Food Sci Biotechnol (2020) 29(4):521–529
https://doi.org/10.1007/s10068-019-00692-8

Isolation and physicochemical property of individual parenchyma cells from mealy sweet potato

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Received: 26 August 2019 / Revised: 14 September 2019 / Accepted: 20 September 2019 / Published online: 14 October 2019

Abstract This study prepared the dehydrated sweet potato parenchyma cell (SPPC) by isolating intact, individual parenchyma cells (PC) from sweet potato (SP) flesh using pectinase, and compared its chemical compositions, solubility and swelling power, gelatinization, and pasting viscosity to sweet potato starch (SPST) and flour (SPFL). The highest yield of SPPC was achieved when frozen SP whole-tissues were treated with pectin lyase. The majority constituting SPPC was intact, individual PCs fully filled with SPST granules. SPPC possessed lower crude protein and ash contents than SPFL. SPPC revealed lower solubility and swelling power, higher gelatinization temperatures, and lower pasting viscosity than SPST, while it showed lower solubility, higher swelling power, lower gelatinization temperatures, and higher pasting viscosity than SPFL. Overall, SPPC characteristics may result from intact PC walls surrounding clusters of SPPC granules, and SPPC could be considered an alternative to SPFL and SPST for expanding industrial applications of SP.

Keywords Sweet potato · Sweet potato starch · Sweet potato flour · Individual parenchyma cell · Physicochemical property

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Introduction

Sweet potato (*Ipomoea batatas* L.) is one of starchy tuberous roots, and is well adapted to the varied types of soils and the poorly growing environments, achieving its higher yield production per cultivated area (Park et al., 2011; Yoon et al., 2018). Sweet potato (SP) is cultivated mainly in Asian, African, North and South American, Southern European, and Oceanian countries with its worldwide annual production of approximately 112.8 million metric tons in 2017 (Statista, 2019). Its domestic annual production in 2017 was about 325 thousand metric tons, corresponding to about 0.29% of its worldwide annual production (KOSIS, 2019). Relative to potato, SP possesses abundant carbohydrates (starch, simple sugars, and dietary fiber) and bioactive components (ß-carotene, anthocyanin, ascorbic acid, and polyphenols), which plays an important role in human diets as energy and nutrition sources (Ahmed et al., 2010; Kim et al., 2011; Yoon et al., 2018). In Korea and African countries, thus, it has been used as emergency foods since a long time ago, when facing a food shortage (Amajor et al., 2014; Yang et al., 2012).

SP, in Korea, is predominantly consumed as a raw material with the purpose of its simple cooking (boiling, steaming, baking, deep-fat frying, pan-frying) (Yang et al., 2012), while only 9.7% (in 2017) of its domestic annual production is used as main or minor ingredients of the processed foods (aTFIS, 2019). The poor utilization of raw SP in food industries is due to the rapid spoilage during storage, resulting from its high moisture content, abundant nutrients, and relatively thin skin vulnerable to the external impact (Ahmed et al., 2010; Lee et al., 2019). To resolve the poor shelf-life of raw SP, thus, it is usually processed in forms of the dehydrated product and its flour, and the starch which are more stable and can be used throughout the year

(Yadav et al., 2007). Sweet potato starches (SPST) have been used as thickening agents of the processed foods and sources of the starch noodle and alcohol fermentation (Menon et al., 2015). However, the pasting viscosities of SPST are higher and more dramatically changed over temperature profiles than those of corn starches widely used in food industries (Abegunde et al., 2013; Cui et al., 2018). The paste and gel of its commercial products appear darker due to the oxidation of polyphenol residues (Ahmed et al., 2010). Thus, SPST is rarely utilized for the processed foods, except for starch noodles and alcohol fermentation. Meanwhile, the dehydrated SP and its flour (SPFL) are commercially prepared by either hot-air drying or drum-drying, which has been used as ingredients of soup, gravy, bakery foods, snack foods, confectionery (Ahmed et al., 2010; Yadav et al., 2007). When the dehydrated products are applied to the processed foods, however, they can cause discoloration resulting from the oxidation of polyphenols by oxidase and the Maillard reaction between reducing sugars and proteins during cooking (Ahmed et al., 2010). Thus, their applications seem to be limited to the processed foods in which the browning is demanded. Furthermore, the dehydrated SP products possess starches gelatinized to different extents depending on drying methods and conditions (Ahmed et al., 2010; Kim et al., 2011; Yadav et al., 2007; Yoon et al., 2018) and amylolytic enzymes still active (Dziedzoave et al., 2010; Kim et al., 2011; Yoon et al., 2018), which makes it difficult to modulate the physical properties and end-use qualities of foods containing dehydrated SP products. Accordingly, to further extend industrial uses of SP-based, dehydrated products, their shortcomings that food processors make their uses reluctant need to be resolved.

