Physicochemical Properties and Food Uses of Starch from the New Sweetpotato Cultivar Konamizuki

(Received July 14, 2016; Accepted October 25, 2016)
(J-STAGE Advance Published Date: November 10, 2016)

Kanae Tokimura,1 Kiyotaka Fujita,2 and Kanefumi Kitahara2,†
1 Kagoshima Prefectural Osumi Food Technology Development Center
(4938 Hosoyamada, Kushira, Kanoya, Kagoshima 893–1601, Japan)
2 Course of Biological Science and Technology, The United Graduate School of Agricultural Sciences, Kagoshima University
(1–21–24 Korimoto, Kagoshima 890–0065, Japan)

Abstract: Starch from the new sweetpotato cultivar Konamizuki (KM) was evaluated as a food material, and its basic properties were characterized. Change in elastic modulus during cold storage of KM starch gels and syneresis after freeze-thaw treatment were limited and indicated slow retrogradation properties. In addition, KM starch paste had higher and more stable storage modulus than other starches, suggesting desirable gel-forming properties. These KM gel properties reflected distinctive structural properties, including larger quantities of short unit chains with degree of polymerization 6–10 and amylose-like long chains of the amylopectin, as well as longer amyloses and longer amylose-like chains of the amylopectin compared with other starches. Finally, KM starch was used in the production of tapioca pearls and starchy noodles, and subsequent sensory analyses indicated highly desirable properties as a food material for starchy gel products.

Key words: sweetpotato starch, Konamizuki, low gelatinization temperature, physicochemical properties, amylopectin structures

INTRODUCTION

Kagoshima Prefecture is located in the southern part of the Kyushu region in southern Japan, where agricultural production from horticultural crops and animal husbandry has prospered in the temperate climate. Sweetpotato (Ipomoea batatas L.) is an important upland crop for the regional economy of Kagoshima Prefecture, and about 590,000 tons, amounting to 40 % of the total production of Japan, are produced per year. In Kagoshima, particularly, the sweetpotatoes are used for making a traditional spirit Shochu and manufacturing starch. To promote consumption of sweetpotato starch, the new sweetpotato cultivar Konamizuki (KM) has been developed at the Kyushu Okinawa Agricultural Research Center, National Agriculture and Food Research Organization of Japan.3 Tuberous roots of KM have a unique starch that gelatinizes at approximately 20 ºC lower than starches from the other sweetpotato cultivars. The starch has less gelatinization enthalpy change, slower retrogradation rate, and higher susceptibility to acid and enzyme degradation.2,3 Hence, this unique and innovative sweetpotato starch may have high functional potential as food material. In a recent study, starch qualities of the tuberous roots from KM were investigated under various conditions, and the effects of planting times, harvest times, and cultivation periods on pasting properties of starches were examined using a rapid visco-analyser.4 These experiments showed increased polyphenol contents and polyphenol oxidase activities, and consequent deterioration of starch whiteness in tuberous roots harvested in December, potentially reflecting low seasonal temperatures.

Ishiguro et al.5) studied retrogradation of 10 kinds of sweetpotato starch gels and reported that the retrogradation estimated by the gel hardness and the leaked water from gels during storage related to the amylose contents and the short chain distributions of sweetpotato amylpectins. However, the suitability of KM starch for foods, such as confectionary products and noodles, has not been reported previously. In this study we examined the basic characteristics of structures and gel properties of starches. Then we performed product trials with KM starch and compared physical properties with those of starches from ordinary sweetpotato cultivars and commercial starches. Subsequently, relationships between molecular structures and physical properties of KM starch were discussed.

