science, engineering and health studies

Research Article

Science, Engineering and Health Studies
https://li01.tci-thaijo.org/index.php/sehs
ISSN (Online): 2630-0087

Influence of barrel temperatures on physical and cooking properties of extruded glass noodles from edible canna starch

Vilai Rungsardthong[1], Surasit Chockpokasombut[1], Nattawut Kornkomjayrit[1], Suriya Rutatip[1], Dudsadee Uttapap[2] and Buddhi Lamsal[3]*

[1] Faculty of Applied Science, Food and Agro-Industry Research Center, King Mongkut's University of Technology North, Bangkok 10800, Thailand
[2] School of Bioresources and Technology, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand
[3] Food Science and Human Nutrition Department, Iowa State University, Iowa 50011, USA

***Corresponding author**:
Vilai Rungsardthong
vilai.r@sci.kmutnb.ac.th

***Received**: 26 November 2020*
***Revised**: 14 June 2021*
***Accepted**: 4 August 2021*
***Published**: 27 December 2021*

***Citation**:*
Rungsardthong, V., Chockpokasombut, S., Kornkomjayrit, N., Rutatip, S., Uttapap, D., and Lamsal, B. (2021). Influence of barrel temperatures on physical and cooking properties of extruded glass noodles from edible canna starch. Science, Engineering and Health Studies, 15, 21030011.

ABSTRACT

Conventional method for glass noodle production is a complicated process which mainly uses the expensive mung bean starch. In this research, the glass noodles were extruded for study from mung bean starch (MBS) and two cultivars of edible canna starches: Thai-purple (TPC), and Japanese-green (JGC). The influence of barrel temperatures on physical properties and cooking qualities of the noodles were investigated. Each starch mix with initial moisture content at 30% (w/w) was extruded with a die diameter of 0.6 mm. The glass noodles extruded from MBS presented cooking time, 2.70-3.50 min, cooking weight, 365.95-376.47%, and cooking loss 6.01-7.84%, while those noodles from TPC, and JGC starch indicated cooking time 2.45-3.00, 2.22-3.00 min, the cooking weight 236.15-384.75%, 253.17-352.25%, and the cooking loss at 18.10-24.60%, and 11.79-18.47%, respectively. The noodle from TPC starch exhibited firmer texture than that from JGC starch. The 9-points hedonic scale sensory evaluation showed that TPC glass noodles had the comparable texture acceptability to the MBS commercial glass noodles by conventional method, but had lower color acceptability. Further improvement of the starch color and cooking loss reduction would increase the potential for the extrusion of edible canna starch for the glass noodle production.

Keywords: glass noodle; mung bean starch; edible canna starch; extrusion; texture; cooking quality

1. INTRODUCTION

Clear glass noodle is popularly consumed in Asian countries, and now also in the Western countries. The other general names of the glass noodles are vermicelli, harusame, and cellophane noodles, which is commonly made from mung bean starch (Kasemsuwan et al., 1998; Wang et al., 2012). Starch from mung bean can produce the best glass noodles because it exhibits high amylose content, limited swelling during gelatinization, and high shear resistance (Kasemsuwan et al., 1998; Wu et al., 2015). Attempts have been made to substitute or supplement the costlier mung bean starch with starch from other cheaper alternatives, such as edible canna, pea, sorghum, sago, and potato for noodle production (Charnsri et al., 2005; Wang et al., 2012; Kaur et al., 2015; Photinam et al., 2016; Wahjuningsih et al., 2020).

Edible canna (*Canna edulis* Ker) has large starchy rhizomes, traditionally used as a staple food for Andean people from ancient time and is presently cultivated for starch production in China, Taiwan, and Vietnam (Charnsri et al., 2005). Canna starch displayed the pasting profiles similar to mung bean starch pastes, for example, significant setback, high shear, and thermal resistance (Santacruz et al., 2002; Thitipraphunkul et al., 2003), indicating the potential for inclusion in noodle production. Glass noodles were fabricated from 3 cultivars of canna starches namely; Thai-purple, Japanese-green, and Thai-green by traditional process in our previous study (Charnsri et al., 2005). Descriptive sensory evaluation showed no significant differences ($p< 0.05$) in the overall acceptability between the noodles from canna starches and the commercial noodles from mung bean starch. However, the glass noodles made from Thai-purple starch had higher textural acceptability than the noodles made from Japanese-green and Thai-green starches, which showed no significant difference for this attribute. Wandee et al. (2015) reported the application of canna starch and its derivatives for improving rice noodle quality.

Glass noodle production by traditional method starts with the mixing of dry and pre-gelatinized starches and water to form a homogeneous dough following extrusion to obtain the desired shape. Subsequently, the noodles are cooked in boiling water, cooled in water (4°C), and stored in freezer (-18°C) before the air drying (Galvez et al., 1994). This process of glass noodle production is a non-continuous process, complicated, high energy and time-consuming, and generates high amounts of wastewater.

