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Review

Starch noodles: History, classification, materials, processing, structure, nutrition, quality evaluating and improving

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ABSTRACT

Starch noodles, produced from purified starch of various plant sources, are a major category of Asian noodles. This review summarizes the current knowledge on: (1) Definition, naming, history and categories of starch noodles. (2) The morphological, physico-chemical, thermal, rheological characteristics and molecular structure of materials including mung bean starch, pea starch, sweet potato starch, potato starch and corn starch. (3) Processing technology of starch noodles including dropping, extruding and cutting. (4) Structure of starch noodles: it is composed of hydrolysis-resistant crystalline zone, network-like framework and filler mass. (5) Nutrition of starch noodles: it could be evaluated by the digestibility of starch, hydrolysis properties of gelatinized and retrograded starches, hydrolysis property of starch noodles. (6) Quality evaluating of starch noodles: it includes sensory, cooking and texture property. Correlation between the physical properties of starch, processing variables and the sensory, cooking and texture property of starch noodles are summarized. (7) Quality improving for non-mung bean starch noodles: (a) using other materials such as red bean starch, pigeonpea starch, potato starch, sweet potato starch, corn starch, to substitute totally or partly mung bean starch; (b) adding chemically modified starch; (c) adding physically modified starch; (d) biologically treating starch; (e) using additives such as chitosan, polysaccharide gums.

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1. Introduction

1.1. Definition

Starch noodles, produced from purified starch from various plant sources, are a major category of Asian noodles. They are produced by the following steps: (1) mixing dry and gelatinized starch to form a slurry or dough, (2) extruding it directly into boiling water to cook, (3) cooling the formed noodles in cold tap water, (4) holding at refrigerated or freezing temperature, (5) warming in cold tap water, and then drying (Galvez, Resurrection, & Ware, 1994). Starch noodles are obviously different from other types of noodles, such as pasta and wheat flour, since it is made from gluten-free starch. Thus, starch itself plays an essential role in both the production of starch noodle and the final quality of starch noodle. Excellent starch noodles would have clear or transparent and fine threads, high tensile strength, and low cooking loss even with prolonged cooking (Collado, Mabesa, Oates, & Corke, 2001; Purwani, Widaningrum, Thahir, & Muslich, 2006).

1.2. Naming

Using starch of various sources to manufacture products in noodle shapes has been practiced for centuries in China and subsequently spread to neighboring countries. These products are called "starch noodles" or "cellophane noodles" because of their translucent or transparent appearance of pre- or post-cooking (Hui, 2007). Nomenclature of Chinese starch noodles is difficult due to the vast spectrum available and the many dialects of Chinese being used to name them. Mung bean threads were probably the first starch noodles manufactured (Hui, 2007). In Chinese, therefore, starch noodles are called lǜ dòu miàn ("mung bean noodles"; literally "green bean noodles"), fěn sī ("soft white noodle"), or dōng fěn ("winter white noodle"). The Korean sweet potato vermicelli ("*dang myun*") is a product similar to mung bean threads. It also has excellent *al dente* properties, which remain upon re-heating. In Japanese cuisine, they are called harusame, lit. "Spring rain." Japanese harusame is a similar starch noodle product, as it is also made from potato, sweet potato, rice, or mung bean starches (Hui, 2007). In Vietnamese it is called *bun tau* or *bun tao*. In Thailand *wún-sên* is an almost clear noodle made from mung bean starch and water. While in the Philippines, rice flour, maize starch (MS), and mung bean starch are made into starch noodles locally known as *bihon* for those with thin strands or *pancit malabon* for those with thick strands (Collado et al., 2001).

1.3. History

Starch noodles have been Chinese favorite food for at least 1400 years. Before that age, most grains with abundant starch content were simply boiled whole just as cooked rice. The first written account of starch noodles dates from the North Wei Dynasty. Jia Sixie, in the later part of Wei, the North Dynasty, recorded the production of starch and starch noodles detailedly in his famous book "Qi Min Yao Shu". Although the processing method was simple, the principle is same as that in the producing by machine nowadays (Zhang & Chi, 2001). The production of mung bean starch noodles and the market were also mentioned in others bookmaking, Ben Xin Zhai Shu Shi Pu and Dong Jing Meng Hua Lu, in Song Dynasty. Although the old legend said that Sun Bin invented the starch noodles. However, there is no recordation about it. The origin of noodles remains an unsolved historical question. Longkou starch noodles, the first export production from Longkou haven, are produced around Zhaoyuan county, Shandong province. Historical sources said that a small quantity of mung bean starch noodles, which packed with bulrush and contained 120 Kg per bundle, was transferred from Zhaoyuan county to Longkou county, and then exported aboard in 1860. Large numbers of starch noodles, produced in Zhaoyuan county, were transported aboard from Longkou haven by shipboard in 1881. Starch noodle is a familiar product and food in Hubei province, Hunan province, Hebei province, Shanghai city, Beijing city, Tianjin city, and so on, around and after 1949 (Zhang & Chi, 2001). Starch noodles, which have been an important part of the Chinese diet from ancientry, like other great Chinese concepts, spread to the surrounding Asian cultures and beyond.

1.4. Categories

Starch noodles can be classified according to different parameters such as the type of raw materials, the size of starch noodle strands, the manufacturing method, producing area and the form of the product on the market. Starch noodles can be classified into mung bean starch noodles and coarse grain starches noodles *according to the type of raw materials used in their manufacture*. Traditionally, mung bean starch is used as a main and excellent ingredient in starch noodle making. Coarse grain starches noodles are made from various legume starches such as broad bean, pea, cowpea, bean, and various tuber or root starches such as potato, sweet potato, cassava, and a variety of grain starches such as maize, wheat, sorghum. But the qualities of mung bean starch noodles are the best. There are three kinds of starch noodles, namely thin starch noodles, thick starch noodles (vermicelli) and flat starch noodles (broad strips), *according to its shape or width*. The thin starch noodle is the most common one for it is easy to cook. There are a great variety of starch noodles *according to the producing areas in China*, such as Zhaoyuan starch noodles, Hankou starch noodles, Hebei starch noodles, Hunan starch noodles, Shanghai starch noodles, Yunnan starch noodles (Zhang & Chi, 2001). Although starch noodles texture and size may vary somewhat from area to area, the styles are still recognizable. Of course, the significant difference comes after cooking.

2. Materials for starch noodles – different starch properties

Starch is a primary material in the production of starch noodles as the main ingredient. Owing to the absence of gluten as compared with wheat flour, physico-chemical, thermal, rheological properties of starch would decide the quality of starch noodle. Meanwhile, the influence of starch functionality on starch noodle quality would be noticed as a result of the retrogradation step included in the manufacturing process (Chang, Lin, & Chen, 2006).

Starches of various legumes such as broad bean, pea, cowpea, bean, and various tuber or root starches such as potato, sweet potato, cassava, and other grains, are competitive with the mung bean starch on a cost basis.

2.1. Mung bean starch

Mung bean (*Vigna radiata* (L.) Wilczek) is native to the northeastern India–Burma (Myanmar) region of Asia (Liu & Shen, 2007). Mung bean starch is the best raw material to produce high quality starch noodles for its high amylose content, restricted swelling during gelatinization and high shear resistance of its paste (Lii & Chang, 1981), and the mung bean starch noodle is, consequently, regarded as the best of all kinds of starch noodles (Kasemsuwan, Bailey, & Jane, 1998; Muhammad, Kusnandar, Hashim, & Rahman, 1999).

2.1.1. Morphological property of mung bean starch

Mung bean starch granules are small, smooth, and either spherical or elliptical. Large granules were kidney-shaped or oval, small granules were spherical, and some of them had internal fissures. It seems that large granules had more internal fissures than small granules (Liu & Shen, 2007). Mung bean starches have polarization cross and obvious concentric circles from electron microscopy. The long axis looked like strands of rope twisted to the right. The granular size of mung bean starch ranged from 6.5 to 43.4 μm (Liu & Shen, 2007; Tan, Tan, Gao, & Gu, 2007). They were 14–15 μm in width, 18–21 μm in length with oblong or kidney-like shapes (Liu & Shen, 2007).

2.1.2. Chemical property of mung bean starch

Excluding ash, the components of mung bean starches from different isolating methods have significant difference (Table 1). Crude protein and lipid contents of mung bean starches isolated by different methods range from 0.07% to 1.34%, 0.05–0.74%, respectively (Liu & Shen, 2007). Amylose contents of mung bean starches range from 30.9% to 34.3%, and are far more than that of sweet potato starch (Tan, Gu, Zhou, Wu, & Xie, 2006). Amylose is the most important factor affecting the starch gel strength because of its prompt association, retrogradation and its interaction with lipids to form helical complex and with amylopectin to give strong gel networks (Jane & Chen, 1992). Any pigmentation in the starch would be carried over to the noodles. This reduces the quality and the acceptability of the noodles (Galvez and Resurrection, 1992). A low value of chroma and a high value of lightness are desired for the starches. Liu and Shen (2007) reported that starch from centrifugation was darker (L∗), greener (a∗), and more yellow (b∗) than starch from sour liquid processing.

2.1.3. Physical property of mung bean starch

The solubility and the swelling power of starch were correlated with the temperature directly. With the temperature increasing, solubility and swelling power increased. The values of solubility and swelling powder of mung bean starch of centrifugation were higher than that from sour liquid processing. The trend curve of viscosity showed the viscosity of mung bean starch is low if temperature is lower than 65 °C. From 65 to 95 °C, the viscosity of mung bean starch of centrifugation increased gradually, but that of sour liquid processing starch increased sharply from 75 to 95 °C and was significantly lower than that of centrifugation at 65–75 °C, while significantly higher if the temperature was over 75 °C (Liu & Shen, 2007). The amylose portion of the starch likewise affected its swelling and hot-paste viscosity. Schoch and Maywald (1968) stated that as the amylose content increased, the swelling tended to be restricted and the hot-paste viscosity tended to be stabilized. Higher amylose contents are desired for the manufacture of starch noodles (Liu & Shen, 2007). The mung bean starch preparations had typical C-type X-ray diffraction patterns. There are diffraction intensity of peak 1 and the intensity difference between peaks 4a and 4b for lactic acid fermentation solution (LFS).

2.1.4. Thermal property of mung bean starch

The profile of mung bean starch measured by RVA was similar to that of type C starches (Fig. 1), i.e., without an apparent pasting peak during cooking and an obvious breakdown of hot paste, obtained by a Brabender Viscoamylograph (Schoch & Maywald, 1968). The LFS-isolated starch had significantly lower values of peak, hot paste and final viscosity than those of other starches. However, no significant difference in pasting properties was found among starches isolated by NaOH, Na_2SO_3 and distilled water (Chang et al., 2006). The pasting properties of starch were considered to be affected by its amylose content and chain-length distribution of amylopectin, a larger proportion of long chains resulting in a lower peak viscosity if the starches had similar amylose contents (Jane et al., 1999). Moreover, the LFS-isolated starch had lower setback than the other starches, which might relate to the lower degree of polymerization of amylose fraction (Jane & Chen, 1992).

The thermal transition profile of LFS-isolated starch exhibited a narrow, mono-modal distribution. The onset (T_o) and peak (T_P) temperatures of pasting of LFS-isolated starch were significantly higher than those of the other starches. Jane et al. (1999) investigated the relationship between chain length of amylopectin and gelatinization properties of starches with different X-ray patterns. They indicated that a higher average chain length of amylopectin or a lower proportion of short chains might contribute to higher gelatinization temperature of starch (Chang et al., 2006).

2.1.5. Molecular structure of mung bean starch

Chang et al. (2006) investigated the molecular structure of mung bean starch isolated from different steeping liquor and indicated that the first fraction (F1) with a shorter retention volume corresponds to mung bean amylopectin, and the second fraction (F2) to the low molecular weight molecules consisting of mung bean amylose and low molecular weight amylopectin. The weight-average molecular weight (M_w) of F1 and F2 fractions among mung bean starches isolated by different steeping liquors were similar and ranged from 7.25 to 8.06×10^7 and $9.09–10.17 \times 10^5$ Da, respectively. The chain-length distribution of mung bean starch isolated using different steeping liquors was observed after debranching by isoamylase. The HPSEC profile was divided into amylose (DF1), and longer B chains (DF2, B2 chains or longer), B1 chains (DF3) and A chains (DF4) of amylopectin (Chang et al., 2006). The weight-average degree of polymerization DPw of DF1, DF2, DF3 and DF4 for the isolated mung bean starches had ranges of 4516–5665, 61.1–63.8, 25.9–27.3 and 12.6–13.5, respectively. The relatively lower values of the weight-percentage of DF4 fraction and S/L ratio for the LFS-isolated starch could be attributed to the degradation of amylopectin and amylose during steeping in lactic acid fermentation solution. The importance of molecular characteristics of starch on noodle quality had been reported by Mestres, Colonna, and Buleon (1988). They illustrated that the amylose and amylopectin macromolecules would reorganize into a new crystalline structure during processing. Furthermore, the extent of retrogradation would depend on the amylopectin structure

Table 1
Chemical composition of mung bean starches from different isolated methods (% dry basis).

Mung bean starch	Moisture	Fat	Protein	Ash	Amylose	Reference
Sour liquid processing	12.93	0.13	1.34	0.15	34.3	Liu and Shen (2007)
Centrifugation	10.74	0.05	0.32	0.12	32.7	Liu and Shen (2007)
Tap water	8.99 ± 0.13	0.74 ± 0.07	0.68 ± 0.08	0.14 ± 0.04	33.7 ± 0.41	Tan (2007)
LFS	–	0.20 ± 0.03	0.08 ± 0.02	–	30.9 ± 0.1	Chang et al. (2006)
NaOH	–	0.16 ± 0.03	0.08 ± 0.01	–	30.9 ± 0.1	Chang et al. (2006)
Na_2SO_3	–	0.19 ± 0.02	0.09 ± 0.00	–	31.0 ± 0.2	Chang et al. (2006)
Distilled water	–	0.19 ± 0.01	0.07 ± 0.02	–	31.1 ± 0.2	Chang et al. (2006)

LFS, LACTIC acid fermentation solution. Many values were expressed as the mean ± standard deviation.

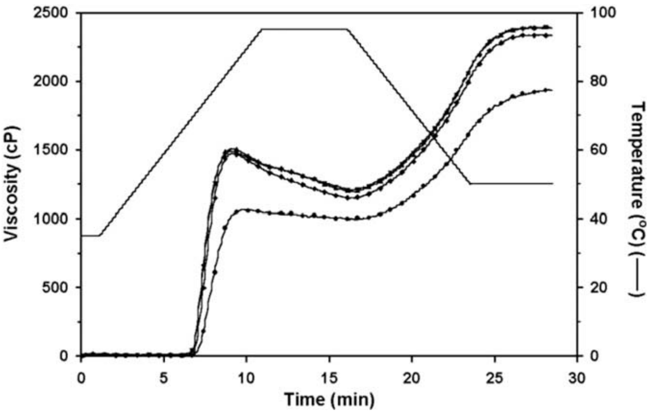

Fig. 1. Pasting profiles of mung bean starches isolated by LFS (●), NaOH (□), Na2SO3 (▲), and distilled water (▼), respectively (Chang et al., 2006).

as the starches shared similar amylose content. Starch with a higher proportion of long chains in its amylopectin fraction tends to have a higher extent of retrogradation (Wang, Wang, & Porter, 2002). Therefore, this may be one of the reasons that the manufacturers of mung bean starch noodle tend to use LFS-isolated mung bean starch. Chang et al. (2006) summarized the results of molecular weight distribution of starch, and indicated that mung bean starch was degraded during isolation with lactic acid fermentation solution. On the other hand, the LFS-isolated starch was found to have relative higher weight percentage of long chains (B2 or longer), lower weight percentage of A chains and lower *S*/*L* ratio than those of starches isolated using other liquors. Furthermore, a narrow and mono-modal gelatinization peak with higher gelatinization temperature was also observed on the LFS-isolated starch.