The recent studies were reported to develop the dehydrated potato materials to overcome the drawbacks of potato flour and starch in their industrial applications (Kim and Kim, 2015a; 2015b; Shin et al., 2015). Their strategy was that either ungelatinized and gelatinized (Kim and Kim, 2015a; 2015b) or raw and frozen (Shin et al., 2015) whole-tissues (comprising parenchyma cells) of potatoes disassembled to intact, individual parenchyma cells (PC) by degrading pectic substances present to the middle lamellae among primary PC walls with pectinases, followed by their recovering and dehydrating. Similar to the potato flesh, the sweet potato flesh consists of PC filled with starch granules (Ahmed et al., 2010). Therefore, the objective of this study was to prepare the dehydrated material of intact, individual PC (with native starch granules) isolated from SP whole-tissues using food-grade pectinase, and to characterize the dehydrated sweet potato parenchyma cell (SPPC) so as to investigate whether it was able to replace SPST and SPFL.

Materials and methods

Materials

Mealy SP (cultivated in 2017), as a source for preparing starch, dehydrated PC, and flour in this study, was purchased from Haenam Sweet Potato Grower Association (Haenam, Jeollanam, Korea). SP was stored at 4 °C and 95–98%RH during its pre-treatment. The pre-treatment (washing, peeling, cutting, freezing) of SP was completed within one week to minimize the loss of starch within SP by amylolytic enzymes (Zhang et al., 2002). Pectinex Ultra SP-L (rich in endo-polygalacturonase from *Aspergillus niger*; aqueous solution) and Novozym 33095 (rich in pectin lyase from *Aspergillus aculeatus and Aspergillus niger*; aqueous solution) were obtained from Apisbio (Daegu, Korea). The pectinase activities of Pectinex Ultra SP-L and Novozym 33095 were 540 U/mL and 1150 U/mL, respectively. Here, one unit (U) of pectinase activity was defined as the amount of enzyme required to release 1 μmol of α-D-galacturonic acid per minute at 40 °C and pH 3.5. Congo red was purchased from Sigma-Aldrich Co. (St. Louis, MO, USA). Total starch assay kit (K-TSTA) was obtained from Megazyme International Ltd. (Wicklow, Ireland). All chemicals and reagents used in this study were of analytical grade.

Pre-treatment of sweet potato

SP was washed, peeled, and cut to 1 cm thickness using a French fry cutter (WestonSupply.com, Strongsville, OH, USA). SP strips were transferred in a PVC zipper storage bag, frozen for 48 h at − 45 °C, and stored at − 18 °C until SPPC preparation.

Isolation of parenchyma cells from sweet potato

SPPC was isolated independently from raw and frozen whole-tissues of SP according to the method of Shin et al. (2015) with slight modification. Raw SP was washed, peeled, cut to a cube shape (1 cm × 1 cm × 1 cm). The frozen SP whole-tissues (pre-treated as mentioned above) were thawed for 18 h at 4 °C in an aqueous of solution of 0.1% (w/v) sodium metabisulfite, recovered with a 20 mesh sieve (No. 20; Chunggye, Seoul, Korea), and cut to a cube shape (1 cm × 1 cm × 1 cm). Both raw and thawed SP cubes were washed with deionized water (DIW) to remove starch granules on their surfaces. The SP cubes (75 g, w.b or wet weight basis) and ascorbic acid (400 mg) were added to 350 mL of the reaction medium (100 mM citrate buffer, pH 3.5), and pre-incubated at 50 °C for 30 min. After 30 min, 1 mL of the diluted pectinase solution (5.75

U) was added to the reaction mixture. Pectinex Ultra SP-L and Novozym 33095 were 95 and 200 times diluted with DIW, respectively. The reaction mixtures were further incubated at 50 °C for 3 h under continued stirring (100 rpm), after which it was passed through a serial of 20 and 140 mesh sieves (No. 20 & 140; Chunggye). The isolated SPPC was defined as a sieve overs on a 140 mesh sieve through a 20 mesh sieve. SPPC was washed with DIW on the 140 mesh sieve to remove both broken/rupture SPPC walls and released starch granules. The washed SPPC was dispersed in ethanol (95%), shortly stirred with a spatula, and allowed to settle SPPC down at room temperature (~ 24 °C) for 30 min. Then, the supernatant was carefully discarded. These dehydration steps (SPPC dispersion, stirring, settling down, and supernatant removal) were repeated a total of four times. The dehydrated SPPC of the final step was recovered on a 140 mesh sieve, dried at 45 °C for 48 h, and stored in a Teflon sample bottle at room temperature (24 °C). The isolation yield of SPPC was calculated as the percent ratio of dry weights of the isolated SPPC to the initial SP cube.

