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# Pasting properties of commercial and experimental starch pearls

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Commercial starch pearls manufactured from sago, tapioca, sweet potato or other starches from Hong Kong, the Philippines and Singapore were characterized. Samples were milled and pasting properties were evaluated. There were marked differences in pasting characteristics which were attributed to the pH of the starch pearls. The milled alkaline starch pearls showed high cold paste viscosities and setback ratios while the acidic milled starch had low cold paste viscosities and setback ratios. Furthermore, in alkaline milled starch, the addition of sugar drastically lowered the setback ratios while the setback ratios of the milled acidic starches were minimally affected. From the laboratory preparation of starch pearls from commercial tuber starches (potato and cassava), it appeared that the process of pearling effected a mild starch modification which increased the stability ratio of the milled starch pearl compared to the unprocessed starch. © 1998 Elsevier Science Limited. All rights reserved.

## INTRODUCTION

Sago pearls were originally manufactured from starch extracted from the sago palm (*Metroxylon sagu* and *M. rumphi*), a plant found throughout Asia and the Pacific Basin. In the nineteenth century, sago was a staple in the diet on tea clipper ships during the return trip to Europe, and the surplus was added to the diet of the industrial north of England. By the latter half of the century, it was established in use in well-liked desserts such as pudding, blancmange and other products (Stanton, 1993). Sago starch pearls are highly digestible and are often fed to children and invalids. Consumers have developed a fascination for the unique gummy or elastic texture of the product. Owing to increased demand, imitation sago pearls are now produced from tapioca, potato, bean, sweet potato and corn (Magda, 1993).

The general procedure for the preparation of starch pearls involves several steps: (1) wetting the starch; (2) drying to 50% moisture; (3) granulation into beads, which can be done manually or by mechanized granulators (Magda, 1993; Raja *et al.*, 1979); (4) stirring the pearls or beads for 8–10 min evenly on a hot plate or hearth smeared with oil to prevent sticking—mechanical roasters were developed to speed up the process and improve the quality of sago (Varadharaju *et al.*, 1992); (5) drying the wet starch at 40–60°C in a stream of hot air to approximately 10% moisture; (6) cooling and packing.

In common cooking applications, sago pearls are boiled in water for 15 to 20 min, covered, allowed to cool down, washed with cooled water to prevent the pearls adhering to each other, and then used either as garnishing of sweet cold drinks or further cooked by boiling or baking with sugar, coconut milk and/or milk to make a porridge or pudding (Solomon, 1992). To simulate actual cooking conditions, viscosity profiles of both the raw starch and the fully gelatinized starch should be studied. Furthermore, as starch pearls are eaten as sweetened desserts, the effects of sugar on their pasting properties are also of great importance. In this study, different commercial starch pearls were evaluated for cooking quality and physical characteristics, especially by use of viscoamylography. The effects of double heating and cooling cycles and the addition of sugar on the viscosity profiles of the milled starch pearls were also determined.

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**Table 1. Commercial starch pearls collected from Hong Kong, the Philippines and Singapore**

