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A comparative study of edible canna (*Canna edulis*) starch from different cultivars. Part I. Chemical composition and physicochemical properties

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Abstract

The chemical composition and physicochemical properties of starches isolated from three cultivars (Japanese-green, Thai-green and Thai-purple) of edible canna rhizomes were studied. Scanning electron microscopy investigations showed that the starch granules from all cultivars of canna were oval-shaped granules with smooth surfaces and were around 10–100 μm in sizes. Proximate composition studies showed that the protein content in the canna samples varied between 0.069 and 0.078%, lipid between 0.014 and 0.019% and ash between 0.25 and 0.33%. All canna starches contained considerably high phosphorus (371–399 ppm), followed by calcium (113–154 ppm) and potassium (35–61 ppm). The absolute amylose content ranged from 19 to 25%. All three starches displayed a B-type X-ray diffraction pattern. The viscograms of canna starches determined by Rapid Visco Analyzer showed that Thai-green and Japanese-green starches paste were quite stable during cooking and had high setback. The enthalpy for gelatinization and dissociation of retrograded canna starches, investigated using differential scanning calorimeter, were 17.6–18.4 and 12.3–15.0 J/g of starch, respectively. The results obtained from freeze-thaw stability and light transmittance measurements indicated that all canna starches had a high tendency for retrogradation.

Keywords: *Canna edulis*; Edible canna starch; Cultivar; Physicochemical properties; Composition

1. Introduction

Edible canna (*Canna edulis* Ker) is a perennial herb of the family *Cannaceae*, native to the Andean region in South America. This plant has a large starchy rhizomes, which traditionally used as a staple food for Andean people for more than 4000 years. This crop is now cultivated as the source for starch production in small-scale factories in China, Taiwan and Vietnam. The starch is mainly used for making glassy noodles. There have been some reports on the physicochemical properties of edible canna starch (Perez, Breene, & Bahnassey, 1998; Santacruz, Koch, Svensson, Ruales, & Eliasson, 2002; Soni et al., 1990). The reports indicated the interesting properties of edible canna especially pasting properties. Soni et al. (1990) reported that Brabender viscosity of *C. edulis* starch is more than three times higher than that of maize starch and has shown no thinning. The studies of Perez et al. (1998) showed that canna starch produced a clear paste and had much higher viscosity than cassava starch at the same concentration.

All the reports mentioned above reported the properties of only the Andean canna starch. In Thailand, edible canna are also found and recognized as an unutilized starchy plant resource. There are some variations in the botanical features of Thai edible canna found in different areas. In the south of Thailand, the rhizomes are white but the whole leaves are green, while in other parts especially the northeast, the plant has a purple color at the tip of rhizomes, and the rim of the leaves are also purple. The former is called 'Thai-green' whereas the latter, is called 'Thai-purple'. Both of them were verified by Botany and Weed Science Division, Department of Agriculture, Ministry of Agriculture and Cooperation, Thailand as *C. edulis* Ker.

Starches from different cultivars of wheat (Wootton & Mahdar, 1993), maize (Yun & Metheson, 1993), barley (Yoshimoto, Tashiro, Takenouchi, & Takeda, 2000), cassava (Sriroth et al., 1999) have been shown to vary in

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protein, ash, lipid, amylose contents, crystallinity and gelatinization properties. Such variations in starch composition and properties between edible canna cultivars have not been demonstrated. Most of the studies on edible canna starch have been on a single cultivar. Therefore, it is difficult to ascertain whether the data reported are truly representative of edible canna starch. For this reason it was considered worthwhile to investigate the chemical composition and its physicochemical properties of edible canna starch from different cultivars.

The objective of this study was to determine the properties of edible canna starches from the cultivars, namely Thai-green, Thai-purple and Japanese-green (brought from Tsukuba University, Japan). In addition, starches from mung bean and cassava were also studied in comparison with the canna starches.

2. Materials and methods

2.1. Materials

Three cultivars of edible canna (Thai-purple, Thai-green and Japanese-green) were grown on experimental plots under identical environmental condition at the Corn and Sorghum Research Center, Kasetsart University, Thailand. Nine months rhizomes were harvested for starch extraction. Cassava tuber (Kasetsart 50 variety) was provided by Rayong Field Crops Research Institute, Rayong, Thailand. Mung bean was purchased from local supplier in Bangkok. All chemicals used in this experiment were analytical grade.