Preparation of starch and flour from sweet potato

SPST was isolated from frozen SP whole-tissues (Kim, 2013). The frozen SP whole-tissues (1 kg, w.b) were thawed for 18 h at 4 °C in an aqueous solution (1 L) of 0.1% (w/v) sodium metabisulfite. The thawed SP whole-tissues were ground with a mixer (HMF-552; Hanil Electric, Seoul, Korea), passed through a 140 mesh sieve. The filtrate was kept at 4 °C for 5 h, after which the supernatant was carefully discarded. The precipitate was re-suspended in DIW (1 L). The noted procedure (from starch precipitation to re-suspension) was conducted a total of five times. The SPST cake of the final step was suspended in ethanol (99%, 500 mL), stirred for 30 min, and recovered on a Büchnel funnel by vacuum filtration. The resultant SPST was dried at 45 °C for 24 h, and stored in a Teflon sample bottle at room temperature (~ 24 °C). For SPFL, the frozen SP whole-tissues stored at − 18 °C were transferred in a freezer (− 45 °C), held for 48 h, and freeze-dried for 4 days. The freeze-dried SP whole-tissues were ground with a mixer (HMF-552; Hanil Electric), passed through a 60 mesh sieve (No. 60; Chuggye), and stored in a Teflon sample bottle at room temperature (~ 24 °C).

Microscopy

SPPC was stained with Congo red (specific to cellulosic materials), according to the method outlined by Kim and Kim (2015a). Its morphology were viewed using a light microscope (CX41; OLYMPUS Corporation, Tokyo, Japan) at 100 times magnification.

Chemical compositions

The proximate compositions of SP materials were assayed according to AACC approved methods 44-19 for moisture, 46-08 for crude protein (%N × 6.25), 08-01 for crude fat, and 30-26 for crude ash (AACC, 2000). Their total carbohydrate contents were determined by subtracting the sum of protein, lipid, and ash contents (%, d.b or dry weight basis) from 100. Total starch contents of SPPC and SPFL were analyzed with a total starch assay kit according to AACC approved method 76-13 (AACC, 2000). Soluble pectic substances in SPPC and SPFL were extracted at 25 °C with 0.1 N NaOH including 0.75% sodium hexametaphosphate, and quantified using a sulfuric acid-carbazole method (Nurdjanah et al., 2013). Amylose and phosphorus contents of SP materials were assayed by a colorimetric method (Chrastil, 1987) and using inductively coupled plasma-atomic emission spectroscopy (ICP-AEC) (Anderson, 1996).

Solubility and swelling power

The swelling power of SP materials were determined at 85 °C according to the method of Kim and Kim (2015b). Their solubility was evaluated with soluble starch fraction and pectin contents within the supernatants obtained from measuring their swelling power, according to colorimetric (Chrastil, 1987) and sulfuric acid-carbazole methods (Nurdjanah et al., 2013), respectively.

Differential scanning calorimetry (DSC)

Gelatinization temperature and enthalpy of SP materials were analyzed with DSC (DSC 4000; Perkin-Elmer Inc., Waltham, MA, USA) (Kim and Kim, 2015b). The sample (5 mg, d.b) was directly weighed into a stainless steel pan, and DIW was added up to a total weight of 20 mg. The hermetically sealed pan was held for 24 h at room temperature (~ 24 °C). After equilibrium, the pan was scanned from 25 to 100 °C with a heating rate of 5 °C/min. A reference for DSC analysis was a sealed empty pan.

Rapid visco analyzer (RVA)

Pasting viscosity profiles of SP materials were obtained using RVA (RVA-3D; Newport Scientific, NSW, Australia) (Shin et al., 2015). The SP materials (2 g, d.b) were directly weighed into aluminum canisters, followed by adding DIW or 10 mM $HgCl_2$ solution up to a total weight of 28 g. The specimens were tested according to the programmed temperature profile: holding for 1 min at 50 °C, heating with a heating rate of 12 °C/min from 50 to 95 °C, holding for 2.5 min at 95 °C, cooling with a cooling rate of

12 °C/min to 50 °C, and holding for 2 min at 50 °C. During RVA operation, the plastic paddle rotation maintained a constant speed (160 rpm).