MATERIALS AND METHODS

Materials. The four sweetpotato cultivars Shiroyutaka (SY), Koganesengan (KS), Daichinoyume (DY), and KM were cultivated at the experimental farm of the Osumi branch, Kagoshima Prefectural Institute for Agricultural Development Center (Kanoya, Kagoshima, Japan) from mid-April to mid-October in 2012 and 2013. SY and DY
are commonly used for starch production, whereas KS is used in the production of traditional spirits Shochu. Starch samples were prepared from ten tuberous roots of each cultivar as follows: Tuberous roots (500–1,000 g each) were ground in a roll grinder (Konakka Industry Ltd. Co., Kagoshima, Japan) and aliquots (about 2 kg) of mashed samples were passed through a sieve with an opening size of 355 μm with water and then through a sieve with an opening size of 90 μm to remove cell debris. Starch suspensions were then left to precipitate overnight and the supernatants were removed. The precipitated starch was suspended again in fresh water, passed through a sieve with an opening size of 45 μm and repeatedly suspended and settled in fresh water until a colorless supernatant was obtained. Collected starch samples were then dried under atmospheric conditions and were finally passed through a sieve with an opening size of 355 μm. Defatted starches and amylopectins were prepared according to previously described methods. 

Commercially available sweetpotato (mainly SY cultivar) and KM starches were purchased from South Satsuma Agricultural Cooperatives (Minamikyushu, Kagoshima, Japan). Cassava and potato starches were purchased from the Nihon Starch Co., Ltd. (Kagoshima, Japan) and Kiyosato Agricultural Cooperatives (Shari, Hokkaido, Japan), respectively. Wheat flour was purchased from the Nippon Flour Milling Co., Ltd. (Tokyo, Japan).

**Pasting and general properties of starches.** Pasting properties of starches were measured using a rapid visco-analyser (RVA-3D; Newport Scientific Pty. Ltd., Australia). In these procedures, 7 % (w/w) starch suspensions (total 25 g) were heated from 35 °C to 95 °C at a rate of 5 °C/min, were kept at 95 °C for 5 min, and were then cooled to 35 °C at the same rate. The paddle was rotated at 960 rpm for the first 10 s and was subsequently maintained at 160 rpm throughout measurements. Apparent amylose contents and phosphate content bound to the glucose residues of the starch samples were then determined using previously reported methods. 

Particle size distributions of starch granules were measured in water using a laser diffraction analyzer (Helos by Sympatec GmbH, Germany) with a parallel plate geometry (35 mm-diameter, 0.5 mm-gap). Starch paste samples [7 or 6 % (w/w)] were determined by varying shear rates from 1 to 80 s⁻¹ (up curve), and from 80 to 1 s⁻¹ (down curve). Paste samples were then left to rest for 15, 30, 60, and 90 min at 25 °C, and were then transferred to the rheometer for measurement.

**Structural properties of starches.** Starches and amylopectins were debranched using isoamylase (Megazyme, Biocon Japan Ltd., Aichi, Japan). The chain length distributions were analyzed using gel-permeation chromatography with refractive index detection (GPC-RID) with a column system comprising two linked columns for amylopectin (Superose 6 10/300 GL and Superdex Peptide 10/300 GL, GE Healthcare Japan, Tokyo, Japan) as previously reported, and with another system for amylose (TSKgel GMPW XL and TSKgel guard column PWXL, Tosoh Bioscience, Tokyo, Japan). Both columns were eluted with 100 mM sodium phosphate buffer containing 0.02 % sodium azide (pH 6.2) at a flow rate of 0.5 mL/min. The two column chromatography systems were calibrated using commercial pullulan standards (Shodex STANDARD P-82 and P-2; Shoko Co., Ltd., Tokyo, Japan) and four linear amylose standards with degrees of polymerization (DP) of 1953, 722, 438, and 215 [Amylose AS-320, AS-110, AS-70, and AS-30, Ajinoki Co., Ltd., Aichi, Japan (discon-
Application of KM starches in tapioca peals and starchy noodles. Commercial KM starch was used in the production of trial tapioca pearls (spherical agglomeration of starch granules) and starchy noodles (Korean-style cold noodles), and qualities of boiled products were compared with those made from commercial sweetpotato, cassava and potato starches. Because large quantities of starches were required to produce the trial products, KM starch used in this experiment was the commercially available starch product.

