



Pasting properties of a heat-moisture treated canna starch in relation to its structural characteristics

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ARTICLE INFO

Article history:

Received 18 September 2007

Received in revised form 17 June 2008

Accepted 26 August 2008

Available online 5 September 2008

Keywords:

Edible canna starch

Heat-moisture treatment

Physicochemical properties

Pasting properties

Modified starch

ABSTRACT

Native and moistened canna starches (moisture contents of 15%, 18%, 20%, 22%, and 25%) were heat treated at 100 °C for 16 h. Heat-moisture treatment (HMT) did not alter the shape or size of starch granules. Heat-treated starches showed lower paste viscosity, more stable paste (with no breakdown) and noticeable decrease in setback value compared to untreated native starch. These changes were more obvious when the starch samples contained more moisture. Starch gel morphology investigated by I₂ staining revealed that the granules of untreated native canna starch were completely ruptured, whereas those of HMT22% and HMT25% samples remained in granular form. These gel morphologies were correlated and provided the information to explain the pasting behaviors of treated and untreated canna starches. Shifts of gelatinization endotherms towards higher temperatures (1–8 °C) with broadened peaks following the moisture contents in starch samples were found after HMT. Amylose leaching of treated samples tended to be lower when the moisture content of the samples increased. HMT did not alter crystalline type of canna starch (B-type), but with increase of the moisture, slight reduction of a peak at 5.7° and a fusion of doublet at 22° and 24° were observed.

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1. Introduction

Starch has found widespread application in the food industry. In many applications the properties of a native starch are not optimal; therefore, starch is often chemically modified in order to improve its performance (Jacobs & Delcour, 1998). However, current market trends are driving producers towards more natural food components, so there is interest in finding new ways to improve the properties of native starches without using chemical modification (Ortega-Ojeda & Eliasson, 2001). Heat-moisture treatment (HMT) is a physical modification technique that is considered to be natural and safe when compared to chemical modification (Lawal, 2005).

HMT involves the treatment of starch at elevated temperatures (above the gelatinization temperature) and at very restricted moisture content (18–30% moisture w/w) (Anderson & Guraya, 2006; Collado & Corke, 1999; Gunaratne & Hoover, 2002). Information obtained from previous studies on the effect of HMT on various starches indicated that the swelling of starch granules was generally reduced, as reported for potato, true yam, taro, cassava, and

new cocoyam starches (Gunaratne & Hoover, 2002), mucuna bean starch (Adebowale & Lawal, 2003), and wheat, oat, lentil, yam, and potato starches (Hoover & Vasanthan, 1994). Heat-moisture treated starches tended to have a higher gelatinization temperature, as reported for potato starch (Gunaratne & Hoover, 2002; Hoover & Vasanthan, 1994; Vermeylen, Goderis, & Delcour, 2006), maize/corn starch (Maruta et al., 1994; Miyazaki & Morita, 2005; Takaya, Sano, & Nishinari, 2000), true yam, taro, cassava, and new cocoyam starches (Gunaratne & Hoover, 2002), mucuna bean starch (Adebowale & Lawal, 2003), and wheat, oat, lentil, and yam starches (Hoover & Vasanthan, 1994). Many starches (sweetpotato, maize, amylomaize, mucuna bean, oat, lentil, yam, and potato) exhibited lower paste viscosity and less breakdown after HMT (Adebowale & Lawal, 2003; Hoover & Manuel, 1996; Hoover & Vasanthan, 1994; Maruta et al., 1994; Singh, Raina, Bawa, & Saxena, 2005), although viscosity of some starches (waxy maize and wheat starches) remained unchanged or increased (Hoover & Manuel, 1996; Hoover & Vasanthan, 1994). These ultimate changes in properties of starch after HMT such as stable paste viscosity, limited swelling, and high gelatinization temperature resemble the typical characteristics of crosslinked starch. Therefore, HMT might be used as a means to produce starch having properties analogous to those of chemically modified crosslinked starch.

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Edible canna (*Canna edulis* Ker.) is a rhizomatous perennial herb of the family *Cannaceae*, native to the Andean region of South America. This plant has large starchy rhizomes, which have been used as a traditional staple food for Andean people for more than 4000 years. This crop is now cultivated as the source for starch production of small-scale factories in China, Taiwan, and Vietnam. There have been reports on physicochemical and rheological properties (Hung & Morita, 2005; Pancha-arnon, Puttanlek, Rungsardthong, Pathipanawat, & Uttapap, 2007; Pérez, Breene, & Bahnassey, 1998; Santacruz, Koch, Svensson, Ruales, & Eliasson, 2002; Santacruz, Ruales, & Eliasson, 2003; Soni, Sharma, Srivastava, & Gharia, 1990; Thitipraphunkul, Uttapap, Piyachomkwan, & Takeda, 2003a), molecular structure (Thitipraphunkul, Uttapap, Piyachomkwan, & Takeda, 2003b), chemical modification (Chuenkamol, Puttanlek, Rungsardthong, & Uttapap, 2007; Saartrat, Puttanlek, Rungsardthong, & Uttapap 2005) and utilization (Chansri, Puttanlek, Rungsardthong, & Uttapap, 2005) of edible canna starch. The reports documented the interesting properties of edible canna starch, especially pasting properties. As a whole, the canna starch was characterized by very large granules, clear paste, high viscosity, low breakdown, high retrogradation and high resistance to hydrolysis by α -amylase. The high viscosity and clear paste of the canna starch give it interesting potential for use as a thickening agent. However, according to the reports of Chuenkamol et al. (2007) and Saartrat et al. (2005), native canna starch displayed unsatisfactorily low resistance to low pH and high shear. Therefore, this study aimed to improve the integrity of the canna starch by physical treatment, HMT. Canna starches with varied moisture content (15–25%) were subjected to heat treatment at 100 °C for 16 h, and the treated starches were analyzed for their changes in morphology, chemical composition, crystalline pattern, and pasting property, compared to the native starch.