| Sample code | Country retailed | Country of origin | Raw material | Diameter (mm) | Moisture (%) | pH | Hunter colour | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | *L* | *a* | *b* |
| PS1 | Philippines | Philippines | Tapioca | 3.01 | 15.0 | 9.4 | 92.0 | 0.56 | 8.58 |
| PS2 | Philippines | Philippines | Tapioca | 3.01 | 13.7 | 9.4 | 92.1 | 1.19 | 6.78 |
| PS3 | Philippines | Philippines | Not listed | 7.45 | 15.0 | 9.4 | 91.6 | 0.72 | 7.46 |
| PS5 | Philippines | Philippines | Tapioca | 4.39 | 13.8 | 9.4 | 92.1 | 0.64 | 8.38 |
| PS6 | Philippines | Philippines | Tapioca | 2.60 | 13.3 | 9.3 | 91.6 | 0.90 | 5.46 |
| HKS1 | Hong Kong | Thailand | Starch | 2.01 | 12.0 | 4.7 | 94.9 | − 0.08 | 4.52 |
| HKS2 | Hong Kong | Hong Kong | Not listed | 2.08 | 12.8 | 4.8 | 96.0 | − 0.15 | 3.97 |
| HKS3 | Hong Kong | Thailand | Tapioca | 6.68 | 11.3 | 5.4 | 96.3 | 0.06 | 4.01 |
| HKS4 | Hong Kong | Hong Kong | Not listed | 2.03 | 13.2 | 4.7 | 94.9 | − 0.15 | 4.58 |
| HKS5 | Hong Kong | Hong Kong | Starch | 2.20 | 7.9 | 5.4 | 94.0 | − 0.15 | 4.46 |
| HKS6 | Hong Kong | Thailand | Potato and bean flour | 2.13 | 10.7 | 4.8 | 94.2 | − 0.12 | 4.85 |
| HKS7 | Hong Kong | UK | Tapioca | 2.13 | 12.0 | 5.6 | 94.1 | − 0.07 | 4.89 |
| HKS8 | Hong Kong | USA | Tapioca | 7.27 | 13.5 | 6.8 | 91.6 | 0.17 | 4.90 |
| HKS9 | Hong Kong | Malaysia | Sago | 2.16 | 14.3 | 4.7 | 90.2 | 0.64 | 7.65 |
| HKS10 | Hong Kong | China | Sweet potato | 2.21 | 9.3 | 5.4 | 94.2 | 0.26 | 5.85 |
| SS1 | Singapore | Sarawak | Sago | 1.95 | 9.4 | 5.6 | 95.2 | 0.10 | 4.01 |
| SS2 | Singapore | Sarawak | Sago | 4.28 | 9.2 | 5.2 | 95.5 | 0.29 | 3.85 |
| SS3 | Singapore | Sarawak | Sago | 2.01 | 8.0 | 5.5 | 95.6 | 0.00 | 4.04 |
| | | | Mean | 3.31 | 11.9 | 6.4 | 93.7 | 0.27 | 5.46 |
| | | | SD | 1.91 | 2.34 | 1.95 | 1.86 | 0.41 | 1.60 |

SD, standard deviation ($P < 0.05$).

## MATERIALS AND METHODS

### Materials and sample preparation

A total of 18 starch pearl samples were purchased from retail sources in the Philippines (PS), Hong Kong (HKS) and Singapore (SS) (Table 1). The ingredients on the package label were noted. Purity in terms of botanic source for commercial starch pearls was difficult to check. Microscopic examination revealed that a large proportion of the milled starch pearls consisted of crystalline structures from retrograded gelatinized starch and the rest was starch granules. In products like these, flour and starch are used in labels loosely without caution as to their exact meaning. The main aim of the paper was to determine viscosity/texture profiles that could be imitated by varying the starch source, factors like pH, and heat–moisture treatment, and the accuracy of source identification is not critical for this purpose. The diameter of the pearls was measured using a micrometer; moisture contents were determined by a rapid microwave method (Davis & Lai, 1984); the pH of the milled sago slurry was determined using a pH meter (Sentron 2001, Integrated Sensor Technology, Roden, The Netherlands); and colour was determined with a Minolta Chroma Meter CR-300 (Minolta Camera Company, Tokyo, Japan).

The sago pearls (5 g) were cooked in 50 ml boiling water in a beaker for 10 min, covered with a Petri dish; cooled down to room temperature and allowed to stand for 30 min. The cooked sago was washed in cold water, drained for another 30 min in a stainless steel strainer and weighed. The cooking recovery was computed as the difference between the weight of the raw and cooked sago. The diameters of the cooked sago pearls were measured using a micrometer. Clarity is an outstanding characteristic of this product. The clarity of the milled sago samples was determined following Craig *et al.*, 1989. Colours of cooked sago samples were also determined using the Minolta Chroma Meter CR-300.

### Pasting treatments using the Rapid Visco-Analyser

Sago samples were milled in a Udy Cyclone Mill (Udy Corporation, Ft. Collins, Colorado, USA) with a 0.5 mm screen. A Rapid Visco-Analyser Model 3-D (RVA) (Newport Scientific Pty. Ltd., Narrabeen, Australia) was employed to determine the pasting properties of the starch samples.

Different pasting treatments were used, as follows:

*Treatment A* (single heating and cooling cycle). The samples (2.75 g, 14% moisture) were placed in the aluminum RVA sample canister, 25 g water was added, and a 25 min heating and cooling cycle under constant shear with a plastic paddle was imposed, where samples were held at 50°C for 1 min, heated from 50 to 95°C in 7.5 min, held for 8 min at 95°C, cooled to 50°C in 7.5 min, and held at 50°C for 1 min.