Extrusion technology, on the other hand, is a continuous process for a variety of food products such as snacks, breakfast cereals, pasta, and instant rice products (Korkerd et al., 2016; Wongsa et al., 2017, Rungsardthong et al., 2021). The screw barrel of the extruder can be typically separated into three zones: feeding, kneading, and the final cooking zone, in which the temperature of each zone is one of the major parameters influencing various properties of the extruded products (Mercier et al., 1989). The extruder barrel temperature and residence time contribute to different degree of starch gelatinization and protein denaturation that leads to different physical properties of the extrudate such as expansion ratio, rehydration ratio, and water absorption (Sue et al., 2015). The other key extrusion process variables impacting extrudate properties are the initial feed moisture content, screw speed and composition of the feed (Lusas and Riaz, 1994). Though there are several reports on the extrusion of noodles from pea, rice, mung bean, and modified starches (Charutigon et al., 2008; Wang et al., 2012; 2014; Sereewat et al., 2015; Thapnak et al., 2019, Srirachan et al., 2021), the extrusion of glass noodles from edible canna starches is not reported in the literature, which is done in this study and compared with mung bean starch. Thai-purple and Japanese-green cana starches were selected for extrusion study based on the texture of the glass noodles produced through conventional method in our preliminary study. The influences of the barrel temperatures on physical properties and cooking qualities of the glass noodles were evaluated. Sensory test of the extruded glass noodles was also carried out comparing them with traditionally produced commercial glass noodles.

2. MATERIALS AND METHODS

2.1 Materials

Two cultivars of the edible canna starches, Thai-purple (TPC), and Japanese-green (JGC) were isolated from the rhizome of 8 months old canna plants at the Rayong Field Crops Research Center, Rayong, Thailand, following a procedure detailed by Puncha-arnon et al. (2007). Mung bean starch (MBS) and commercial mung bean glass noodle made with the conventional method was purchased from a supermarket in Bangkok (Thailand). All other chemicals and reagents used in the research were analytical grade products.

2.2 Chemical composition and pasting profile

The moisture content of the MBS, TPC and JGC starches was determined following AACC 44-19 (2000) method. The protein, lipid and ash contents were analyzed with AOAC 12.1.07 (2000), 920.39C (2000), and AOAC 32.1.05 (2000), respectively. The amylose content of the samples was analysed following as explained in Charutigon et al. (2008). The amylose standard curve was prepared using a pure amylose from potato (Sigma) as the standard. The starch content in TPC and JGC was determined following the enzyme digestion method of Rasmussen and Henry (1990) with slight modifications, as well as the phenolsulfuric method (Dubois et al., 1956). Carbohydrate content in MBS was calculated by difference with other component from the proximate analysis.

The pasting profiles of MBS, TPC, and JGC starch slurry at 12 g/100 g slurry (dry weight basis) were analysed with a Rapid Visco Analyzer (RVA-4SA, Newsports Scientific, Warriewood, Australia). The starch slurry was stirred at 900 rev/min for 10s following with the reduction of the shears input and held constantly at 160 rpm. The cooling and heating cycles were 13 min, starting at 50°C for 1.00 min before heating to 95°C for 3.32 min and holding for 2.50 min, then cooling to 50°C for 3.48 min with the final holding of 2.00 min.

2.3 Extrusion of glass noodles from MBS, TPC, and JGC

Glass noodles were extruded from MBS, TPC, and JGC starches by the method slightly modified from Thapnak et al. (2019). A calculated amount of water was mixed to each starch to adjust the initial moisture content of each starch to 30% (w/w) with a mixer (Kenwood, UK) at low speed (Level 1). The starches were incubated at 30°C for 5 h to equilibrate the moisture content before being fed into the extruder.

The single-screw extruder (Brabender-19/20 DN) with specifications as described by Sereewat et al. (2015): a barrel bore (D) 19.1 mm, barrel length (L) of 20 D, and 4:1 screw compression ratio, was used in the experiment. The extrusion of MBS was carried out at the barrel temperatures of zones 1: 2: 3 as 70: 90: 90°C, 70: 90: 100°C, 70: 100: 90°C, and 70: 100: 100°C, respectively (modified from Sereewat et al., 2015 and our preliminary study). To study the optimum temperature at each barrel zone for TPC, and JGC starch, four additional variations in barrel temperatures were performed at 70: 70: 90°C, 70: 70: 100°C, 70°C: 80: 90, and 70: 80: 100°C, respectively. Each starch feed was extruded via a circular die of 0.60 mm diameter and the extruded glass noodle was cut at 30 cm length. After drying at the ambient temperature (28-33°C) for about 24 h, the products were preserved in polyethylene bags at ambient temperature for further measurements of their appearance and cooking qualities.