Statistical analysis

The preparation of SP materials were repeated at least three times. All characteristic measurements were conducted at least three times for their treatments each. The collected data were first analyzed by Analysis of Variance (ANOVA), and expressed as mean ± standard deviation (SD). Significance among means of SP material characteristics were identified with a Tukey's HSD range test at $p < 0.05$. All statistical analyses were done using Minitab 16 (Minitab Inc., State College, PA, USA).

Results and discussion

Isolation of sweet potato parenchyma cells from sweet potato whole-tissues

Effects of the status of SP whole-tissues and the type of pectinase on the isolation yield of SPPC were investigated and shown in Fig. 1. The yields of SPPC isolated with polygalacturonase (Pectinex Ultra SP-L) from raw and frozen SP whole-tissues were 10.8% and 43.5%, respectively (Fig. 1A). The noted difference is consistent with the study isolating PC from raw and frozen potato whole-tissues by pectinase (Jung et al., 2015). The higher yield of SPPC isolated from frozen (relative to raw) SP whole-tissues may be because accessibility of pectinase to pectic substances present to middle lamellae among PC walls (Kim and Kim, 2015a) was further facilitated by PC shrinkage resulting from loss of fluids within PC (drip phenomenon) during their thawing (Jung et al., 2015). Regarding the impact of pectinase types on SPPC yields, pectin lyase (Novozym 33095) and polygalacturonase yielded 62.1% and 47.0% (based on dried weights of SP whole-tissues) of SPPC from frozen SP whole-tissues, respectively (Fig. 1B), in agreement with the trend observed by Jung et al. (2015) for the production of potato PC from its frozen whole-tissues. The molecular weights (determined by SDS-PAGE) of the purified prectinase from *A. niger* were 106–124 kDa for polygalacturonase (Anand et al., 2017) and 23.3 kDa for pectin lyase (Poturcu et al., 2017). Thus, pectin lyase much smaller than polygalacturonase may by easier to access pectic substances among parenchyma cells composing SP flesh, resulting in the higher yield of SPPC from frozen SP whole-tissues. Meanwhile, the dehydrated SPPCs prepared form frozen SP whole-tissues using both pectinases were stained with Congo red, followed by viewing with a light microscope

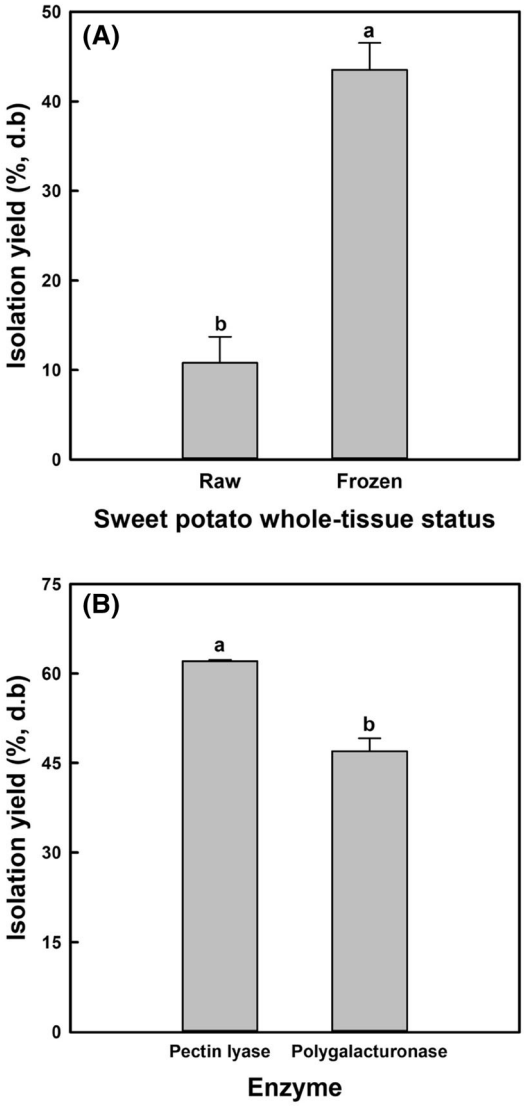

Fig. 1 Effects of the sweet potato whole-tissue status (**A**) and the enzyme type (**B**) on the isolation yields of parenchyma cells from sweet potato. Bars sharing the same lowercase letters are not significantly different at $p < 0.05$

(Fig. 2). A Congo red dye is specific to cellulose lamellae (Shin et al., 2015), which highlighted parenchyma cell walls mainly comprised of cellulose and hemicellulose to a red color (Fig. 2). Regardless of pectinase types, the majority of the dehydrated SPPC was intact, individual PCs fully filled with SPST granules (Fig. 2). Both empty PCs and damaged PC fragments were not frequently observed, and free SPST granules were not present. Consequently, the dehydrated SPPC can be prepared by isolating PCs from frozen SP whole-tissues using pectin lyase for its higher yield and purity. Thus, its characterization was conducted with the dehydrated SPPC by pectin lyase from frozen SP whole-tissues.