2. Materials and methods

2.1. Materials

Edible canna (Vietnam variety) was grown on experimental plots at the Rayong Field Crops Research Center, Rayong, Thailand. Eight-month-old rhizomes were harvested, and starch was isolated according to a procedure described by Thitipraphunkul et al. (2003a).

2.2. Chemical compositions analysis

Standard AOAC methods (1990) were used for the measurement of moisture, nitrogen, lipid and ash. Protein was determined from estimates of total nitrogen using a conversion factor of 6.25. The phosphorus content was determined by a colorimetric chemical method (Smith & Caruso, 1964). Apparent amylose content was determined by a procedure described by Gunaratne and Hoover (2002). The amylose content was calculated from a standard curve prepared by using mixtures of pure amylose and amylopectin fractionated from canna starch (over the range of 0–100% amylose).

2.3. Heat-moisture treatment

Native canna starch with an initial moisture content of 15% was adjusted to the desired moisture content (18%, 20%, 22%, or 25%) by soaking 100 g of starch in 100 ml of water overnight at 4 °C. The excess water in equilibrated slurry was then drawn out by vacuum suction to get a starch cake with moisture content of around 50%. The cake was then air-dried to allow the moisture content to drop to the desired level. Starch samples (native and moistened canna starches) in 200 ml screw-capped bottles were heated at 100 °C

for 16 h. After HMT, the starches were dried at 40 °C overnight. Untreated native canna starch was used as a control. In the following sections, heat-treated canna starches with moisture content of 15%, 18%, 20%, 22%, and 25% are denoted as HTN15%, HMT18%, HMT20%, HMT22%, and HMT25%, respectively.

2.4. Scanning electron microscopy (SEM)

Starch samples were prepared by sprinkling the starch on double-sided adhesive tape attached to a circular specimen stub, and coated with gold using a Balzers SCD 004 sputtering coater. The samples were viewed using a JEOL JSM-5410 LV scanning electron microscope at an accelerating voltage of 15 kV.

2.5. 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 rotating 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.

2.6. Light microscopy of starch gel

Starch gels obtained from RVA experiments were stained with 0.2% I₂/KI and observed under light microscope at 200 \times .

2.7. Differential scanning calorimetry (DSC)

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 24 h at 4 °C. The scanning temperature range and the heating rate were 30–120 °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.

2.8. X-ray diffraction pattern

Crystal structure of starch was studied with an X-ray diffractometer (Bruker AXS Model D8 Discover) using the conditions described by Hizukuri (1988). Starch samples were equilibrated in a saturated relative humidity chamber for 24 h at room temperature. Starch X-ray diffraction was performed on an X-ray diffractometer with copper K α radiation. Signals of the reflection angle of 2θ , from 4° to 45°, were recorded.

2.9. Amylose leaching

An appropriate amount of starch (200–400 mg, db) in water (10 ml) in a volume calibrated sealed tube was heated at 70, 80 or 90 °C for 30 min. The tube was then cooled at ambient temperature and centrifuged at 2000g for 30 min. The supernatant (1 ml) was withdrawn and mixed with 5 ml of I₂/KI solution and then diluted by distilled water to a final volume of 25 ml. The content was allowed to stand for 15 min at ambient temperature, before absorbance measurement at 600 nm. Amylose content was determined from a standard curve prepared by using pure canna amylose over the concentration of 0.2–0.6 mg/ml (modified from Gunaratne & Hoover, 2002). Amylose leaching expressed as a percentage ofle-

ached amylose per total amylose in the starch sample (dry weight basis) was calculated using the equation shown below:

$$\text{Amylose leaching (\%)} = \left(\frac{\text{Total amylose in the supernatant (mg)}}{\text{Total amylose of the starch sample (mg)}} \right) \times 100$$

3. Results and discussion

3.1. Chemical composition

Moisture of native canna starch sample was around 15%. The starch contained very low amounts of protein (0.065%) and lipid (non-detectable). Ash, amylose and phosphorus contents of the native starch were 0.34%, 34% and 368 ppm, respectively. The phosphorus in canna starch was reported to be phosphate monoester in which a major part (about 70%) was linked to C-6 of amylopectin, and the phosphate groups are located mostly in long B-chain of amylopectin (Takeda & Hizukuri, 1982; Thitipraphunkul et al., 2003b).