*Treatment B*. Sugar (1.4 g) was added to the raw milled starch slurry and the sample was run on a 25 min RVA setup similar to Treatment A.

*Treatment C* (single heating and cooling cycle repeated twice). After the first heating and cooling cycle as in Treatment A, sugar (1.4 g) was added to gelatinized milled starch pearls before loading the sample again in the RVA and running for another 25 min single heating and cooling cycle.

*Treatment D* (double heating and cooling cycles). This involved holding the starch slurry at 50°C for 1 min, heating from 50 to 95°C for 7.5 min, holding at 95°C for 8 min, cooling to 50°C in 7.5 min, holding at 50°C for 2 min; and again heating from 50 to 95°C for 7.5 min, holding at 95°C for 8 min, cooling to 50°C in 7.5 min and holding at 50°C for 2 min for a total profile of 51 min.

*Treatment E.* The sugar was added to the starch slurry, mixed and subjected to the 51 min RVA run which involved a double heating and cooling cycle as in Treatment D.

Pasting characteristics of the peak viscosity (PV) (highest viscosity achieved during heating), hot paste viscosity (HPV) (minimum viscosity while held at 95°C), cold paste viscosity (CPV) (viscosity at the end of hold time at 50°C), stability ratio (HPV/PV) and setback ratio (CPV/HPV) were noted. These pasting attributes have previously been used to distinguish starches from different species (e.g. Leelavathi *et al.*, 1987).

## Starch gel texture

A QTS-25 texture analyzer (Stevens Advanced Weighing Systems, Leonard Farnell and Co. Ltd., UK) was used to measure the starch gel texture. The gel made from a single 25 min RVA run was placed in aluminum foil trays (30 mm × 30 mm × 15 mm), wrapped with plastic film to prevent drying, cooled to room temperature (23–25°C) and allowed to stand for 2 hr. The set gel was cut using a shear blade (70 mm × 100 mm) in compression mode through a slotted base using a crosshead speed of 30 mm $min^{-1}$. Hardness (g) (the maximum positive load) was noted.

## Production of starch pearls

Starch pearls from commercial potato starch and tapioca were prepared. Starch was moistened with distilled water to make a thick slurry of 60–70% moisture and loaded into a 10 ml plastic syringe. The slurry was extruded onto a paper towel which absorbed excess moisture and made the slurry drop roll into spherical beads of approximately 3 mm diameter. These were heated on an oil-coated Petri dish on a hot-plate set on medium heat with stirring for about 8 min, after which the pearls were cooled at room temperature and stored in sealed polyethylene bags. The starch pearls were milled and pasting profiles were compared to the native starch from which they were prepared.

## Statistical analysis of data

Pearson correlations of the pasting attributes of the milled starch pearls with pH and hardness of the starch gel from milled starch pearls were calculated. Analysis of variance of

