Regular Paper

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)

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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 390,000 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.¹⁾ Tuberous roots of KM have a unique starch that gelatinizes at approximately 20 °C 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 con-

ditions, 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 amylopectins. 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

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Abbreviations: KM, Konamizuki; SY, Shiroyutaka; KS, Koganesengan; DY, Daichinoyume; RVA, rapid visco-analyser; G' , storage modulus; GPC-RID: gel-permeation chromatography with refractive index detection; DP, degree of polymerization; SLC, super-long chain.

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 (Konaka 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.⁶⁾

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-analyzer (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 contents⁷⁾ and phosphate content bound to the glucose residues of the starches⁶⁾ were determined using previously reported methods. Particle size distributions of starch granules were measured in water using a laser diffraction analyzer (Helos system particle size analyzer; JEOL Ltd., Tokyo, Japan) after sonication for 1 min, and median granule sizes were determined. Duplicate experiments were in strict agreement.

Rheological properties of starch gels and pastes. A starch gel, a Japanese traditional confectionary *Warabi-mochi*, was prepared using previously reported methods.⁸⁾ Briefly, a mixture of starch (40 g, dry matter), granulated sugar (50 g), and water (210 mL) was heated from 25 °C to 95 °C at a rate of 3 °C/min, was maintained at 95 °C for 5 min and was then continuously mixed at 100 rpm for 15 min and then 70 rpm for 10 min using a stirrer. After termination of heating, aliquots of the paste (17 g) were poured into plastic cylindrical tubes (30 mm in diameter) with flat bottoms. Bubbles were removed from paste samples by steaming the tubes for 5 min and then immediately pressing the pastes using a piston. Gels (20 mm in height) were formed after standing at 20 °C for 2 h, and were stored in a refrigerator at 5 °C up to 3 days. Rupture tests were performed daily for 3 days using a rheometer (model RE33005, Yamaden Co., Ltd., Tokyo, Japan). Prior to measurements, starch gels

were left to stand at 20 °C for a few hours until a constant temperature was reached, and were then cut into half cylinders with heights of 10 mm. Gels were then compressed using a wedge type plunger with a tip width of 1 mm at a speed of 1 mm/s. The compression rate was 98 % of the gel thickness and apparent elastic moduli of 0.05–0.15 of the strain rate on the rupture curve recorded as a gel firmness value. Measurements were performed six times and were presented as means $\pm$ standard deviations. Apparent elastic moduli were expressed according to slopes of rupture curves during compression of starch gels using a rheometer. In these analyses, lower apparent elastic moduli indicate soft starch gels, and sustained low apparent elastic moduli indicate slow retrogradation.

Syneresis after freeze–thaw treatment of starch gels was evaluated after heating 8 % (w/w) starch suspension (total 28 g) as described for RVA measurements except with a final temperature of 50 °C. Aliquots of the paste (5 g) were poured into four 50 mL-conical tubes, were centrifuged at $1,700 \times G$ for 15 min to remove bubbles, and were then stored at –20 °C for 2 weeks. After thawing the frozen gels at 30 °C for 1 h, conical tubes were centrifuged at $1,700 \times G$ for 15 min, and syneresis was determined according to weight loss (%) following removal of expelled water from the conical tube.

Dynamic viscoelastic properties of starch pastes were measured at 20 °C using a rheometer (Rheostress RS1, Haake GmbH, Germany) with a parallel plate geometry (35 mm-diameter, 0.5 mm-gap). Starch paste samples [7 or 6 % (w/w), 25 g] were prepared using RVA as described above and time dependent storage moduli (G') of 7 % (w/w) starch pastes were measured at a frequency of 1 Hz for 2 h. Paste samples were then immediately transferred to the rheometer, and sample edges were covered with a thin layer of silicone oil to prevent water evaporation. Flow curves of 6 % (w/w) starch pastes 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).⁶⁾ 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,^{6,7)} and with another system for amylose (TSKgel GMPW_{XL} and TSKgel guard column PW_{XL}, 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-

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	Shiroyutaka	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	Shiroyutaka	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.

tinued commercial products)], respectively.

Application of KM starches in tapioca pearls 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, weak–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.³⁾ 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.

Fig. 1. Changes in apparent elastic moduli of 13 % (w/w) starch gels during storage at 5 °C.

Samples were taken from sweetpotato crops grown in 2012 and 2013 and were compared with commercial potato and cassava starches. Error bars indicate standard deviations ($n=6$). $\circ$, Shiroyutaka; $\diamond$, Koganesengan; $\triangle$, Daichinoyume; $\square$, Konamizuki; $\blacklozenge$, Potato; $\bullet$, Cassava.

Fig. 2. Syneresis of 8 % (w/w) starch gels after freeze-thaw treatment.

White and black bars indicate syneresis values in samples from 2012 and 2013, respectively, except for commercial potato and cassava starches. Error bars indicate standard deviations ($n=3$).

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.³⁾ In agreement, the present KM starch gels

Fig. 3. Time dependent storage moduli (G') of 7 % (w/w) starch pastes at 20 °C.

