Effect of barrel temperatures and starch type on some properties of extruded glass noodles

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Abstract. Traditional production of glass noodles is a long and complicated processes mainly uses mung bean starch which is costly. This research aimed to study the extrusion effect of barrel temperature of zone 3 on size, cooking time and stability time (time until the noodles tear in boiling water) compared to the control, the commercial glass noodle produced by the traditional processes. The effects of using starch blends from mung bean starch (MBS) and pea starch (PS), potato starch (PTS), cassava starch (CS) and modified cassava starch (MCS) at the ratio of 80:20, 70:30, 60:40 and 0:100 (w/w) on the size and cooking properties of the glass noodles were investigated and compared to the control. Results showed that the increased barrel temperature of zone 3 of the extruder increased the size of the dried and cooked glass noodles. The starch blends of MBS and PTS glass noodle resulted to the highest cooking loss (7.94-25.09%). The cooking weights (%) of glass noodle were lower with the decrease of MBS followed with the increase of cooking losses (%) in most cases. However, the starch blends of MBS and MCS showed the lowest values of cooking loss at all ratios used (5.30-5.83%). The extruded glass noodles showed similar appearance with lower cooking time (2 min) and stability time (8 min) compared to the control (3 min and 20 min, respectively). Based on the results of this study, it can be concluded that the starch blends of MBS and MCS glass noodle yields cooking properties better than other types of starch blends for the extruded glass noodles.

1. Introduction

Glass noodles, also known as vermicelli, cellophane noodles, crystal noodles, is a popular type of noodles generally consumed in East and Southeast Asian countries, as well as in western countries. Glass noodles have generally made from mung bean (Vigna radiate) starch [1-2]. The most important characteristics of glass noodles are clear, transparent and glossy. For cooked or boiled glass noodles

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with a short cooking time, the product should have bland taste, firm and elastic texture and minimal surface stickiness and minimal cooking loss [1]. The traditional production of glass noodles is a long, non-continuous processes, requires high energy and time-consuming. In addition, the traditional process generates a lot of waste water and large volume of solid loss [3]. The traditional method for the glass noodle production starts from the mixing of uncooked mung bean starch (85%) and cooked mung bean starch (15%) in a single speed pinhead mixer for 3 min. Then the dough will be extruded through dies having a diameter of about 1.60 mm by a cylindrical forming machine (without heating). Extruded glass noodles are immersed in boiling water for 10 s, cooled in cooling water (4°C) for 3 to 5 min and stored at -10°C for 24 h. Finally, glass noodles will be dried on the polyethylene sheet in a hot air drier at 40 ºC and transferred to a covered airtight container [4].

Extrusion is the continuous process combining mixing, cooking and forming in the extruder under high temperature and shorter time (HTST). The advantages are high production capacity, versatility, but minimal use of energy, less water and time requirement and low production cost per unit [3][5][6]. Extrusion process has long been produced either commercial snack products or noodles. There are many reports on extruded food products such as pea starch noodle [2], instant rice [5], high nutritional snack [7], pea and lentil starch blend noodle [8] and paste-like product from pea starch [9]. Several types of extruders in the market generally divided based on the number of screw into a single-screw and a twin-screw extruder. Twin screw extruder offers better mixing, quality control and processing flexibility [10] but single screw extruders are relatively inexpensive and easy to maintain. Typically, a single screw barrel can be divided into three processing zones: feeding zone, kneading zone and the final cooking zone, while the temperature of each zone will influence the properties of the raw material inside the barrel [11]. The major parameters which influence the property of the extrudate are process variables including temperature, screw speed, and initial moisture content of the feed, while the composition of the feed is also very important [5][6][12].