Tapioca pearls were prepared using a small pan-type granulator (DPZ-01R, AS ONE Co., Osaka, Japan) as follows: Initially, starch pearl nuclei were prepared by passing starches with about 40 % moisture content through a sieve with an opening size of 1.0 mm into a granulator. Subsequently, small particles were grown to diameters of 4−5 mm in a rotating container with a tilt angle of 45° by adding starch and water alternately. Grown particles were then steamed for 40−60 s to gelatinize the surface starches and were then air-dried. Texture properties were analyzed after trial tapioca pearls were boiled for 15 min and allowed to stand for 5 h in water. Swelled tapioca pearls were then heated in fresh boiling water for 15 min and were compressed twice using a 20 mm diameter circular flat plunger at a speed of 1 mm/s in a rheometer (model RE33005, Yamaden Co., Ltd.). The compression distance was fixed at 50 % of the sample thickness. Hardness was defined as the peak force over the first compression of measurement, and cohesiveness was defined as a ratio of the second compression area to the first compression area. Measurements were conducted 10 times for all samples and average hardness and cohesiveness values were calculated.

Trial starchy noodles were prepared by mixing starch (1.5 kg) and wheat flour (1.5 kg), and adding water to a moisture content of about 37 %, and mixtures were then stirred with steam to produce noodle dough with moderate elasticity. Noodles were then extruded using an Extruder (Fuji Tekkou Co., Ltd., Kagoshima, Japan) and were subdivided into airtight-film bags and kept at 5 °C prior to texture analyses and sensory evaluations. Subsequently, starchy noodles were boiled for 2 min, cooled immediately in water, and compressed twice using a wedge type plunger with a 3 mm tip at a speed of 1 mm/s. Measurements of the compression distance was fixed at 80 % of the noodle thickness. The hardness and cohesiveness values of the noodles were obtained by the same methods as those of tapioca pearls. The mean of hardness and cohesiveness were calculated from 15 replicate measurements of each sample. Finally, our center staff of nineteen people (13 male and 6 female, 30−63 years old) scored the noodles in a 5-point scale of elastic feeling and hardness (1−5, week−strong), and throat comfort and overall quality (1−5, bad−good) using a reference point of 3.0 for starchy noodles that were produced using commercial sweetpotato starch.

RESULTS AND DISCUSSION

RVA pasting properties of sweetpotato starches.

To confirm universal properties of starches, we examined duplicate starch samples from sweetpotatoes cultivated in 2012 and 2013. Pasting properties of four sweetpotato starches were determined using RVA (Table 1). In these analyses, KM starches from 2012 and 2013 crops had pasting temperatures of 59.2 and 60.1 °C, respectively, and these values were lower than those for all other starches, which was consistent with previous result. Peak viscosity values for all starch samples were similar in two years. KM starches from both cultivation years had the lowest breakdown values and highest final viscosities.

Rheological properties of starch gels.

Changes in apparent elastic moduli of warabi-mochi starch gels (13 % starch content) were determined during storage at 5 °C over 3 days (Fig. 1). Starch gels were produced using four kinds of sweetpotato starches from 2012 and 2013 crops, and commercial cassava and potato starches. Apparent elastic moduli of KM starches did not change during storage at 5 °C for 3 days and were comparable to those of cassava starch, whereas those of SY starches increased during cold storage, and those of KS and DY increased to a lesser degree. Although respective variations during storage slightly differed among samples from 2012 and 2013, similarities of KM starches in 2 years indicated universal properties. In syneresis comparisons of 8 % (w/w) starch gels after freeze-thaw treatment (Fig. 2), both KM starch gels of different year samples had lower values than other sweetpotato starches. Moreover, syneresis values of potato starches were similar to those of ordinary sweetpotato starches, whereas cassava starches gave similar syneresis values to those of KM starches.