2.1.6. Rheological property of mung bean starch

Starch noodle is produced from purified starch. The forming and quality of starch dough is crucial to the processing of starch noodles. The drop of starch dough and the formation of filament depend on the rheological properties of the dough itself, especially shear-thinning properties and gravity, which decreases viscosity, increases the fluidity of starch dough and facilitates the dropping of filaments. Tan et al. (2007) investigated the rheological behavior of mung bean starch dough (MBSD) under different conditions, which is essential for the production of starch noodles.

2.1.6.1. Thixotropic flow properties. The shear sensitivity of mung bean starch dough can be estimated from the hysteresis loops of the flow curves (Fig. 2). After two serial sweepings of shear rate over the range from 0 to 500 s^{-1} (Uplink) were carried out, continued by a descending sweep from 500 to 0 s^{-1} (Downlink), MBSDs with different moisture contents, starch paste contents and temperatures, exhibited high thixotropy. The greater is the area between the ascending and descending curves, the more sensitive is the starch dough to mechanical shearing. The flow curve of MBSD exhibited unclosed hysteresis loops with different area and yield stress, indicating the extent of restoration after breakdown in inner structure of starch dough. The structural breakdown process taking place in starch dough during shear was irreversible and the rebuilding of its inner structure of the sheared starch dough during shear was slow or negligible. This demonstrated that the starch dough was non-Newtonian, shear-thinning and thixotropic (Tan et al., 2007). Because hysteresis loop is partly interpret in terms of time dependency at different shear stress levels (Härröd, 1989). Tan et al. (2007) measured the changes of viscosity of mung bean starch doughs with time at various constant shear rates (Fig. 3). The higher the applied shear rate, the larger the rate and extent of viscosity reduction, and the more pronounced time-dependence level the mung bean starch dough.

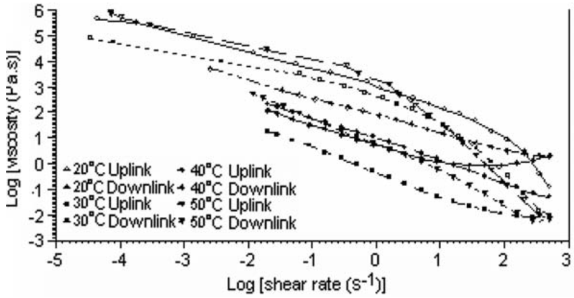

Fig. 2. Variation of viscosity with shear rate of mung bean starch dough under different temperatures (Tan et al., 2007).

2.1.6.2. Modeling of flow behavior for mung bean starch dough. The MBSD showed an initial Newtonian plateau (region where the viscosity remains approximately constant) and a relatively high yield stress. The flow behavior of the MBSD could describe by model-cross model. The values of viscosity at zero-shear rate can predict the yield intensity, which implied the energy required at the beginning of stirring for starch dough and offered some references for the design of stirring equipment, while the values of viscosity at infinite-shear rate can predict the maximum shear-thinning of starch dough, which implied the fluidity of starch dough. A high zero-shear viscosity produced a "damping" effect on shear rate at various locations, as reported by Prakash and Kokini (2000). It is essential to supply sufficient power to overcome these rheological effects and promote stirring efficiently. The starch dough is required a lower η_0 to minimize the energy when the stir begins, and a higher η_∞ to contain starch dough glutinosity for the compactness of starch noodle under durative or infinite stirring (Tan et al., 2007).

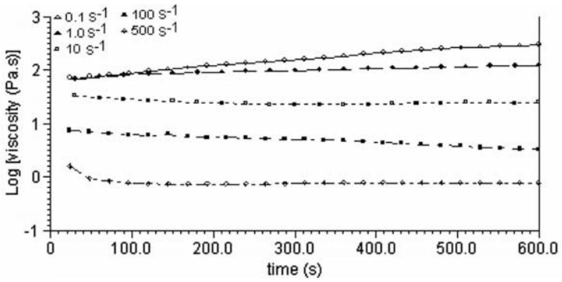

Fig. 3. Variation of viscosity with time of mung bean starch dough under different constant shear rates (Tan et al., 2007).

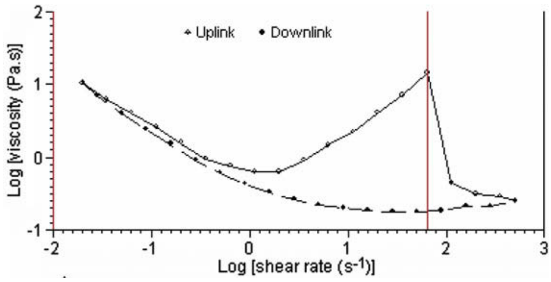

Fig. 4. Variation of viscosity with shear rate of pure mung bean starch slurry without starch paste (Tan et al., 2007).

2.1.6.3. Flow behavior of pure mung bean starch slurry without starch paste. The flow behavior of pure starch slurry (the mixture of starch and water), the main part of starch dough, exhibited a unique rheological behavior (Fig. 4) (Tan et al., 2007). After undergoing a process of shear-thickening, the viscosity of mung bean starch slurry dropped rapidly over 65 s^{-1}. When the shear rate decreased from 500 to 0 s^{-1}, the viscosity of starch slurry ascended slowly and restored to initial viscosity. The flow curve of mung bean starch slurry fitted Herschel–Bulkley model. The starch slurry, which was also a thixotropic fluid, displayed a close hysteresis loop and had only a little yield stress during initial shearing. In the uplink of Fig. 4, it can be seen that the shear-chickening behavior of the starch slurry was preceded by shear-thinning behavior. The critical shear rate (γ_c) was 2.00 s^{-1} at which the flow behavior transformed from shear-thinning to shear-thickening (Christianson & Bagley, 1983).

2.2. Pea starch

Legume starches have occupied an important place in noodle preparation in several countries of the world so many researchers investigated the potential of other legume starches for noodle preparation. Lii and Chang (1981) prepared noodles from red bean (*Phaseolus radiatus var. Aurea*) starch and reported that noodles were of acceptable quality but not as good as mung bean starch noodles. The properties of kidney bean (*Phaseolus vulgaris*) starches, pigeonpea starch, and pea/lentil starch were examined by Yang, Change, and Lii (1980), Singh, Voraputhaporn, Rao, and Jambunathan (1989), Rask (2004) with special reference to noodle preparation, respectively.

Pea is a nutritionally important grain legume of the tropical and subtropical regions of the world. Pea starch is the second excellent material followed by mung bean starch for processing starch noodles. Ratnayake and Hoover (2002) and Rask (2003) provided an overview on the composition, structure and properties of pea starch. There are two different seed phenotypes. They are genetically different so the morphologies and characteristics of the starches are different too (Table 2) (Ratnayake & Hoover, 2002).The physical characteristics of pea amylose and amylopectin are listed in Tables 3 and 4, respectively. Functional properties of pea starch have been described by Ratnayake and Hoover (2002). The swelling factor of smooth pea starch ranges from 4 to 27 at 50–95 °C But wrinkled pea starch has a lower swelling power. Gelatinization parameters for smooth, wrinkled and mutant pea starches are listed in Table 5 (Ratnayake & Hoover, 2002).

2.3. Sweet potato starch

Sweet potato starch noodles are extensively produced in China, where it is estimated that 28% of the processed sweet potato is made into starch noodles. This product is also widely consumed in Korea, Vietnam, and Taiwan (Wang, Song, & Zhang, 1995). Studies on noodles based on sweet potato starch are of interest to many developing and developed countries because it plays a vital role in food production, such as in substitution for expensive mung bean starch. A number of studies on the distinctive properties of sweet potato starch have been undertaken in the last three decade.

2.3.1. Morphological property of sweet potato starch

Sweet potato starch granules may be smooth, oval spherical, oval round, round polygonal or polygonal with different sizes and some of them had internal fissures. Sweet potato starches have polarization cross and obvious concentric hilum from electron microscopy. The size of the starch granule may be estimated by the rate of sedimentation, by using of instrument such as Coulter or microscopic. The sizes of sweet potato starch granules ranged from 2 to 42 μm (Tan et al., 2007). Sweet potato starch granules are of a similar size to those of cassava and maize but are smaller than those of potato which also have a large range of granular size. There is a negative correlation among sweet potato cultivars between particle size and susceptibility to α-amylase and acid degradation (Tian, Rickard, & Blanshard, 1991).

2.3.2. Proximate analysis of sweet potato starch

The protein contents of three sweet potato starches (Chen, Schols, & Voragen, 2003a, 2003b) and seven sweet potato starches

Table 2
Proximate composition and morphology of pea starch (Ratnayake & Hoover, 2002).

Pheno-type	Yield pure starch (%)	Protein content (%)	Ash content (%)	Amylose (%)	Granular shape appearance	Granule size (μm)
Smooth pea	35–40	0.52–0.70	0.01–0.07	24–65	Large and small granules, oval or spherical	Large: 22.9–30.4 mall: 5–20
Wrinkled pea	18–22	0.34–0.46	0.01–0.08	60.5–88	Mixture of simple and compound granules 4–6 associated pieces in a ring formation	~10–40 17–30

Table 3
Physico-chemical characteristics of pea amylose (Ratnayake & Hoover, 2002).

Starch source	Iodine binding capacity	Intrinsic viscosity (η [Ml/g])	Average degree of polymerization (DP$_n$)	Number average molecular weight (M_n)	Weight-average molecular eight (M_w)	β-Amylolysis (%)	Branch points per molecules
Smooth pea	18.8–19.2	180–264	1300–1400	170,000	N/A	81.6–86.9	3.2
Wrinkled pea	17.9–19.2	136–172	1000–1100	125,000	12,88,000	79–85	2–3

Table 4
Physico-chemical characteristics of pea amylopectin (Ratnayake & Hoover, 2002).

Starch source	Iodine affinity	Average ranch chain length	Branch points per molecules	Molecular eight (M_n)	Weight-average degree of polymerization (DP)	β-Amylolysis (%)	Crystallinity (%)	β Polymorph (%)
Smooth pea	1.28	22–24.2	–	80.6 × 106	–	96–97	18.9–36.5	12.0–49.0
Wrinkled pea	5.26	34	8.2	19.4 × 106	6195	98	Not reported	Not reported

Table 5
Gelatinization parameters of wild and mutant pea starches (Ratnayake & Hoover, 2002).

Source	Transition Temperatures (°C)			Enthalpy △H (J/g)
	T_O	T_P	T_c	
Smooth pea	55–61.4	60–67.5	75–80	14.1–22.6
Wrinkled pea	117	133	138	2.9
Pea mutants				
Wild type	–[a]	61.8	–[a]	10.8
r	–[a]	52.5–60.0	–[a]	2.4
rb	–[a]	66.1	–[a]	12.6
rug3	–[a]	70.0	–[a]	7.5
rug4	–[a]	65.4	–[a]	9.8
rug5	–[a]	49.0–57	–[a]	5.1
lam	–[a]	58.6	–[a]	6.8

[a] Not available; temperature of: $T_{O,}$ onset; T_P mid-point T_c conclusion.

(Tan, 2007) in China were 0.17–0.23% and 0.20–0.42%, respectively. They were higher than that of Irish potato starch but lower than that of mung bean starch. The lipid contents of these sweet potato starches were lower than that of mung bean starch. High lipid contents may result in low clarity of the starch paste (as with cereal starches) and repressing starch granule swelling (Kasemsuwan et al., 1998). Sweet potato starch is also similar to cassava starch in its lipid, phosphorus contents and hence the properties (Eliasson, 2004). Like potato starch, the amylose of sweet potato starch contains less phosphate than the amylopectin. High level of phosphate ester groups gives amylopectin of potato starch a slight negative charge, resulting in some coulombic repulsion that may contribute to the rapid swelling of potato starch granules in warm water and to several properties of potato starch pastes like high viscosity, high clarity, and low rate of retrogradation (Bemiller & Whistler, 1996).

2.3.3. Physical property of sweet potato starch

2.3.3.1. Swelling and solubility. Data on the swelling power of sweet potato starch has been compared by Tian et al. (1991) and the values varied considerably not only among varieties, but also at different temperatures. The mean swelling volume of the different genotypes sweet potato starch was 33.0 mL/g, in a fairly narrow range from 30.9 to 35.2 mL/g, while mean solubility was 12.7% (ranged from 10.7% to 14.4%) (Collado & Corke, 1997). The swelling power of mung bean starch at 90 °C was low (10%) while that of sweet potato ranged from 26% to 33% (Tan, 2007). The comparatively lower swelling volume of sweet potato starch has been attributed to a higher degree of intermolecular association compared to cassava or potato starch. Collado and Corke (1999) had examined the swelling volume of starches of a number of Philippine accessions and found the range to be 24.5–32.7 mL/g with a mean value of 29.9 mL/g, showing weaker associative force compared to legume starches. There was no significant correlation between amylose content and swelling volume. The solubility of starch extracted from seven sweet potato collections from Peru indicated that solubility increased with temperature and reached nearly 10%, while for commercial starch, it was 28% (Garcia & Walter, 1998). The authors found that the selection index did not have a noticeable effect, but location had significant influence at about 60 °C. Collado and Corke (1999) found the solubility to be in the range 12–24%.

2.3.3.2. Water-binding capacity (WBC). The water-binding capacity of sweet potato starch ranged from 66.3 to 211.6 as reported by Tian et al. (1991). In general, tuberous starches have higher water-binding capacities than those of cereal origin, and the majority of workers have demonstrated that sweet potato starch has a higher water-binding capacity than potato (93%) and cassava starches (72–92%).

2.3.3.3. Syneresis. Syneresis, in general, is related to "freeze–thaw" stability, and the latter can be used as an indicator for the tendency of starch to retrograde (Eliasson & Kim, 1992). Chen et al. (2003a, 2003b) found that the syneresis values (without a freeze–thaw treatment) of sweet potato starch were lower than that of mung bean starch but higher than that of potato starch. The retrogradation tendency measured by the syneresis of freeze–thaw stability and by the syneresis without freeze–thaw treatment (stored at 2 °C) did not agree with each other. The retrogradation tendency, as measured by setback ratio of paste viscosity at the higher starch concentration, agreed well with the results measured by syneresis without freeze–thaw treatment (Chen et al., 2003a, 2003b).