3.2. Granule morphology by SEM

Scanning electron micrographs of native and heat-moisture treated starch granules are shown in Fig. 1. Native canna starch granules were rounded, oval or disk-shaped with smooth surfaces. Heat-moisture treatment did not alter the shape and size of starch granules. Similar observations have been reported for heat-moisture treated finger millet (Adebowale, Afolabi, & Olu-Owolabi, 2005), new cocoyam (Lawal, 2005), potato, taro, true yam and cassava (Gunaratne & Hoover, 2002) starches.

3.3. Pasting properties

The RVA pasting profiles of native and heat-moisture treated starches are shown in Fig. 2, and their corresponding pasting parameters are summarized in Table 1. Native canna starch exhibited quite stable viscosity with slight breakdown during the holding period at 92.5 °C, and very high setback upon cooling down. Heat treatment of moisture-unadjusted canna starch sample (HTN15%) resulted in lower paste viscosity, more stable viscosity (with no breakdown) and noticeable decrease in setback

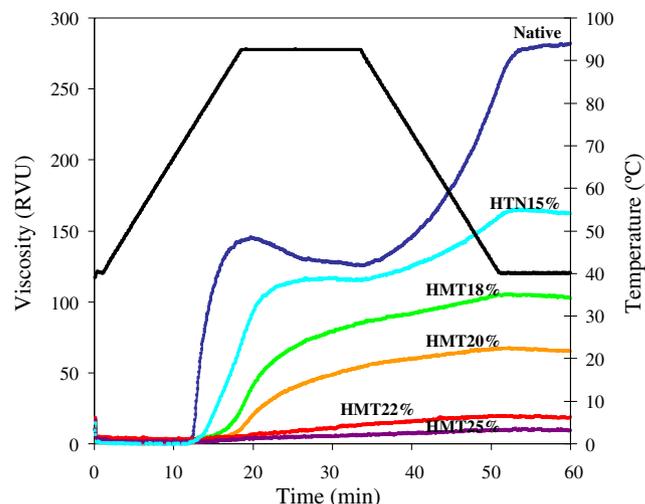


Fig. 2. Pasting profiles of native and heat-moisture treated canna starches (6%, w/w) measured by RVA.

value. These changes were more obvious when the starch samples contained more moisture, especially for starch with 25% moisture content, the viscosity of which was found to approach zero. Pasting temperature of the starch samples increased with increasing moisture content as well. The native starch had pasting temperature of 73.7 °C, whereas that of the HMT starches ranged from 74.3 to 82.4 °C. The lower paste viscosity and higher pasting temperature indicated that the canna starch was strengthened by HMT. Reduction in viscosity and increase in pasting temperature after HMT were consistent with most of the other starches as reported for new cocoyam starch by Lawal (2005), as well as lentil, potato and yam starches by Hoover and Vasanthan (1994). They claimed that structural rearrangement contributed to these changes. The extent of starch-chain associations within the amorphous regions and the degree of crystalline order are altered during HMT. The magnitude of these changes was dependent upon the moisture content of the starch sample. In this study, these phenomena – including the lower setback after HMT – will be discussed in relation to the starch gel morphology as shown in Fig. 3.

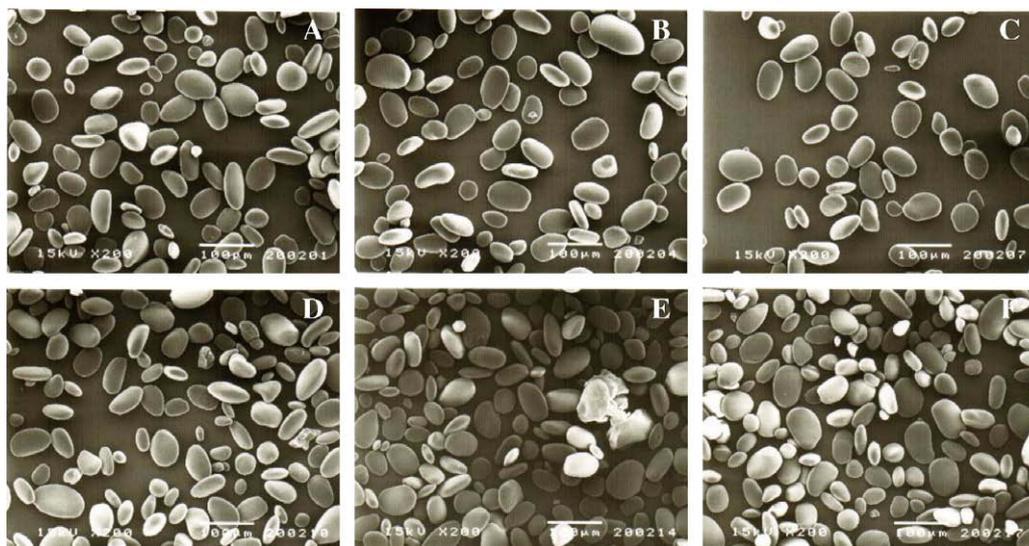


Fig. 1. Scanning electron micrographs (bar as 100 µm) of native canna starch (A), HTN15% (B), HMT18% (C), HMT20% (D), HMT22% (E), and HMT25% (F).