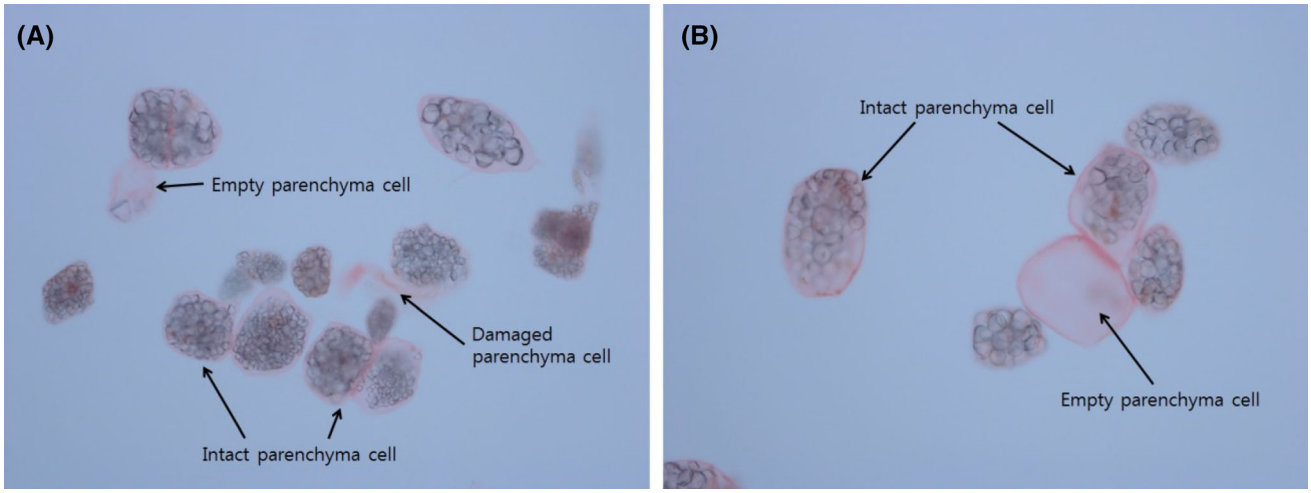

Fig. 2 Light microscope (LM) images of parenchyma cells (PC) isolated from the frozen whole-tissues of sweet potato with pectin lyase (**A**) and polygalacturonase (**B**)

Chemical compositions

Chemical compositions were assayed for SPST, SPPC, and SPFL, and depicted in Table 1. The crude protein, crude fat, crude ash, and total carbohydrate contents of SPST was 0.5%, 0.0%, 0.1%, and 99.3%, respectively (Table 1), consistent with those reported in literature (Abegunde et al., 2013). Relative to SPPC and SPFL, its crude protein, crude fat, and crude ash were lowest and its total carbohydrate was highest (Table 1). For comparison in proximate compositions of SPPC and SPFL, crude protein and crude ash, aside from their crude fat showing only minute difference (0.2%) and total carbohydrate being determined according to other attributes, were significantly higher for SPFL than SPPC (Table 1). It is comparable with the trends observed in proximate compositions between potato PC and flour (Kim and Kim, 2015a; 2015b). Both protein and ash liberated from SP whole-tissues into the reaction medium during pectinase treatment may be lost at a washing step of the isolated SPPC, resulting in the noted differences between SPPC and SPFL (Kim and Kim, 2015a; 2015b). Total starch contents of SPPC and SPFL were 88.2% and 62.1%, respectively, and non-starch polysaccharide contents (subtracting total starch contents from total carbohydrate contents) were 10.5% for SPPC and 32.7% for SPFL (Table 1). For pectin contents, SPFL (6.2%) was much higher than SPPC (0.6%) (Table 1). Kim and Kim (2015a) identified the presence of pectin residues on potato PC walls by optically viewing after their staining with ruthenium red (specific to anionic polysaccharide). Thus, the lower content of pectin in SPPC may be due to pectin residues on its cell walls. On the other hand, amylose contents increased in orders of SPST (25.4%), SPPC (23.7%), and SPFL (19.5%) (Table 1). Phosphorus contents also increased in orders of SPPC (129.2 ppm), SPPC (109.8 ppm), and SPFL (87.3 ppm) (Table 1). The trend

Table 1 Mean values for chemical compositions of starch (SPST), parenchyma cells (SPPC), and flour (SPFL) prepared from the frozen whole-tissues of sweet potato