2.3.3.4. Crystalline structure. Sweet potato starch has a variable X-ray pattern of "A" pattern, "C" or intermediate between "A" and "C" (Eliasson, 2004). Takeda, Tokunaga, Takeda, and Hizukuri (1986) observed "A" pattern for two varieties and "C_A" for another variety. The absolute crystallinity for this starch was 38%. Type A starches tend to have higher levels of crystallinity (33–45%) and higher gelatinization temperature (Tian et al., 1991).

2.3.4. Pasting and gelatinization properties

Some genotypes of sweet potato starch showed a broad peak almost like a plateau, which reflected in P_{time}, and stability ratio (Tan, 2007). While some sweet potato starches have distinct and sharp peak. The average P_{time} was 1.4 min, and the average stability ratio was 0.43. For the sweet potato genotypes evaluated, P_{time} was highly correlated with stability ratio (Collado & Corke, 1997). The average peak viscosity (PV) was 385 RVU, ranged from 331 to 428. PV was significantly negatively correlated with amylose content. The average P_{temp} was 80.4 °C ranged from 78.3 to 84.1 °C (Collado & Corke, 1997). The values of RVA parameters for these sweet potato starches were far lower than those of mung bean starch (Tan, 2007).

Most of researchers have examined the DSC characteristic of 70 sweet potato genotypes from the China and Philippines, and obtained considerable variation in all the parameters (Collado & Corke, 1997, 1999; Tan, 2007). Sweet potato has been reported to gelatinize at 58–90 °C, with a gelatinization enthalpy ranging from 10.0 to 16.3 J/g. The P_{temp} correlated with the T_{end}, but values from the RVA were lower than those from DSC. From Tan's (2007) research results, the gelatinization enthalpy of seven sweet potato starches in China varied significantly from 0.71 to 11.9 J/g. The starch from fresh tubers and freeze-dried sweet potato tubers gave nearly equal values (67–73 °C), but the small granules gelatinized at 75–88 °C (Eliasson, 2004). Sweet potato starch behaves similarly to cassava starch in its viscosity characteristics, viz., peak viscosity, viscosity breakdown and setback viscosity (Eliasson, 2004). Chen et al. (2003a, 2003b) also reported that the gelatinization temperature range of the three sweet potato starches was obviously higher than those of potato starch and mung bean starch.

2.3.5. Molecular structure

Noda, Takahata, Sato, Ikoma, and Mochida (1996) used HPAEC-PAD to research on sweet potato starch and found the amylopectin showed peaks at DP = 12 and DP = 8. The concentrations of the peaks at DP = 6 and DP = 7 were 7.1–7.5% and 6.7–7.0%, respectively. Takeda et al. (1986) found a trimodal pattern for the sweet potato amylopectin while Hizukuri (1969) reported a bimodal distribution. They concluded that sweet potato has a higher proportion of "A" chains and short "B" chains compared to potato. Seog, Park, Nam, Shin, and Kim (1987) reported alkali number values between 7.66 and 12.13 for six Korean sweet potato varieties compared to 5.33 for cassava starch. Tan et al. (2006) studied the structure of sweet potato starch and compared with mung bean starch, as a standard starch for the production of starch noodles. They concluded that the amylopectin in sweet potato (A_p-SP) possessed a molecular weight of 2.23×10^7 Da, corresponding to approximately 137,600 (DP) which was characteristic of hydroglucose residues. The intermediate materials in sweet potato starch (SPS) were present in high yields (approximately 11.0%).

The amylose content of starch isolated from sweet potato roots grown in China, Japan, India, Indonesia, Philippines, Peru, and Ghana, ranged from 8.5% to 37.4% (Collado & Corke, 1997; Tan et al., 2006; Tian et al., 1991; Chen et al., 2003a, 2003b). In general, amylose content of sweet potato was slightly higher than that of cassava but less than that of wheat, maize or potato (Tian et al., 1991). The absolute amylose content in SPS was 28.9%. Both amylose molecules possessed 9.0 chains with chain lengths 226 for amylose in sweet potato (A_m-SP), indicated that the A_m-SP contained a high molar fraction (Tan et al., 2006). Takeda and Hizukuri (1987) also reported that sweet potato amylose was composed of 9.8 chains. Sweet potato amylose appears to have more branches per amylose molecule than that from legume, cassava, potato, wheat or maize. This is one of the reasons of the lower retrogradation tendency of sweet potato amylose. About 70% sweet potato amylose molecules were branched compared with the ratio of 42% in cassava and 27% in wheat (Tian et al., 1991). A_p-MB has longer peak chain length of long-branch chains than A_p-SP (DP 40) compared with DP35 at peak. The resolution of the linear oligosaccharide peak fractions revealed five populations for A_p-SP of chain-length distributions from the amylopectin molecules. A_p-SP contained more short chains than long chains. The chemical analysis indicated that the long chains of A_p-MB (DP40) were longer than those of A_p-SP (DP35), but the short chains of A_p-SP (DP8) were shorter than those of A_p-MB (DP15) (Tan et al., 2006).

2.3.6. Rheological properties

The rheological properties of sweet potato starch extracted by enzymatic process did not vary among the different concentrations of enzyme up to 0.1% (Moorthy & Balagopalan, 1999). Guraya, Toledo, and Kays (1998) reported the apparent viscosity of a large number of sweet potato varieties varied considerably in the range of 71–442 cPs and storage led to reduction in viscosity. The rheological properties of sweet potato starch have been examined using Bohlin rheometer (Garcia & Walter, 1998). During heating, the G' and G'' increased while phase angle decreased which indicated the change from sol to gel. The initial increase has been attributed to progressive swelling of starch granules leading to close packing. When the starch granules became very soft, deformable and compressible, decreases in G' and G'' were observed. The elastic nature prevailed over the viscous nature of the paste. In terms of the summing-up on a number of starch rheology researches from Tian et al. (1991), sweet potato amylose has a limiting viscosity higher than that of wheat but lower than that of cassava or Irish potato amylose.

2.4. Potato starch

Nowadays potato plays an important role in the food industry, especially its starch used to produce starch noodle in China is vary large. Potato starch is often used for its characteristics, which differs significantly other plant starches. Identification of native starch sources is required for desired functionality and unique properties (Singh & Singh, 2001).

2.4.1. Morphological property of potato starch

Starch from different potato varieties differed significantly in granule size and shape. Starch granules ranged from large to small and oval to irregular or cuboidal with diameter ranged in 15–20 μm and 20–45 μm, respectively. The morphology of starch granule depends on the biochemistry of the chloroplast or amyloplast, as well as physiology of the plant (Singh & Singh, 2001).

2.4.2. Physico-chemical characteristics of potato starch

The amylose contents of potato starches ranged from 25.1% to 31.6% (Kaur, Singh, & Sodhi, 2002; Singh, Singh, & Sodhi, 2002). Mealy potatoes have higher amylose contents than waxy potatoes (Kaur et al., 2002). The difference in swelling powers and solubility of different starches may be attributed to the difference in viscosity patterns and weak internal organization resulting from negatively charged phosphate groups within the potato starch granules (Kim, Wiesenborn, Lorenzen, & Berglund, 1996). The difference in morphological structures of granules may also be responsible to the difference of swelling power and solubility of the three starches (Singh & Singh, 2001). The turbidity values of gelatinized starch suspensions from the three potato cultivars differed significantly. The light transmittance values of starch suspensions from potato cultivars decreased while turbidity values increased progressively during storage. The granule swelling, granule remnants, leached amylose and amylopectin, amylose and amylopectin chain lengths have been reported to be responsible for turbidity development in starches during storage. Starches of mealy potato cultivars having larger sized granules showed higher transmittance and lower turbidity values.

2.4.3. Thermal properties of potato starch

The $\triangle H_{gel}$ and T_o value of various potato starches ranged from 12.55 to 13.85 J/g and 59.72 to 60.69 °C, respectively. T_p and T_c of starches of different cultivars ranged from 63.26 to 64.58 °C and 67.28 to 68.35 °C, respectively. Kaur et al. (2002) reported similar ranges of transition temperatures and enthalpies of gelatinization for starches of three potato cultivars. The order-disorder phase transition showed melting of crystals which was illustrated by DSC endotherms, in the range of 50–70 °C, for various native starches. The $\triangle H_{gel}$ reflected the loss of double helical rather than crystalline order. The starch of potato cultivars with smaller starch granules showed lower $\triangle H_{gel}$ and vice versa. Granule shapes, percentage of large and small granules, and presence of phosphate esters have been reported to affect the gelatinization enthalpy values of starches (Singh & Singh, 2001).

2.4.4. Rheological properties of potato starch

The three cultivars studied by Kaur et al. (2002), showed TG′ of 60.1–62.7 °C during the heating cycle, which proved the difference between gelatinization temperatures of these starches. The difference in G', G'' and $\tan\sigma$ during the heating cycle may be attributed to the difference of starch granular structure which in turn depends on their biological origin. The extent of breakdown in G' was measured as the degree of disintegration of starch granules (Singh & Singh, 2001). During cooling of heated starch pastes from 75 to 25 °C, G' and G'' values increased and $\tan\sigma$ value decreased. Higher G', G'' and lower $\tan\sigma$ of potato starch means the formation of more rigid gel structure. Decrease in $\tan\sigma$ values during cooling of starches was reported to be evidence of gel formation (Redy & Seib, 2000).

2.5. Corn starch

Using corn in starch noodle making will be a good trial, but the traditional production experience and the previous study showed that corn starch noodle is not as good as mung bean starch noodle. Yuan, Lu, Cheng, and Li (2008) introduced spontaneous lactic acid fermentation to corn starch to improve the texture of corn starch noodle. Starches of different corn types differ widely with the morphological, rheological, functional and thermal properties (Sandhu, Singh, & Kaur, 2004).

2.5.1. Morphological properties of corn starches

The form of starch granules separated from different corn types range from small to large and oval to polyhedral (Sandhu et al., 2004). Singh, Singh, Kaur, Sodhi, and Gill (2003) reported angular shape of corn starch granules. The figure clearly indicates that diameter of majority of starch granules ranged from 6 to 30 μm with some granules with diameter in the range of 0.4–4 μm (Sandhu et al., 2004). Singh et al. (2003) reported average size of individual corn starch granules in the ranges of 1–7 μm for small and 15–20 μm for large granules. When viewed under scanning electron microscope, the surface of the granules showed the presence of surface pores. Fannon and BeMiller (1992) also observed the presence of pores on the surface of corn, sorghum and millet starch granules.

2.5.2. Physico-chemical characteristics of corn starches

Normal maize starch consists of 75% branched amylopectin; the remaining 25% is linear amylose. Amylose content of starches separated from different corn types ranged from 15.3% to 25.1% (Sandhu et al., 2004). An amylose content of 22.1% in corn starches has been reported earlier by Singh and Singh (2003). Cluskey, Knutson, and Inglett (1980) observed that amylose content of dent corn starch granules, fractionated according to size ranged from 24% for the largest to 22% for the smallest granules. The swelling power and solubility of starches from different corn types ranged from 14.9 to 17.9 g/g and 12.5–20.3%, respectively. Among various pop corn grain fractions, medium grain fraction had highest swelling power and solubility. Lower amylose content-higher swelling power applies only for starches granules obtained from same corn type (Sandhu et al., 2004). The starch granules with higher amylose content, on the other hand, being better reinforced and thus more rigid, probably swells less freely. Water bonding capacity (WBC) of the starches from different corn types ranged from 96% to 107%. The turbidity values of the starch paste from all corn fractions increased progressively during storage (Sandhu et al., 2004). The increase in turbidity during storages was attributed to the interaction between leached amylose and amylopectin chains that led to the development of function zones, which reflect or scatter a significant amount of light (Perera & Hoover, 1999). Turbidity development in starch pastes during storage was reported to be affected by factors such as granule swelling, granule remnants, leached amylose and amylopectin, amylose and amylopectin chain lengths (Jacobson, Obanni, & BeMiller, 1997).

2.5.3. Thermal properties of corn starches

$\triangle H_{gel}$ of corn starches ranged from 8.9 to 10.9 J/g. The lower $\triangle H_{gel}$ of baby corn starch may be attributed to its small granule size and lowest amylose content. T_o, T_p and T_c of starches of different corn types ranged from 66.3 to 69.3 °C, 71.5 to 73.1 °C and 76.5 to 78.0 °C, respectively (Sandhu et al., 2004). Perera, Lu, Sell, and Jane (2001) reported value of T_o for normal corn starches to be 64.4 °C. Highest T_p and T_c of 73.1 and 78.0 °C were observed in starch separated from dent corn long grain fraction. Li, Berke, and Glover (1994) reported values of T_o, T_p and T_c and $\triangle H_{gel}$ among several maize populations in the range of 64.3–69.6 °C, 70.1–73.9 °C, 76.8–79.6 °C and 2–2.9 cal/g, respectively. The gelatinization ranges of $8.7\sim16.4$ °C for starches of five open pollinated corn populations were reported by White, Abbas, Pollak, and Johnson (1990). Starches of dent corn and pop corn both with large grain fraction showed higher T_o, T_p, $\triangle H_{gel}$, PHI and narrower R may have a higher degree of molecular order than starches from other fractions. Similar observations for corn starches have been reported earlier by Krueger, Knutson, Inglett, and Walker (1987).

2.5.4. Rheological properties of corn starches

Sandhu et al. (2004) studied the rheological properties of starches separated from different corn types during heating. The temperature at which G' was maximum ($T_{G'}$) ranged from 73 to 73.7 °C. Peak G' and G'' values of different corn starch gels ranged from 2172 to 5354 and 383 to 920 Pa, respectively (Sandhu et al., 2004). Starch gel from dent corn bold grain fraction had higher $T_{G'}$, peak G' and G'' than starch gel from dent corn long grain fraction. The extent of breakdown in G' is a degree of disintegration of starch granules (Singh et al., 2002). Pop corn with large grain fraction showed maximum breakdown in G', followed by baby corn starch gel whereas it was lowest for pop corn gel with small grain starch. Peak $\tan\sigma$ values of starch gels from all corn types were <1 (Sandhu et al., 2004). The differences in G', G'' and $\tan\sigma$ during the heating cycle may be attributed to the difference in the starch granule structure which in turn depends on their biological origin (Svegmark & Hermansson, 1993). Lii, Tsai, and Tseng (1996) reported that rheological behavior of gelatinized starch suspension was primarily due to intergranular interaction, such as entanglement between surface molecules of adjacent granules and the properties of the granules themselves.

3. Processing technology

The characteristics of starch noodles, unlike wheat based noodles, depends heavily upon the functional properties of the starch as it undergoes one or two heat treatments during processing. The heat treatment may involve boiling or steaming that gelatinizes the starch and the subsequent retrogradation sets the structure of the starch noodles. The processing technology is unique and can be divided into three styles, namely, dropping, extruding and cutting.