Table 1. Pasting properties of sweetpotato starches determined using RVA at a concentration of 7 % (w/w)

| Year | Starches | Peak viscosity (RVU) | Breakdown (RVU) | Final viscosity (RVU) | Setback (RVU) | Pasting temperature (°C) |
|------|----------|----------------------|----------------|-----------------------|---------------|-------------------------|
| 2012 | Shioyutaka | 214 | 88 | 217 | 91 | 74.4 |
|      | Koganesengan | 185 | 64 | 203 | 82 | 73.8 |
|      | Daichinoyume | 216 | 100 | 202 | 87 | 71.7 |
|      | Konamizuki | 199 | 62 | 227 | 90 | 59.2 |
| 2013 | Shioyutaka | 221 | 97 | 213 | 88 | 75.5 |
|      | Koganesengan | 196 | 79 | 203 | 85 | 75.7 |
|      | Daichinoyume | 212 | 97 | 199 | 84 | 73.4 |
|      | Konamizuki | 197 | 58 | 244 | 105 | 60.1 |

Measurements were performed in duplicate, and the mean values were shown in the table.
The present data show that KM starch gels have distinctive slow retrogradation properties in comparison with other sweetpotato starches, and these properties were reproducible over two cultivation years. In a previous study, a slow retrogradation property of KM starch was shown according to the development of turbidity in 2% starch paste during cold storage.

In agreement, the present KM starch gels were stable against freeze-thaw treatments, indicating advantageous properties for use in foods. Dynamic viscosity and flow properties of starches. Time dependent changes in storage moduli (G') of 7% (w/w) starch pastes were determined in KM, ordinary sweetpotato, potato, and cassava starch pastes (Fig. 3). These analyses showed higher G’ values of KM starch pastes in four sweetpotato starches than in potato and cassava starches. Moreover, G’ values of KM starch pastes remained high for 120 min except for KS starches, indicating the ease and stability of gel formation. In contrast, G’ values of KS starch pastes increased linearly during the experiments, suggesting unique molecular characteristics.

Shear stresses of 6% (w/w) starch pastes were determined as a function of shear rates, and representative flow curves of starch pastes after preparation for 15 and 90 min were generated using starch samples from 2013 (Fig. 4). Starch pastes generally have either thixotropic or rheopetic properties as non-Newtonian liquids. Although these properties can be investigated using several differing methods, the most common involves testing of hysteresis loops. In the present experiments, the four sweetpotato and cassava starch pastes showed thixotropic properties because the up curve values were greater than the down curve values of hysteresis loops, whereas hysteresis loops
of potato starch pastes showed rheopectic properties because the up and down curves were in the opposite manner to the other starches (Fig. 4). The overall hysteresis areas obtained from the flow curves of all starch samples are shown in Table 2. The present negative hysteresis loop areas of flow curves from potato starch pastes indicated characteristic rheopectic properties, whereas those of KM starches from both years had much larger hysteresis loop areas than those of the other starch pastes. Taken together, these data demonstrate that KM starch paste has high resistance to shear stress, suggesting strong gel-forming ability.

**Structural properties of starches.**

Table 3 shows the general properties of the present starches. Apparent amylose contents of the four starches from 2012 crops ranged from 15.4 to 19.6 %, and those from 2013 crops ranged from 16.0 to 19.6 %. The apparent amylose contents of SY starch had the highest values in each year. Phosphate contents of KM starches were 1.16 and 1.50 μmol/g in samples of 2012 and 2013, respectively, and were lower than those of the other sweetpotato starches (3.61–7.70 μmol/g starch). Among the present starches, DY starch had intermediate phosphate contents. Median granule sizes of starches ranged from 13.3–20.2 μm. The highest granular size was recorded with KM starches (18.1 and 20.2 μm, respectively), followed by DY starches (15.3 and 17.3 μm, respectively) from both years.