Sweet potato material	Crude protein (%, d.b)	Crude fat (%, d.b)	Crude ash (%, d.b)	TC[1] (%, d.b)	TS[2] (%, d.b)	NSP[3] (%, d.b)	Pectin (%, d.b)	AM[4] (%, d.b)	Phosphorus (ppm, d.b.)
SPST	0.5 ± 0.0^{c}	0.0 ± 0.0^{b}	0.1 ± 0.1^{c}	99.3 ± 0.0^{a}	–	–	–	25.4 ± 0.2^{a}	129.2 ± 2.4^{a}
SPPC	0.7 ± 0.0^{b}	0.1 ± 0.0^{b}	0.5 ± 0.0^{b}	98.7 ± 0.1^{b}	88.2 ± 0.4^{a}	10.5 ± 0.3^{b}	0.6 ± 0.1^{b}	23.7 ± 0.1^{b}	109.8 ± 3.0^{b}
SPFL	2.2 ± 0.0^{a}	0.3 ± 0.1^{a}	2.7 ± 0.1^{a}	94.8 ± 0.1^{c}	62.1 ± 0.3^{b}	32.7 ± 0.2^{a}	6.2 ± 0.4^{a}	19.5 ± 0.1^{c}	87.3 ± 12^{c}

Mean values of three replicate measurements; values sharing the same uppercase letters within columns are not significantly different at $p < 0.05$

[1]Total carbohydrate (%) = 100 − (protein + lipid + ash)

[2]Total starch content

[3]Non-starch polysaccharide content

[4]Apparent amylose content

observed in amylose or phosphorus contents of SP materials is paralleled to that in their total starch contents (Table 1). Phosphate groups are known to be naturally esterified onto amylopectin branch-chains of SPPC (McPherson and Jane, 1999). Accordingly, both amylose and phosphorus contents of SP materials probably depend on their total starch contents.

Solubility and swelling power

Solubility and swelling power of SPST, SPPC, and SPFL prepared from the frozen SP whole-tissues was measured at 85 °C, and depicted in Table 2. Their solubility was assessed with starch fraction and pectin contents in the supernatants obtained from examining their swelling power. The solubility (determined by starch fraction contents) increased in orders of SPFL (67.5%), SPST (13.2%), and SPPC (6.1%) (Table 2). The highest starch fraction contents of SPFL relative to others may be due to the fact that SPST in SPFL (prepared through freeze-drying) was degraded by attack of amylolytic enzymes activated during its heating in excessive water (Dziedzoave et al., 2010; Yoon et al., 2018; Zhang et al., 2002). Also, the lower starch fraction contents of SPPC than SPST are in agreement with the differences in solubility between potato starch and PC (Kim and Kim, 2015b). It may be attributed to the restriction of starch leaching from swollen SPST granules by intact cell walls of parenchyma cells in which SPST granules were entrapped (Fig. 2), as suggested by Kim and Kim (2015a; 2015b) and Shin et al. (2015). Meanwhile, as anticipated by pectin contents of SP materials in Table 1, the higher pectin content was identified in the supernatant from SPFL (9.8%) than SPPC (0.3%), although it was not detected in SPST (Table 2). Nevertheless, the pectin content (9.8%) in the supernatant from SPFL was higher than that (6.2%) of SPFL itself provided in Table 1. The noted discrepancy might be because the release of cell wall-bound pectin in SPFL is further facilitated by its heating SPFL in excessive water (Brejnholt, 2010).

Swelling power increased in orders of SPST (19.2 g/g), SPPC (7.8 g/g), and SPFL (2.7 g/g). The lowest swelling power of SPFL relative to others, in this study, may mainly result from damage of starch granules in SPFL by its α- and ß-amylase activities (Dziedzoave et al., 2010; Yoon et al., 2018; Zhang et al., 2002), although non-polysaccharides (pectin, cellulose, hemicellulose) and proteins firstly holding water in SPFL prevent the interaction between SPST and water, restricting its swelling (Liu et al., 2007). Moreover, the lower swelling power of SPPC than SPST is similar to that observed for potato PC and starch (Kim and Kim, 2015b; Shin et al., 2015). As previously explained, this phenomenon may also be due to the fact that parenchyma cell walls restrict swelling of starch granules in SPPC (Kim and Kim, 2015b; Shin et al., 2015).