3.1. Traditional processing technology

3.1.1. Dropping method

The dropping method is the most traditional one in China. About 5% of starch is cooked in water using a double boiler to prepare starch paste and used as dough binder. The cooked gelatinized starch (starch paste) is then mixed with 95% of starch and water to give 50% moisture content in the dough and then mixed and stirred at the rate of 100 r/min about 10 min using a blender to distribute water evenly and to obtain a smooth ball (starch dough) that does not stick to the hands. The dough was extruded through the holes (diameter about 0.5–1.5 cm) of the stainless steel cylinder by gravity, directly into hot water (98–100 °C), and heated for 30–60 s before transferring into cold water (when noodles floated upon the surface of water then transfer them into cold water). After rinsing in cold water, the strands were drained, subsequently, separated and hung to partially dry, kept at 4 °C for 2 h and −10 °C for overnight, dried at 40 °C in convection dryer, and then packed in polyethylene bags and stored at room temperature (Tan et al., 2006). Fig. 5 describes the procedures used to make traditional mung bean threads.

3.1.1.1. Forming of starch dough. The forming and quality of starch dough is a crucial step in the processing of starch noodles. The drop of starch dough and the formation of filament depend on the rheological properties of the dough itself, especially shear-thinning properties and gravity, which decreases viscosity, increases the fluidity of starch dough and facilitates the dropping of filaments. In addition, process parameters such as the content of moisture and starch paste, stirring rate and temperature in starch dough, are also important. Tan et al. (2007) investigated the rheological behavior of mung bean starch dough (MBSD) under different conditions.

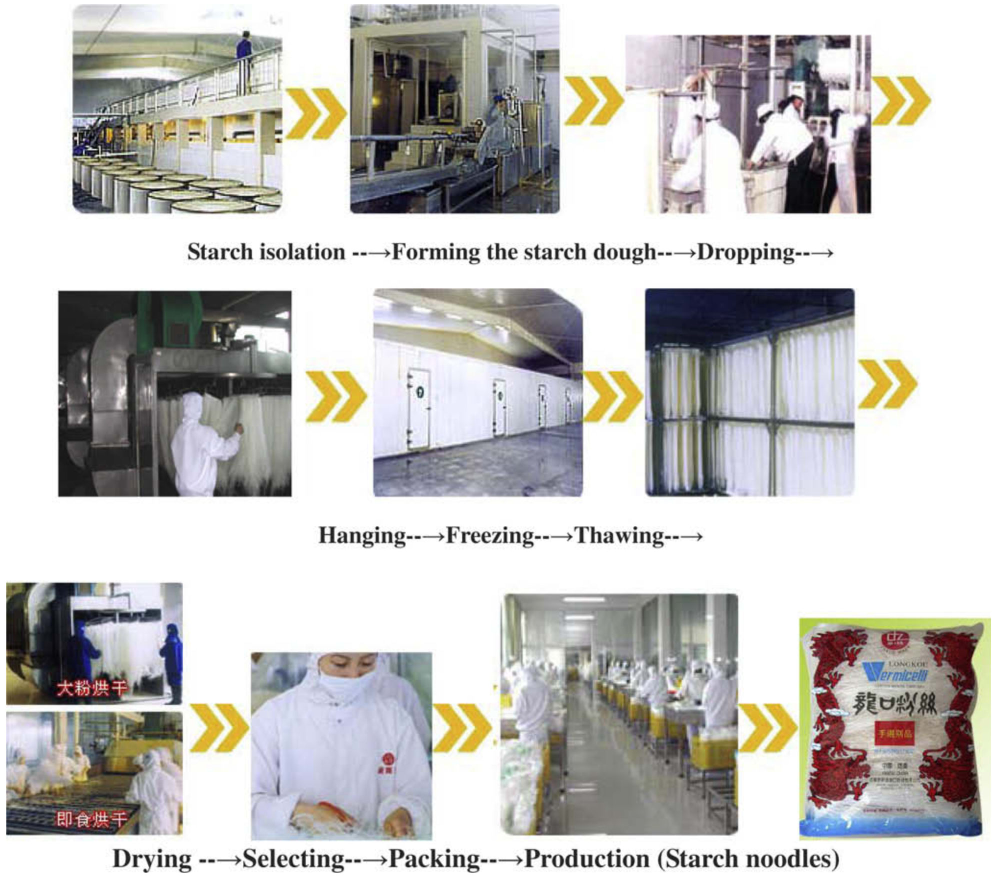

Fig. 5. Production process flow chart of starch noodles in modern manufactory in China (http://www.vermicelli-longkou.com).

MBSD exhibited unique rheological behavior which depended on a wide range of factors such as starch paste content, moisture content, temperature, agitation rate and time. The zero-shear viscosity (the viscosity at zero-shear rate, η_0) of MBSD decreased while the hysteresis loop area reduced with increase of temperature from 20 to 40 °C. However, the MBSD exhibited the highest zero-shear viscosity and the largest hysteresis loop area at 50 °C due to the forthcoming gelatinization of starch which led to a too high viscosity to flow, while those corresponding values at 20 °C and 30 °C were also higher than those at 40 °C. It could be explained that the short-term retrogradation of amylose in starch paste at 20–30 °C induce the difficulty to flow for MBSD. It thus indicated that stirring MBSD at 40 °C was suitable in view of its smallest hysteresis loop area and its lowest zero-shear viscosity, which gave rise to better fluidity (Tan et al., 2007).

Increasing moisture content obviously led to a decrease in the starch dough viscosity, and the hysteresis loop area. The viscosity of starch dough with lower moisture content (41 w/w%) at zero-shear rate reached 1.72E6 Pa·s, then dropped sharply on 7–8 magnitude over the range of shear rate of 0–500 s^{-1}. Under lower moisture content ($\leqslant$41 w/w%), for blender, higher energy was needed to stir starch dough in starch noodle production. However, the hysteresis loop area and zero-shear viscosity dropped markedly when moisture content was 44 w/w%, which was a suitable value for stir and drop. Some broken streams during drop due to high moisture contents (47 w/w% and 50 w/w%) in MBSD, although their hysteresis loop areas and zero-shear viscosities were lower than those of that with moisture content (44 w/w%) (Tan et al., 2007).

The moisture in the final starch dough, which had a statistically significant main effect on all physical properties of the noodles, was considered to be the most important factor that affects all response variables measured, followed by holding temperature and cooking time. Note that the moisture in the starch dough also indicates the amount of total starch which is (100 − %moisture) (Galvez et al., 1994). Noodles with low moisture content (50%) had low cooking loss, high *L*-value (hence, opaque), and high maximum cutting stress and work to cut. Correspondingly, those with higher moisture had higher cooking loss, lower *L*-value or higher transparency, and lower maximum cutting stress and work to cut (Galvez et al., 1994).

A decrease in the content of starch paste obviously decreased the viscosity and the area of hysteresis loop of starch dough. The viscosity of starch dough with 36 w/w% and 50 w/w% of starch paste content dropped sharply from 5 to 6 magnitude and exhibited high zero-shear viscosity values (1.55E5 and 1.93E5 Pa · s, respectively), large areas of hysteresis loops (2.0E4 and 3.3E4 s^{-1} Pa · s, respectively) and low fluidities. If there was no or only small amount (e.g.12 w/w%) of starch paste used in dough, the starch dough would display too large fluidity to form starch noodles in view of lack of glutinosity. Thus MBSD with 24 w/w% starch paste not only exhibited a small hysteresis loop area and a low zero-shear viscosity but also formed streams (Tan et al., 2007).

Mung bean starch dough has the characteristics of highly time-dependence. At fixed shear rates of 100 s^{-1} and 10 s^{-1}, the viscosity of starch dough decreased rapidly with time within the first 120 s and 300 s, respectively, and then approached to a constant value corresponding to an equilibrium state. This moderate time-dependence fitted the mixing of starch dough in the starch noodles processing. While at fixed shear rate of 1.0 s^{-1} and 0.1 s^{-1}, the viscosity did not decrease but slightly increased within 10 min of shear and then did not approach to a constant value. This implied that the mixing of starch dough was time-consuming in processing (Tan et al., 2007).

The MBSD with moisture content of 44 w/w%, starch paste content of 24 w/w%, shear rate of 10 s^{-1} and temperature of 40 °C exhibited a better flow performance to stir and hang during starch noodle production (Tan et al., 2007).

3.1.1.2. Cooking of starch noodles. After obtained a smooth ball (starch dough) that does not stick to the hands, the starch dough is extruded using a dropper into boiling water for 30 s. This course, virtually, is the gelatinization of starch. Noodles are dropped into boiling water and removed after they are sufficiently cooked as they floated up to the surface of the water. This is due to the change in specific gravity of the noodle strand as it is cooked or gelatinized. Uncooked starch granules have a specific gravity of about 1.5, so uncooked noodles settle directly to the bottom of the cooking container, but as they gelatinize, the granules swell as they absorb more water and float (Tam, Corke, Tan, Li, & Collado, 2004).

Cooking temperature is immobile because starch strands drop into boiling water (100 °C or close to 100 °C). Cooking time, therefore, is a variable parameter in the cooking step. Galvez, Resurrection, and Ware (1995) studied the formulation and process optimization of mung bean noodles using response surface methodology. They found that as cooking time increased the region that satisfied the operating specifications drastically decreased in size. This was primarily due to decreased acceptance cores for the texture of cooked noodles as cooking time increased. When the cooking time was 20s, the region of overlap represented a moisture content in the final slurry or dough between 48% and 53% and a holding temperature between 4–12 °C. When the cooking time increased to 30s, the region of overlap represented a very narrow range of moisture content in the final slurry or dough of 48% to 49% and holding temperature of 11–12 °C. When the cooking time was further increased to 40s, there was no region of overlap. No combination of moisture content or holding temperature would satisfy all the required operating specifications (i.e., acceptance scores greater than both commercial samples) (Galvez et al., 1995).

But, if the solid content in the starch noodle is too high, water content in the noodles may become insufficient for starch to fully gelatinize (Lee, Woo, Lim, Kim, & Lim, 2005). The noodles which contained 38–45% solids provided a uniform and translucent appearance. Under polarized microscopy, no starch granules with birefringence were observed, indicating full gelatinization. Therefore, high solubility at high solid content formed insufficient gelatinization with excess presence of starch in the noodle matrix.

Water uptake during cooking was closely related to the texture and cooking qualities of starch noodles (Lee et al., 2005). Insufficient water uptake (swelling) usually results in noodles with hard and coarse texture, but excess water uptake often results in too soft and sticky (Jin M., J., & X., 1994). Takahashi, Hirao, Kobayashi, Kawabata, and Nakamura (1987) determined the degree of gelatinization of mung bean starch noodles during the process of Harusame noodle manufacture and preservation. They found that the degree of gelatinization was 56% immediately after extrusion at 80 °C, 83% after heating in boiling water for 3 min and 74% after direct drying. The degree of gelatinization of mung bean starch noodles at each stage was 5–16% lower than that of noodles made from potato and sweet potato starch mixture (1:1), so they underwent retrogradation easily compared with other starch noodles.

3.1.1.3. Cooling of starch noodles. Cooked starch strands are transferred to cold water and drained. Strands are separated and hung to partially dry, kept at 4 °C for 2 h and −10 °C for overnight. A series of processing steps, theoretically, are the retrogradation of starch during cooling. Starch retrogradation occurred during aging and effectively stabilized the starch chains in the gel matrix. Retrogradation is responsible for stability of the starch noodles and the capacity to withstand boiling temperature. During retrogradation, cooled gelatinized starch reformed to an ordered system. Process such as low-temperature conditioning was applied after the gelatinization of the noodle strands to enhance retrogradation in the production of starch noodles (Tam et al., 2004). These may involve a simple washing in water as in rice noodles, or freezing and thawing treatments as in mung bean starch noodles. Earlier research revealed that amylose crystallization in retrograded B-form kept the structure intact in rice noodles and mung bean starch noodles, which are able to withstand boiling temperatures (Mestres et al., 1988).

In the manufacture of starch noodles, retrogradation is achieved by holding at low temperature (−18 to 5 °C) for a certain period (12–24 h) (Galvez et al., 1994). Lee et al. (2005) studied the effect of processing variables on texture of sweet potato starch noodles. They found that the cooking loss of noodles decreased as aging time increased but increased as the solid content increased. The firmness (or hardness) of starch gel increased linearly with aging time or solid content of noodles. Starch retrogradation rate was highly dependent on the starch content in the gel. Maximum rate of retrogradation was observed at a solid content of 50–55% (Longton & Legrys, 1981). Thus, as the starch solid content in the noodles increased to 45%, the starch retrogradation rate might continuously increase. Lower cooking loss was demonstrated in mung bean noodles kept at a higher holding temperature (Galvez et al., 1994). Among process variables studied by Galvez et al. (1994), holding temperature (cooling temperature) had significant main effect on cooking loss and transparency.

3.1.1.4. Drying of starch noodles. After starch strands were retrograded by cooling, it should be dried at 40 °C in convection dryer, and cooled to room temperature finally before packing. Lee et al. (2005) studied the effect of drying temperature on the quality of starch noodles. They found drying temperature had no significant effects on the cooking loss of noodles. The surface firmness of pasta increased as drying temperature increased (Pavan, 1979). However, Aktan and Khan (1992) reported no significant different in noodle firmness between drying at 40 and 70 °C. Lee et al. (2005) also found that the effect of drying temperature on noodle texture was far less significant than those of solid content and aging time.

There are a number of researchers whom focused on the processing variables of starch noodles. In preparing starch noodles from mung bean and red bean, Lii and Chang (1981) used 5% gelatinized starch, 54% moisture in the final dough, cooking time 10–20 s, holding temperature −10 °C and holding time of 24 h. However, the optimum conditions obtained in Galvez's et al. (1995) study require lower moisture in the final dough or slurry and high holding temperature. In another study, Singh and coworkers (1989) prepared starch noodles from mung bean and pigeonpea with much higher moisture content (1:7 starch:water) and the holding temperature (5 °C). Galvez et al. (1995) indicated that moisture content and cooking time were the most important factors that affected consumer acceptance of mung bean noodles. Products with better quality than commercial samples were obtained when moisture content of final dough was 48–53%, holding temperature 4–12 °C and cooking time 20 s or when moisture content of dough was 48–49%, holding temperature 11–12 °C, and cooking time 30 s when using 5% total starch as gelatinized starch and holding time 36 h. Mung bean noodles processed at optimized conditions had predicted sensory and physical properties of models established by Galvez et al. (1995). Lee et al. (2005) concluded that the starch noodles prepared from slurry of 45% solids, aged for 21 h, and then dried either at 25 °C or 65 °C were most comparable to the commercial starch noodles in textural properties and cooking loss. In conclusion, starch noodles from different materials starches should manufactured from different processing variables.

3.1.2. Cutting method

Cutting method is also a traditional method without freezing (Lee et al., 2005). The most representative product is *Kuzukiri*, a similar type of starch noodles in Japan. Starch slurry is cooked on a steel belt that moved into a steam chamber. Gelatinized starch is then quickly chilled and moved from the belt in a sort of elastic sheet. The starch sheet is subsequently aged in a refrigerator and then cut into thin noodle strands which are then dried in an air oven. This non-freezing process is simple and cost-effective and good for straighter strands producing compared with conventional methods (droping). However, the noodles from this process are often inferior in texture and quality after cooking compared with noodle produced with freezing.