2.4 Physical and cooking properties of the glass noodles

Appearances (smoothness, transparency, size and uniformity) of the dried glass noodles were visually observed. The measurements of the noodle diameter were carried out at 5 different points using a Vernier caliper (Mitutoyo Corp. Co., Ltd., Tokyo, Japan). The data from the measurement of ten specimens were averaged.

Cooking qualities including cooking time, cooking weight and cooking loss of the glass noodles were determined following AACC method (2000). Briefly, five grams of the 5 cm-long glass noodles were cooked in 300 mL of distilled water. Samples were taken out every 10 s and the optimum cooking time was the time for the noodles to be fully cooked, at which the white, hard core of the noodle disappeared when gently squeezed between two glass plates. The stability time was the time until glass noodles were broken in cooking water. For cooking weight, the rice noodles (5.0 g) cut into smaller pieces were boiled in 300 mL water until they were completely cooked. The water in the cooked noodles were drained, and weighed. Cooking weight was calculated from the difference of noodle weights before and after cooking. Cooking loss was calculated as the solid in the beaker after evaporating the water in the cooking weight process, at 105 ± 1°C. At least five measurements were carried out for each extruded sample. The calculations were done as follows:

Cooking weight = [weight of cooked noodle (g)/weight of sample (g)] × 100

Cooking loss = [solid in beaker after evaporation (g)/ weight of sample (g)] × 100

The noodles extruded from TPC starch, and JGC starch, with extrusion temperature of zone 1: 2: 3 at 70: 70: 100°C, and commercial noodles from mung bean were measured for their colour and tensile stress. For colour measurement, a Hunter Lab spectrophotometer (Color Quest XE, Hunter Lab, Inc. USA), in terms of the CIE Lab system. L* is lightness on a 0 to 100 scale from black to white; a* presented (+) red or (−) green; and b* indicates (+) yellow or (−) blue. Five samples were applied and data were averaged. For comparison, the color and tensile stress of commercial noodle made from mung bean starch was also measured. Tensile stress was determined using a texture analyzer (TA-XT2i, Stable micro system Co. Ltd., Surrey, U.K.). Noodles were cooked for their cooking time before the measurement. A 15 N load cell was applied for the measurement of the noodle tensile stress at a test speed of 10.0 mm/s. The tensile stress (N/mm2; Pa) was determined as the first peak signifying first crack in the noodle from the force-displacement curve (mm). At least ten specimens were tested for each sample.

2.5 Sensory evaluation

Sensory test was performed with a 9-point hedonic scale as detailed previously by Sereewat et al. (2015). Each category was rated from 1 (dislike very much) to 9 (like very much). The glass noodles from TPC extruded at the barrel temperatures of 70: 70: 100°C (die), and commercial noodles from mung bean were cooked for their optimal cooking time and served as warm products to 50 untrained panellists. The panellists were 19-23 years old female and male students at the King Mongkut's University of Technology North Bangkok. The products were evaluated in terms of colour, flavour, clarity, texture, and overall acceptability.

2.6 Statistical analysis

All experiments were performed in three replications and the data was shown as means ± standard deviation. The results were statistically analyzed using Duncan's pairwise test with SPSS 21.0 at significant level of p<0.05.

3. RESULTS AND DISCUSSION

3.1 Chemical composition of MBS, TPC and JGC

Table 1 presents the chemical compositions of MBS, TPC and JGC starch. All starches exhibited very low amount of protein, lipid, and ash. However, TPC starch showed much lower starch content at 82.54% (wwb) than JGC at 89.18% (dwb). JGC starch exhibited brighter color than the TPC starch, which showed a very light gray color. These results showed that Thai-purple raw canna starch contained higher amounts of other components which might be the crude fiber or other ingredients that could affect the quality of the noodles (Charnsri et al., 2005). The amylose content of TPC, and JGC was approximately the same, 25.31, and 24.42% (dwb), which was much lower than that of MBS, 46.03% (dwb). Mung bean starch contains higher amylose content and indicates higher setback than canna starch. Generally, higher amylose content leads to higher retrogradation, higher textural firmness and noodle stability (Boers et al., 2015). However, the glass noodles made from both TPC and JGC starch by conventional method exhibited comparable properties to the commercial mung bean glass noodles (Charnsri et al., 2005), despite lower amylose content.