Chain length distributions of the starches and their isolated amylopectins were evaluated using GPC-RID with two different GPC-column systems after debranching of samples using isoamylase. Chromatograms of chain length distributions of debranched starches and their enlarged views of amylose fractions (Fig. 5) show two main fractions at 11.5–17.7 and 17.5–20.5 min. Amylose was predominantly eluted in the former fraction, and unit chains comprising amylopectin were eluted in the latter fraction. Enlarged

![Fig. 4. Representative flow curves of 6 % (w/w) starch pastes after preparation at 15 and 90 min using starch samples from 2013. Closed symbols indicate data from the increasing shear rate mode and open symbols indicate data from the decreasing shear rate mode. ●, 15 min - increasing; ○, 15 min - decreasing; ▲, 90 min - increasing; △, 90 min - decreasing.](image)

### Table 2. Hysteresis loop areas (Pa/s) of 6 % (w/w) starch pastes at 20 °C.

| Year | Starches          | 15 min | 30 min | 60 min | 90 min |
|------|-------------------|--------|--------|--------|--------|
| 2012 | Sweetpotato       |        |        |        |        |
|      | Shiroyutaka       | 2120   | 2170   | 2450   | 2770   |
|      | Koganesengan      | 1580   | 1750   | 2230   | 2600   |
|      | Daichinoyume      | 2280   | 2390   | 2540   | 3040   |
|      | Konamizuki        | 2510   | 2490   | 3030   | 3280   |
|      | Potato             | -1160  | -1100  | -410   | -380   |
|      | Cassava            | 2080   | 2030   | 2210   | 2280   |
| 2013 | Sweetpotato       |        |        |        |        |
|      | Shiroyutaka       | 2630   | 2670   | 2890   | 3540   |
|      | Koganesengan      | 2490   | 2770   | 3250   | 4160   |
|      | Daichinoyume      | 2670   | 2800   | 2990   | 3140   |
|      | Konamizuki        | 2940   | 3230   | 4030   | 4560   |

### Table 3. General properties of sweetpotato starches.

| Year | Starches | Amylose content (%) | Phosphate content (μmol/g) | Median granule size (μm) |
|------|----------|---------------------|----------------------------|---------------------------|
| 2012 | Shiroyutaka | 19.6                | 7.70                       | 14.5                      |
|      | Koganesengan | 15.4                | 6.13                       | 13.3                      |
|      | Daichinoyume | 15.9                | 3.61                       | 15.3                      |
|      | Konamizuki  | 17.4                | 1.16                       | 18.1                      |
| 2013 | Shiroyutaka | 19.6                | 7.43                       | 15.4                      |
|      | Koganesengan | 17.3                | 6.80                       | 15.3                      |
|      | Daichinoyume | 16.0                | 3.91                       | 17.3                      |
|      | Konamizuki  | 17.7                | 1.50                       | 20.2                      |
views (Fig. 5) show that KM amylose was eluted earlier than the other starch amyloses from both years, indicating for the first time that KM starches have longer amyloses. In contrast, distributions of KS amylose were the smallest among the present starches. Hence, because amylose gel properties depend on chain lengths,

these data may reflect rapid increases of KS starch pastes in $G'$ values (Fig. 3). By another GPC column system, chain length distributions of isolated amylopectins showed clear differences between KM amylopectin distributions and those of the other amylopectins (Fig. 6). In agreement with a previous report,

large quantities of amylose-like long chains and short chains with DP 6–10 of KM amylopectin were observed. In further analysis, distributions of the amylose-like long chain in amylopectins were determined, and enlarged views showed higher molecular weight fractions of the amylose-like long chains (Fig. 7). These show the amylose-like long chains of KM amylopectin were longer than those of other amylopectins, and were similar between samples from 2012 and 2013. Previously, amyloses leached from granules were shown to play important roles in determining viscoelastic properties. However, amylose contents of KM starches were comparable to those of the other sweetpotato starches (Table 3). In previous reports, a highly positive relationship between RVA setback values of the rice starches and super-long chain (SLC) contents of the amylopectins was reported. In addition, Lu et al. reported that SLC in rice amylopectin may be the key factor that determines the retrogradation of amylopectin and influences the texture of starch gel. Taken together, these data indicate that KM starch is rich in longer amylose molecules and amylose-like chains in the amylopectins, likely leading to high elasticity and good gel-forming properties (Figs. 3 and 4) of cross-linked structures comprising long starch molecules.