2.2. Starch isolation

The slurry of canna rhizome was prepared by adding some water into approximately 1-cm cubes of cleaned rhizome, and then ground in a blender. The pulp in slurry was removed by screening through a bolting cloth and the suspension obtained was filtered through a 88 μm sieve. The filtrate was allowed to settle until a dense, firm starch layer was deposited. The supernatant was decanted and starch cake was rewashed at least three times. The starch cake was then dried in an oven at 50 °C for 15 h. Cassava starch was isolated in the same manner whereas mung bean was soaked overnight in water before grinding.

2.3. Scanning electron microscopy

Scanning electron micrographs were taken with a JEOL, JSM-5800 scanning electron microscope (SEM) at an accelerating voltage of 20 kV.

2.4. Chemical composition of starch

Standard AOAC methods (1990) were used for the measurement of moisture, nitrogen, fat and ash. Protein was determined from estimates of total nitrogen using a conversion factor of 6.25.

For measurement of inorganic constituents, the starch sample (500 mg) was firstly digested with 30% hydrogen peroxide (1 ml) and 65% nitric acid (6 ml) in Microwave Digester (MILESTONE, model mls 1200 mega). K, Ca, Mg, Fe and Na were analyzed by atomic absorption photometry using HITACHI, model Z-9000. Phosphorus content was determined by a colorimetric chemical method (Smith & Caruso, 1964).

2.5. Iodine affinity and amylose content

Iodine affinity (IA, g/100 g) was determined using the amperometric titration method (Larson, Gilles, & Jenness, 1953) with some modifications (Takeda, Hizukuri, & Juliano, 1987). Absolute amylose content were calculated using the formula $(IA_{defatted\ starch} - IA_{amylopectin})/(IA_{amylose} - IA_{amylopectin}) \times 100$ (Takeda, Takeda, & Hizukuri, 1983).

Defatted starch was prepared by three replication of dissolution in dimethyl sulfoxide and precipitation with ethanol (Takeda, Hizukuri, & Juliano, 1986). Amylose and amylopectin were fractionated by the method of Takeda et al. (1986).

2.6. X-ray diffraction pattern

X-ray diffraction patterns of wet specimens were obtained with an X-ray diffractomer (Rotaflex RV-20013, Rigaku Denki Co., Tokyo, Japan) using the conditions described by Hizukuri et al. (1988).

2.7. Pasting properties

Pasting properties of starch slurry at a concentration of 6% (w/w) were determined by a Rapid Visco Analyzer (RVA-3D, Newport Scientific, Narrabeen, Australia) with a paddle rotated at a fixed speed of 160 rpm. The starch slurry was heated from 40 to 92.5 °C at the rate of 3 °C/min, maintained at 92.5 °C for 15 min, and then cooled to 40 °C at the same rate.

2.8. Differential scanning calorimetry

Thermal properties of starches were determined by differential scanning calorimeter (DSC-Pyris 1, Perkin Elmer, Norwalk, CT). Starch (3 mg) was weighed in a DSC pan and water (6 mg) was added. The pan was sealed and allowed to stand for 12 h at 4 °C. The scanning temperature range and the heating rate were 30–150 °C and 5 °C/min, respectively. Water (6 mg) was used as a reference. The transition temperatures reported are the onset temperature (T_o), peak temperature (T_p) and conclusion temperature (T_c). The enthalpy of gelatinization (ΔH) was estimated by integrating the area between

the thermogram and a base line under the peak and was expressed in terms of joules per gram of dry starch. The retrogradation study was performed following the same method, using the same gelatinized starch samples that had been stored at 4 °C for 7 days.

2.9. Freeze-thaw stability

Freeze-thaw stability of gelatinized starch (10%, w/w in water) were measured by the method of Yuan and Thompson (1998). Aqueous suspension of starch (10%, w/w) was rapidly heated to 95 °C under constant agitation. The suspensions were contained in microcentrifuge tubes and then keep at 95 °C for 15 min before being cooled to 25 °C. The gels obtained were subject to cold storage at − 18 °C for 20 h. The frozen gels were then thawed at 30 °C for 4 h. The exuded water, at the end of thawing, was gravimetrically determined after centrifugation at 8000*g* for 10 min.