Mung bean starch (MBS) is considered as the best raw material for high quality glass noodles because of its high amylose content, restricted swelling during gelatinization, and high shear resistance of its paste [1][13][14]. Amylose content is one of the most important factor affecting the starch gel strength due to its prompt association, retrogradation and interaction with lipid to form helical complex, as well as the complex with amylopectin to give strong gel networks [6]. However, the cost of MBS is quite high compared to other starches such as pea starch, potato starch, cassava starch, and modified starch. In this study, a more cost competitive starch type will be chosen and used as a starch blend to produce the extruded glass with comparable properties to the noodle produced by the long traditional processes. Besides MBS, pea starch noodles produced by a twin-screw extruder has a bright color similar to that of the commercial mung bean starch noodles prepared by traditional method [2]. Cooking time and surface stickiness of cooked pea starch noodles were within the ranges exhibited by commercial mung bean starch noodles. Upon comparing with commercial products, cooked pea starch noodles had a bland taste and firmer texture [2].

Therefore, this study aimed to explore the use of mung bean starch and other alternative ingredients to produce glass noodles by direct extrusion process. Physical properties, cooking quality, texture analysis as well as rehydration time and noodle stability (time until the noodles tear in boiling water) of the extruded noodles were also evaluated compared to the commercial glass noodles produced by traditional long process.

2. Material and methods

2.1. Materials and chemical composition

Mung bean starch (MBS), pea starch (PS), potato starch (PTS), cassava starch (CS) and cross-linked modified cassava starch (MCS) were kindly supplied from Thai Vermicelli Industry Co., Ltd. (Bangkok, Thailand). Glass noodles produced by the traditional process used as the control. Chemical analysis of the moisture, ash, protein, and lipid contents of each starch was carried out following AACC 2012 [15].
2.2. Pasting properties
Pasting properties of MBS, PS, PTS, CS, and MCS were determined according to the method described by Charугiоn et al. (2008) [5] using a rapid viscosity analyzer (RVA-4SA, Newport Scientific, Narrabeen Australia). Each sample (3.0 g, dry matter) was prepared into a RVA canister and adjusted to 28 g by adding distilled water. Peak time (PT), peak viscosity (PV), holding strength (HS), final viscosity (FV), breakdown (BD), setback (SB), and pasting temperature (PTT) were determined.

2.3. Effects of barrel temperature on properties of extruded MBS glass noodle
Direct extrusion for the glass noodle production was carried out by using a single screw extruder (Brabender 19/20, DGE 330, PL 2200, Germany) with the following conditions: barrel bore (D), 19.1 mm, barrel length (L) = 20D, 4:1 screw compression ratio, and the screw speed was operated at 40 rpm. The barrel consists of three independent temperature zones, zone 1 (entering zone), zone 2 (kneading zone) and at the barrel end, indicated as zone 3. According to our experience and preliminary study in extrusion of the noodle from various starch and flour, the screw speed and initial moisture content of the feed as well as the temperature for the zone 1 and zone 2 were fixed in this study. In this study, the effect of the third zone temperature and starch blend on the quality of the extruded glass noodle were investigated. Barrel temperatures were maintained at 50 °C (zone 1), 70 °C (zone 2). The effect of the third zone of barrel temperature at 70, 80, 90, 100, 110, 120, and 130 °C was investigated. The initial moisture content of MBS was adjusted to 35% (w/w). The hydrated starch was extruded through a circular die of 0.50 mm round opening and cut into 30 cm length as they exited the extruder die. Then, the noodles were dried at 80 °C for 10 min. The dried noodles were kept in sealed polyethylene bags until analysis. The diameter of glass noodles was measured by a Vernier caliper. The stability time and cooking time was performed in accordance with AACC 2012 [15]. The stability time is the boiling time used until glass noodles were broken. The optimum cooking time is the time required for the disappearance of opaque of central core of the noodles when gently squeezed the cooked noodles between two glass plates.

