ordinary-harvest rice in many cases. Particularly for sweetness and deliciousness, the cooked early-harvest rice scored high, which was believed to contribute to the high score for overall judgment. To verify the sensory evaluation results, certain characteristics which directly influence the palatability were measured using instruments.

Table 3 shows that the cooked early-harvest rice had a significantly lower a^* value (more greenish) than the ordinary-harvest rice. However, the overall color difference between the two was small (2.52), suggesting that the panelists in the sensory test could not clearly identify the color difference between them (Table 2). For the degree of gelatinization, the cooked early-harvest rice showed a slightly higher value than the cooked ordinary-harvest rice, although the difference was not significant. The amount of hot-water extractable starch, affecting the brightness and stickiness of the cooked rice (Arai & Watanabe, 1994), was significantly greater in the cooked early-harvest rice than in the cooked ordinary-harvest rice, and for the texture parameters, the cooked early-harvest rice was significantly lower in hardness and significantly greater in stickiness. Ebata *et al.* (1982) reported that green kerneled rice harvested at an early ripening stage was greater in stickiness when cooked than the ordinary-harvest rice. This result, together with the present findings, confirmed that rice harvested at an advanced time has greater stickiness when cooked.

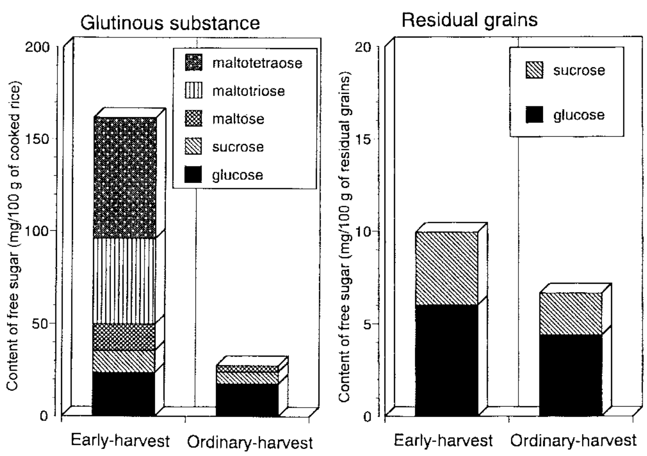

Fig. 1. Free sugars contained in the glutinous substance and the residual grains of cooked rice. Glutinous substance was obtained by extraction from cooked rice with boiling water. Residual grains of cooked rice excluded the glutinous substance.

Characters related to "sweetness" and "deliciousness" of the cooked early-harvest rice The substances providing the sweetness and deliciousness in the sensory test were examined, because the cooked early-harvest rice showed especially high scores for these two items. Generally, the taste of cooked rice originates both from the sensation created by the glutinous substance when it comes in contact with the tongue the food is taken into the mouth, and the sensation felt when the grains of rice are masticated. Thus, in the present study these two parts were separately examined for their related characters.

To determine the substance providing sweetness, the free sugar content was analyzed by HPLC (Fig. 1). The free sugars contained in the glutinous substance were greater by about 6 times in the cooked early-harvest rice than in the cooked ordinary-harvest rice. In the glutinous substance, the component sugars were glucose, sucrose and maltose for the cooked ordinary-harvest rice, but for the cooked early-harvest rice a considerable increase in the maltoligosaccharides malttriose and malttetraose were also noted. The residual grains of cooked rice, on the other hand, contained only a small amount of free sugars compared to that in the glutinous substance, but nevertheless the total amount of free sugars in the grains of early-harvest rice was still greater than that in the grains of ordinary-harvest rice. However, the only component sugars were glucose and sucrose in both cases; no unique form of sugar was detected in the grains of the early-harvest rice, as was the case with the glutinous substance. In general, the greater sweetness detected in the cooked early-harvest rice in the sensory test can no doubt be attributed to the greater amount of free sugars contained in the glutinous substance as well as in the grains of cooked rice in the early-harvest rice.