2.10. Light transmittance

Light transmittance of starch solution (1%, w/w in water) was measured by the method of Craig, Maningat, Seib, and Hoseney (1989). The solutions were prepared in screw-capped tubes and heated in water bath at 96 °C for 30 min. The tubes were shaken every 5 min by vortex mixer. After that, the tubes were taken out and left at 25 °C. %Transmittance of the solutions at 5, 30 and 60 min were then measured at 650 nm.

3. Results and discussion

3.1. Scanning electron microscopy

The starch granules from three cultivars of canna when viewed by SEM were rounded and oval-shaped granules with smooth surfaces (Fig. 1). The granules were 10–100 μm in size, which was similar to that reported by Santacruz et al. (2002).

3.2. Proximal analyses and inorganic components of starch

The proximal analyses and inorganic components of the starch samples are presented in Table 1. The moisture of all starch samples ranged from 9.11 to 10.22%. Under average ambient temperature and humidity conditions the moisture content of most native starches is around 12% (Ahmad, Williams, Doublier, Durand, & Buleon, 1999). The starches isolated from all three canna cultivars contained comparable amounts of protein (0.069–0.078%) which were lower than that of cassava starch (0.157%) and much lower than that of mung bean starch (0.559%). For lipid contents, the same trend was also found. There were 0.014–0.019% of lipid contents in canna starches, while in cassava and mung bean starches there were 0.034 and 0.139%, respectively. The low contents of lipid and protein are typical for root and tuber starches. The ash contents of all canna starches were relatively high (0.25–0.33%), comparing with mung bean starch (0.16%).

For the inorganic constituents, all edible canna starches contained the same level of phosphorus (371–399 ppm), which were higher than cassava (113 ppm) and mung bean (108 ppm) starches. The phosphorus contents in canna starches are quite high when compared to potato starch, which is known to have the highest phosphorus among known starches (480 ppm, Kasemsuwan & Jane, 1996; 750 ppm, McPherson & Jane, 1999). The phosphorus, although existing at a low concentration, plays an important role in starch functional properties (Jane, Kasemsuwan, Chen, & Juliano, 1996). Phosphorus in starch is found in three major forms; phosphate monoester, phospholipids and inorganic phosphate (Lin & Czuchajowska, 1998). It would be interesting to study further for the forms of phosphorus in edible canna starches. For the contents of other elements, calcium appeared to exist in the highest concentration for all starch samples, followed by potassium. Both of them have been reported to have profound influence on pasting properties of potato starches (Inatsu et al., 1983).

3.3. Iodine affinity and amylose content

Table 2 summarizes the IA (g/100 g) and amylose content of canna, cassava and mung bean starches. Mung bean had the highest absolute amylose content (28%), followed by Japanese-green (25%), Thai-green (22%), Thai-purple (19%) and cassava (18%). The absolute amylose contents of Japanese-green and Thai-green were in the same level as reported by Santacruz et al. (2002) (23.4–24.2%) and Jane et al. (1999) (22.7%). Canna starches showed lower absolute amylose content than their apparent amylose content. These over-estimation of the apparent values could be attributed to the molecular structure of amylopectin. Displaying the B-type X-ray pattern, canna starches were presumed to have a large proportion of long amylopectin branch chains (Hizukuri, 1986). Like amylose, these long branch chains can bind iodine to form a single helical complex, developing a blue color, and consequently inflate the apparent amylose content of starch.