3.2. Modern processing technology

Extrusion cooking has become a popular processing method for starch-based foods and for pre-gelatinized starches. It has also been used for the production of pre-cooked cereal-based blends and pasta products (Li & Vasanthan, 2003). *The extruding method* involves this process for producing starch noodles, which comprises adding 45–55 parts by weight of hot water to 100 parts by weight of starch obtained from at least one member-selected from the group consisting of various starches and a product thereof followed by being mixed to prepare large particles of dough, extruding the dough under degassing at vacuum to produce a dough sheet, gelatinizing the dough sheet with steam, retrograding the gelatinized dough sheet by cooling without freezing; cutting the dough sheet into noodles. Starch noodles can be produced efficiently in simple procedures without preparing starch paste separately and need not special rollers. Further, starch noodles produced in this method are highly transparent and less melted by boiling (US Patent 5916616).

3.2.1. Forming of starch dough

The materials starch is at least one member from potato, sweet potato, tapioca, corn, wheat. Starch dough is first prepared by adding hot water to starch and kneading it. Starch dough is prepared by adding 45–55 parts by weight of hot water to 100 parts by weight of starch under stirring in a mixer. Adding hot water in an amount of less than 45 parts by weight results in small, hard and brittle particles of dough that cannot be formed into a dough sheet by extrusion thorough an extruder. Hot water is preferably at the temperature of not less than 90 °C; otherwise it leads to small, hard and brittle particles of dough that is formed by extrusion into a readily broken dough sheet which will cause inconvenience in the subsequent rolling step (US Patent 5916616).

3.2.2. Extruding

Starch dough prepared is then subjected to extrusion into a dough sheet. The extrusion should be conducted under degassing at degrees of vacuum of not less than 650 Torr or otherwise the dough will not form a firm dough sheet by extrusion owing to voids. Further, there occurs the non-uniform distribution of the water in the dough sheet, and results in lack of uniform transparency in starch noodles. By degassing at degrees of vacuum of not less than 650 Torr, the dough sheet can be made uniform and set firm. Starch dough is preferably passed through the degassing zone for a period of time of not less than 15 s, more preferably 25–45 s, so it can be sufficiently degassed and set firm to give an excellent dough sheet (US Patent 5916616).

3.2.3. Gelatinization and retrogradation of dough sheet

The dough sheet after rolling is then placed in an immersion chamber to add water to it, followed by complete gelatinization with steam in a steamer. Subsequently, it is cooled and retrograded. The dough sheet is cooled, preferably by refrigeration, although suitable cooling means is acceptable if the dough sheet is cooled without being frozen. The specific temperature to which the dough sheet is cooled can vary depending upon the particular dough composition. Generally, the dough sheet is cooled until it reaches a temperature just to 0–10 °C, preferably to about 1–8 °C (US Patent 5916616).

3.2.4. Cutting and drying of starch noodles

Retrograded dough sheet is cut linearly into noodles with a cutting roller. The noodles are dried and cut into suitable length. The noodles are dried to a water content of not more than 14.5% by weight, preferably 10–14.5% by weight, to permit occurrence of mold, while moisture content of less than 10% by weight causes breakage in the starch noodles during transport, which results in a decrease in the value of the product. After immersion step, the dough sheet can be transferred on a conveyer successively subjected to the above steps in series. When the dough sheet of same thickness is processed in the apparatus of same throughput capacity, the wider the dough sheet becomes, the slower the transfer speed of the dough sheet can be made (US Patent 5916616).

There were a number of researchers interested in the extruding method of starch noodles. Takashi, Kobayashi, Kainuma, and Nakamura (1985) stated starch noodles manufactured by extruding as follows: Starch + water → Extrusion (Nozzle diameter 0.9 mm, at 80 °C) → Drying(into starch nooldes) → Heating in boiling water for 3 min → Cooling in cold water → Draining (→Freezing →Thawing) → Drying → Harusame (starch noodles). Li and Vasanthan (2003) also used an extrusion cooker to prepare starch noodles with hypochlorite oxidation of field pea starch. Starch was mixed well with water to 48% moisture and extruded in a co-rotating twin-screw extruder with a 1.0 mm die opening and a screw speed of 40 rpm at 70 °C. Noodles were collected after torque and die pressure reached steady state, and stored at 4 °C for 24 h prior to drying at 40 °C overnight. Li and Vasanthan (2003) thought the noodles extruded at higher temperatures (80 °C) were chalky in appearance due to the presence of small air bubbles in the finished products. Maintaining the mixing chamber and screw under vacuum to remove air trapped in the dough/slurry may minimize this problem. After extrusion cooking, starch noodles were held at 4 °C to accelerate the retrogradation of starch, which would contribute to the development of mouthfeel, texture and flavor. Different with conventional dropping noodle making, extruded noodle making needs not the processes of pre-gelatinized starch, cooking in boiling water, and cooling (in cold water) after extrusion step.

4. Structure of starch noodles

Mung bean starch noodle (MBSN) is favored for its desired appearance and excellent texture. However, other starch noodles produced from sweet potato starch, potato starch, and corn starch and so on, is moderately elastic or dull, opaque, or has high cooking loss and swelling in cooking. Why do these non-mungbean starch noodles have poor cooking quality compared to transparent, glossy and elastic mung bean starch noodle? An understanding of the structure of starch noodle is a prerequisite to undertaking additional efforts to improve the quality of non-mungbean starch noodles. Traditionally, these differences in the quality of starch noodles have been attributed to the content of amylose (Cheng & Shuh, 1981), the ratio of amylose and amylopectin, fat and protein in starch (Kim et al., 1996), and starch granule size (Chen et al. (2003b)). However, chemical structures of starches, including amylose molecular size, chain length, and branched property of amylose and amylopectin may also be different. Mestres et al. (1988) and Xu and Seib (1993) investigated the structure of MBSN by hydrolyzing MBSN with acid and enzymes, and then described MBSN as a ramified three-dimensional network held together by short segments of strongly retrograded amylose that melts at temperatures above the boiling point of water. Tan et al. (2006) investigated elaborately the structure of starch noodles made from mung bean and sweet potato by utilizing the methods used by Mestres et al. (1988) and Xu and Seib (1993), and analyzed the properties of these starches at same time.

4.1. Gel-permeation chromatography of starch noodles

The gel-permeation chromatography of the acid-resistant molecules in MBSN showed two peaks with $\overline{\text{DP}}$ 68 and 49, whereas those in sweet potato starch (SPSN) showed five peaks with $\overline{\text{DP}}$ 68, 55, 49, 41 and 22, respectively; This implied that retrograded amylopectin in SPSN was degraded partly to short chain segments during acid treatment, whereas retrograded amylopectin in MBSN was difficult to degrade to short chains, and retained a large number of long chains. The α-amylase resistant residues in MBSN showed four peaks with $\overline{\text{DP}}$ 57, 50, 43 and 35; whereas those in SPSN showed six peaks at $\overline{\text{DP}}$ 57, 50, 43, 31, 14 and 6. It implied that the population of long chains in SPSN decreased and the fraction with short chains increased during α-amylase treatment. The oligosaccharides with very short chains may be represented by segments of α-amylase-degraded long chains. In MBSN, the long chains were still dominant, which may be due to differences in the arrangement of long chains in the amylopectin clusters compared to that of SPSN. The β-amylase and pullulanase resistant residues in MBSN showed four peaks with $\overline{\text{DP}}$70, 57, 40 and 30, whereas those in SPSN showed seven peaks at $\overline{\text{DP}}$70, 61, 45, 36, 25, 16 and 8; This implies that SPSN was hydrolyzed more rapidly than MBSN because of more A chains (external chain) in Ap-SP than in Ap-MB and the greater ratio of long chains to short chains in MBS than in SPS. The residues from acid and enzymes in MBSN contained mainly high molecular weight fractions which appeared at the void volume, and some low molecular weight fractions such as limit dextrins, indicating the difficulty to hydrolyze MBSN (Tan et al., 2006). Those high molecular weight fractions may be the short amylose chains, generated by the degradation of amylose, which can form double helical again to resist hydrolysis. This phenomenon was analogous with enzyme-resistant retrograded starch, and based on restricted enzyme access to potential substrates arranged in double helical aggregates (Gidley et al., 1995).

4.2. Microscopic observation of starch noodles

The smoother surface of MBSN than SPSN might be due to stronger gel strength and elasticity of MBSN, which can withstand shrinkage better during drying. The inside of MBSN contained long, thick and orderly filaments that may be cellulose-like crystalline areas because a higher amylose content and longer chain length of amylopectin in MBS lead to ease of retrogradation. The leakage of water during cooling generated a compact structure inside MBSN, while there were many pore on the inside of SPSN because higher amylopectin content and shorter chain length of amylopectin lead to less retrogradation and loose inside structure; and the leakage of water after freezing and drying generated many pores on the inside of SPSN (Tan et al., 2006).

4.3. X-ray analysis of starch noodles

For original SPSN, three peaks were observed at 2θ values of 16.3, 22.0 and 27.2 Å, corresponding to d-spacing (inter planar distances) of 5.4, 4.1 and 2.6 Å, respectively. For resistant residues hydrolyzed using a mixture of β-amylase and pullulanase, one peak disappeared and two peaks remained at 2θ values of 17.1 and 21.9 Å, corresponding to d-spacing of 5.2 and 4.1 Å, respectively. The crystallites within enzyme-resistant residues from SPSN were smaller and/or less perfectly packed than in original SPSN because of their weaker retrograded amylopectin state of crystallinity (Tan et al., 2006). The X-ray diffraction pattern of the MBSN gave strong peaks at $2\theta = 17.0$, 23.0 and 22.1 Å, corresponding to d-spacing of 5.2, 4.0 and 3.9 Å, respectively, which can be attributed to different crystalline structures of typical patterns of B-type peak (Mestres et al., 1988) and should be distinguished from that of SPSN. Upon cooking and then hydrolysis with β-amylase and pullulanase, the X-ray diffraction pattern changed and was indicated by three smaller peaks at 2θ of 16.8, 19.4 and 22.0 Å, corresponding to d-spacing of 5.3, 4.6 and 4.0 Å, respectively. This can be attributed to that retrograded amyloses are still partly hydrolyzed by enzymes. Such a description is in line with model studies on amylose gels and enzyme-resistant material from amylose gels which show weak X-ray diffraction (Cairns, Leloup, Miles, Ring, & Morris, 1990). The acid/ enzyme-resistant residues exhibited weaker diffraction peaks than original starch noodles, which showed the presence of poor B-patterns, especially MBSN in our research. This was in agreement with findings of Sievert, Czuchajowska, and Pomeranz (1991). The appearance of broad diffraction lines strongly suggested that smaller and /or less perfect crystallites were present in acid/enzyme-resistant residues than in MBSN, where the sharp, well-resolved pattern reflected higher degree of crystallite perfection. However, generally, crystallinity is a property of the amylopectin fraction (Tan et al., 2006).

4.4. Structure of starch noodles

Mestres et al. (1988) and Xu and Seib (1993), based on their findings of acid and enzyme hydrolysis of uncooked and cooked MBSN at 35 °C, proposed that junction zones anchor the three-dimensional structure. The cause of SPSN loose structure compared to MBSN, allows further speculation based on the three-phase theory (micelle, paracrystalline fringe and filler mass) proposed by Xu and Seib (1993). Tan et al. (2006) conjectured that SPSN has loose structure due to its crystalline inferiority to MBSN. In MBSN, the micelle contains retrograded segments of amylose molecules and is resistant to acid and enzymes (Xu & Seib, 1993). The most highly organized zone containing crystallites is caused by moderate chain length in A_m-MB, in order and in close juxtaposition due to fewer amylose branches comprised 1.8 branch chains per molecule, facilitating chains juxtapose closely. However, much shorter chains in A_m-SP and more amylose branches comprising 9.0 chains per molecule were adverse to ordered and juxtaposed chains. Thus SPSN had less compact micelle than MBSN. The hydrolysis-resistant crystalline zone is considered to be the structural center, a composite of intensity features from ordered (double helical), which is produced by amyloses and long chains in amylopectin, and a small amount of non-ordered (amorphous single chain) materials, which consists of amylose-lipid and lipid-(long chains in amylopectin). Paracrystalline finger composed of less organized material is attached to the micelle. Xu and Seib (1993) argued that the molecules in this zone are all linear; that zone does not swell sufficiently. But our findings provide additional information that the second zone is composed of branched amylopectin, which can form network-like framework due to its cohesiveness. Both amylopectins possess five fractions and different length branched chains, but large amounts of short branched chains in SPS form network-like framework, and decrease the ability for crystallization in SPSN, while large amounts of long branched chains in MBS can crystallize so that this zone is still organized in MBSN. The third, and most prominent zone in the starch noodle is the filler mass or amorphous zone. The filler mass is composed of cracked gelatinized starch granules and their fragments, which exhibit good viscosity and cling tightly to the other two zones. Besides occupying a large volume in a starch noodle, the filler mass would be hydrolyzed by acid and enzymes in SPSN and MBSN. The structure of starch noodles is thus composed of three phases (Tan et al., 2006): hydrolysis-resistant crystalline zone (double helical and amorphous single chain), network-like framework (amylopectin) and filler mass (cracked gelatinized starch granules and their fragments). Because of low content of branched amylose and much high content of amylopectin in SPS, SPSN has low crystallinity and high adhesiveness; whereas there is high content amylose with little branching and moderate amylopectin in MBS, thus, MBSN has high crystallinity, good cohesiveness and excellent quality.

5. Nutrition of starch noodles

Starch is the major component of starch noodle, and it could improve its nutritional value after gelatinized and retrograded, principally by improving in vivo starch digestibility. Many factors affect native starch digestibility. The rate of starch digestion in legumes is lower both in vitro and in vivo, than that of cereals. In vivo, starch is hydrolyzed by salivary and pancreatic α-amylase. However, a proportion of starch in starchy foods generally escapes from digestion. This fraction is called 'resistant starch' (Hoover & Zhou, 2003). Rice noodles were demonstrated to have lower glycemic blood index of diabetic patients (Panlasigui et al., 1990). Starch noodles are retrograded and are, therefore, a source of resistant starch (RS). There is considerable interest in the nutritional implications of RS in foods, since relatively slow rate of starch hydrolysis in the gastrointestinal tract of humans may have some physiological effects of dietary fiber (Englyst, Kingman, & Cummings, 1992).

5.1. Digestibility of starch

Sandhua and Lim (2008) investigated the digestibility of common legumes in India (black gram, chickpea, mung bean, lentil, field pea and pigeon pea) and their structural (amylose content and crystallinity) properties. They found that all legume starches exhibited characteristic C-type diffraction pattern with relative crystallinity ranged from 27.2% to 33.5%. Slowly digestible starch (SDS) contents were list as follow: mung bean > chickpea > field pea > lentil > black gram > pigeon pea, whereas, the resistant starch (RS) contents were in following order: pigeon pea > lentil > black gram > field pea > chickpea > mung bean. The hydrolysis indices (HI) of the legume starches ranged from 8.2 to 20.0, and the estimated glycemic indices (GI) based on HI were between 44.2% and 50.7%. Several significant correlations were observed among different starch properties revealed both by Pearson correlation (PC) and principal component analysis (PCA). Together, the first two PCs represent 86.6% of total variability. Digestibility of starch was negatively correlated with starch granule diameter and M_w of amylopectin and amylose.