**Application of KM starches to the production of tapioca pearls and starchy noodles.**

After producing tapioca pearls (spherical agglomeration of starch granules) and starchy noodles (Korean-style cold noodles) using commercial KM starch, qualities of boiled products were compared with those produced with commercial ordinary sweetpotato (mainly SY cultivar), cassava, and potato starches.

In these experiments, tapioca pearls are partially cooked as small spheres (1–6 mm diameter) of cassava starch, and after absorbing water during boiling, these become thick and clear, and finally glossy gel particles with an elastic mouth feel. Subsequently, hardness and cohesiveness of boiled tapioca pearls were investigated during storage at 5 °C for 2 days (Table 4). Tapioca pearls that were produced using commercial sweetpotato starch were almost cracked, precluding examination of hardness and cohesiveness. However, analyses of KM starch pearls showed sig-
significantly higher hardness and cohesiveness values compared with those of the cassava starch pearls during the entire storage period. These results indicate that the KM starch can be used to produce tapioca pearls with more moderate firmness and elasticity than regular soft-type tapioca pearls. In a previous study, Xu and Seib20) indicated that pearls including high molecular weight amylose are resistant to disintegration during cooking, reflecting the presence of networks of micelles between and within granules. Thus, the structural features of KM starch likely contribute to the unique pearl texture.

Potato starch noodles had the highest hardness values (1.56 N) among KM (1.00 N) and commercial sweetpotato (0.68 N) starches (Table 5). Similarly, cohesiveness of KM starch (0.80) was significantly greater than that of potato (0.78) and commercial sweetpotato (0.72) starches likely reflecting differing textures of the respective tapioca pearls. In a previous study, Xu and Seib30) indicated that pearls including high molecular weight amylose are resistant to disintegration during cooking, reflecting the presence of networks of micelles between and within granules. Thus, the structural features of KM starch likely contribute to the unique pearl texture.

In conclusion, KM starch has distinctive properties including low pasting temperature, slow retrogradation, high gel-forming ability, and distinctive gel texture compared with the other tested starches. In addition, characteristic molecular structures of KM amylose and amylopectin were related to rheological properties. Finally, qualities of tapioca pearls and starchy noodles indicated that KM starch has excellent properties for use as a food material in starchy gel products. Further studies are required to develop additional foods containing KM starch and to reinvigorate regional economies.

ACKNOWLEDGMENTS

The authors are grateful to the staff of the Osumi Branch, Kagoshima Prefectural Institute for Agricultural Development for providing sweetpotato tuberous roots. The authors wish to thank Dr. Kaoru Koyama of National Agriculture and Food Research Organization, Japan, for her helpful suggestions during this study, and Ms. Saki Kanahara for her experimental assistance. This study was supported by a research and development projects for application in promoting new policy of agriculture, forestry and fisheries of Japan.
REFERENCES

1) K. Katayama, T. Sakai, Y. Kai, Y. Nakazawa, and M. Yoshinaga: “Konamizuki”: A new sweetpotato cultivar. Bull. NARO Kyushu Okinawa Agric. Res. Center, 58, 15–36 (2012). (in Japanese)

2) K. Katayama, K. Kitahara, T. Sakai, Y. Kai, and M. Yoshinaga: Resistant and digestible starch contents in sweet potato cultivars and lines. J. Appl. Glycosci., 58, 53–59 (2011).

3) K. Kitahara, T. Yamasaki, K. Fujita, and T. Suganuma: Physicochemical properties of starches from recently bred sweetpotatoes in Japan. J. Appl. Glycosci., 61, 81–88 (2014).