3.2 Pasting profiles of TPC and JGC starches

The pasting property of canna starch is characterised as a hot paste with high stability and setback, which is used to evaluate their suitability for glass noodle production. The pasting properties of the TPC and JGC starches (12% w/w) compared to MBS are presented in Table 2. The JGC starch exhibited higher peak viscosity, break down, and final viscosity than TPC (p<0.05). The result could be due to the higher starch content in JGC which showed higher capacity for the water absorption. Soni et al. (1990) and Charnsri et al. (2005) reported that the viscosity of edible canna starch is higher than that of maize starch and mung bean starch, and showed no thinning. Starch from mung bean presented high amylose content, restricted granule swelling power, and showed high gel stability (Wu et al., 2015). MBS exhibited lower peak viscosity, breakdown, and final peak viscosity but higher pasting temperature and setback than both canna starches. TPC starch indicated higher holding strength and set back than JGC. The pasting temperatures of TPC and JGC starches were approximately the same at 72.53 and 72.60°C, which were lower than the pasting temperature of mung bean starch at 75.76°C (Charnsri et al, 2005). On cooling, TPC starch had higher setback (90.92 RVU) than JGC starch (75.38 RVU), which is much lower than MBS setback (139.22 RVU). Visually, canna starches produced very clear and elastic pastes which are the main characteristics required for preparing a clear noodle. Similar trends were observed by Charnsri et al. (2005) who reported the pasting profiles of TPC and JGC starch at 6% (w/w).

Table 1. Chemical composition of mung bean starch (MBS), Thai-purple canna starch (TPC) and Japanese-green canna starch (JGC)

Chemical composition (%)	MBS	TPC	JGC
Dry weight basis (%)			
Protein[ns]	0.42 ±0.03	0.43 ± 0.02	0.39 ± 0.01
lipid	0.12 ±0.01[a]	0.06 ± 0.01[b]	0.04 ± 0.01[b]
Ash[ns]	0.24 ± 0.02	0.20 ± 0.01	0.18 ± 0.01
Starch	*	82.54 ± 6.23[b]	89.18 ± 3.24[a]
Amylose	46.03 ± 1.39[a]	25.31± 1.59[b]	24.42 ± 0.96[b]
Wet weight basis (%)			
Moisture	11.23 ±0.09[a]	10.33 ± 0.08[b]	9.31 ± 0.06[c]

Values are expressed as means ± SD (n=3)
Different superscript letters in the same row indicate significant differences ($p<0.05$)
ns: not significantly different ($p>0.05$)
*The carbohydrate content in MBS was 99.22% (dwb), calculated by different method

Table 2. Pasting properties of mung bean starch (MBS), Thai-purple canna starch (TPC) and Japanese-green canna starch (JGC)

	MBS	TPC	JGC
Peak viscosity (RVU)	640.19 ± 2.46[c]	984.09 ± 1.42[b]	1,126.13 ± 1.13[a]
Holding strength (RVU)	272.39 ± 1.0[c]	397.63 ± 0.80[a]	315.46 ± 0.04[b]
Breakdown (RVU)	367.80 ± 1.96[c]	586.45 ± 0.63[b]	809.23 ± 1.58[a]
Final viscosity (RVU)	395.52 ± 0.85[c]	488.54 ± 0.54[b]	810.67 ± 1.09[a]
Peak time (min)[ns]	4.53 ± 0.09	3.67 ± 0.01	3.84 ± 0.22
Pasting temperature (°C)	75.76 ± 0.06[a]	72.53 ± 0.08[b]	72.60 ± 0.05[b]
Setback (RVU)	139.22 ± 0.56[a]	90.92 ± 0.26[b]	75.38 ± 0.46[c]

Values are expressed as means ± SD (n=3)
Different superscript letters in the same row indicate significant differences ($p<0.05$)
ns: not significantly different ($p>0.05$)

3.3 Influence of extrusion temperatures on properties of the glass noodles

The influence of extrusion temperatures on MBS glass noodle properties are presented in Table 3. The glass noodles were semitransparent with uniform size, and exhibited a slightly lower cooking time, cooking weight, and cooking loss with the increase of temperature in Zones 2 and 3. The noodles had good cohesiveness and were transparent after cooking. Their cooking loss ranged between 6.01-7.84%, which was in accordance with our previous study (6.59%) on the extrusion of glass noodles from mung bean starch but with different barrel temperature (Thapnak et al., 2019). However, this cooking loss is higher than the cooking loss in commercial noodles (3.10%), but still in the acceptable range of noodles for commercialization (less than 12.5% wet weight; Yeh and Jaw, 1999). Longer time for the retrogradation of the glass noodles made from MBS by conventional method could lead to a higher strength of the gel-like network structure of the noodles than the extruded noodles that undergo higher shear, higher temperatures, and shorter residence times. Cooking loss is one of the main criteria for consumer acceptance. The weight loss during cooking mainly occurs from the soluble and loosely bound gelatinized starch on the noodle surface which depends on the starch gelatinization degree and the gel network strength of the noodles. The strength of the gel network was related to chemical compositions, the ratio of amylose/amylopectin, and the molecular structure of the starch. Hydrogen bonding during the extrusion could lead to a gel network, which strengthens the starch structure of the noodles (Boers et al., 2015). The extruded glass noodles from MBS exhibited better cooking qualities and stability than the use of other starches with lower amylose content such as potato starch, pea starch, and cassava starch (Thapnak et al., 2019). MBS is known as the most suitable starch for making glass noodles because due to its high amylose content and paste property (Kasemsuwan et al., 1998; Wu et al., 2015).