Samples were taken from crops grown in 2012 and 2013 and were compared with those from commercial potato and cassava starches. $\circ$, Shiroyutaka; $\diamond$, Koganesengan; $\triangle$, Daichinoyume; $\square$, Konamizuki; $\blacksquare$, Potato; $\bullet$, Cassava.

were stable against freeze-thaw treatments, indicating advantageous properties for use in foods.

Dynamic viscoelasticity 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 rheopectic properties as non-Newtonian liquids.⁹⁾ Although these properties can be investigated using several differing methods, the most common involves testing of hysteresis loops.¹⁰⁾¹¹⁾¹²⁾¹³⁾ 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

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.

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 $\mu\text{mol/g}$ in samples of 2012 and 2013, respectively, and were lower than those of the other sweetpotato starches (3.61–7.70 $\mu\text{mol/g}$ 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

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
	Koganengan	1580	1750	2230	2600
	Daichinoyume	2280	2390	2540	3040
	Konamizuki	2510	2490	3030	3280
	Potato	-1160	-1100	-410	-380
2013	Cassava	2080	2030	2210	2280
	Sweetpotato				
	Shiroyutaka	2630	2670	2890	3540
	Koganengan	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 ($\mu\text{mol/g}$)	Median granule size (μm)
2012	Shiroyutaka	19.6	7.70	14.5
	Koganengan	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
	Koganengan	17.3	6.80	15.3
	Daichinoyume	16.0	3.91	17.3
	Konamizuki	17.7	1.50	20.2

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. 5. Chain length distributions of debranched starches in gel-permeation chromatography with refractive index detection (GPC-RID) analyses.

Samples were collected from crops grown in 2012 and 2013. Inserted enlarged views of higher molecular weight fractions predominantly indicate distributions of amylose fractions. GPC system was calibrated using four linear amylose standards with degree of polymerization (DP) of 1953, 722, 438, and 215. —, Shiroyutka; ·····, Koganesengan; —·—, Daichinoyume; — — —, Konamizuki.

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,¹⁴ 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,³⁾ 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.¹⁵⁾ However, amylose contents of KM starches were comparable to those of the other sweetpotato starches (Table 3). In previous reports,¹⁶⁾¹⁷⁾ a highly positive relationship between RVA setback values of the rice starches

Fig. 6. Chain length distributions of debranched amylopectins in GPC-RID analyses.

Samples were collected from crops grown in 2012 and 2013. GPC system was calibrated using commercial pullulan standards. —, Shiroyutka; ·····, Koganesengan; —·—, Daichinoyume; — — —, Konamizuki.

and super-long chain (SLC) contents of the amylopectins was reported. In addition, Lu *et al.*¹⁸⁾ 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.¹⁹⁾ 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-

Fig. 7. Chain length distributions of amylose-like long chain fractions of amylopectins in GPC-RID analyses.

Samples were collected from crops grown in 2012 and 2013. GPC system was calibrated using four linear amylose standards with DP 1953, 722, 438, and 215. —, Shiroyutka; ·····, Koganesen-gan; —·—, Daichinoyume; — — —, Konamizuki.

nificantly 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 starchy noodles (Table 5). In subsequent sensory analyses of starchy noodles, potato starch noodles received the highest scores for elastic feeling and hardness, whereas KM starch noodles had the highest scores for texture, throat comfort, and overall quality (Table 6).

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

Table 4. Hardness and cohesiveness of boiled tapioca pearls.

Starches	0 day Immediately after preparation	Storage at 5 °C	
		1 day	2 days
Hardness (<i>N</i>)			
Konamizuki	0.85 ± 0.13	1.99 ± 0.33	2.28 ± 0.53
Cassava	0.39 ± 0.04	0.94 ± 0.18	0.79 ± 0.11
Cohesiveness (-)			
Konamizuki	0.95 ± 0.01	0.88 ± 0.01	0.87 ± 0.01
Cassava	0.89 ± 0.02	0.84 ± 0.01	0.67 ± 0.05

Data are presented as means ± standard deviations (*n* = 10). Each set value between two starches was significantly different; *p* < 0.01.

Table 5. Hardness and cohesiveness of boiled starchy noodles.

Starches	Hardness (<i>N</i>)	Cohesiveness (-)
Sweetpotato		
Commercial	0.68 ± 0.14 ^c	0.72 ± 0.02 ^c
Konamizuki	1.00 ± 0.09 ^b	0.80 ± 0.01 ^a
Potato	1.56 ± 0.26 ^a	0.78 ± 0.01 ^b

Data are presented as means ± standard deviations (*n* = 15). Values with different letters within the same column were significantly different; *p* < 0.01.

Table 6. Sensory analyses of starchy noodles.

Starches	Elastic feeling	Hardness	Texture	Throat comfort	Overall
Sweetpotato					
Commercial	3.0	3.0	3.0	3.0	3.0
Konamizuki	4.0 ± 0.00	3.9 ± 0.32	3.9 ± 0.71	3.5 ± 0.84	3.9 ± 0.88
Potato	4.7 ± 0.49	4.7 ± 0.48	2.7 ± 1.05	2.4 ± 0.68	2.6 ± 0.90

Sensory evaluations were scored from 1 to 5 in comparison with a reference point (3.0) of starchy noodles that were produced using commercial sweetpotato starch. Data are presented as means ± standard deviations (*n* = 19).

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.

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