**Table 2. Physical characteristics of cooked starch pearls**

| Sample code | Diameter (mm) | Cooking recovery (%) | Clarity transmittance (%) | Hunter colour | | | Hardness (g) |
|---|---|---|---|---|---|---|---|
| | | | | *L* | *a* | *b* | |
| PS1 | 5.0 | 481 | 38.6 | 40.5 | 1.3 | 5.5 | 585 |
| PS2 | 5.0 | 448 | 46.2 | 45.1 | 2.2 | 9.4 | 443 |
| PS3 | 11.0 | 355 | 41.2 | 44.9 | 1.2 | 5.0 | 559 |
| PS5 | 7.0 | 449 | 39.9 | 41.1 | 1.3 | 5.5 | 580 |
| PS6 | 4.5 | 400 | 55.0 | 41.8 | 1.7 | 2.3 | 312 |
| HKS1 | 4.5 | 548 | 46.2 | 45.6 | 1.1 | − 0.6 | 123 |
| HKS2 | 4.5 | 534 | 42.7 | 47.4 | 0.8 | 0.2 | 146 |
| HKS3 | 9.0 | 383 | 42.8 | 46.7 | 1.2 | 2.1 | 145 |
| HKS4 | 4.5 | 546 | 44.6 | 43.8 | 0.6 | − 0.9 | 86 |
| HKS5 | 4.5 | 552 | 37.1 | 49.1 | − 0.7 | − 5.3 | 89 |
| HKS6 | 4.5 | 536 | 44.6 | 47.7 | 1.4 | 0.8 | 104 |
| HKS7 | 4.5 | 484 | 44.3 | 48.7 | 1.4 | 3.3 | 142 |
| HKS8 | 11.0 | 295 | 37.6 | 47.0 | 1.3 | 3.6 | 169 |
| HKS9 | 5.0 | 473 | 33.6 | 44.9 | 0.3 | − 3.1 | 174 |
| HKS10 | 5.0 | 476 | 30.0 | 45.2 | − 0.1 | − 1.4 | 84 |
| SS1 | 3.5 | 458 | 41.6 | 43.9 | 0.9 | 1.0 | 136 |
| SS2 | 6.5 | 380 | 42.6 | 45.1 | 1.1 | 2.8 | 197 |
| SS3 | 4.0 | 478 | 41.2 | 45.9 | 1.0 | 0.8 | 133 |
| Mean | 5.8 | 460 | 41.7 | 45.3 | 1.0 | 1.7 | 233 |
| SD | 2.3 | 73 | 5.4 | 2.4 | 0.7 | 3.5 | 179 |

SD, standard deviation ($P < 0.05$).

the pasting treatment means with pH as a covariate was performed using the GLM procedure of SAS 6.04 software (SAS Institute, Inc., Cary, North Carolina, USA).

## RESULTS AND DISCUSSION

### Size, colour and moisture

The sago samples had a diameter range of 1.95 to 7.45 mm with a mean of 3.31 ± 1.91 mm. The Hong Kong samples (HKS) and Singapore samples (SS) were generally lighter in colour than Philippine samples (PS). The mean $L^*$ value (brightness) was 93.7 ± 1.9. The moisture range of HKS samples was 7.9–14.3%, for SS samples was 8.0–9.4%, and for PS samples was 13.3–15.0%. The PS samples had a higher moisture content because most of them are sold in the market in open boxes. It was also noted that the PS samples had higher pH values (9.3 to 9.4) than the HK and SS samples which had acidic to neutral pH (4.7 to 6.8) (Table 1).

On cooking, the small sago samples showed a higher percentage increase in size and cooking recovery than the bigger pearls (Table 2). The PS samples showed a lower increase in size and lower cooking recovery compared to the other samples. In some of the samples, especially samples HKS8 and SS2, the low recovery may largely be due to the high percentage of broken pearls and rough surfaces. The milled samples had transmittance values ranging from 30.0 to 55.0%. The HKS and SS samples were generally lighter than the Philippine samples which were slightly yellowish. In the alkali noodles, it was found that the alkaline conditions facilitate the detachment of flavones from polysaccharides which enables the development of the yellow colour (Miskelly & Moss, 1985).

### Pasting properties

It was not possible to identify by viscoamylography the original starch from which the commercial pearl samples were made. Some of the samples were from local markets and were unlabelled, but in those that were packaged and bought from supermarkets the ingredients were either listed as sago, tapioca, potato, bean or a combination of these, or simply as starch and water.

There was great variation in the viscosity profiles of the milled starch pearls in the 25 min single heating and cooling cycle of the RVA viscoamylography (Table 3). There was wide variation in PV with a mean of 267 ± 78, CPV with a mean of 203 ± 144 and setback ratio (CPV/HPV) with mean of 3.0 ± 1.78. However, there was smaller variation with regards to the HPV with a mean of 64.7 ± 15.9 and stability ratio (HPV/PV) with a mean of 0.2 ± 0.05. It was noted that the milled alkaline starch pearls had higher PV, and unusually high CPV which was sometimes higher than the PV. Based on a classification of viscosity patterns of thick-boiling starch (Schoch & Maywald, 1968), the acidic starch pearls are typically Type A with high swelling capacity, but with tenuous internal bonding forces that account for the low HPV, stability ratios and setback ratios. Root or tuber crops are known to be free swelling with very low shear stability during cooking. These starches have high peak viscosities and great breakdown during cooling due to their enormously swollen granules. They are also characterized by high levels of highly branched amylopectin which does not ordinarily associate or retrograde on standing because the outer branches are not sufficiently long and are therefore non-congealing (Pomeranz, 1991; Zobel, 1984). On the other hand, the pasting characteristics of the alkaline starch pearls does not fall in the normal classification of starch because of their high