Table 1
The RVA pasting parameters of native and heat-moisture treated canna starches

Starch	Pasting temperature (°C)	Peak viscosity (RVU)	Final viscosity (RVU)	Breakdown (RVU)	Setback (RVU)
Native	73.7	145.8	276.2	24.1	154.6
HTN15%	74.3	113.4	158.8	−0.2	45.1
HMT18%	76.2	65.9	100.7	−3.1	31.7
HMT20%	77.4	39.2	65.5	−2.3	24.0
HMT22%	80.8	8.7	19.7	−0.2	10.8
HMT25%	82.4	4.9	8.4	0.7	4.1

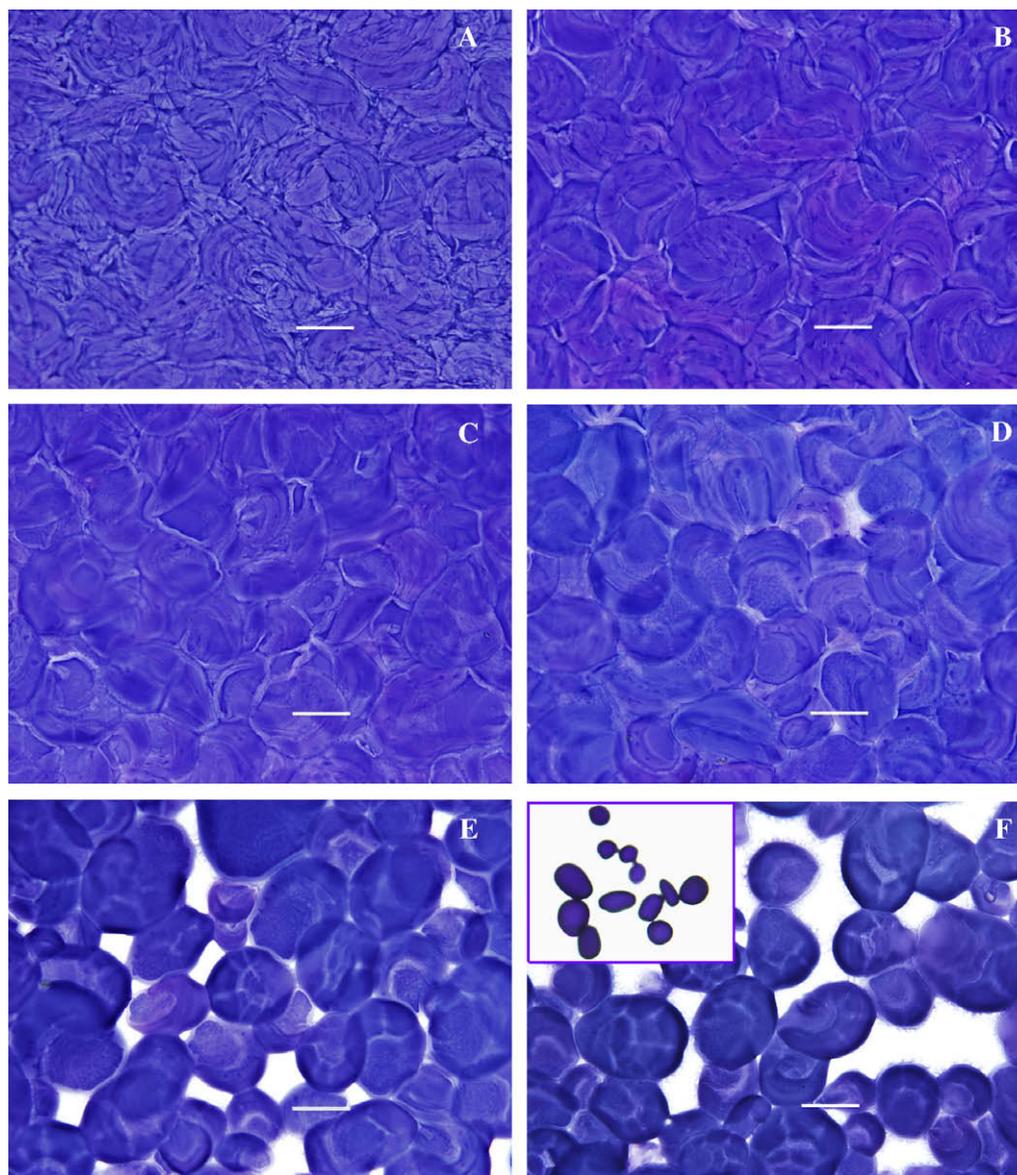


Fig. 3. Light micrographs (200 \times , bar as 50 μ m) of native (A), HTN15% (B), HMT18% (C), HMT20% (D), HMT22% (E), and HMT25% (F) starch gels compared with ungelatinized native starch granules (inset).