3.4. X-ray diffraction pattern

All cultivars of canna gave B-type X-ray diffraction pattern (Fig. 2), being in agreement with the previous reports (Hanashiro, Abe, & Hizukuri, 1996; Jane et al., 1999). B-type pattern is typical to tuber and root starches (Hoover, 2001) and is characterized by a small peak at 5.6°, only one peak at 17° and a doublet at 22 and 24°. Mung bean and cassava starch, used as references, displayed A-type pattern (a doublet at 17 and 18° and a single peak at 23°). Even cassava is a root starch, but has been shown A-type (or

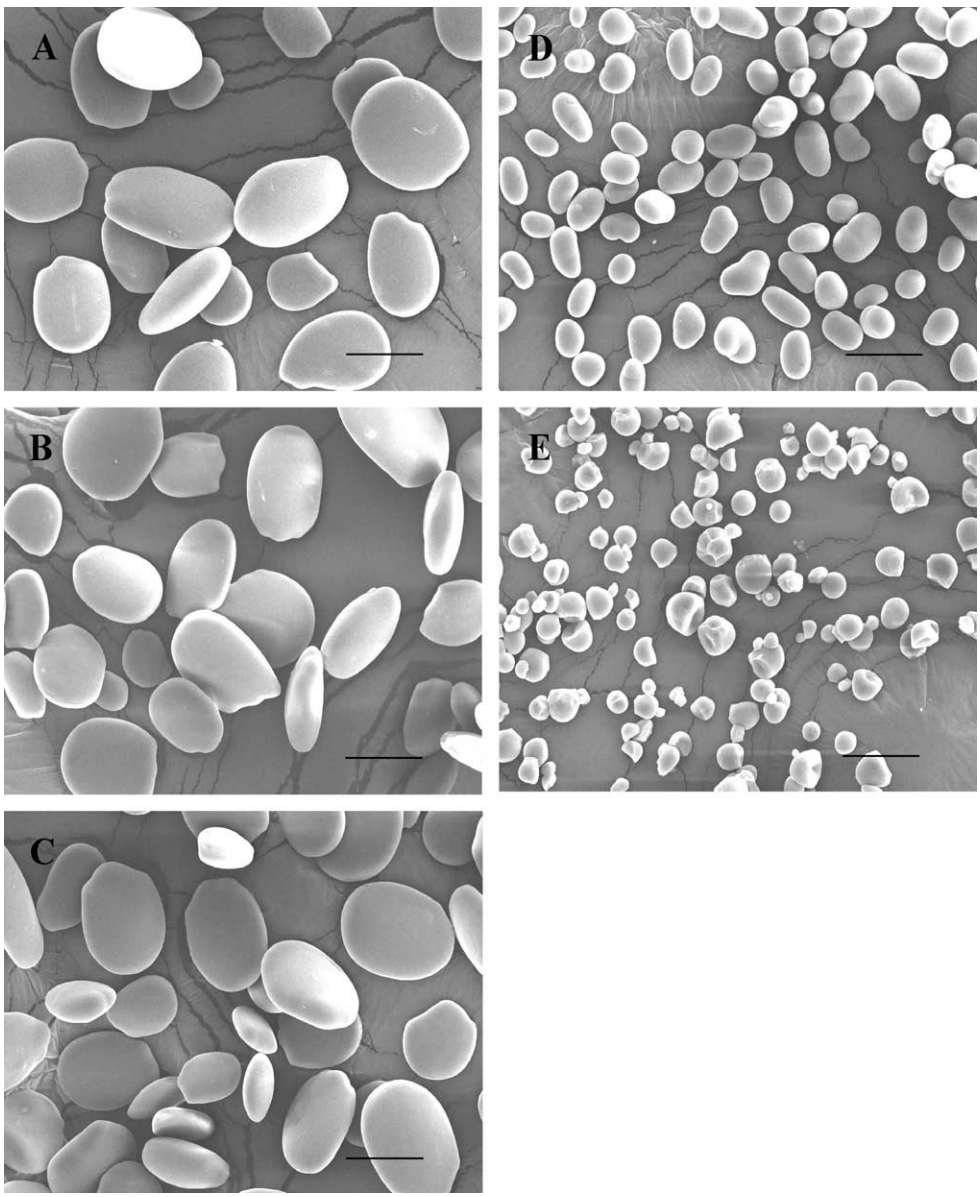

Fig. 1. Scanning electron micrographs (× 500, bar as 50 μm) of starches: (A) Japanese-green canna, (B) Thai-green canna, (C) Thai-purple canna, (D) Mung bean and (E) cassava.