**Table 3. Pasting properties of milled starch pearls**

| Sample code | Peak RVU | Hot paste RVU | Cold paste RVU | Stability ratio | Setback ratio |
|---|---|---|---|---|---|
| PS1 | 420 | 89 | 502 | 0.21 | 5.6 |
| PS2 | 419 | 69 | 429 | 0.16 | 6.2 |
| PS3 | 268 | 70 | 406 | 0.26 | 5.8 |
| PS5 | 384 | 83 | 426 | 0.22 | 5.1 |
| PS6 | 337 | 55 | 335 | 0.16 | 6.1 |
| HKS1 | 217 | 56 | 103 | 0.26 | 1.8 |
| HKS2 | 265 | 70 | 131 | 0.26 | 1.9 |
| HKS3 | 269 | 72 | 144 | 0.27 | 2.0 |
| HKS4 | 226 | 55 | 106 | 0.24 | 1.9 |
| HKS5 | 135 | 25 | 52 | 0.19 | 2.1 |
| HKS6 | 221 | 59 | 104 | 0.27 | 1.8 |
| HKS7 | 263 | 72 | 131 | 0.27 | 1.8 |
| HKS8 | 247 | 90 | 180 | 0.36 | 2.0 |
| HKS9 | 230 | 76 | 176 | 0.33 | 2.3 |
| HKS10 | 170 | 51 | 94 | 0.30 | 1.8 |
| SS1 | 242 | 51 | 102 | 0.21 | 2.0 |
| SS2 | 285 | 69 | 137 | 0.24 | 2.0 |
| SS3 | 217 | 52 | 101 | 0.24 | 1.9 |
| Mean | 268 | 65 | 203 | 0.25 | 3.0 |
| SD | 78 | 15.9 | 144 | 0.05 | 1.78 |

SD, standard deviation ($P < 0.05$).

**Table 4. Pearson correlation of pasting attributes, pH of milled starch pearls and hardness of their starch gels ($N = 18$)**

| | Peak (RVU) | Hot paste (RVU) | Cold paste (RVU) | Stability ratio | Setback ratio | Hardness (g) |
|---|---|---|---|---|---|---|
| Hot paste viscosity | 0.65 ** | | | | | |
| Cold paste viscosity | 0.88 *** | 0.57 * | | | | |
| Stability ratio | − 0.45 | 0.37 | 0.39 | | | |
| Setback ratio | 0.79 *** | 0.31 | 0.95 *** | − 0.56 * | | |
| Hardness | 0.81 *** | 0.54 * | 0.97 *** | − 0.37 | 0.90 *** | |
| pH | 0.78 *** | 0.40 | 0.94 *** | − 0.47* | 0.96 *** | 0.92 *** |

*, **, *** refer to significance level at $P < 0.05$, $P < 0.01$, $P < 0.001$ respectively.

peak viscosity, low hot paste viscosity and stability ratio, and high cold paste viscosities and setback ratios. However, the pasting profile of the alkaline starch pearls resembles the pasting profile of Amylomaize I (13–15% starch concentration) pasted in 0.1 N NaOH, which showed a high peak viscosity and extensive breakdown on cooking approaching that of potato starch in water (Pomeranz, 1991) and which also showed high cold paste viscosities upon cooling. Amylomaize has a high content of linear amylose fraction (55%) and because the granules are so strongly bonded internally the paste shows little or no breakdown upon cooking to 95°C in water.

Correlation analysis of milled starch pearl parameters showed that the pH was highly and significantly correlated to the PV, CPV, setback ratio and hardness of the starch gel ($P < 0.001$) and to the stability ratio ($P < 0.05$). Similarly the CPV and stability ratio were highly and significantly correlated to the starch gel hardness ($P < 0.001$) (Table 4).

As pH significantly affects pasting characteristics, it was used as covariate on the effect of the pasting treatments on the viscosity profiles of the milled starch pearls. The main distinctive difference between milled starch pearls from alkaline and acidic starch pearls was in the setback ratio, so it was the pasting parameter used in the statistical analysis (Table 5).