3.4. Starch gel morphology

Starch gels from the RVA experiments were cast into a thin film on a slide, and the I₂-stained film was viewed under light microscope at 200 \times . Micrographs of native and heat-moisture-treated starch gels, as well as ungelatinized native starch granules, are shown in Fig. 3. The ungelatinized starch granules had a deep-blue color with a smooth surface, and the space surrounding the granules was clear. After one cycle of heating up, holding at 92.5 °C

and cooling down, the untreated starch granules (Fig. 3A) were broken into small pieces, and the space surrounding the granules became blue due to the complexes of leached amylose and iodine. The granules of HTN15%, HMT18% and HMT20% starches were also broken, especially at one end. The extent of disintegration decreased with increase in moisture content of starch samples. The backgrounds were still blue in color, indicating the leakage of amylose and amylopectin molecules. On the other hand, starch granules of HMT22% and HMT25% samples remained in granular

form. Starch granules were highly swelled (5–10 times compared to the ungelatinized native starch granules), and thin channels inside the granules were observed. Blue staining of the granules was inhomogeneous, i.e. the inner part and the area around the channels were pale, and much darker coloration was found on the periphery of the granules. The space surrounding the granules was clear, indicating slight/no leakage of the amylose and amylopectin.

These gel morphologies corresponded to the pasting behaviors of starches as shown in the previous section. The highest paste viscosity found in untreated native canna starch was due to a complete rupture of the starch granules. Subsequently, the network formation upon cooling was rendered easier by the highly dispersed amylose; thereby the setback value was high. Reduction in viscosity, breakdown and setback after HMT could be related to the gel morphologies by the finding that fewer and fewer granules were destroyed by heat and shear during RVA experiments as the moisture content of the starch samples increased, therefore the paste viscosities were less and less developed. In addition, the smaller amounts of leaked amylose, which plays a major role in network formation, resulted in steadily decreasing setback values. However, it was still uncertain how heat-moisture treatment affected the integrity of canna starch granules. One possible way was that phase separation between amylose and amylopectin might occur by the moving out of amylose to the granule periphery, as evidenced by the dense stain around the edges of granules. Channels found inside the granules might be equivalent to the voids/hollows found in HMT potato and corn starches (Kawabata et al., 1994) and potato starch (Vermeulen et al., 2006). These channels might be enlarged by vapor pressure generated during HMT, and this pressure might in turn increase the compaction of the matter inside the granules, consequently making the granules more robust.

Besides the disruption and recrystallization of crystal structure, starch-chain associations (amylose–amylose and amylose–amylopectin chains) (Gunaratne & Hoover, 2002; Vermeulen et al., 2006), phase separation between amylose and amylopectin, and compaction of granular matter by vapor pressure force, chemical bonding/interactions that occur during HMT might be another factor influencing the strength of heat-moisture treated starch. As reported by Thitipraphunkul et al. (2003a), canna starch contained high amounts of phosphorus (371–399 ppm) and calcium (113–154 ppm). Other cations such as potassium, magnesium and sodium were also found. The function of calcium and other inorganic elements was still not clearly known, but it was hypothesized that these elements, especially calcium, might act as bridges linking the phosphate groups existing in amylopectin molecules by ionic interaction. This linking might be enhanced by HMT. However, there was no noticeable change in FTIR spectrum of heat-moisture treated starch with moisture content of 25%, when compared to that of the native starch (data not shown).

3.5. Thermal properties by DSC

Thermal transition behaviors of native and HMT canna starches determined by DSC are presented in Fig. 4, and their corresponding thermal parameters are summarized in Table 2. Peak temperature (T_p), often referred to as the gelatinization temperature, of native canna starch was 71.9 °C. After HMT, the endotherms were shifted to a higher temperature with a broader shape, and the peak areas were unchanged or slightly decreased. The more moisture content in starch samples during HMT, the higher the gelatinization temperatures that were obtained. At 25% moisture content, the gelatinization temperature was approximately 8 °C higher than that of the native starch. The broadened peaks of HMT starches indicated greater inhomogeneity in structural organization of amylose and

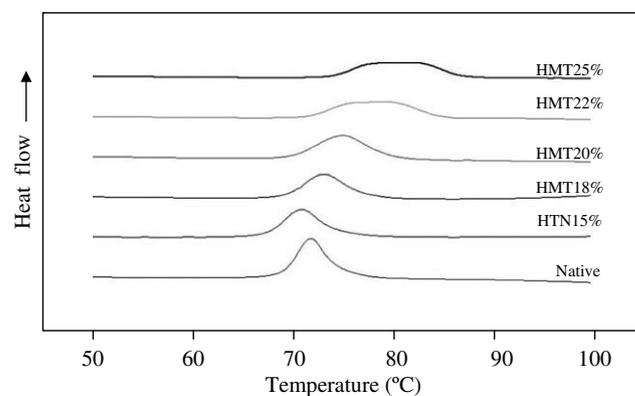


Fig. 4. Gelatinization thermograms of native and HMT canna starches.