2.4. Effects of type of starch blends and ratio of starch blends on properties of extruded glass noodle
Five starch types were used for the formulation to produce the glass noodle by the extrusion. MBS, PTS, MBS, CS, and MCS. The glass noodles were also extruded by using 100% MBS. Four types of starch blends (MBS: PTS, MBS: PS, MBS: CS and MBS: MCS) at different ratios at 80:20, 70:30, 60:40 and 100:0 (w/w) were compared and extruded using the prior condition described in 2.3. The barrel temperature of the third zone at 120 °C was chosen to run this experiment. The analysis of size, cooking time, cooking weight and stability time were determined. The noodles (25 g) were cooked in a beaker filled with 300 ml water. Then, the noodles were rinsed in cold water (25 °C ± 1 °C) and drained using a sieve for 15 min before being weighed. The remain solid contents in the cooking water were dried at 105 °C overnight. The cooking weight was the weight of cooked sample compared to the weight of dry sample before cooking while cooking loss was evaluated by determining the amount of solids lost into the cooking water. The extruded products also compared with the commercial glass noodle which made by the traditional long processes.

2.5. Statistical analysis
All experiments were carried out for triplication and the data was expressed as means±standard deviation. The results were statistically analyzed by Duncan’s and SPSS 21.0 with significant difference at p<0.05.

3. Result and discussions

3.1. Chemical properties of each type of starch
The moisture, protein, and ash content of MBS, PTS, PS, CS, and MCS ranged from 9.96-15.38%, 0.18-0.39%, and 0.04-0.24%, respectively as shown in Table 1. The moisture content of PTS was slightly higher than those of other starches. MBS contained highest amylose content followed with pea starch, potato starch, modified cassava starch, and cassava starch, respectively. MBS is suitable for the production of glass noodle as it contains high amount of amylose content. No lipid content of all starch samples was detected.

Table 1. Chemical compositions of each starch used for the extrusion of glass noodles.

| Starch                  | Moisture (%) | Protein (%) | Ash (%) | Amylose (%) |
|-------------------------|--------------|-------------|---------|-------------|
| Mung bean starch (MBS)  | 11.14±0.05b  | 0.38±0.01a  | 0.22±0.09a | 50.78±0.07a |
| Potato starch (PTS)     | 15.38±0.24c  | 0.28±0.01b  | 0.18±0.07a | 37.09±0.04c |
| Pea starch (PS)         | 9.97±0.43a   | 0.39±0.00a  | 0.24±0.04a | 40.76±0.10b |
| Cassava starch (CS)     | 9.96±0.22b   | 0.18±0.00c  | 0.20±0.08a | 33.94±0.04d |
| Modified cassava starch (MCS) | 10.93±0.11c | 0.19±0.01c  | 0.04±0.03b | 35.62±0.10e |

Values are mean ± SD of triplicate samples (n=3)
ns = means within a column for each attribute constituent with the same letter are not significantly different (p<0.05)

The inorganic compounds found in the ash depend on the origin of starch. Cereal starches were reported to contain less inorganic composition (potassium, sodium, calcium and magnesium) but the starch from tuber crop was associated with potassium and phosphorus [16]. Negative charge of phosphorus on surface starch along with other negative charges affected the swelling property of the starch gel [7].

3.2. Pasting properties of each type of starch

Starch gelatinization is a process of breaking down intermolecular bonds of starch molecules in the presence of water and heat which allows hydrogen bonding sites (the hydroxyl hydrogen and oxygen) to engage with more water molecules. Penetration of water thus increased the randomness in the starch granule structure, and caused swelling. Eventually, amylose molecules leak into the surrounding water led to disintegrations of granule structure. The starch granules dissolved irreversibly in water act as a plasticizer [17]. The pasting viscosity (PV) indicates the functional property of starch and varies by type of starch. The PV of potato starch (PTS) and cross-linked modified cassava starch (MCS) were 834.90 and 829.33 RVU and those of mung bean starch (MBS), cassava starch (CS) and pea starch (PS) were 629.19, 434.07 and 364.36 RVU, respectively (Figure 1).