**Table 5. The effect of pasting treatments on the stability ratio of the pasting profiles of the milled commercial starch pearls**

| Sample code | Pasting treatments | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| PS1 | 5.64 | 4.50 | 3.56 | 5.81 | 3.95 |
| PS2 | 6.22 | 4.59 | 4.38 | 5.43 | 3.93 |
| PS3 | 5.80 | 3.10 | 3.40 | 5.29 | 3.76 |
| PS5 | 5.13 | 4.12 | 3.94 | 5.10 | 3.73 |
| PS6 | 6.09 | 4.09 | 3.91 | 5.64 | 3.78 |
| HKS1 | 1.84 | 1.79 | 1.63 | 1.59 | 1.66 |
| HKS2 | 1.87 | 1.64 | 1.57 | 1.67 | 1.45 |
| HKS3 | 2.00 | 1.92 | 1.76 | 1.85 | 1.75 |
| HKS4 | 1.93 | 1.71 | 1.64 | 1.67 | 1.50 |
| HKS5 | 2.08 | 1.98 | 1.92 | 2.08 | 1.43 |
| HKS6 | 1.76 | 1.70 | 1.61 | 1.56 | 1.52 |
| HKS7 | 1.82 | 1.74 | 1.63 | 1.60 | 1.55 |
| HKS8 | 2.00 | 2.05 | 1.76 | 1.81 | 1.79 |
| HKS9 | 2.32 | 1.73 | 1.96 | 1.97 | 1.56 |
| HKS10 | 1.84 | 1.87 | 1.53 | 1.71 | 1.35 |
| SS1 | 2.00 | 2.00 | 2.27 | 2.20 | 1.74 |
| SS2 | 1.99 | 2.00 | 1.72 | 1.65 | 1.74 |
| SS3 | 1.94 | 1.90 | 1.67 | 1.58 | 1.61 |
| Mean | 3.02 | 2.47 | 2.33 | 2.79 | 2.21 |
| SD | 1.78 | 1.07 | 1.00 | 1.71 | 1.04 |

SD, standard deviation ($P < 0.05$).

The effect of pasting treatments on the setback ratio of the milled starch pearls was significantly affected by pH. Similarly there was a significant interaction of treatment and pH ($P < 0.001$) on the setback ratio of the milled starch pearls. For the alkaline starch pearls, the setback ratio was decreased drastically by the addition of sugar regardless of when it was added. The effect of the number of cycles of heating and cooling on the sensitivity to shearing was rather minimal. Treatment A was not significantly different from Treatment D. Among the acidic starch pearls, although there was an evident decrease in setback ratio of starch slurries where sugar was added, the effect was relatively less compared to the addition of sugar to the alkaline starch pearls, which caused approximately 20 to 50% decrease in setback ratios when sugar was added to gelatinized milled starch pearls (Treatment C) or the raw milled starch slurry (Treatment B and D). The pasting profiles of an alkaline milled starch pearl, PS1, and an acidic milled starch pearl, HKS5, for Treatments D and E are shown in Fig. 1A and Fig. 1B. When the pH of the aqueous milled starch slurry was adjusted to 6.0, the pasting profiles of the alkaline milled starch pearls were similar to the acidic starch pearls (Table 6).

At basic pH, starches exhibit fast hydration and consequent swelling (Maywald *et al.*, 1968). The restrictive effect on gelatinization caused by sugar was apparent. Several explanations for this phenomenon have been proposed including competition between starch and sucrose for available water, inhibition of granular hydration and sucrose starch interaction (Lund, 1984; Spies & Hoseney, 1981).

We note that the pasting properties relate directly to starch swelling and integrity of the swollen granules. These parameters in turn are related directly to textural properties. The RVA is used as the test instrument for the gel texture of certain products (e.g. noodles) through measurement of the viscosity profiles (e.g. Crosbie, 1991).