Table 3. Influence of barrel temperature on cooking qualities of extruded glass noodles from mung bean starch

Temperature (°C) zone 1: 2: 3	Cooking time (min)	Cooking weight (%)	Cooking loss (%)
70: 90: 90	3.50 ± 0.10[a]	372.85 ± 4.52[a]	7.84 ± 0.09[a]
70: 90: 100	2.90 ± 0.02[b]	376.47 ± 5.21[a]	7.15 ± 0.20[a]
70: 100: 90	2.85 ± 0.02[b]	365.95 ± 358[b]	6.45 ± 0.05[b]
70: 100: 100	2.70± 0.01[b]	368.33 ± 4.24[b]	6.01 ± 0.14[b]
Commercial mung bean glass noodle	4.01 ± 0.01[a]	380.09 ± 4.02[a]	3.10 ± 0.02[c]

Values are expressed as means ± SD (n=3)
Different superscript letters in the same column indicate significant differences ($p<0.05$)

The noodles prepared from TPC starch were uniform, smooth on surface, and semitransparent and less bright in color than the noodles from JGC starch. This could be due to the components other than the starch in TPC as discussed earlier. An increase of barrel temperature in Zones 2 and 3 to 100°C resulted in a slight increase in the noodle diameter from TPC starch (Table 4), that indicates expansion of the noodles when the starch was extruded at higher barrel temperatures. The increase in barrel temperatures yielded the noodles with lower cooking times and cooking weights. Higher temperatures result in higher degree of gelatinization in starch, thus shorter cooking times. The absorption of water during boiling/ cooking in the water seemed to decrease with the cooking time. However, cooking losses that ranged between 18.10-25.15% were much higher than the acceptable range of commercial noodles. The glass noodles extruded at barrel temperatures of 70: 90: 90°C produced comparatively stable strands after cooking for 4 min as shown in Figure 1A. However, further increase in Zone 2 temperature to 100°C resulted in noodles with broken strands (Figure 1B), and melted gel (Figure 1C) after cooking for 4 min.

The influence of barrel temperatures on the properties of the noodles from JGC starch was similar to that of TPC starch as presented in Table 5. Similar trends were observed for cooking times and cooking weights as for TPC noodles described above. Much lower cooking loss was observed for JGC noodles: the noodles extruded at 70: 70: 100°C temperatures showed the lowest % cooking loss at 11.79%, however, their texture was rather softer and the cooked noodle strands stuck together easily. The high pressure and temperature in the barrel might cause the excessive damage to the starch granules. Very short time during extrusion, less than 1 min with no cooling down period for the retrogradation, could affect the setback of the noodle to obtain less stable noodle texture. Use of modified starch such as cross-linking starch could limit the swelling capacity and water absorption of the starch granules, consequently, decrease cooking weight and maintain gel network strength and noodle stability (Rickard et al., 1991). Further study on the blending of canna starch with mung bean starch and other starches or ingredients such as modified starch, pea starch etc. is required in ways to reduce the cooking loss and improve their noodle stability (Thapnak et al., 2019).

In comparison, the glass noodles prepared from canna starch by traditional methods exhibited very low cooking losses, 0.55-0.93%. The preparation of the starch dough by conventional method requires freezing for longer time during the kneading and cooking of noodle (Charnsri et al., 2005) than the high temperature and short time during extrusion, resulting in stronger gel network. The noodles exhibited clear and dense texture when they were kept at 4°C. The retrogradation occurred when the noodles were held at lower temperatures (-18°C to 5°C) for a period of time, 12 to 24 h (Galvez et al., 1994).

Table 4. Influences of barrel temperature on cooking qualities of glass noodles extruded from Thai-purple canna starch

Temperature (°C) zone 1: 2: 3	Diameter (mm)	Cooking time (min)	Cooking weight (%)	Cooking loss (%)
70: 70: 90	0.81 ± 0.01^{b}	3.00 ± 0.01^{a}	378.25 ± 2.75^{a}	21.55 ± 0.21^{c}
70: 70: 100	0.81 ± 0.03^{b}	2.85 ± 0.01^{a}	384.75 ± 0.78^{a}	18.10 ± 0.28^{f}
70: 80: 90	0.80 ± 0.01^{b}	2.95 ± 0.01^{a}	337.55 ± 2.33^{c}	25.15 ± 0.07^{a}
70: 80: 100	0.80 ± 0.01^{b}	2.80 ± 0.02^{a}	315.85 ± 2.47^{d}	22.90 ± 0.28^{b}
70: 90: 90	0.81 ± 0.02^{b}	2.90 ± 0.10^{a}	352.15 ± 3.61^{b}	24.60 ± 0.14^{a}
70: 90: 100	0.82 ± 0.02^{b}	2.52 ± 0.02^{b}	345.65 ± 4.17^{b}	21.40 ± 0.14^{c}
70: 100: 90	0.84 ± 0.03^{b}	2.48 ± 0.02^{b}	280.90 ± 3.81^{e}	20.15 ± 0.07^{d}
70: 100: 100	0.90 ± 0.01^{a}	2.45 ± 0.08^{b}	236.15 ± 2.06^{f}	19.65 ± 0.2^{e}