Table 2

Thermal properties of native and heat-moisture treated canna starches

Starch	Gelatinization				
	T_o (°C)	T_p (°C)	T_c (°C)	$T_c - T_o$ (°C)	ΔH (J/g)
Native	69.2 ± 0.1	71.9 ± 0.1	74.8 ± 0.3	5.6 ± 0.2	15.1 ± 1.5
HTN15%	67.8 ± 0.1	70.9 ± 0.1	74.2 ± 0.1	6.4 ± 0.2	12.4 ± 1.4
HMT18%	69.5 ± 0.3	73.4 ± 0.1	77.6 ± 0.2	8.0 ± 0.5	12.9 ± 0.7
HMT20%	69.9 ± 0.3	75.3 ± 0.1	79.5 ± 0.7	9.6 ± 0.4	15.4 ± 1.0
HMT22%	72.0 ± 0.1	79.2 ± 0.2	84.9 ± 0.1	12.9 ± 0.1	14.6 ± 0.2
HMT25%	74.3 ± 0.1	80.5 ± 2.0	87.3 ± 0.3	13.1 ± 0.2	15.2 ± 1.0

amylopectin within the granules. As compared to the starch gel morphology described in Section 3.3, this inhomogeneous nature may be reflected by the non-uniform staining of gelatinized starch granules. The differences in degree of heterogeneity among the starches have been ascribed to the interplay of many factors, e.g. molecular structure of amylopectin, amylase-to-amylopectin ratio, crystalline-to-amorphous ratio, and phosphorous content (Gunaratne & Hoover, 2002).

3.6. Crystalline structure

Native canna starch gave a B-type X-ray diffraction pattern which is typical of tuber and root starches and is characterized by a small peak at 5.6°, only one peak at 17° and a doublet at 22° and 24°. Fig. 5 shows that HMT did not alter the crystalline pattern of canna starch. However, slight changes, i.e. reduction of peak area at 5.7° and a merging of doublet at 22° and 24°, could be observed. Such changes were more obvious with starch samples having higher moisture content during HMT. Transformations from B to A or B+A type by HMT have been reported for potato starch by Vermeulen et al. (2006), Kawabata et al. (1994), Gunaratne and Hoover (2002), and Hoover and Vasanthan (1994), and for yam starch by Gunaratne and Hoover (2002), and Hoover and Vasanthan (1994). As stated by Genkina, Wasserman, Noda, Tester, and Yuryeva (2004), HMT often results in transformation of the less thermodynamically stable B-polymorphic structure (with hexagonal packing of double helices and about 36 water molecules inside every cell) to a more stable monoclinic structure of A-type polymorphs (with about six water molecules inside the helices). In this study, the conditions used (100 °C with up to 25% moisture) may not have been severe enough to alter the crystalline structure of canna starch.

3.7. Amylose leaching

Amylose leaching of native and heat-moisture treated canna starches at 70, 80 and 90 °C is presented in Table 3. Amylose leaching of native starch at 70 °C, just below the gelatinization

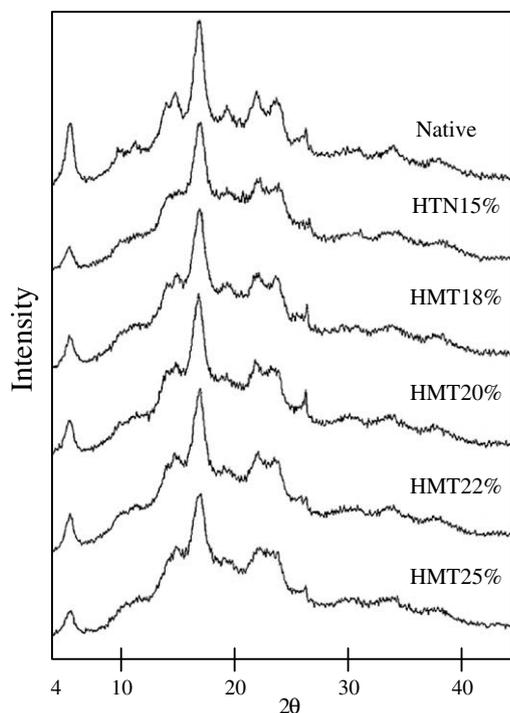


Fig. 5. X-ray diffraction patterns of native and heat-moisture treated canna starches.

temperature of the native starch (72 °C), was 2.1%, which was comparable to that of HTN15% but higher than that of the other HMT starches. Amylose leaching decreased with increase in the moisture content of starch samples during heat treatment, and no amylose was detected in the supernatant of starch samples with 20%, 22% or 25% moisture. This was attributed to the increased integrity of starch granules as shown by the higher gelatinization temperature of starch samples after treatment. At 80 °C, the temperature greater than/equal to the gelatinization temperature of all starch samples, the amylose leaching of native starch was found to be 2.6%, whereas that of HTM starches was between 2.3% and 4.6%. Amylose leaching of treated samples tended to be lower when the moisture content of the samples increased. Similar trends were found at 90 °C. These results agree with those of the previous study by Gunaratne and Hoover (2002), which showed a decrease in amylose leaching (at 50–90 °C) of true yam, taro, new cocoyam, cassava, and potato starches in heat-moisture treatment; and in all cases, the leaching of native starch was higher than that of the treated starches. Additional interactions between amylose–amylose and amylose–amylopectin chains during heat-moisture treatment were suggested to be involved in the decrease of amylose leaching.