## Commercial starches and their starch pearls

The process of making pearls may be considered a form of heat–moisture treatment. Heat–moisture treatment involves the heating of starches at high temperature, usually above the gelatinization temperature (>100°C), at a very

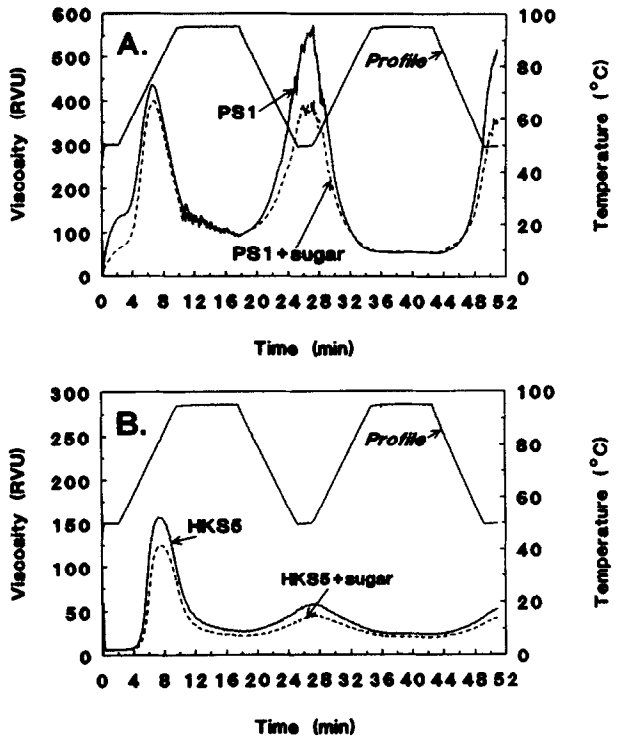


**Fig. 1.** The pasting profiles of (A) a milled alkaline starch pearl sample (PS1) and (B) a milled acidic starch pearl sample (HKS5) pasted in double heating and cooling cycles in the Rapid Visco-Analyzer with and without sugar.

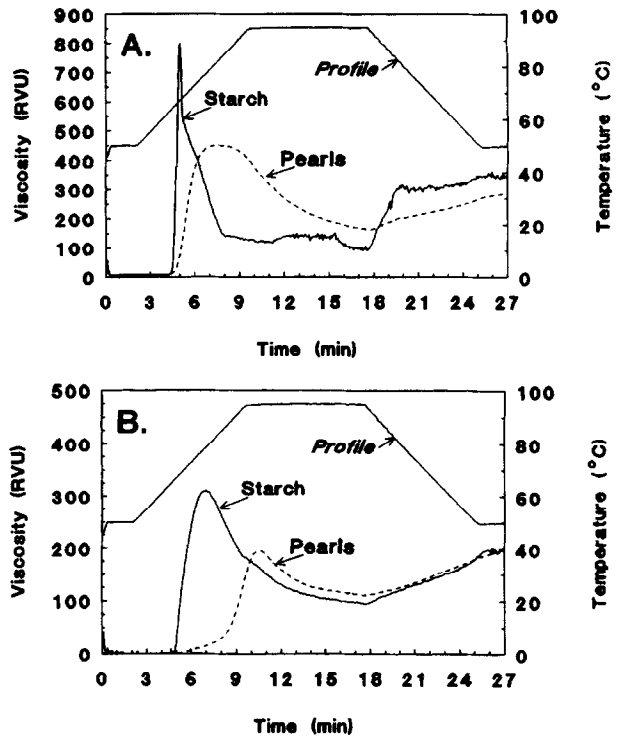


**Fig. 2.** The pasting profiles of commercial potato starch (A) and commercial tapioca starch (B) and of milled starch pearls prepared from them.

limited moisture content (18–30%) (Hoover *et al.*, 1994; Murata *et al.*, 1994; Abraham, 1993; Kulp & Lorenz, 1981; Sair, 1964). Higher moisture contents were avoided because this inevitably results in gelatinization. This is differentiated from annealing, a process which involves incubation of starch in excess water for a period of time at a temperature (45–55°C) above the glass transition but below the gelatinization temperature (Larsson & Eliasson, 1991; Jacobs *et al.*, 1995). In both processes, there is an increase in size and perfection of crystalline zones, reflected in a higher and narrower range of gelatinization temperatures. In the case of pearled starches, the starch pearls were exposed to roasting temperatures of 120 to 180°C for 8 to 10 min in open pans (Varadharaju *et al.*, 1992). For the heat–moisture treatment, the process was normally undertaken for 16 hr at 100°C in a closed or sealed system to prevent evaporation (Hoover *et al.*, 1994; Kulp & Lorenz, 1981; Sair, 1964).