Table 1
Chemical composition of starches

Characteristic	Composition (%)				
	Japanese-green canna	Thai-green canna	Thai-purple canna	Mung bean	Cassava
Moisture	10.02	9.78	9.39	9.11	10.22
Protein	0.069	0.078	0.076	0.559	0.157
Lipid	0.014	0.019	0.019	0.139	0.034
Ash	0.25	0.29	0.33	0.16	0.26
Inorganic composition (ppm)					
P	371	362	399	108	115
Ca	136	113	154	113	208
Mg	17	27	17	45	29
K	61	46	35	59	2
Na	30	27	40	18	23
Fe	40	50	19	18	57

Table 2
Iodine affinity and amylose content of starches

Property	Japanese-green canna	Thai-green canna	Thai-purple canna	Mung bean	Cassava
Iodine affinity (g/100 g)					
Defatted starch	5.62	4.98	4.21	5.89	3.56
Amylose	20.6	20.2	19.7	19.6	20
Amylopectin	0.54	0.63	0.62	0.52	0.13
Amylose content (%)					
Apparent amylose content (*A*)[a]	28	25	21	30	18
Actual amylose content (*B*)[b]	25	22	19	28	18
A − *B*	3	3	2	2	0

[a] Calculated by $(IA_{defatted\ starch}/20)(100)$.
[b] Calculated by $[(IA_{defatted\ starch} - IA_{amylopectin})/(IA_{amylose} - IA_{amylopectin})] \times 100$.

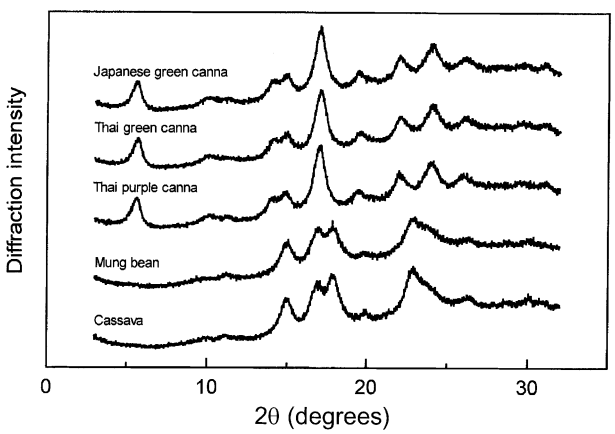

Fig. 2. X-ray diffraction patterns of native starches.

C_A-type in some reports) as reviewed by Jane et al. (1999). Mung bean starch has been typically shown A-type pattern (Jane et al., 1999).

3.5. Pasting properties

Fig. 3 shows the viscograms of the canna, cassava and mung bean starches (6% w/w) determined by a RVA. The pasting temperatures of canna starches were approximately at 71–72 °C, higher than cassava starch (68 °C) but lower than mung bean starch (76 °C). Canna starch showed higher peak viscosity than mung bean and cassava starches, especially Thai-purple starch gave substantially higher viscosity (258 RVU). Thai-purple starch also exhibited the highest breakdown (115 RVU, compared to 18 and 27 RVU for Japanese-green and Thai-green starches, respectively). This suggested that the intermolecular forces within the Thai-purple starch granules were much weaker than other two cultivars. On cooling, Thai-purple starch had a moderate setback (65 RVU), whereas the Japanese-green and Thai-green starches had high (122 and 100 RVU, respectively) and comparable setback to mung bean (115 RVU). The results agreed well with previous reports (Perez et al., 1998; Perez, Lares, & Gonzales, 1997).

The difference in pasting profiles of canna starches between Japanese-green, Thai-green and Thai-purple could be mainly attributed to their difference in amylose contents. It has been shown that amylose compared to amylopectin inhibits the swelling of starch granules (Tester & Morrison, 1992). Thus, Thai-purple starch swelled most rapidly and showed more breakdown because of its low amylose content. The amylose content also affected the setback of starch. Japanese-green and Thai-green canna starches, which had higher amount of amylose, showed higher setback than Thai-purple. Mung bean starch, consisting of a high absolute amylose content (28%) also displayed a very good paste stability (breakdown, 13 RVU) and high set back (115 RVU).

3.6. Differential scanning calorimetry

DSC results obtained for the various starch samples are given in Table 3 and representative curves are shown in Fig. 4. Thermograms of all three canna starches were similar. No significant differences in the gelatinization enthalpy, onset temperature, peak temperature, and conclusion temperature, among canna starch samples were observed. The values of peak temperature, often referred to as the gelatinization temperature, were higher than that reported by Santacruz et al. (2002) (61.2 °C).