Table 3
Amylose leaching (%)^a of native and heat-moisture treated canna starches at different temperatures

Starch (gelatinization temperature; °C)	Temperature (°C)		
	70	80	90
Native (72)	2.1 ± 0.1	2.6 ± 0.2	2.6 ± 0.1
HTN15% (71)	2.3 ± 0.1	4.4 ± 0.3	8.2 ± 0.5
HMT18% (73)	0.6 ± 0.1	4.6 ± 0.2	8.5 ± 0.4
HMT20% (75)	≈0	4.4 ± 0.1	6.2 ± 0.3
HMT22% (79)	≈0	2.6 ± 0.1	5.1 ± 0.3
HMT25% (80)	≈0	2.3 ± 0.2	4.4 ± 0.1

^a % of dry weight of total amylose in the starch sample.

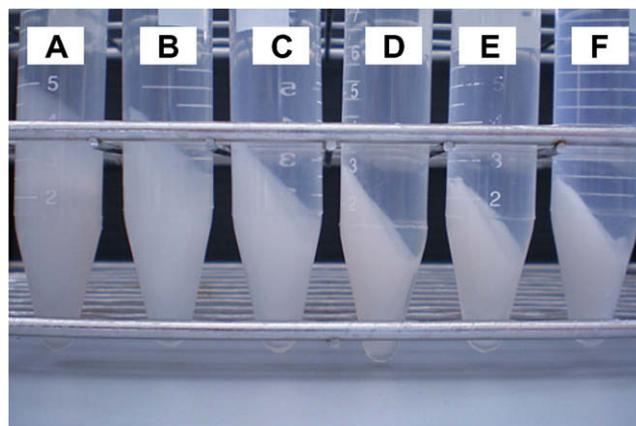


Fig. 6. Starch gel after heating at 80 °C for 30 min in amylose leaching test.

For canna starch, HTN15%, HMT18% and HMT20% and all treated samples exhibited higher amylose leaching than the native starch when leaching at 80 and 90 °C, respectively. This result was the opposite of what had been expected. As shown previously in Section 3.4 (starch gel morphology), the native starch could be easily broken into small pieces by heating in excess water; therefore, its amylose leaching would be higher than that of the heat-moisture treated starches. Reduced amylose leaching of the native starch could be explained by the typical retrogradation behavior of canna starch. Fig. 6 shows the starch gels after centrifugation. The fact that the native starch had the highest amount of starch gel implied that network formation of broken granule fragments occurred rapidly. It is generally accepted that amylose molecules played a major role in the network formation; consequently, the free amylose in supernatant was lessened. The difference in amylose leaching of the other starch samples was a net result of the amylose leached from the granules and that involved in network formation.

4. Conclusion

Under the HMT conditions used in this study (100 °C and 15–25% moisture), some properties of canna starch i.e. pasting properties, starch gel morphology, thermal properties and amylose leaching, were profoundly changed. However, minor or no changes were found for the granule morphology and crystalline pattern. The extent of these changes was more pronounced with more moisture content in the starch sample during HMT. It is interesting that HMT of canna starch resulted in a modified product that displayed much lower paste viscosity, higher paste stability and lower retrogradation. As evidenced by gel morphology, granules of HMT22% and HMT25% swelled, but were not broken. Gelatinization temperatures of treated starches were also increased. These findings indicated that the pasting characteristics of HMT canna starch were similar to those of chemically cross-linked starch. However, the properties of the HMT canna starch in other aspects (such as stability to acid, stability to shear) should be investigated and compared to certain cross-linked starches.

References

- Adebowale, K. O., Afolabi, T. A., & Olu-Owolabi, B. I. (2005). Hydrothermal treatment of Finger millet (*Eleusine coracana*) starch. *Food Hydrocolloids*, 19, 974–983.
- Adebowale, K. O., & Lawal, O. S. (2003). Microstructure, physicochemical properties and retrogradation behaviour of mucuna bean (*Mucuna pruriens*) starch on heat moisture treatment. *Food Hydrocolloids*, 17, 265–272.
- Anderson, A. K., & Guraya, H. S. (2006). Effects of microwave heat-moisture treatment on properties of waxy and non-waxy rice starches. *Food Chemistry*, 97, 318–323.