**Table 6. Pasting properties of the milled basic starch pearls as affected by pH adjustment to pH 6.0**

| Sample code | Peak RVU | Hot paste RVU | Cold paste RVU | Stability ratio | Setback ratio |
|---|---|---|---|---|---|
| PS1 | 270 | 87 | 183 | 0.32 | 2.10 |
| PS2 | 229 | 68 | 141 | 0.30 | 2.00 |
| PS3 | 220 | 81 | 154 | 0.37 | 1.90 |
| PS5 | 205 | 69 | 129 | 0.34 | 1.87 |
| PS6 | 209 | 70 | 122 | 0.33 | 1.74 |
| Mean | 227 | 75 | 146 | 0.33 | 1.92 |
| SD | 26 | 9 | 24 | 0.03 | 0.14 |

The short exposure time to high temperature of the starch pearls during roasting may have resulted in a mild modification of the pasting properties (Fig. 2A and Fig. 2B). After the starch pearls from the commercial starches were prepared there was marked reduction in peak viscosities, and delayed swelling which was more pronounced in tapioca starch than in potato starch. There was also an increase in stability ratio (HPV/PV) from 0.13 to 0.36 in potato starch and 0.32 to 0.58 in tapioca starch. There was a decrease in the setback ratio (CPV/HPV) as the starch was pearled. In potato starch, the setback ratio was reduced to 1.75 from 3.40 while in tapioca it was reduced to 1.73 from 2.02 in the unprocessed starch. These values are closely similar to those of acidic starch pearl samples. Reduction in viscosities may have also been due to partial gelatinization of the starch during the pearling process. It was reported by Xu & Seib (1993) that starch pearls are more than 50% gelatinized. Furthermore, it was reported that for starch pearls the raw material should easily swell and solubilize under moist heat for partial gelatinization which appeared to be essential in the formation of the pearl structure. This attribute may have been enhanced by alkaline pH which hastens swelling and gelatinization (Maywald *et al.*, 1968; Lund, 1984; Pomeranz, 1991). The PS samples were very hard and difficult to mill compared to the

other starch pearls. Exuded amylose is believed to create a network of micelles between and within granules or zones which restricts disintegration of the pearl during cooking. The cooked pearl therefore sets to a rubbery gelled particle.

The degree of gelatinization indeed varies among commercial samples since they were processed under different conditions. In laboratory samples, the degree of gelatinization is normally determined by comparing the gelatinization enthalpy of the original native starch and the processed starch. For commercial samples, we did not have the original starch sample from which the pearls were processed. The difference in processing conditions may have also been related to the difference in pH. The acidic starch pearls may have undergone some degree of fermentation. In Asian countries, this is even induced by the use of a 'sour liquor' believed to prevent starch deterioration.

Starch pearls are made effectively from free-swelling starches like tuber starches. They are able to gelatinize easily, even under limited moisture as in the process of pearling, and exude sufficient amylose to bind the granules into a compact structure which is sustained after cooking. Starch pearls prepared from cereal starches like wheat were weak and unable to withstand cooking (Xu & Seib, 1993). This contrasts with starch noodle production where restricted swelling starches (Jin *et al.*, 1994; Lii & Chang, 1981) are required and where the noodle structure formation is done in excess boiling water for full gelatinization and a subsequent curing under refrigerated temperature is needed to set the structure.

## CONCLUSION

There were marked differences in the pasting profiles of the milled starch pearls. pH accounted for the major differences in pasting profiles. The alkaline milled starch pearls had high cold paste viscosities and setback ratios, whereas the acidic starch pearls had low cold paste viscosities and setback ratios. The setback ratio correlated significantly with the hardness of the starch gel from the milled starch pearls. Under the different pasting treatments, the difference in setback ratio was also affected by the pH of the starch pearls. The addition of sugar to the alkaline milled starch pearls lowered the setback ratio drastically regardless of the number of heating and cooling cycles, whereas the setback ratios of acidic milled starch pearls were minimally affected. The starch pearls may have undergone a mild form of starch modification through its short exposure to heat–moisture treatment during roasting. This may have accounted for the pasting characteristics of the milled starch pearls. In view of the unusual pasting characteristics of the basic starch pearls, further study on the effect of pH on heat–moisture treatment of starches from rootcrops is recommended, which may widen their functionality in food applications.

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