There are two possibilities should be considered for the higher levels of free sugars in the cooked early-harvest rice. One is that a greater amount of free sugars was already present in the rice grains. The other is that the early-harvest rice had higher amounts of starch degradation enzymes than the ordinary-harvest rice, so that the starch was hydrolyzed in the process of soaking and cooking of the grains, generating the additional free sugars (Sakamoto & Maruyama, 1990; Tajima *et al.,* 1992; Tajima *et al.*, 1994). To confirm this possibility, the amount of free sugars in the grains of both groups (not cooked rice) was determined in the presence or absence of mercuric chloride, which completely inhibits starch degradation enzyme activity. The grains were divided before determination into an outer part (surface of 10% to 22% of a brown rice grain) and the inner part (the remaining central part). These two parts roughly correspond to the glutinous substance and the residual grain of cooked rice, respectively.

Figure 2 shows that in the presence of mercuric chloride the free sugars detected in the outer part were glucose and sucrose in both rice groups. In the absence of mercuric chloride, the early-harvest rice had increased glucose levels in its outer part and maltose and the maltoligosaccharides malttriose and malttetraose were newly detected. In the outer part of the ordinary-harvest rice grain, an increase in glucose and the emergence of maltose were noted, but maltoligosaccharides were not detected. These results confirmed that the maltose and maltoligosaccharides detected in the glutinous substance of the cooked early-harvest rice were not initially contained in the outer part of this rice but were produced by starch degradation enzymes like α-amylase in the process of soaking and/or cooking. Further study is necessary on the factors which increase starch degradation enzyme activities following early harvest.

In the inner part, the free sugars detected in the presence of mercuric chloride were glucose and sucrose in both the early-harvest and ordinary-harvest rice. In the absence of mercuric chloride, the glucose level increased considerably and maltoligosaccharides emerged in the grains of both groups. In the inner part, on the other hand, the increase in glucose was much more appreciable than that of maltoligosaccharides for both harvest times, suggesting the participation of α-glucosidase activity.

The content of sucrose in the inner part of the grains and the residual grains of cooked rice of the early-harvest rice was higher, although only slightly, than in the ordinary-harvest rice. Sucrose is carried to the endosperm and is then decomposed to triose phosphoric acid and taken in the amyloplast (Nakamura *et al.*, 1989). Thereafter, triose phosphoric acid in the amyloplast is converted to ADP- (or UDP-) glucose, which is synthesized via glucose-1-P to serve as the substrate of starch synthesis (Murata *et al.*, 1964; Murata & Akazawa, 1966). Therefore, it was presumed that the early-harvest rice contained a slightly greater amount of sucrose prior to its participation in the synthesis of starch in the endosperm than that found in the ordinary-harvest rice, which helped to impart sweetness to the cooked rice.

In the sensory test, the cooked early-harvest rice was evaluated as being stronger not only in sweetness but also in deliciousness than the cooked ordinary-harvest rice. An important component of the deliciousness of cooked early-harvest rice may be the content of L-glutamic acid (Tamaki *et al.*, 1989b; Matsuzaki *et al.*, 1992). Thus, the L-glutamic acid content for the glutinous sub-

Table 4. L-Glutamic acid content of the cooked early-harvest and ordinary-harvest rice.

	Early-harvest	Ordinary-harvest
	av.±s.e.	av.±s.e.
Glutinous substance[c]	1.84±0.08[a]	1.31±0.03
Residual grains of cooked rice excluding glutinous substance[d]	0.34±0.02[b]	0.22±0.02

[a] and [b] indicate significant difference at 5% and 0.1% levels, respectively, between the two types of rice. [c] mg/100 g of cooked rice. [d] mg/100 g of residual grains of cooked rice.

Table 5. Degree of gelatinization and texturometric characters of the cooked early-harvest and ordinary-harvest rice at 24 h after cooking.

Characteristic	Early-harvest	Ordinary-harvest
	av.±s.e.	av.±s.e
Degree of gelatinization (%)	93.3±0.2	92.5±0.1
Texturometric		
Hardness (kgf)	2.11±0.02[b]	2.23±0.03
Stickiness (kgf)	0.50±0.02[a]	0.44±0.02
Stickiness/hardness	0.23±0.01[a]	0.19±0.01

[a] and [b] indicate significant difference at 5% and 1% levels, respectively, between the two types of rice.