The holding strength (HS) of MCS, PS, MBS, PTS and CS were 596.83, 278.53, 260.39, 159.61 and 139.17 RVU, respectively. Breakdown (BD), the difference between PV and HS, indicates an ability of starch molecule resist to temperature and agitation of PS, MCS, CS, MBS, and PS were 85.83, 232.50, 294.68, 368.80, and 675.30 RVU, respectively. Setback (SB), the difference between PV and HS, indicatethes re-association between starch molecules during cooling commonly involving retrogradation, or re-ordering of the starch molecules resulting in texture property of various starch gel. The highest setback values (347.74 RVU) of PS indicates highest retrogradation, while PTS, MCS, CS, and MBS showed the lower retrogradation (183.22, 147.80, 140.83, and 139.22 RVU, respectively). The setback value is related to amylose content of starch. Cereal starch (for example MBS) having higher amylose content dictates higher setback value than tuber crop starch (PTS and CS) [18].

Pasting temperature (PTT) is the temperature at which initial swelling of starch granules suspended in water resulting in gelatinization of starch molecule (the breakdown of bonds within starch molecules). The pasting temperature of MBS, PS, MCS, CS, and PTS were 74.76, 72.73, 68.66, 64.28, and 64.28 °C, respectively. Swelling and soluble capacity of starch from tuber crop (CS, PTS) is higher than those of cereal starch due to its lower gelatinization temperature [19]. In addition, phosphate group of PTS could affect high swelling due to electromotive force formation.
Figure 1. Pasting properties of different starch type.
Note: MBS (mung bean starch), PS (pea starch), PTS (potato starch), CS (cassava starch), and MCS (modified cassava starch)

Table 2. Temperature effects of third zone barrel of extruder on some properties of extruded glass noodles.

| Barrel temperature (°C) of zone 3 | Size (mm) | Cooking time (min) | Stability time (min) |
|-----------------------------------|-----------|--------------------|---------------------|
|                                   | Dried product | Cooked product |                                   |
| 70                                | 0.57±0.01c   | 0.69±0.01d   | 2.00±0.01b | 5.00±0.01c |
| 80                                | 0.62±0.03ed  | 0.72±0.01f   | 2.00±0.01b | 5.00±0.01c |
| 90                                | 0.63±0.05ed  | 0.75±0.01f   | 2.00±0.01b | 6.00±0.01d |
| 100                               | 0.68±0.05d   | 0.82±0.05c   | 1.00±0.01c | 7.00±0.01c |
| 110                               | 0.77±0.10c   | 0.98±0.02d   | 1.00±0.01c | 8.00±0.01b |
| 120                               | 1.05±0.05b   | 1.19±0.02c   | 1.00±0.01c | 8.00±0.01b |
| 130                               | 1.12±0.03d   | 1.25±0.03b   | 1.00±0.01c | 7.00±0.01c |
| Commercial product (produced by traditional processes) | 1.03±0.03b | 1.46±0.07a | 3.00±0.01a | 20.00±0.01a |

Values are mean ± SD of triplicate samples (n=3)
ns = means within a column for each attribute constituent with the same letter are not significantly different (p>0.05)

3.3. Effects of barrel temperature of zone 3 on quality of extruded MBS glass noodles
Results showed that the increased barrel temperature of the extruder significantly affected the size of dried and cooked extruded noodles as well as the cooking time and stability times as shown in Table 2. The increased size of extruded glass noodle could be due to a sudden change in the pressure at the die exit resulting in the expansion of the extruded products [20-21]. The noodle surface was smooth when extruded at the temperature of no greater than 120°C. If the barrel temperature of third zone increased from 90 to 100°C or higher, the stability time increased except for the product extruded using the temperature of 120 and 130 °C but the cooking time decreased from 2.00 to 1.00 min. The short cooking time would benefit to the product for grouping into an instant product. However, the cooking time of commercial product was 3 min and had long stability time of 20 min. The increased temperature as well as the geometry of the extruder including screw design, shallow groove and slope could increase shear forces and mixing led to the gelatinization of the starch gel. When samples areto
extrude under different temperature and pressure conditions of the extruder, starch will gelatinize and melt, and water will evaporate, thereby increased product expansion with stable swelling at atmospheric pressure [6]. According to the size similarity of extruded glass noodle and control, the extrusion condition of the barrel temperature of zone 3 at 120 °C was chosen for further study.