- Association of Official Analytical Chemists (AOAC), (1990). Official methods of analysis (15th ed.). Virginia: The Association of Official Analytical Chemists.
- Chansri, R., Puttanlek, C., Rungsardthong, V., & Uttapap, D. (2005). Characteristics of clear noodles prepared from edible canna starches. *Journal of Food Science*, *70*, 337–342.
- Chuenkamol, B., Puttanlek, C., Rungsardthong, V., & Uttapap, D. (2007). Characterization of low-substituted hydroxypropylated canna starch. *Food Hydrocolloids*, *21*, 1123–1132.
- Collado, L. S., & Corke, H. (1999). Heat-moisture treatment effects on sweetpotato starches differing in amylose content. *Food Chemistry*, *65*, 339–346.
- Genkina, N. K., Wasserman, L. A., Noda, T., Tester, R. F., & Yuryeva, V. P. (2004). Effects of annealing on the polymorphic structure of starches from sweet potatoes (*Ayamurasaki* and *Sunnyred* cultivars) grown at various soil temperatures. *Carbohydrate Research*, *339*, 1093–1098.
- Gunaratne, A., & Hoover, R. (2002). Effect of heat-moisture treatment on the structure and physicochemical properties of tuber and root starches. *Carbohydrate Polymers*, *49*, 425–437.
- Hizukuri, S. (1988). Recent advances on molecular structure of starch. *Journal of Japan Society Starch Science*, *31*, 185.
- Hoover, R., & Manuel, H. (1996). Effect of heat-moisture treatment on the structure and physicochemical properties of legume starches. *Food Research International*, *96*, 731–750.
- Hoover, R., & Vasanthan, T. (1994). Effect of heat-moisture treatment on the structure and physicochemical properties of cereal, legume, and tuber starches. *Carbohydrate Research*, *252*, 33–53.
- Hung, P., & Morita, N. (2005). Physicochemical properties and enzymatic digestibility of starch from edible canna (*Canna edulis*) grown in Vietnam. *Carbohydrate Polymers*, *61*, 312–314.
- Jacobs, H., & Delcour, J. A. (1998). Hydrothermal modifications of granular starch with retention of the granule structure, a review. *Journal of Agricultural and Food Chemistry*, *46*, 2895–2905.
- Kawabata, A., Takase, N., Miyoshi, E., Sawayama, S., Kimura, T., & Kudo, K. (1994). Microscopic observation and X-ray diffractometry of heat/moisture-treated starch granules. *Starch/Stärke*, *46*, 463–469.
- Lawal, O. S. (2005). Studies on the hydrothermal modifications of new cocoyam (*Xanthosoma sagittifolium*) starch. *International Journal of Biological Macromolecules*, *37*, 268–277.
- Maruta, I., Kurahashi, Y., Takayano, R., Hayashi, K., Yoshino, Z., & Komaki, T. (1994). Reduced-pressurized heat-moisture treatment. A new method for heat-moisture treatment of starch. *Starch/Stärke*, *46*, 177–181.
- Miyazaki, M., & Morita, N. (2005). Effect of heat-moisture treated maize starch on the properties of dough and bread. *Food Research International*, *38*, 369–376.
- Ortega-Ojeda, F. E., & Eliasson, A. C. (2001). Gelatinisation and retrogradation behaviour of some starch mixtures. *Starch/Stärke*, *53*, 520–529.
- Pérez, E., Breene, W. M., & Bahnassey, Y. A. (1998). Variations in the gelatinization profiles of cassava and arrowroot native starches as measured with different thermal and mechanical methods. *Starch/Stärke*, *50*, 70–72.
- Puncha-arnon, S., Puttanlek, C., Rungsardthong, V., Pathipanawat, W., & Uttapap, D. (2007). Changes in physicochemical properties and morphology of canna starches during rhizomal development. *Carbohydrate Polymers*, *70*, 206–217.
- Saartrat, S., Puttanlek, C., Rungsardthong, V., & Uttapap, D. (2005). Paste and gel properties of low-substituted acetylated canna starches. *Carbohydrate Polymers*, *61*, 211–221.
- Santacruz, S., Koch, K., Svensson, E., Ruales, J., & Eliasson, A. C. (2002). Three underutilised sources of starch from the Andean region in Ecuador. Part I. Physico-chemical characterization. *Carbohydrate Polymers*, *49*, 63–70.
- Santacruz, S., Ruales, J., & Eliasson, A. C. (2003). Three underutilised sources of starch from the Andean region in Ecuador. Part II. Rheological characterization. *Carbohydrate Polymers*, *51*, 85–92.
- Singh, S., Raina, C. S., Bawa, A. S., & Saxena, D. C. (2005). Effect of heat-moisture treatment and acid modification on rheological, textural, and differential scanning calorimetry characteristics of sweetpotato starch. *Journal of Food Science*, *70*, 373–378.
- Smith, R. J., & Caruso, J. (1964). Determination of phosphorus. In R. L. Whistler (Ed.), *Methods in Carbohydrate Chemistry: Starch* (Vol. 4, pp. 42–46). Orlando FL: Academic Press.
- Soni, P. L., Sharma, H., Srivastava, H. C., & Gharia, M. M. (1990). Physicochemical properties of *Canna edulis* starch-comparison with maize starch. *Starch/Stärke*, *42*, 460–464.
- Takaya, T., Sano, C., & Nishinari, K. (2000). Thermal studies on the gelatinisation and retrogradation of heat-moisture treated starch. *Carbohydrate Polymers*, *41*, 97–100.
- Takeda, Y., & Hizukuri, S. (1982). Location of phosphate groups in potato amylopectin. *Carbohydrate Research*, *102*, 321–327.
- Thitipraphunkul, K., Uttapap, D., Piyachomkwan, K., & Takeda, Y. (2003a). A comparative study of edible canna (*Canna edulis*) starch from different cultivars. Part I. Chemical composition and physicochemical properties. *Carbohydrate Polymers*, *53*, 317–324.
- Thitipraphunkul, K., Uttapap, D., Piyachomkwan, K., & Takeda, Y. (2003b). A comparative study of edible canna (*Canna edulis*) starch from different cultivars. Part II. Molecular structure of amylose and amylopectin. *Carbohydrate Polymers*, *54*, 489–498.
- Vermeylen, R., Goderis, B., & Delcour, J. A. (2006). An X-ray study of hydrothermally treated potato starch. *Carbohydrate Polymers*, *64*, 364–375.