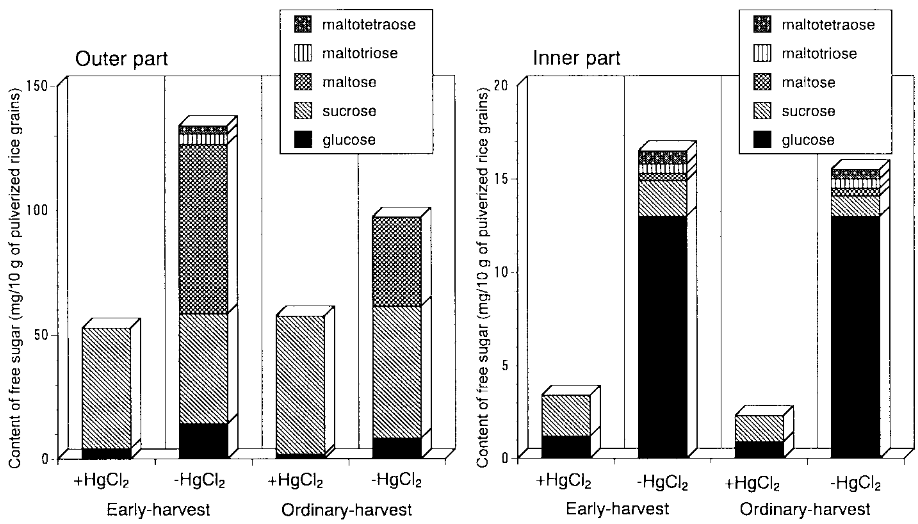

Fig. 2. Free sugars contained in the outer and inner parts of milled rice grains. Outer part, surface of brown rice grain from 10% to 22% of the whole grain. Inner part, the remaining central portion.

stance and the residual grains of cooked rice of both groups was determined.

Table 4 shows that the cooked early-harvest rice had significantly higher content of L-glutamic acid in both the glutinous substance and the residual grains than its counterpart. In particular, the L-glutamic acid content in the glutinous substance of this rice was above the threshold value (Yamaguchi, 1979), implying that the amount contributed to the better taste in the sensory test. We are now investigating the degradation enzyme activities to learn the factor responsible for the increased L-glutamic acid in the early-harvest rice.

Preservability of the taste of cooked early-harvest rice Cooked rice is often eaten immediately after cooking, but on some occasions it is also eaten after sitting for a period of time. Thus, preservability of the taste is an important factor in the quality of cooked rice. To examine whether the taste quality understood of cooked rice was sustained or not, it was kept at 25°C for 24 h, and the texture parameters and degree of gelatinization, tentatively regarded as important factors affecting taste preservability, were determined.

Table 5 shows that the cooked early-harvest rice was slightly higher in its degree of gelatinization after sitting for 24 h than the cooked ordinary-harvest rice. The latter rice was significantly lower in its hardness value, higher in stickiness and higher in stickiness/hardness value than the cooked ordinary harvest rice. The cooked early-harvest rice would thus have better texture after preservation than the cooked ordinary-harvest rice.

In this study, we focused on a kind of Koshihikari as representative among many species of Japanese rice. In the near future, we will report some interesting results on the features of other species and on different harvest-year products.

References

Arai, E. and Watanabe, M. (1994). Gelatinizability of starch as a factor affecting the quality of cooked rice. *J. Appl. Glycosci.*, **41**, 193–196.

Arai, E., Shimizu, C. and Watanabe, M. (1997). Quality improvement of cooked rice by hot-water soaking. *Nippon Kasei Gakkaishi*, **48**, 789–795 (in Japanese).

Asaoka, M., Okuno, K., Sugimoto, Y. and Fuwa, H. (1985). Developmental changes in the structure of endosperm starch of rice (*Oryza sativa* L.). *Agric. Biol. Chem.*, **49**, 1973–1978.

Ebata, M., Hirasawa, K. and Shibata, S. (1982). Studies on the texture of cooked rice. II. Effects of kernel size, apparent quality of brown rice and degree of kernel maturation. *Jpn. J. Crop Sci.*, **51**, 212–247.

Fisher, R.A. (1958). "Statistical Methods for Research Workers." 13th ed., Hafner Publishing, New York, pp.122–128.

Fraser, J.R. and Hoodless, R.A. (1963). Calcium chloride starch-dispersing media. *Analyst*, **88**, 558–560.

Juliano, B.O. (1971). A simplified assay for milled-rice amylose. *Cereal Sci. Today*, **16**, 334–340, 360.