Apolonio et al. (2004) studied the regarding starch digestibility of five common bean varieties after cooked. They found that cooking time of different cultivars ranged between 2.55 and 5.92 h. Available starch (AS) values decreased with the storage time and the bean sample with the lowest AS content (control sample, without storage) showed the shortest cooking time. A similar pattern was found for resistant starch (RS); the varieties with the longest cooking time presented the widest range in RS values, measured as the difference between the control sample and the value obtained in the sample stored during 96 h. The retrograded RS (RRS) depended on the variety and even more on the molecular structure of each starch.

Comparatively, the sweet potato starch with glucoamylase was better digestible than some legume and cereal starches. The poor digestibility of the latter, particularly the legume starches, were ascribed to their high amylose contents which were branched and relatively high molecular weight considerably, as well as due to the presence of very highly branched amylopectin and the intermediate fraction (Madhusudhan & Tharanathan, 1996). On the other hand, the high digestibility of cereal (and some tuber) starches could be due to their low amylose values (therefore more of amylopectin) and comparatively less branching and low molecular weight of the constituent fractions. Zhang and Oates (1999) studied the relationship between α-amylase degradation and physico-chemical properties of sweet potato starches. They found that susceptibility to pancreatic α-amylase varied between starches produced by different clones. Structural characteristics at various levels, such as ratio of major fractions, size of amylose, gelatinization temperature and granule morphology, were also different between clones. Correlating structural attributes with susceptibility suggested that granule structures, including amylopectin/amylose ratio and molecular associations were important critical factors in the hydrolysis of sweet potato starch granules.

5.2. Hydrolysis property of gelatinized and retrograded starch

Gelatinization converts starch into physical form that is desirable in many foods including starch noodle. Starch gels are, however, thermodynamically unstable and their technological suitability would be affected by the unstable. Upon cooling, starch molecules reassociate in a complex recrystallization process known as retrogradation, which is often associated with water separation from the gel. These changes may result in textural and visual gel deterioration. Retrogradation is also important from view of nutritional, since most of the resistant starch in processed foods consists of retrograded α-glucans. Tovar, Melito, Herrera, Rascón, and Pérez (2002) investigated the possible relationships between resistant starch formation and other phenomena associated with retrogradation, such as syneresis, by hydrating and gelatinizing starches from three cereals (maize, sorghum and rice), two legumes (jack bean and lentil) and arracacha roots (*Arracacia xanthorrhiza*). Drained gels were stored for 24 h at 4 °C before the analyses. The results indicated that neither apparent amylose contents nor water exclusion values showed clear correlation with RS-III content in the gels. Legume starches reached 6–7% (dmb) RS-III levels, while the lowest values (2–3.6%) were recorded for maize, rice and arracacha samples. Jack bean starch gels showed the greatest syneresis indices, followed by the cereals, arracacha and lentil preparations. Data support the perceived idea of different mechanisms governing syneresis and RS-III formation in gelatinized starches (Tovar et al., 2002). The results summarized by Faulks and Bailey (1990) showed that the extent of hydrolysis of gelatinized legume starches ranged from 70.5% for wrinkled pea to 90.4% for red lentil. However, the extents of hydrolysis of retrograded starch gels were lower than that of their freshly gelatinized counterparts. It was postulated that in gelled starches, there were hierarchy structures with differing susceptibility to amylolysis, and that retrogradation increased the degree of ordering, decreased the extent of hydrolysis.

5.3. Hydrolysis property of starch noodles

Tan et al. (2006) investigated the hydrolysis property of starch noodles from mung bean and sweet potato. The two-stage hydrolysis pattern was quite obvious in cooked MBSN and SPSN. A fast hydrolysis rate during the first 6 days followed by a slower rate between 7 and 20 days for both starch noodles hydrolyzed with 1 M HCl at 35 °C was observed. When both starch noodles were hydrolyzed with α-amylase at 35 °C, they displayed a pattern with considerably fast hydrolysis rate during the first 3 days and slower rate between 4 and 20 days. Another fast hydrolysis rate during the first 12 h followed by a slower rate between 13 and 60 h for both starch noodles hydrolyzed with a mixture of β-amylase and pullulanase at 35 °C was also observed too. Comparatively, the SPSN had higher digestibility with 1 M HCl, α-amylase, β-amylase and pullulanase than those of the MBSN. Lower digestibility of the latter can be attributed to their high amylose contents (~40%), which have relatively high molecular weight and comparatively less branching. On the other hand, the high digestibility of SPSN could be due to their low amylose contents and the presence of very highly branched amylopectin and low molecular weight of the constituent fractions.

Faster hydrolysis pattern corresponds to the hydrolysis of amorphous parts of all starch noodles. During the second stage, the crystalline starch is slowly degraded (Tan et al., 2006). This is analogous to the phenomenon observed with cellulose and a number of semicrystalline synthetic polymers. Hydrolytic action in these materials occurs most rapidly in the disordered regions, whereas the crystalline area is more resistant (Banks & Greenwood, 1975). The slower hydrolysis rate of the crystalline parts of the starch noodles may be due to two reasons. First, the dense packing of starch chains within the crystallites does not readily allow the penetration of HCl and enzymes into these regions. Second, acid hydrolysis of a glucosidic bond may require a change in conformation for the glucose unit, from chair to half-chair (Tan et al., 2006). Obviously, if the hydrolyzed bond exists within a crystallite, this change in conformation would require a high energy of activation. All glucosidic oxygens are buried in the interior of the double helix in starch crystallites and are, therefore, far less accessible to acid or enzyme attack (Biliaderis, Grant, & Vose, 1981).

6. Quality evaluating of starch noodles

Noodles qualities are defined by visual attributes of the uncooked and cooked noodles. The cooking and eating qualities such as absence of discoloration, high glossiness, and high transparency are important considerations of consumers when purchasing dry starch noodles. Fine straight strands, whiteness, translucency, and absence of broken strands contribute to better-priced noodles. In cooked starch noodles, mouthfeel and texture were the most important characteristics. The noodles should remain firm, chewy and not sticky on standing after cooking. Starch noodles should also have a short cooking time with little loss of solid in the cooking water (Galvez & Resurrection, 1992). It was recently demonstrated that starch noodle quality has three distinct aspects: sensory property (appearance of dry starch noodles), cooking property (eating quality) and texture property of cooked starch noodles (Baek, Cha, & Lim, 2001; Chen et al., 2002; Collado & Corke, 1997; Collado et al., 2001; Kaur, Singh, & Singh, 2005; Lee et al., 2005; Muhammad et al., 1999; Tam et al., 2004; Tan, 2007).

6.1. Sensory property

Sensory property is defined as the acceptance of the sensory attributes of a product by consumers who are the regular users of the product category (Galvez & Resurrection, 1992). There are many methods of sensory evaluation of starch noodles. Galvez et al. (1995) used the following method to evaluate the sensory property of starch noodles. Screened to be regular users of mung bean starch noodles, 76 consumers of oriental origin participated in the tests. The tests, designed so that each sample was evaluated by at least 24 consumers, were conducted in two parts: (1) evaluation of dry samples and (2) evaluation of cooking samples. Dry samples were evaluated by consumers for acceptability of appearance. Cooked samples were evaluated for acceptability of appearance and texture/mouthfeel. Dry noodle samples were cut onto strands approximately 6 cm long and presented in coded plastic petri plates arranged on table tops. Participants evaluated 10 samples each. They were allowed to open the petri plates for closer examinations of the samples. Cooked samples were cut into 2–3 cm lengths, and presented in 20-g amounts in coded 1-oz covered plastic cups. Two sets of five samples each from the 26 treatment combinations were presented to participants who were asked to place a spoonful of the sample in their mouths when evaluating for acceptability of texture/mouthfeel.

After freshly cooked noodles were prepared by boiling them in water for 10 min and then cooling them in tap water (about 20 °C), Kasemsuwan et al. (1998) arranged 10 trained panel members to evaluate the firmness, chewiness, clarity, flavor, and general acceptability of starch noodles, using an unstructured 6 in. line-scale. Panelists tasted the noodles under red lights (to mask possible color differences). Noodles were evaluated in sets of five samples per plate and each set was replicated twice; scores of each characteristic were averaged.

Muhammad et al. (1999) arranged 20 trained panelists to evaluate the elasticity, stickiness and taste of cooked noodles. Noodles were cooked in 200 mL of boiling distilled water for 1 min, drained for 30 s, cooled for 2 min, and were served to the panelists in 3–4 g portions. Elasticity of the cooked noodles was judged by stretching them until they broke, and stickiness was evaluated by tasting whether the noodles adhered to the tongue or not. Samples were scored on a five-point scale as follows: elasticity (1 = extremely non-elastic; 5 = extremely elastic), stickiness (1 = extremely sticky; 5 = extremely not sticky) and taste (1 = not acceptable; 5 = highly acceptable).

Among these sensory attributes, transparency was demonstrated to be a very important appearance characteristic of dry or uncooked mung bean noodles which affect their marketability (Galvez, 1992). Transparent noodles are perceived as high-quality products by consumers. Very low values for maximum cutting stress and work are not desirable. These two physical attributes have a significant positive correlation with sensory mouthfeel attributes of hardness or firmness. Sensory mouthfeel attributes of hardness or firmness have a significant positive correlation with maximum cutting stress and work. A specific range of hardness is required in mung bean noodles (Galvez et al., 1994).

6.2. Cooking property

In cooking stage, small parts of starch noodles will be separated from the noodle itself and suspended in the water. The noodle becomes weaker and less slippery while the cooking water becomes cloudy and thick. This is usually quantitatively described by the term "cooking loss" (Chen et al., 2002). During cooking or keeping in water the starch noodles will also absorb water constantly and the starch noodle will become swollen. This is normally quantified by "swelling index" or "cooked weight".

The *cooking loss* and *cooked weight* of starch noodles were measured by the following method. Noodles (5 g) were cut into 3–5 cm lengths and cooked in 200 mL of boiling distilled water for 1 min more than the optimum cooking time. The optimum cooking time was determined by crushing cooked noodles between a pair of glass plates until the white hard core in the noodles strand disappeared. The cooked noodles were then filtered through a nylon screen, rinsed with distilled water, and drained for 5 min. Cooking loss (CL) was determined by evaporating the combined cooking water and rinse water to dryness at 110 °C and expressed as the percentage of solid loss during cooking. Cooked weight (CW) was calculated as a percentage of dry cooked noodle weight prior to cooking (Li & Vasanthan, 2003).

There was another method of cooking test from Mestres et al. (1988). Spring water (150 mL) was heated under reflux in a 250 mL beaker. When the water was boiling, 5 g cut noodles (2 cm long) were added. Optimum cooking time was determined with crushing test. Cooking continued 1 min more than the optimum cooking time. The sample was then drained for 5 min and rapidly weight (W1, g). Cooked product was predried in an IR oven and dried in an oven at 130 °C to constant weight (W2, g). Cooking water was centrifuged (7500 × g) for 10 min. Then dry matter contents of the sediment and supernatant (W3, g and W4, g, respectively) were determined as reported previously. Total cooking losses, which include solid losses and soluble losses, were calculated with the following equations (DM = dry matter ratio of crude samples):

$$\text{Total cooking loss (TCL, \%)} = (5 \times \text{DM} - \text{W2}) \times 100/(5 \times \text{DM}) \tag{1}$$

$$\text{Solid loss (SL1, \%)} = \text{W3} \times 100/5 \times \text{DM} \tag{2}$$

$$\text{Soluble loss (SL2, \%)} = \text{W4} \times 100/5 \times \text{DM} \tag{3}$$

Swelling index after cooking was calculated by the equation:

$$\text{Swelling index (SI, \%)} = (\text{W1} - \text{W2}) \times 100/\text{W2} \tag{4}$$

Cooking loss is a measure of cooking quality of noodles. This may be considered a measure of resistance of the noodles to disintegration upon prolonged boiling. Low cooking loss is desirable as possible. The Chinese Agriculture Trade Standards for starch noodles set ⩽10% solid loss during cooking as accepted (NY 5188-2002). The Thai Standards for transparent noodles, however, state that solid loss during cooking should be ⩽9% (Sisawad & Chatket, 1989). Galvez et al. (1994) considered a cooking loss of 10% or less as acceptable. In general, the cooking loss of mung bean starch noodle is the lowest among various pure starch noodles. The swelling indexes of starch noodles from sweet potato, potato, or corn, were higher than that of mung bean starch noodle, which showed a more favorable behavior. Mung bean starch noodle absorbed water slowly in the first 0.5 h but rapidly during the period of 0.5–1 h. Cooking loss and swelling index are affected by recrystallization of the starch which also influences starch gel properties. The high firmness of the starch gel can predict low swelling index of the starch noodle (Chen et al., 2002).

6.3. Texture property

There are many attributes to reflect the texture property of starch noodle, such as cohesiveness, adhesiveness, extension, cutting behavior (hardness, firmness), and strength. The cohesiveness, extension and cutting behavior are important attributes which can directly reflect the characteristic of starch noodles.

6.3.1. Cohesiveness of starch noodles

The cohesiveness of starch noodles was determined by attaching two noodle strands to each other and pulling them apart using a texture analyzer. The test speed was 1.00 mm/s and 5 kg force transducer was used usually. Stickiness is another important factor in starch noodle production influencing the quality of the final product. Fresh mung bean starch noodles are known to have low degree of stickiness and are easy to separate from each other during the drying process. Noodles made from other starches, including sweet potato starch, potato starch and cassava starch, are easy to stick strongly to each other, thus causing some difficult to separate during drying. Therefore, the cohesiveness of starch noodles at various stages of the preparation process may not only provide information on the separation ability, but also exhibit the effects of treatments such as freezing (Chen et al., 2002). Cohesiveness is an indicator of the extent of disruption of the noodle structure during first compression and is the ratio of the peak areas of first and second compressions of the fore-time plot in the Texture Profile Analysis (TPA) (Singh et al., 2002). Strictly speaking, measuring the stickiness is not the cohesiveness between starch noodles, but the adhesiveness between the instrument probe and the starch noodles (Chen et al., 2002). The cohesiveness of the sweet potato starch noodles decreased significantly by freezing treatment. This confirmed that freezing is an important step in starch noodle manufacture. Better separation of the noodles at this stage is not only due to the ice-crystal formation between the starch noodle strands but also due to cohesiveness reduction of the starch noodle strands themselves. The cohesiveness of the cooked starch noodle not only affects the cooking property but also affects the mouthfeel of the starch noodle, such as slipperiness.

6.3.2. Extension of starch noodles

The extension of dried and cooked starch noodles (a single strand) was measured by using 25 kg and 5 kg force transducers, respectively, using the texture analyzer. The extension modulus (E) and the relative extension (r_e) were calculated from the following equations: $E = (F/\triangle L)(L/A)$ and $r_e = \triangle L/L$. Here F is the extension force, and A is the cross-sectional area of the starch noodle. $\triangle L$ is the increased length, while L is the original length of starch noodle. The test speed was 1.00 mm/s. The extension modulus (E) represents the stretch firmness of starch noodles, while the relative extension (r_e) of the noodle strand is a measure for the stretchability of the starch noodle. The stretch firmness of the dried mung bean starch noodle, in general, is higher than that of other starch noodles. No clear correlation was found for the stretch firmness and stretchability between dried and cooked starch noodles (Chen et al., 2002).