Thermal property

The gelatinization properties of SPST, SPPC, and SPFL were analyzed with DSC, and shown in Table 3. Gelatinization onset, peak, and completion temperatures of SPST were 64.5, 72.2, and 79.7 °C, respectively, very similar to those of lab-isolated and commercial SP starches by Song et al. (2014). Also, gelatinization onset, peak, and completion temperatures were 65.5, 72.9, and 80.5 °C, respectively, for SPPC and 70.7, 77.5, and 83.7 °C, respectively, for SPFL (Table 3). Gelatinization temperatures of SPPC and SPFL relative to SPST were significantly shifted to higher temperatures (Table 3), indicating the retardation of their gelatinization. The noted phenomenon is consistent with that observed in potato starch, PC, and flour by Kim and Kim (2015b). The possible explanation may be that proteins and non-starch polysaccharides of SPPC and SPFL first absorb and hold water, inhibiting the sufficient hydration of their starches, followed by retarding their gelatinization (Kim and Kim, 2015a; Liu et al., 2007). It is further supported by their non-starch polysaccharide contents shown in Table 1. For the same reasons, moreover, SPFL possessing about threefold higher non-starch polysaccharide content than SPPC (Table 1) appears to show much higher gelatinization temperatures (Table 3). Meanwhile, the gelatinization enthalpy of SPPC and SPFL was significantly lower than that of SPST, and decreased with increasing their non-

Table 2 Mean values for solubility and swelling power of starch (SPST), parenchyma cell (SPPC), and flour (SPFL) prepared from sweet potato

Sweet potato material	Solubility[1] (%, d.b)		Swelling power[1] (g/g)
	Starch fraction	Pectin	
SPST	13.2 ± 0.2^{b}	–	19.2 ± 0.1^{a}
SPPC	6.1 ± 0.3^{c}	0.3 ± 0.1^{b}	7.8 ± 0.1^{b}
SPFL	67.5 ± 1.3^{a}	9.8 ± 0.2^{a}	2.7 ± 0.1^{c}

Mean values of three replicate measurements; values sharing the same uppercase letters within columns are not significantly different at $p < 0.05$

[1]Determined at 85 °C

Table 3 Mean values for gelatinization properties of starch (SPST), parenchyma cells (SPPC), and flour (SPFL) prepared from sweet potato

Sweet potato material	Gelatinization temperature (°C)			Gelatinization enthalpy (J/g dried sample)
	Onset	Peak	Completion	
SPST	64.5 ± 0.1^{c}	72.2 ± 0.1^{c}	79.7 ± 0.1^{c}	11.2 ± 0.9^{a}
SPPC	65.5 ± 0.2^{b}	72.9 ± 0.2^{b}	80.5 ± 0.2^{b}	9.6 ± 0.0^{b}
SPFL	70.7 ± 0.2^{a}	77.5 ± 0.1^{a}	83.7 ± 0.1^{a}	5.2 ± 0.1^{c}

Mean values of three replicate measurements; values sharing the same uppercase letters within columns are not significantly different at $p < 0.05$

starch polysaccharide contents (Table 3). It is compatible with the results observed in potato materials of Kim and Kim (2015b) and Shin et al. (2015). As previously explained, the noted trend may be attributed to insufficient hydration of starches within SPPC and SPFL due to the presence of proteins and non-starch polysaccharides, resulting in limiting the complete melting and/or breakdown of the ordered structures within their starches and consequently, reducing their gelatinization enthalpies (Kim and Kim, 2015a; Liu et al., 2007; Shin et al., 2015).

Pasting viscosity property

Pasting viscosity profiles of SPST, SPPC, and SPFL were investigated using RVA and shown in Fig. 3. For RVA testing of SP materials in DIW, SPST revealed a typical pasting viscosity profile generally reported in literature (Abegunde et al., 2013; Song et al., 2014; Yoon et al., 2018) and much higher pasting viscosities over the programmed temperature profile than others (Fig. 3A). However, pasting viscosities of SPPC gradually increased over the programmed temperature profile since its pasting viscosity slightly fell down after developed the lower peak viscosity (Fig. 3A), similar to those observed in potato PC (Kim and Kim, 2015b; Shin et al., 2015). The observed pattern may be explained by the restricted swelling and starch leaching of starch granules within SPPC, as demonstrated by the lower swelling power and leached starch fraction content of SPPC than SPST (Table 2). As previously suggested, the cell walls of SPPC in which SPST granules were confined (Fig. 2) may inhibit the swelling of SPST granules and the leak of starch molecules leached from swollen starch granules, which prevents the full development of SPPC pasting viscosities (Kim and Kim, 2015a; 2015b; Shin et al., 2015). Furthermore, SPFL failed to develop the pasting viscosities except for much smaller peak viscosity (125 mPa·s) over the programmed temperature profile (Fig. 3A). This may be due to action of α- and ß-amylases still active in SPFL, as suggested by Yoon et al. (2018). To verify the noted suggestion, SP materials were further tested in a solution of 10 mM $HgCl_2$ known as an enzyme inhibitor (Fannon et al., 1992).