Values are expressed as means ± SD (n=3)
Different superscript letters in the same column indicate significant differences ($p<0.05$)

Table 5. Influences of barrel temperature on cooking quality of glass noodle extruded from Japanese-green canna starch

Temperature (°C) zone 1: 2: 3	Diameter (mm)^{ns}	Cooking time (min)	Cooking weight (%)	Cooking loss (%)
70: 70: 90	0.74 ± 0.01	2.52 ± 0.10^{ab}	326.12 ± 0.05^{b}	14.58 ± 0.03^{c}
70: 70: 100	0.74 ± 0.01	2.22 ± 0.10^{b}	352.25 ± 0.01^{a}	11.79 ± 0.02^{d}
70: 80: 90	0.74 ± 0.01	3.00 ± 0.01^{a}	303.72 ± 0.37^{c}	16.39 ± 0.09^{b}
70: 80: 100	0.74 ± 0.01	2.30 ± 0.01^{b}	308.46 ± 0.36^{c}	18.47 ± 0.08^{a}
70: 90: 90	0.75 ± 0.01	2.52 ± 0.10^{ab}	285.85 ± 0.35^{cd}	15.51 ± 0.03^{bc}
70: 90: 100	0.75 ± 0.01	2.22 ± 0.10^{b}	286.32 ± 0.35^{cd}	15.56 ± 0.06^{bc}
70: 100: 90	0.75 ± 0.01	2.37 ± 0.10^{b}	253.17 ± 0.18^{d}	15.27 ± 0.01^{bc}
70: 100: 100	0.75 ± 0.01	2.30 ± 0.21^{b}	296.00 ± 0.22^{c}	15.84 ± 0.02^{bc}

Values are expressed as means ± SD (n=3)
Different superscript letters in the same column indicate significant differences ($p<0.05$)
ns: not significantly different ($p>0.05$)

(A) Stable noodle (B) Broken noodle (C) Melted gel

Figure 1. Stability of glass noodle extruded from edible canna starch (Thai-purple) with barrel temperatures of 70: 90: 90°C, after cooking for 4 min

The main characteristics of glass noodles are being clear, transparent and glossy in appearance, with a shorter cooking time, bland taste, elastic texture, and minimal surface stickiness after cooking (Kasemsuwan et al., 1998). The commercial glass noodles presented the highest tensile stress followed by the noodles from TPC and JGC starch (Table 6). Compared to the noodles from JGC starch, TPC noodles were less bright but firmer, and only slightly stuck together after cooking and draining. The sensory evaluation of appearance and texture of noodles from both TPC and JGC starch by trained panel indicated higher preference for TPC noodles (data not shown). Consequently, the noodle from TPC starch was further used for the hedonic test comparing to a commercial brand of glass noodle from mung bean starch.

Table 6. Properties of extruded glass noodle from canna starches and commercial mung bean glass noodle

	Diameter (mm)^{ns}	L*	a*	b*	Cooking time (min)	Cooking weight (%)	Cooking loss (%)	Tensile stress (g/mm^2)
TPC (Extrusion)	0.81 ± 0.03	42.99 ± 0.23^{c}	1.08 ± 0.03^{a}	9.01 ± 0.17^{a}	2.85 ± 0.01^{b}	384.75 ± 0.78^{a}	18.10 ± 0.28^{a}	20.11 ± 1.21^{b}
JGC (Extrusion)	0.74 ± 0.01	64.51 ± 0.01^{b}	0.26 ± 0.01^{b}	8.02 ± 0.01^{b}	2.22 ± 0.10^{c}	352.25 ± 0.01^{b}	11.79 ± 0.02^{b}	12.36 ± 2.32^{c}
Mung bean (commercial)	0.75 ± 0.02	68.93 ± 0.19^{a}	0.12 ± 0.01^{c}	4.12 ± 0.25^{c}	3.50 ± 0.02^{a}	360.85 ± 6.47^{b}	3.10 ± 0.09^{c}	29.21 ± 3.45^{a}

Values are expressed as means ± SD (n=3)
Different superscript letters in the same column indicate significant differences ($p<0.05$)
ns: not significantly different ($p>0.05$)

3.4 Sensory evaluation

The sensory test of glass noodles extruded from TPC with the commercial mung bean starch glass noodles as reference shows non-significant preference in terms of flavor and texture as presented in Table 7. The noodles from TPC received lower overall acceptability. The results could be due to the inferior color and clarity which are also ones of the major properties of glass noodle. However, improvement in the TPC starch extraction process could help increase the brightness of the starch as well as the color and transparency of the extruded noodles. The use of TPC starch from a better starch extraction process resulted to less impurity would potentially lead to the extruded glass noodles with comparable overall acceptability to the commercial mung bean glass noodles.