4) K. Tokimura, H. Shimozono, T. Kume, S. Nishihara, K. Koyamada, S. Fukumoto, K. Fujita, and K. Kitahara: The starch quality of the tuberous roots of a new sweetpotato cultivar “Konamizuki” cultivated under different conditions. Bull. Appl. Glycosci., 4, 234–240 (2014). (in Japanese)

5) K. Ishiguro, T. Noda, K. Kitahara, and O. Yamakawa: Retrogradation of sweetpotato starch. Starch/Stärke, 52, 13–17 (2000).

6) K. Kitahara, S. Fukunaga, K. Katayama, Y. Takahata, Y. Nakazawa, M. Yoshinaga, and T. Suganuma: Physicochemical properties of sweetpotato starches with different gelatinization temperature. Starch/Stärke, 57, 473–479 (2005).

7) K. Kitahara, K. Hamasuna, K. Nozuma, M. Otani, T. Hamada, T. Shimada, K. Fujita, and T. Suganuma: Physicochemical properties of amyllose-free and high-amyllose starches from transgenic sweetpotatoes modified by RNA interference. Carbohydr. Polym., 69, 233–240 (2007).

8) K. Tokimura, H. Shimozono, K. Ikeda, and H. Tanoue: The retrogradation of starch gels and starch properties from various kinds of sweet potato starches. Oyo Toshitsu Kagaku, 49, 302–312 (2002). (in Japanese)

9) R. Dewar and M. J. Joyce: The thixotropic and rheopectic behaviour of maize starch and maltodextrin thickeners used in dysphagia therapy. Carbohydr. Polym., 65, 296–305 (2006).

10) H. Gambio, D. Gumul, and L. Juszczyk: Rheological properties of pastes obtained from starches derived from immature cereal kernels. Starch/Stärke, 56, 225–231 (2004).

11) M. Sikora, G. Adamczyk, M. Krystynian, A. Dobosz, P. Tomaszik, W. Berski, M. Lukasiewicz, and P. Izak: Thixotropic properties of normal potato starch depending on the degree of the granules pasting. Carbohydr. Polym., 121, 254–264 (2015).

12) J. Tattiyakul and M.A. Rao: Rheological behavior of cross-linked waxy maize starch dispersions during and after heating. Carbohydr. Polym., 43, 215–222 (2000).

13) B. Wang, L.-J. Wang, D. Li, N. Özkan, S.-J. Li, and Z.-H. Mao: Rheological properties of waxy maize starch and xanthan gum mixtures in the presence of sucrose. Carbohydr. Polym., 77, 472–481 (2009).

14) A.H. Clark, M.J. Gidley, R.K. Richardson, and S.B. Ross-Murphy: Rheological studies of aqueous amyllose gels: The effect of chain length and concentration on gel modulus. Macromolecules, 22, 346–351 (1989).

15) W. Zhou, J. Yang, Y. Hong, G. Liu, J. Zheng, Z. Gu, and P. Zhang: Impact of amyllose content on starch physicochemical properties intransgenic sweet potato. Carbohydr. Polym., 122, 417–427 (2015).

16) T. Horibata, M. Nakamoto, H. Fuwa, and N. Inouchi: Structural and physicochemical characteristics of endosperm starches of rice cultivars recently bred in Japan. J. Appl. Glycosci., 51, 303–313 (2004).

17) N. Inouchi, H. Hibiu, T. Li, T. Horibata, H. Fuwa, and T. Itani: Structure and properties of endosperm starches from cultivated rice of Asia and other countries. J. Appl. Glycosci., 52, 239–246 (2005).

18) Z.-H. Lu, T. Sasaki, Y.-Y Li, T. Yoshihashi, L.-T. Li, and K. Kohyama: Effect of amyllose content and rice type on dynamic viscoelasticity of a composite rice starch gel. Food Hydrocolloids, 23, 1712–1719 (2009).

19) M.R. Grace: Baked tapioca products. in Cassava Processing, FAO Plant Production and Protection Series No. 3, Food and Agriculture Organization, Rome, pp. 55–61 (1977).

20) A. Xu and P.A. Seib: Structure of tapioca peals compared to starch noodles from mung beans. Cereal Chem., 70, 463–470 (1993).