Kainuma, K., Matsunaga, A., Itakawa, M. and Kobayashi, S. (1981). New enzyme system bate-amylase-pullulanase to determine the degree of gelatinization and retrogradation of starch or starch products. *Denpun Kagaku*, **28**, 235–240 (in Japanese).

Matsue, Y., Mizuta, K., Furumo, K. and Yoshida, T. (1991). Studies on palatability of rice grown in northern Kyushu. II. Effects of harvest time on palatability and physicochemical properties of milled rice. *Nippon Sakumotsu Gakkai Kiji.*, **60**, 497–503 (in Japanese).

Matsuzaki, A., Takano, T., Sakamoto, S. and Kuboyama, T. (1992). Eating quality and chemical components in milled rice and amino acid contents in cooked rice. *Jpn. J. Crop Sci.*, **61**, 561–567.

Murata, T., Sugiyama, T. and Akazawa, T. (1964). Enzymic mechanism of starch synthesis in ripening rice grains. II. Adenosine diphosphate glucose pathway. *Arch. Biochem. Biophys.*, **107**, 92–101.

Murata, T. and Akazawa, T. (1966). Enzymic mechanism of starch synthesis in ripening rice grains. IV. Starch synthesis in glutinous rice grains. *Arch. Biochem. Biophys.*, **114**, 76–87.

Nakamura, Y., Yuki, K., Park, S.Y. and Ohya, T. (1989). Carbohydrate metabolism in the developing endosperm of rice grains. *Plant Cell Physiol.*, **30**, 833–839.

National Food Research Institute of Japan (1961). Tests on eating qualities of rice. *Shokuryo*, **4**, 29 (in Japanese).

Nelson, H.J. (1944). A photometric adaptation of the Somogyi method for the determination of glucose. *J. Biol. Chem.*, **153**, 375–380.

Okabe, M. (1979). Texture measurement of cooked rice and its relationship to eating quality. *J. Texture Stud.*, **10**, 131–152.

Sakamoto, K. and Maruyama, E. (1990). Purification and some properties of α-amylases from milled rice granules. *Denpun Kagaku*, **37**, 29–34 (in Japanese).

Somogyi, M. (1952). Note on sugar determination. *J. Biol. Chem.*, **195**, 19–23.

Sugiyama, S., Konishi, M., Terasaki, D., Hatae, K. and Shimada, A. (1995). Determination of chemical components and distribution in the milled rice kernel. *Nippon Shokuhin Kogyo Gakkaishi*, **42**, 401–409 (in Japanese).

Taira, H., Taira, H. and Maeshige, M. (1978). Changes in chemical composition of rice kernel from dough ripening to over ripening. *Jpn. J. Crop Sci.*, **47**, 475–482.

Tajima, M., Horino, T., Maeda, M. and Son, J.R. (1992). Maltooligosaccharaides extracted from outer-layer of rice grain (Studies on taste of cooked rice, part I). *Nippon Shokuhin Kogyo Gakkaishi*, **39**, 857–861 (in Japanese).

Tajima, M., Kato, M. and Iizaka, T. (1994). Maltooligosaccharides extracted from cooked rice. *Nippon Shokuhin Kogyo Gakkaishi*, **41**, 339–340 (in Japanese).

Takebe, M., Miyata, K., Kanamura, N. and Yoneyama, T. (1994). Changes in contents of sugars and amino acids in brown rice during grain ripening and influence of nitrogen treatments. *Nippon Dojyo Hiryo Gakkaishi*, **65**, 503–513 (in Japanese).

Tamaki, M., Ebata, M., Tashiro, T. and Ishikawa, M. (1989a). Physicoecological studies on quality formation of rice kernel. II. Changes in quality of rice kernel during grain development. *Jpn. J. Crop Sci.*, **58**, 659–663.

Tamaki, M., Ebata, M., Tashiro, T. and Ishikawa, M. (1989b). Physicoecological studies on quality formation of rice kernel. III. Effects of ripening stage and some ripening conditions on free amino acids in milled rice kernel and in the exterior of cooked rice. *Jpn. J. Crop Sci.*, **58**, 695–703.

Yamaguchi, S. (1979). The umami taste. In "Food Taste Chemistry," ed. by J. C. Boudreau, Am. Chem. Soc., Washington, D.C., pp. 35–51.