Table 7. Sensory qualities of extruded glass noodle from Thai-purple canna (TPC) starch and commercial mung bean glass noodle

Attribute	Glass noodle from TPC starch	Commercial mung bean glass noodle
Color	3.50 ± 1.63^{b}	6.57 ± 1.04^{a}
Flavor^{ns}	4.75 ± 1.70	4.87 ± 1.51
Transparency	4.10 ± 1.58^{b}	5.02 ± 1.01^{a}
Texture^{ns}	5.25 ± 1.04	5.16 ± 0.82
Overall acceptability	5.10 ± 1.18^{b}	6.81 ± 0.87^{a}

Values are expressed as means ± SD (n=3)
Different superscript letters in the same row indicate significant differences ($p<0.05$)
ns: not significantly different ($p>0.05$)

4. DISCUSSION

Physical and cooking properties of the glass noodles extruded from edible Thai and Japanese canna starches showed their potential to be used as an alternative for mung bean starch which is costlier. All noodles extruded from MBS, TPC, and JGC presented uniform size and were semitransparent which turned transparent after cooking. The glass noodles extruded from MBS presented significantly lower cooking losses than the noodles from TPC and JGC starches. However, the texture of glass noodles from TPC was firmer than the softer texture of JGC noodles. Sensory evaluation by hedonic test showed the comparable acceptance of noodle from TPC starch and commercial glass noodles from mung bean.

ACKNOWLEDGMENT

We extend our sincere thanks to National Research Council of Thailand for the financial support.

REFERENCES

AACC. (ed.). (2000). American Association of Cereal Chemists. In *Approved Methods of the AACC.* 10th, St. Paul, MN: Cereals & Grains Association.

AOAC. (2000). Association of Official Analytical Chemists. In *Official Methods of the AOAC International* (Horwitz, W., ed.), 17th, Gaithersburg, MD: AOAC.

Boers, H. M., Hoorn, J. S. T., and Mela, D. J. (2015). A systematic review of the influence of rice characteristics and processing methods onpostprandial glycaemic and insulinaemic responses: review. *British Journal of Nutrition*, 114(7), 1035-1045.

Dubois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., and Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry*, 28(3), 350-356.

Charnsri, R., Puttanlek, C., Rungsardthong, V., and Uttapap, D. (2005). Characteristics of clear noodles prepared from edible canna starches. *Journal of Food Science*, 70(5), 337-342.

Charutigon, C., Jitpupakdree, J., Namsree, P., and Rungsardthong, V. (2008). Effects of processing conditions and the use of modified starch and monoglyceride on some properties of extruded rice vermicelli. *LWT - Food Science and Technology,* 41(4), 642-651.

Galvez, F. C. F., Resurreccion, A. V. A., and Ware, G. O. (1994). Process variables, gelatinized starch and moisture effects on physical properties of mung bean noodles. *Journal of Food Science*, 59(2), 378-381.

Kasemsuwan, T., Bailey, T., and Jane, J. (1998). Preparation of clear noodles with mixtures of tapioca and high-amylose starches. *Carbohydrate Polymers*, 36(4), 301-312.

Korkerd, S., Wanlapa, S., Puttanlek, C., Uttapap, D., and Rungsardthong, V. (2016). Expansion and functional properties of extruded snacks enriched with nutrition sources from food processing by-products. *Journal of* Food Science and Technology, 53(1), 561-570.

Kaur, A., Shevkani, K., Singh, N., Sharma, P., and Kaur, S. (2015). Effect of guar gum and xanthan gum on pasting and noodle-making properties of potato, corn and mung bean starches. *Journal of Food Science and Technology*, 52(12), 8113-8121.

Lusas, E., and Riaz, M. (1994). An introduction to extruders and extrusion principles. *Extrusion communique,* 7(4) 9-34.

Mercier, C., Linko, P., and Harper, J. M. (1989). *Extrusion Cooking*. St. Paul, MN: American Association of Cereal Chemists. Inc.

Photinam, R., Moongngarm, A., and Paseephol, T. (2016). Process optimization to increase resistant starch in vermicelli prepared from mung bean and cowpea starch. *Emirates Journal of Food and Agriculture,* 28 (7), 449-458.

Puncha-arnon, S., Puttanlek, C., Rungsardthong, V., Pathipanawat, W., and Uttapap, D. (2007). Changes in physicochemical properties and morphology of canna starches during rhizomal development. *Carbohydrate Polymers*, 70(2), 206-217.