6.3.3. Cutting behavior of starch noodles

Cutting behavior was measured using a 0.3-mm-dia wire cutting probe to cut a single noodle strand, stabilized on the platform at two sides. Force transducers of 25 kg and 5 kg were used for dried and cooked starch noodle measurements, respectively (Chen et al., 2002). The cutting behavior is usually measured by using a cutting probe to cut the noodle strands placed on a metal platform. Chen et al. (2002) found it was difficult for the cutting probe to cut the noodle strands completely without touching with platform. Thus, the platform also gave a force to the cutting probe, which made it rather difficult to measure values for the real cutting force of noodle strands. The cutting force (F_c) and the increased length ratio (r_c) of dried noodles is a measure of the cutting firmness and the flexibility. For the cooked noodles, the cutting force (F_c) exhibits the firmness which mimics the bite behavior during consumption. The firmness and flexibility of mung bean starch noodle is higher than that of sweet potato, potato and corn starch noodles.

6.4. Correlation between the physical properties of starch and the sensory, cooking and texture property of starch noodles

The characteristics of both dried and cooked starch noodles are affected by the properties of the original starch. However, no significant correlation of either the preference or the attributes (color, transparency, and glossiness) between the dried and cooked starch noodles was found according to Chen et al. (2002). The color, transparency, and glossiness are attributes that play important roles in the appearance of both dried and cooked starch noodles. However, no statistically significant correlation was found between the color, transparency, and glossiness of starch noodles evaluated by the sensory panel, and their starch color and paste clarity. The transparency of starch noodle is not affected by the degree of starch retrogradation.

Since no correlation was found between the noodle quality and the physico-chemical properties, the starch gel properties appear to be more suitable for predicting final noodle quality. High firmness and elasticity of the starch gel also can predict high stretch and bite firmness of the cooked starch noodles. Cooking loss was significantly correlated with cohesiveness, while swelling index was significantly correlated with stretch firm and bite firmness of the cooked starch noodles. Comparing sensory evaluation results with texture analysis results, only a significant correlation between flexibility and preference of sensory evaluation and the cutting force of the dried starch noodles, and significant correlation between sensory chewiness and instrumental cohesiveness of the cooked starch noodles, were found. The attempt to use instrumental results to objectively quantify sensory attributes for foods is not easy. For the time being, both methods of sensory (subjective) evaluation and instrumental (objective) measurement are necessary and important (Chen et al., 2002).

6.5. Correlation between the quality and processing variables of starch noodles

The texture properties of starch noodles were affected by processing variables. Chewiness, gumminess, and hardness, as determined by texture analyzer, were positively related to solid content and aging time. However, drying temperature (25–60 °C) exerted no significant effects on the textural properties of cooked noodles. The elasticity, measured by sensory analysis, positively correlated with solid content and was the highest after 12 h of aging. It was assumed that moisture loss occurred on the noodle surface during aging for an extensive period and caused the decrease in elasticity. The stickiness of surface of the noodles, as measured by sensory analysis, correlated negatively with aging time and drying temperature. While elasticity increased consistently as the solid content increased, stickiness of cooked noodles was the lowest with the solid content of 41%. Excess solid in the noodles included greater starch leaching and thus the noodle surface became stickier. Surface stickiness exhibited positive correlation with solubility. None of processing variables (aging time, solid content, and drying temperature) exerted significant effects on the water uptake of starch noodles (Lee et al., 2005).

6.6. Prediction of the quality of starch noodles

Viscoamylograph pasting profiles of starches are used in the evaluation of suitability for starch noodles. It was suggested that the ideal starch base is one with type C viscoamylograph pasting profile characterized by absence of peak viscosity and one remains constant or even increases during continued heating and shearing, indicative of good hot-paste stability and high cold paste viscosities, such as those generally observed in legume starches. Collado and Corke (1997) claimed that RVA viscoamylography proved to be a sensitive method for monitoring quality of starch for sweet potato starch noodle production. Type C starches show restricted swelling and behave like chemically cross-linked starches (Schoch & Maywald, 1968). This pasting pattern can be observed in legume starches such as lima bean, lentils, garbanzos, yellow peas, and navy bean, chick peas, filed bean, azudki bean, pigeonpea, pinto, navy bean, and mung bean (Collado & Corke, 1997). A type C pasting profile of starch was also observed in some genotypes of potato (Red Pontiac and Mainechip) with stability ratio of 0.95–1.00 (Wiesenborn, Orr, Casper, & Tacke, 1994). The starch noodle produced from these was comparable to the quality of noodle produced from mung bean starch (Kim et al., 1996). Legume starch noodles such as mung bean noodles are known for desirable qualities of greater clarity, glossiness, and high tensile strength as compared with the other tuber and cereal starch substrates (Tam et al., 2004).

Amylose has been indicated as the component of starch that enables it to maintain the integrity of starch noodles. In order to illuminate the contribution of amylose in the production of starch noodles, Tam et al. (2004) used maize starches extracted from selected maize cultivars with 0.2–60.8% amylose contents to produce *bihon*-type noodles. The results indicated that the normal maize starches with amylose content of ≈28% were successfully used for *bihon*-type noodle production, but wax maize starch with 0.2–3.8% amylose content failed to produce *bihon*-type noodles. High-amylose maize starches (>40% amylose) cannot also be used because they do not sufficiently gelatinize at 100 °C under normal atmospheric pressure. Without gelatinization, the amylose molecules are not released to participate in the retrogradation process that sets the noodle structure. Because amylose content was very highly but negatively correlated to peak viscosity and peak time of RVA pasting profile, as well as the swelling volume of maize starch, these parameters may be used to indicate whether amylose content of maize starch are at a suitable level for *bihon*-type noodles (Tam et al., 2004).

However, Chen et al. (2003b) investigated the chemical compositions, physical properties and suitability for starch noodle making of different granule size fractions of potato and sweet potato starches. They found that the ash content, amylose content, phosphorus content, gel firmness, and freeze–thaw stability of small-size granule factions (<20 μm) were significantly different from those of the large-size granule fractions. The processibility and the qualities evaluated by objective and subjective methods of both dried and cooked starch noodles made from small-size granule fractions were significantly better than those made from their initial starch and much better than those made from large-size granule fractions. Their findings showed that a simple fractionation method on starch granule size is sufficient for starch noodle preparation, whereas sweet potato starches performed better with decreasing of granule size. Granule size dimension plays a very important role in starch noodle making and noodle quality. High amylose content and C-type of viscoamlygram-pasting profile of starches are not necessary for starch noodles making, although several earlier publications stressed that these are necessities for starch noodle preparation. Starch gel firmness showed a significant correlation with starch noodle quality. Noodles made from small-size granule fractions (<20 μm) had better processibility (fluidity of starch dough for noodle making) and better quality, which may be attributed to their large specific surface area of granules (Chen et al., 2003a, 2003b).

Surprisingly it has now been found that selected small granular starch is very suited for the preparation of translucent foods (Semeijn & Schols, 2004). For example, with small granular potato starch, in spite of non-“C”- type gelatinization, a glass noodle can be prepared with satisfactory clarity and translucency in the dried state, which was said to be impossible using non-modified potato starch. Accordingly, the invention (US patent 4871, 572) relates to a translucent food prepared from granular starch having preferably 90% of the granules are smaller than 20 μm. As is illustrated in the appended examples, small granular starch imparts superior dough rheological properties, clarity and elasticity to translucent foods. Translucent food products based on small granular starch according to the invention (Semeijn et al., 2004) have furthermore excellent organoleptic characteristics. In addition, the use of small granular starch lowers cooking loss. Besides potato starch and other starches such as sweet potato starch, banana starch, kanna starch, kidney bean starch, red bean starch, tapioca starch, maize starch, wheat starch and various bean starches can be used. It is further possible to use starches with varying amylose contents (0–90%), as long as they are treated in such a way as to fulfill the criteria about granule weight average and size (Semeijn et al., 2004).

6.7. The quality standards for starch noodles in China

There is a standard named "the Chinese Agriculture Trade Standard for Starch Noodles", (NY 5188-2002), which suitable for starch noodles from mung bean, pea, broad bean and other legumes (Tables 6 and 7). There is a Chinese National Standard for Starch Noodles too, namely "Product of designations of origin or geographical indication – Longkou vermicelli" (GB 19048-2003), which suited to starch noodles from mung bean and pea made in the area of Longkou (Tables 8 and 9). There is another Chinese National Standard for Starch Noodles, namely "Product of designations of origin or geographical indication – Lu long vermicelli" (GB 19852-2005), which suitable for starch noodles from sweet potato made in the area of Lu Long (Tables 10 and 11).

Table 6
Sensory attributes of starch noodles in China (NY 5188-2002).

Terms	Request
Color	White and shine, or owing themselves color
Odor and flavor	Owing corresponding smell and flavor with mung bean, pea, broad bean, and other legumes starch. Without peculiar smell.
Configuration	Uniformity, not stick to each other, no break strands, tender, and stretchy, semi-transparency
Impurity	No eyeable impurity from outside

Table 7
Physicochemical attributes of starch noodles in China (NY 5188-2002).

No.	Terms	Request
1	Moisture (%)	⩽15
2	Starch (%)	⩾75
3	Soluble substances after dried (%)	⩽10

Table 8
Sensory attributes of Longkou vermicelli in China (GB 19048-2003).

Terms	Request
Color	White, shine, semi-transparency
Shape	Uniformity, not stick to each other
Handle	Flexible, stretchy.
Mouthfeel	Tender, gliding, and stretchy after cooking
Impurity	No impurity

Table 9
Physicochemical attributes of Longkou vermicelli in China (GB 19048-2003).

Terms	Request
Starch (%)	⩾75.0
Moisture (%)	⩽15.0
Diameter of strand (mm)	⩽0.7
Rate of rupture (%)	⩽10.0
SO_2 (mg/kg)	⩽30.0
Ash (%)	0.5

Table 10
Sensory attributes of Lu Long vermicelli in China (GB 19852-2005).

Terms	Request
Color	Nature, shine, semi-transparency
Shape	Uniformity, not stick to each other
Mouthfeel	Tender, gliding, stretchy and no peculiar smell after cooking
Impurity	No eyeable impurity

Table 11
Physicochemical attributes of Lu Long vermicelli (GB 19852-2005).

Terms	Request
Starch (%)	⩾75.0
Moisture (%)	13.0–17.0
Rate of rupture (%)	⩽10.0
Ash (%)	⩽0.9

7. Quality improving method of non-mung bean starch noodles

Glass noodles are translucent both before and after cooking, are resilient after cooking, and have bland taste. Mung bean starch provides unique properties for this application and is the ideal material for noodle manufacture. In recent years, the demand of starch noodle is gradually increasing in China and abroad, and the limited output of mung bean cannot meet the needs. Furthermore, mung bean starch is much more expensive than other starches. So looking for other materials substitute mung bean totally or partly will be valuable. The utilization of different substrates for starch noodles includes other legumes, tuber and tuber-legumes starch blends. Some well known starches include pea starch, broad bean starch, sweet potato starch, potato starch, corn starch, and so on, but the qualities of noodle based on these starches are generally inferior to that of noodles based on mung bean starch. Proposals to use leguminose starches have been published, but the availability is much limited. Another frequently described possibility is a partial or complete replacement of mung bean or sweet potato starch by chemical or genetically modified starches, particular that derived from tapioca and potato (Semeijn et al., 2004).

7.1. Using other materials to substitute totally or partly mung bean starch (starch noodles from various sources)

7.1.1. Noodles made from red bean starch

Lii and Chang (1981) investigated the quality of red bean starch noodles and compared with mung bean starch noodles. The results indicated that solid loss was higher for red bean starch noodles and even higher than that of noodles prepared from mixture of red bean and mung bean starches (1:1). However, the 5.77% solid loss was still far below the acceptable 10% level set by the Chinese Agriculture Trade Standard for Starch Noodles (NY 5188-2002). The tensile strengths of the noodles decreased in following order: mung bean, mixture of red bean and mung bean (1:1), and red bean. Lower content of linear fractions in red bean starch may cause less retrogradation of the starch in the noodle. Organoleptic evaluation indicated that noodles made from mung bean, and mixed bean starches had the similar scores based on texture. Red bean starch noodles were slightly softer in texture, but gave fairly good quality, although not as good as mung bean starch noodles.

7.1.2. Noodles made from pigeonpea starch

Singh et al. (1989) investigated the quality of pigeonpea starch noodles and compared with that of mung bean starch noodles. Sensory properties such as color, texture, clarity, and general acceptability, were evaluated. Starch extracted from whole seed and dhal samples of both legumes showed noticeable differences in noodle qualities. The whole-seed starch isolated from pigeonpea produced noodles with poor to fair quality, with an average score of 1.9 on general acceptability, whereas the noodles of whole-seed starches of mung bean were rated as fair to good with an average score of 2.8. The scores on noodle clarity and color from whole-seed starch of pigeonpea were lower than those of the mung bean. The scores on noodle clarity and color from whole-seed starch of pigeonpea were lower than those of the mung bean. Dhal starch of pigeonpea produced noodles with better quality than mung bean, as revealed by various sensory properties and noodle color. On the other hand, some starch bound pigments might have been extracted in the case of mung bean dhal starch. No marked differences were observed in the quality of hard noodle of mung bean and pigeonpea dhal starches. These results indicated that in the case of whole-seed starch, noodle quality was better from mung bean than that from pigeonpea, except for texture, for dhal starch. Quality of hard noodle made from dhal starch of pigeonpea or mung bean was comparable. Starch from pigeonpea dhal was as good for noodle preparation as that from mung bean dhal or even better. It was apparent that pigeonpea could be used as a potential starch source for making transparent noodles.

7.1.3. Noodles made from edible canna starch

The overwhelming portion of edible canna starch production in Vietnam is processed into transparent starch noodles, a luxury food of south-east Asia and traditionally made of costly mung bean starch. Good cellophane noodles are about 1 mm thick; display high tensile strength and good transparency. Dry matter loss during prolonged cooking is less than 10%. Starch noodles of non-canna origin are usually produced through extrusion cooking, which requires extruded noodles to pass through a cooling water bath. By contrast, canna noodles are manufactured by different process involving the steam-sheeting of starch/water dough. Gel sheets are stretched and semi-dried on bamboo frames. The gel sheets are then folded and cut into straight noodles. They are finally dried to a moisture content of about 18–21% (Hermann, 1996).