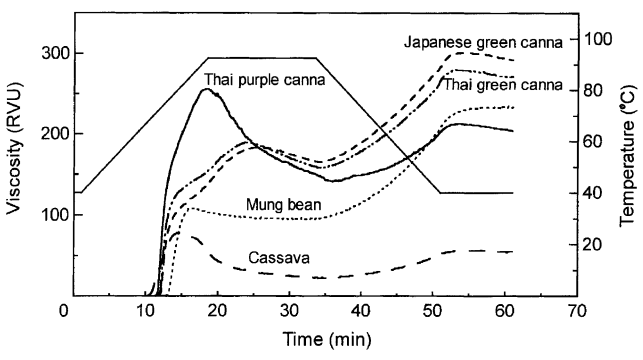

Fig. 3. Pasting profiles of starches (6%, w/w) measured by RVA.

Table 3
Thermal properties of starches

Starch	Gelatinization (°C)[a]				Retrogradation (°C)[a]				
	T_o	T_p	T_c	ΔH (J/g)[b]	T_o	T_p	T_c	ΔH (J/g)[b]	$\%R$
Japanese-green canna	66.7	68.9	71.6	18.3	49.2	55.8	77.1	15.0	82
Thai-green canna	66.8	68.7	70.9	18.4	42.7	60.5	73.0	12.3	67
Thai-purple canna	65.8	67.7	70.3	17.6	44.2	59.1	72.1	12.5	71
Mung bean	65.6	68.8	72.4	11.0	44.7	57.0	67.1	8.4	76
Cassava	65.5	69.7	80.6	18.1	42.7	55.2	63.4	6.3	34

[a] Transition temperature: T_o (onset temperature); T_p (peak temperature); T_c (complete temperature).
[b] Enthalpy change.

The enthalpy (ΔH) of canna starches were similar to that of cassava starch, but their thermogram patterns were different. The narrow shape of canna starches thermograms indicate that the canna starches might have more homogeneous microstructure than cassava starch. Comparing with mung bean starch, the enthalpy of canna starches was much higher. The enthalpy values have been reported by several workers to be influenced by many factors, e.g. molecular architecture of the crystalline region, amylose to amylopectin ratio, the present of short amylopectin chains, amount of double-helical order (see review of Hoover (2001)).

3.7. Retrogradation of starch gels

The degree of retrogradation developed during gel storage was determined by monitoring changes in retrogradation enthalpy and changes in freeze-thaw stability.

3.7.1. Retrogradation enthalpy

The DSC parameters of retrograded edible canna, mung bean and cassava starches are presented in Table 3. Onset thermal transition temperatures of dissociating retrograded starches after storage at 4 °C for 7 days ranged from 42.7 to 49.2 °C and were lower than the onset gelatinization temperatures of native starches (65.5–66.8 °C). The percentages of retrogradation ($\%R$, calculated by $\Delta H_{\text{retrograded starch}}/\Delta H_{gelatinization} \times 100$) ranged from 34% for cassava to 82% for Japanese-green canna starches. All edible canna starches displayed high retrogradation (67–82%) and Japanese-green cultivar had the highest retrogradation among them. Mung bean starch also showed high retrogradation (76%) whereas cassava starch had the lowest retrogradation (34%). The high retrogradation of mung bean starch could be attributed to the presence of a high amount of amylose (28%). Interestingly, edible canna starches had high retrogradation at the same level as mung bean starch, but they had significantly lower absolute amylose content (19–25%) than mung bean starch. In other words, Thai-purple canna starch had slightly higher absolute amylose content (19%) than cassava (18%), but their percentages of retrogradation were greatly different. These results suggested that even though the retrogradation of starch was mainly dependent on amylose content but other factors could also contribute to the extent of retrogradation. The differences in molecular structure of amylose and amylopectin have been reported on affecting the retrogradation rates of kuzu and lily starches (Suzuki, Hizukuri, & Takeda, 1981; Takeda et al., 1983).