Rasmussen, T. S., and Henry, R. J. (1990). Starch determination in horticultural plant material by an enzymatic-colorimetric procedure*. Journal of the Science of Food and Agriculture,* 52(2), 159-170.

Rickard, J. E., Asaoka, M. and Blanshard, J. M. V. (1991). The physicochemical properties of cassava starch. *Tropical Science,* 31**,** 189-207.

Rungsardthong, V., Wutthisilanon, S., Thongkum, T., Suthtinium, T., Puttanlek, C., and Uttapap, D. (2021). Quality assessment of rice spaghetti made from jasmine rice flour and sweet potato flour supplemented with protein sources by direct extrusion. *Journal of Food Processing and Preservation,* 45(5), e15450.

Santacruz, S., Koch, K., Svensson, E., Ruales, J., and Eliasson, A. C. (2002). Three underutilized sources of starch from the Adean region in Ecuador Part I. Physicochemical characterization. *Carbohydrate Polymers*, 49(1), 63-70.

Sereewat, P., Suthipinittham, C., Sumathaluk, S., Puttanlek, C., Uttapap, D., and Rungsardthong, V. (2015). Cooking properties and sensory acceptability of spaghetti made from rice flour and defatted soy flour. *LWT - Food Science and Technology*, 60(2), 1061-1067.

Soni, P. L., Sharma, H., Srivastava, H. C., and Gharia, M. M. (1990). Physicochemical properties of *Canna edulis* starch-comparison with maize starch. *Starch - Stärke*, 42, 460-464.

Sue, S. L., Sulaiman, R., Sanny, M., and Nur Hanani, Z. A. (2015). Effect of extrusion barrel temperatures on residence time and physical properties of various flour extrudates. *International Food Research Journal*, 22(3): 965-972.

Srirachan, S., Mounmued, W., Vatanyoopaisarn, S., Thumthanaruk, B., Puttanlek, C., Uttapap, D., Rungsardthong, V., and Wongsa, J. (2021). Development of rice spaghetti supplemented with defatted soy flour, modified starch, and durian peel powder by extrusion. *Science, Engineering and Health Studies,* 15(21030003), 2630-0087.

Thapnak C., Rungsardthong V., Vatanyoopaisarn S., Vimolchalao C., Puttanlek C., Uttapap D., Wongsa J. and Thumthanaruk B. (2019). Effect of Barrel Temperatures and Starch Type on Some Properties of Extruded Glass Noodles. 5th International Conference on Agricultural and Biological Sciences (ABS 2019), Macao Convention & Exhibition Association, 21-24 July 2019. IOP Conf. Series: *Earth and Environmental Science*, 346, 9.

Thitipraphunkul, K., Uttapap, D, Piyachomkwan, K., and Takeda, Y. (2003). A comparative study of edible canna (*Canna edulis*) starch from different cultivars. Part II: Molecular structure of amylose and amylopectin. *Carbohydrate Polymers*, 54(4), 489-98.

Wandee, Y., Uttapap, D., Puncha-arnon, S., Puttanlek, C., Rungsardthong, V., and Wetprasit, N. (2015). Quality assessment of noodles made from blends of rice flour and canna starch. *Food Chemistry*, 179, 85-93.

Wahjuningsih, B., Sudjatinah, Nurul Azkia, M., and Anggraeni, D. (2020). The study of sorghum (*Sorghum bicolor* l.), mung bean (*Vigna radiata*) and sago (*Metroxylon sagu*) noodles: Formulation and physical characterization. *Research in Nutrition and Food Science,* 8(1), 217-225.

Wang, N, Maximiuk, L., and Toews, R. (2012). Pea starch noodles: Effect of processing variables on characteristics and optimisation of twin-screw extrusion process. *Food Chemistry,* 133(3), 742-753.

Wang, N., Warkentin, T. D., Vandenberg, B., and Bing, D. J. (2014). Physicochemical properties of starches from various pea and lentil varieties, and characteristics of their noodles prepared by high temperature extrusion. *Food Research International,* 55, 119-127.

Wongsa, J., Uttapap, D., Lamsal, B. P., Puttanlek, C., and Rungsardthong, V. (2017). Effect of extrusion conditions, monoglyceride and gum arabic addition on physical and cooking properties of extruded instant rice. *KMUTNB International Journal of Applied Science and Technology,* 10(1), 23-30.

Wu, F., Meng, Y., Yang, N., Tao, H., and Xu, X. (2015). Effects of mung bean starch on quality of rice noodles made by direct dry flour extrusion. *LWT-Food Science and Technology,* 63(2), 1199-1205.

Yeh, A. I., and Jaw, Y. M. (1999). Effects of feed rate and screw speed on operating characteristics and extrudate properties during single-screw extrusion cooking of rice flour. *Cereal Chemistry*, 76(2), 236-242.