**Table 3.** Properties of glass noodles extruded with the barrel temperature of third zone at 120 °C by using different starch blends.

| Starch blends sample | Size (mm) | Stabilitytime (min) | Cooking weight (%) | Cooking loss (%) |
|----------------------|-----------|---------------------|--------------------|------------------|
|                      | Dried product | Cooked product |                     |                  |
| MBS: PTS             |            |                     |                    |                  |
| 100:0                | 1.05±0.05cd | 1.19±0.08jk        | 8.0f               | 357.15±1.07b     | 6.59±0.94b       |
| 80:20                | 0.74±0.03k  | 1.17±0.08jk        | 5.0e               | 348.45±1.04b     | 7.94±0.65e       |
| 70:30                | 0.83±0.07ij | 1.11±0.04kl        | 4.0f               | 340.86±1.01d     | 13.96±0.43c      |
| 60:40                | 0.89±0.06hi | 1.28±0.06hi        | 4.0f               | 317.65±1.13c     | 19.20±0.36b      |
| 0:100                | 1.04±0.02def | 1.25±0.03bij       | 3.0f               | 256.43±1.34a     | 25.09±0.16a      |
| MBS: PS              |            |                     |                    |                  |
| 80:20                | 1.32±0.04a  | 1.70±0.05bc        | 7.0e               | 299.67±1.29i     | 6.41±0.46h       |
| 70:30                | 1.11±0.06cde | 1.64±0.06cd       | 6.00d              | 289.62±1.19b     | 7.73±0.67g       |
| 60:40                | 1.32±0.03ae | 1.89±0.05a         | 5.00e              | 272.59±1.28f     | 7.89±0.50f       |
| 0:100                | 1.23±0.04b  | 1.78±0.03b         | 5.00e              | 133.36±1.20a     | 10.40±0.56c      |
| MBS: CS              |            |                     |                    |                  |
| 80:20                | 0.93±0.03ab | 1.58±0.06cde       | 3.00f              | 294.05±0.99g     | 7.61±0.75e       |
| 70:30                | 0.97±0.04fg | 1.08±0.03l         | 3.00e              | 258.28±1.11k     | 9.04±0.29f       |
| 60:40                | 1.04±0.04def | 1.32±0.03h        | 3.00f              | 245.31±1.14m     | 11.82±0.33d      |
| 0:100                | 0.98±0.04ef | 1.42±0.03g         | 3.00f              | 187.66±1.30n     | 13.54±0.59c      |
| MBS: MCS             |            |                     |                    |                  |
| 80:20                | 0.78±0.03jk | 1.04±0.08l         | 8.00b              | 289.39±1.21b     | 5.83±0.74bij     |
| 70:30                | 1.12±0.04c  | 1.51±0.03ef        | 8.00b              | 277.15±1.03b     | 5.70±0.23hij     |
| 60:40                | 1.29±0.02ab | 1.45±0.03ef        | 8.00b              | 252.27±1.10l     | 5.53±0.24hij     |
| 0:100                | 1.03±0.03f  | 1.42±0.05g         | 8.00b              | 146.59±0.87b     | 5.30±0.37f       |
| Commercial product   | 1.03±0.03def | 1.46±0.07fg       | 20.00±0.00a        | 452.31±1.14a     | 2.66±0.02a       |