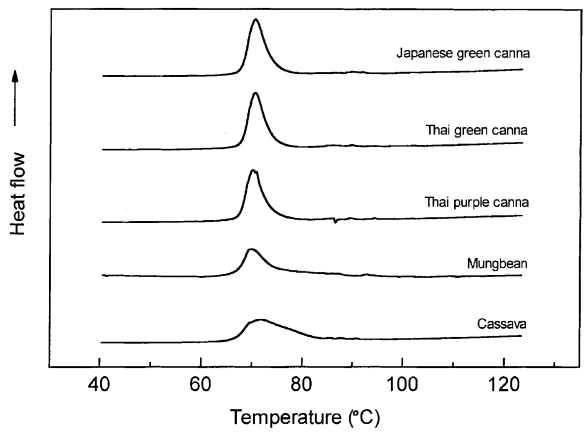

Fig. 4. Differential scanning calorimetry (DSC) thermograms of gelatinized starch.

3.7.2. Freeze-thaw stability

The freeze-thaw stability of starch gel was evaluated from the amount of water released (%syneresis), when starch chains retrograded (reassociated) during the freeze-thaw cycle. As shown in Fig. 5, a sharp increase in %syneresis of all starches was observed during the first 20 h, and the syneresis slowed down afterwards. The high initial rates of syneresis were attributed to crystallization of amylose fraction and the long-term changes were due to reversible crystallization of amylopectin (Miles, Morris, Orford, & Ring, 1985). There were no significant differences in the extents of syneresis among edible canna starches. Edible canna starches showed a higher extents of syneresis than mung bean starch and much higher than cassava starch. These results were consistent with those determined by DSC.

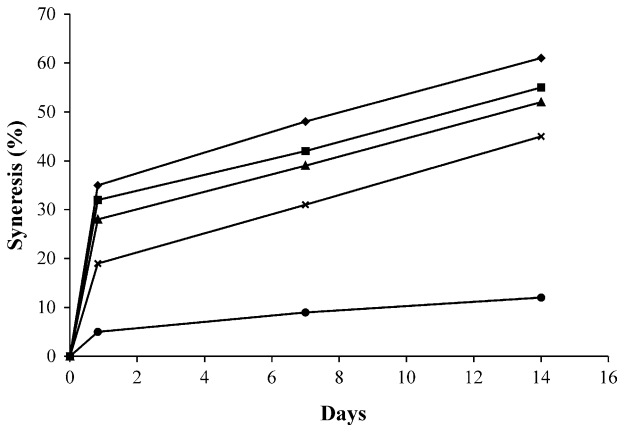

Fig. 5. Syneresis (%) of starch paste: —◆—, Japanese-green canna; —■— Thai-green canna; —▲— Thai-purple canna; — × — Mung bean; —●— Cassava.

3.8. Light transmittance

Light transmittance of gelatinized starch can be used to indicate the clarity of starch paste which varies considerably with the source of starch and can be altered by the association of starch molecules when the paste is stored. The results of transmittance (%*T*) measured at different time intervals are presented in Table 4. Light transmittance of Japanese-green canna starch were very similar to that of Thai-green canna starch throughout the duration of storage, whereas Thai-purple canna starch had nearly the same initial %*T* as the others, but its decrease in %*T* with storage time was significantly lower. This could be explained in part by their amylose contents. Lower content of amylose in Thai-purple starch led to a lesser extent of starch molecular association, resulting in higher transmittance. Low %*T* of mung bean starch indicated that their starch granules could withstand the temperature and shear during gelatinization and maintained their integrity to a higher extent than canna and cassava starches.

In conclusion, there were no significant differences in chemical compositions among three cultivars of edible canna starches, except the amylose contents. All canna starches contained a high of phosphorus, and showed high swelling capacity as evidenced by high initial paste consistency and clarity. The canna starches showed variable levels of apparent and absolute amylose, and low amylose canna starch showed a typical paste breakdown and low setback consistency.

Table 4
Light transmittance of starch solution (1%)

Starch source	Light transmittance (%*T*)		
	5 min	30 min	60 min
Japanese-green canna	80	63	46
Thai-green canna	79	61	47
Thai-purple canna	82	78	64
Mung bean	31	29	25
Cassava	78	66	56

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