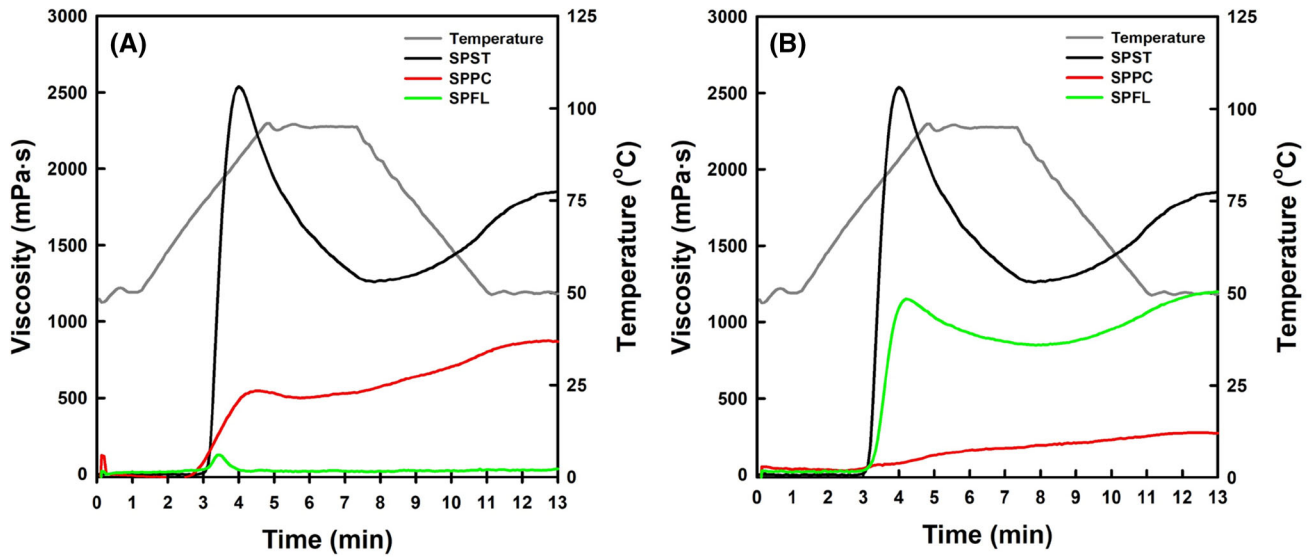

Fig. 3 Pasting viscosity profiles of starch (SPST), parenchyma cells (SPPC), and flour (SPFL) prepared from the frozen whole-tissues of sweet potato by pecin lyase treatment (**A**: deionized water, **B**: 10 mM $HgCl_2$ solution)

Although the pasting profile of SPST in $HgCl_2$ solution (Fig. 3B) was not significantly different from that in DIW (Fig. 3A), SPFL successfully developed the pasting viscosities enough to identify all attributes of pasting viscosity characteristics (Fig. 3B). Accordingly, it may be obvious that α- and ß-amylases in SPFL hinder developing its pasting viscosity. Meanwhile, the pasting viscosity of SPPC in $HgCl_2$ solution (Fig. 3B) was much lower than that in DIW (Fig. 3A), and gradually increased (Fig. 3B). It might be interpreted by the reinforced extensibility of cell walls of SPPC by acting as ionic cross-linkers of divalent mercuric ions about pectin residues on its cell walls. Divalent mercuric ions dissociated from $HgCl_2$ can cross-link the negatively-charged pectin residues present to the surfaces of SPPC through multiple ionic linkages among them (Brejnholt, 2010), which may make its cell walls more rigid and stiffer. Consequently, more rigid and stiffer cell walls of SPPC might much more inhibit the swelling of SPST granules, retarding or restricting its pasting viscosity development.

In conclusion, SPPCs were intactly and individually isolated from frozen SP whole-tissues by pectin lyase treatment, preparing the dehydrated SPPC material. SPPC revealed characteristics, except for its lowest solubility, in swelling power, gelatinization, and pasting viscosity between SPPC and SPFL. It may be due mainly to SPPC morphology entrapping SPST granules in SP parenchyma cells, altering its characteristics. Consequently, the spontaneous enclosure of clusters of SPST granules with SP parenchyma cell walls through dehydrating after isolating intact, individual SPPC from SP whole-tissues could be one of ways of modifying characteristics of SPST without chemical reacting agents. Moreover, the dehydrated SPPC would be a potential alternative to replace the existing SPST and SPFL in order to expand applications of SP in food industries.

Acknowledgements This work was supported by Kyonggi University Research Grant 2017.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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