Note: MBS (mung bean starch), PS (pea starch), PTS (potato starch), CS (cassava starch), and MCS (modified cassava starch)

Values are mean ± SD of triplicate samples (n=3)

ns = means within a column for each attribute constituent with the same letter are not significantly different (p>0.05)

3.4. Effects of type of starch blends and ratio of starch blends on properties of extruded glass noodle

The raw material factor used starch blends (type and ratio) was investigated. Four types of starch blends (MBS:PTS, MBS:PS, MBS:CS and MBS:MCS) and four different ratios of starch blends (MBS:PTS, MBS:PS, MBS:CS and MBS:MCS) varying at 80:20, 70:30, 60:40 and 100:0 (w/w) were extruded at the barrel temperature of 50, 70 and 120 °C for the first, second and third zone. Results showed that the size of extruded glass noodles were slightly different depend on the type and ratio of starch blends. However, when boiling the dried sample, the size of boiled glass noodle of all starch blends used increased. The use of 100% MBS yielded glass noodle with cooking weight at 357.15%
indicated highest water absorbing capacity, followed with the use of PTS, CS, MCS and PS which showed cooking weight at 256.43, 187.66, 146.59 and 133.36%, respectively. Increasing MBS content resulted in gradual rises of amylose content, retrogradation degree, storage modulus (G') and loss modulus (G'\text{''}) while the solubility, swelling power and pasting viscosities decreased [3]. Each starch has different granule size, water absorption ability. The pasting profile affects the cooking properties of the noodles [3]. Starch granules fabricated from semi-crystalline network which amylose and amyllopectin molecule are arranged in crystallite structure and amorphous or gel phase. Short amyllopectin chain arrangements are formed as double helices or crystallite structure while granule amorphous starch consisted of amylose and long chains of amyllopectin [8] [22].

Results showed the lowest stability time of 3 min of glass noodles found in the extruded starch blends of MBS:CS at all ratios while the highest stability time of 8 min was from the extruded starch blends of MBS: MCS. The chemical property of each starch type indicates the product functionality. Cross-linking starch is normally lower the swelling capacity and water absorption of the starch granules, thereby decreasing cooking weight but maintaining the strength of gel network of the noodle and noodle stability [5][22]. Results revealed that, at the same ratio of starch blends used, the starch blends of MBS and PTS glass noodle yielded the highest cooking weight (%). The lowest cooking loss (%) was obtained by the use of starch blends of MBS: MCS (5.30-5.83%) at all ratios. However, if lower ratio of MBS was used, the cooking losses (%) were higher in most cases (Table 3).

Cooking loss was mainly due to solubilization of loosely bound gelatinized starch on the noodle surface. The degree of cooking loss generally depends on the degree of starch gelatinization and the strength of gel network-like structure of the noodles. The surface gelatinization of traditional extruded noodle was critical for hot-water stability of the noodles [9]. The cooking loss of glass noodles from traditional method was 1.66%. For the commercial perspective, consumers can accept the cooking loss of noodles no greater than 10% [20].

4. Conclusion
Glass noodles were successfully prepared using mung bean starch and other starch blends by using direct extrusion process. Processing variables including the barrel temperature of zone 3 had significant effects on physicochemical, cooking quality, and textural characteristics of the glass noodles. The optimum barrel temperature of zone 3 used for the extrusion was 120 °C. The extruded glass noodles showed similar appearance with lower cooking time compared to the control. The highest cooking weight was obtained at 357.15% from MBS while lowest cooking loss was obtained 5.30% from MCS with cooking time 2 min. For all starch blends used, the blend of MBS and MCS yielded the lowest % cooking loss (5.30-5.83%) and longest stability time (8 min) at all ratios of starch blends.

Acknowledgement
The authors would like to thank Thailand Research Fund (TRF) under Research and Researchers for Industries (RRI) program (MSD59J0103) and Thai Vermicelli Industry Co., Ltd. for their financial support.

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