Canna noodles in Vietnam have excellent eating quality, much superior to extrusion noodles made experimentally from sweet potato and cassava starches which are widely available in Southeast Asia. Special but yet poorly understood functional properties of canna starch make it replaced expensive mung bean starch totally as the raw material for cellophane noodles in Vietnam. The high amylose contents (25–30%) of canna starch compared with other root starches explained high peak viscosity observed during gelatinization, which permitted the sheets to be handled easily. Canna starch also displays high gel retrogradation (recrystallization) and transparency which is critical to noodle quality. Canna processing in Vietnam provides employment of many thousands of people in rural communities with as little as 500 m^2 of arable land per capita. Canna use in Vietnam shows how product development can provide new perspectives for crop utilization and stimulate demand for otherwise obsolete crops (Hermann, 1996).

7.1.4. Noodles made from pea/lentil starch

Rask (2004) evaluated the Canadian pea/lentil starch extraction and noodle preparation. Starch noodles using the isolated legume starches from four varieties of peas and lentils were successfully manufactured in their laboratory scale. The optimum processing parameters were: moisture content of dough less than 50%, 40 s cooking and 2 h cooling at 6 °C. Sensory evaluation of focus group with Asian background should be carried out to get comparative evaluations of starch noodles made with mung bean starch and legume starches. Starch noodles made from legume starches have good sensory properties that are superior or the same compared to the starch noodles made from mung bean starch. Starch isolated from peas and lentils would be very competitive with the mung bean starch on a cost basis. If isolated starches are suitable for the manufacture of starch noodles, a new market for Canadian legumes could be realized (Rask, 2004).

7.1.5. Noodles made from mixed potato and mung bean starch

Potato starch plays a very important role in the production of another type of oriental noodle—glass noodles. Many noodle manufacturers made starch themselves, but the problem of fiber and protein disposal are difficult to solve. Using potato starch in place of part of the mung bean starch lessened this disposal problem. The quality of glass noodles can be kept even using potato starch as high as 80%. Mung bean starch and water are made into a slurry and cooked. Then water is added to cool the slurry down below the gelatinization temperature of potato starch. Potato starch is added and the mixture is kneaded to form dough. Noodles are extruded, and then cooked to gelatinize the starch. The moist noodles are held at −12 °C for 12–24 h. Bundles of noodles are hung up to air dry. At present it is still necessary to use 20% mung bean starch to keep texture and transparency but researches are underway to develop glass noodles of 100% potato starch (Labell, 1990).

7.1.6. Noodles made from potato starch

Kim et al. (1996) prepared starch noodles from two types of bean (navy and pinto) and three sources of potato starch (ND651-9, Mainechip, and commercial potato starch). Physicochemical properties of those starches and cooking quality parameters and sensory characteristics of the noodles were investigated. Potato starches contained significantly less amylose and more phosphorus compared to bean starches. Amylograph pasting properties showed lower pasting temperature and peak viscosity for potato starches than for bean starches, but the latter showed higher shear stability. Swelling and solubility of potato starches were significantly higher than those of bean starches. Noodles made from bean starches had similar cooking quality with commercial starch noodles in cooking loss and cooked weight. Texture profile analysis (TPA) results showed starch noodles made from dean starch had high hardness values, but lower cohesiveness values compared to those of potato starches. Sensory panelists scored noodles made from potato starches higher in transparency than those made from bean starches. Both transparency and overall acceptability by sensory evaluation were significantly correlated with cohesiveness of TPA. With respect to texture characteristics of starch noodles, potato starches were more suitable than navy and pinto bean to prepare starch noodles.

7.1.7. Noodles made from corn starch

Singh et al. (2002) analyzed the quality of corn starch noodle and compared with potato starch noodle. They found that the cooked weight of noodle made from corn starch was lower than that of potato starch. Noodles made from starches with higher swelling power exhibited higher cooked weight and *vice versa.* Corn starch noodle had lower cooking loss than that of potato starch noodle. The lower cooking loss might be due to the presence of lipids, high gelatinization temperature and stable granular structure of corn starch. The noodle made from corn starch had lower value of hardness and cohesiveness than that of potato starch. The insufficient release of amylose due to strong internal bonds may lower cohesiveness of noodle made from corn starch. The contribution of lower solubility and swelling power to decrease the cohesiveness of corn starch noodles cannot be ruled out. In conclusion, corn starch is not suitable for the production of noodle compared with potato starch.

7.1.8. Noodles made from sweet potato starch

Generally pure sweet potato starch is considered inferior, compared with other starches such as mung bean, for the production of noodles, so additives and other treatments may be used to overcome this problem partially. The formulation of sweet potato starch often includes the use of potash alum or the addition of elephant yam flour to improve the quality of noodle produced in China. Collado and Corke (1997) investigated the qualities of starch noodles made from 14 sweet potato genotypes in Philippines. They found that there were significant differences in the texture and cooking quality of the starch noodles produced from the different genotypes. There is an important finding that the quality of both dried and cooked starch noodle of *Sushu 8* variety is the best among all sweet potato starches in China studied by Chen et al. (2002). They found that starch with high firmness and elasticity of its gel will result in good quality of starch noodle. Starch noodle quality can be predicted by starch gel properties. The qualities of dried and cooked starch noodles made from the Chinese sweet potato varieties determined by both texture analyzer and sensory evaluation showed some difference. It can be said that dried starch noodle made from *Sushu 8* sweet potato had a final quality well comparable to the noodle made from mung bean starch. This was surely not the case for another starch noodles made from other sweet potato varieties. For the cooked noodles, the quality of *Sushu 8* was even better than that of cooked mung bean starch noodle. Therefore, the statement in the literature cited that sweet potato starch is not very suitable for starch noodle making is generally incorrect for it depends in variety. Whereas the quality of cooked starch noodle of *Sushu 8* variety is just far better than that of other sweet potato starches in China studied by Tan (2007), but still inferior to the quality of mung bean starch noodle. The best performing sweet potato variety in China is for preparing roast sweet potato food and may not yet be tested for starch noodle preparation.

7.2. Adding chemically modified starch

Although attempts have been made to substitute mung bean starch with starches of various resources, we found that starch noodles made from these starches were not as good as mung bean starch noodles. It is considered that better quality noodles can be obtained by substitution of mung bean starch with chemical modified starch. For instance, WO-00/55605 describes the partial replacement of mung bean starch with a genetically modified potato starch with elevating amylose content. US patent 4871572 described the application of cross-linked potato starch in glass noodles. Process for producing glass noodles and demoldable gels using genetically modified starch, preferably from potatoes, was also reported (US Patent, 2003).

7.2.1. Phosphorylate starch

The phosphorylated tapioca starch used undergoes a less breakdown during cooking and also has lower swelling power and solubility compared to native tapioca starch. Muhammad et al. (1999) reported that the results of substituting potato starch with native or phosphorylated tapioca starch in the production of starch noodle. Substituting potato starch with up to 17% native tapioca starch or tapioca starch phosphate, or up to 35% MTS283 (a commercial tapioca starch), improved the strength of uncooked noodles, reduced the stickiness and cooking loss and increased the ability of shape keeping comparison to noodles containing potato starch only. However, substitution with native tapioca starch reduced transparency and the noodles tended to swell more when cooked. Cooked noodles containing either type of phosphorylated tapioca starch were less sticky, more elastic and retained of their shape easier than noodles produced by native tapioca starch. Of the two phosphorylated starches substitution with MTS283 is preferable, due to it improved cooking loss, swelling index and stickiness compared to mung bean noodles. However, the application of native or phosphorylated tapioca starch instead of potato starch reduced the flowability of the dough.

7.2.2. Hypochlorite oxidate starch

Oxidized starches are widely used in food, paper, and textile industries. Oxidation of starch with alkaline hypochlorite is one of the most common used methods. Oxidation causes depolymerization of starch, which lowers gel viscosity and minimizes retrogradation of amylose by introducing carbonyl and carboxyl groups (Li & Vasanthan, 2003). Li and Vasanthan (2003) investigated the effect of hypochlorite oxidation on the Brabendar pasting properties of field pea starch and the suitability of native and oxidized starch for noodle making by extrusion cooking. As the degree of oxidation increased from 0.02% to 0.20%, the cooking loss increased substantially while the noodle diameter, cooked weight, firmness, tensile strength and breaking distance decreased. Upon substitution of native field pea starch with native potato starch (10–40%), noodle diameter, cooking loss and breaking distance increased while cooked weight, firmness and tensile strength decreased. At similar degree of oxidation (0.2%), increasing of potato starch substitution from 20% to 40% would increase the noodle diameter, cooked weight and firmness and decrease the tensile strength and breaking distance. A marginal change was observed in cooking loss. They concluded that field pea starch was oxidized with sodium hypochlorite at a level of active chlorine ranged from 0.89% to 3.28% (starch db). The cooking quality attributes of noodles prepared from native field pea starches were acceptable but were negatively influenced by hypochlorite oxidation. Substitution of potato starch (40%, db) for field pea starch yielded more glossy noodles with better cooking quality.

7.2.3. Cross-linked starch

Noodles prepared from unmodified tapioca starch were too soft and not acceptable. Though tapioca starch is a good candidate to manufacture clear noodles because of its low cost and clarity of the starch paste. Ways to simulate the making of clear noodles from mung bran starch were investigated by studying the molecular structures of mung bean and tapioca starches (Kasemsuwan et al., 1998). The results of the molecular structure study and physical properties were used to develop acceptable products using mixtures of cross-linked tapioca and high-amylose maize starches. The correlation between those parameters and the pasting viscosity were studied using a visco/amylograph. High-amylose maize starch (70% amylose) was mixed at varying ratios (9%, 13%, 17%, 28%, 37%, and 44%) with the cross-linked tapioca starches. Analysis of the noodles included: tensile strength, water absorption, and soluble loss. Noodles made from mixture of cross-linked tapioca starch and 17% high-amylose starch were comparable to the clear noodles made from mung bean starch. The noodles prepared from mixtures of cross-linked tapioca starch and high-amylose starch indicated good quality at both dried and cooked noodles. The sensory evaluation indicated that panelists preferred the noodles made from mixtures of tapioca and high-amylose starch rather than mung bean noodles (Kasemsuwan et al., 1998).

However, the acceptance of genetically and chemically modified food ingredients is low. Although recipes may be cheaper if use these starches, the prices are still rather high. Another disadvantage in acceptance for the public is the label as “food starch modified” on the packaging of the food stuff. It is generally accepted that the application of genetically or chemically modified starches needs to gelatinize according to a “C”-type of gelatinization curve as disclosed in Chen et al. (2002) and Semeijn et al. (2004). Thus, physically treatment on starch emerges timely on this background.

7.3. Adding physically modified starch

The term “hydrothermal treatment” was used by Stute (1992) to describe physical modification of starch resulting from various combinations of moisture and temperature conditions that affect starch properties without visible changes in granule appearance. Physical modification of starch slurries in excess water at temperatures below gelatinization were referred as annealing. Heat-moisture treatment (HMT), on the other hand, refers to the exposure of the starch to higher temperatures normally above the gelatinization temperature (80–120 °C) at very restricted moisture content (<35%). Results on heat moisture treatment may also be influenced by partial gelatinization (Eerlingen, Jacobs, Van Win, & Delcour, 1996). Stute (1992) investigated the impact of HMT on viscoamylograph of potato starch. Either higher onset of temperature for viscosity development, lower peak viscosity, or higher, lower end viscosity was observed, depending on treating conditions. Same observations were reported for cassava (Abraham, 1993), maize and lentil, oat and yam (Hoover & Vasanthan, 1994), and sweet potato (Collado & Corke, 1999; Collado et al., 2001) starches.

Collado et al. (2001) found that sweet potato starch (SPS) has limited uses, but modification of its properties can make it more suitable for use in traditional products especially starch noodles. They applied heat-moisture treatment to native sweet potato starch (HMTSPS), which was used as a substrate and composite with maize starch (MS) to produce *bihon*-type starch noodles. Their results indicated that noodles from SPS exposed to HMT were not sticky and were comparable to those from maize starch regarding to handling. Noodle cooking time ranged from 2.5 min in 100% SPS to 3.0 min in other samples. Cooking loss ranged from 2.5% for the commercial sample to 4.0% for 100% native SPS. The rehydration rate was lowest with the native SPS noodles at 234% (W/W), and highest for 100% HMTSPS with 262% (W/W). Starch noodles with HMTSPS (100% and 50%) had higher color scores and were significantly more yellow than commercial sample and 100% MS. HMTSPS (100%) noodles were significantly less clear than the commercial samples but not significantly different from the commercial sample and 100% MS. HMTSPS (100%) had the highest smoothness score and was significantly different from 100% MS. Preliminary quality scoring showed that acceptability scores of raw starch noodles, plain boiled, and sautéed noodles made from 100% HMTSPS and 50% HMTSPS: 50% MS were not significantly different from the commercial *bihon*. However, consumer testing is recommended to further validate acceptability to the sweet potato for *bihon*. Still other possibilities include the used of additives and of blends with other locally produced starches to determine their comparative advantage to use HMT to modify SPS in noodle production (Collado et al., 2001).

7.4. Biologically treating starch

Using corn in starch noodle making will be a good trial, but traditional production experience showed that crude corn is not suitable for starch noodle making. Generally, a favorable mouthfeel for starchy noodles can be achieved or enhanced by adding sodium alginate, alum and other food additives as well as by modifying the starch using chemical and physical treatment such as oxidation and cross-linking. However, these chemicals are unpopular with consumers because of the health hazards associated with them. Spontaneous lactic acid fermentation is an important process in improving the texture of rice noodles (Lu, Li, Min, Wang, & Tatsumi, 2005). Fermentation may change the amorphous region of the starch granule as well as the chemical components and thereby modify both physical properties of rice flour and texture of rice noodle. On the other hand, the method using sour liquid to extrude the starch is a traditional way in China, and is also widely used to product starch noodle. The ingredient sour liquid is an aqueous acidic fermented liquid extracted from mung bean starch slurry, which had abundant streptococcus lactics. The noodle prepared by this method is more transparent and flexile than that by centrifugation. It could be a practical way to introduce spontaneous lactic acid fermentation to corn starch to improve the texture of corn starch noodle.

Yuan et al. (2008) studied the effect of spontaneous fermentation on physical properties of corn starch and rheological characteristics of corn starch noodle, and to compare sensory characteristics of fermented corn starch noodle with those of mung bean starch noodle in order to study the feasibility of spontaneous fermentation on improvement of corn starch noodle quality. They found that maximum tensile stress was lowest for controlling starch noodle, and gradually increased with fermentation time, indicating that fermented corn starch noodles are harder than control sample. Fermentation can hydrolyze short chains of amylopectin in the amorphous regions, leading to higher ratio of long-to-short chains in amylopectin and higher tendency for long chains to gel, thus resulted in rigid gel and harder noodles. Maximum tensile strain was obtained from the ratio of maximum extension to the original length of starch noodle. It also increased with fermentation time till the 19th day, but after that, the strain decreased from 39.0% at 19th day to 33.2% at 21st day (Yuan et al., 2008).

Fermented corn starch noodle scored significantly higher than control corn starch noodle for hardness, which was consistent with the result of tensile experiment. Besides, fermented samples also had higher scores for all the other four sensory attributes, indicating fermentation improved the eating quality of corn starch noodle significantly. Compared with mung bean starch noodle, fermented corn starch noodle had lower hardness score. In fact, cooked starch noodles should be neither too hard nor too soft. Fermented corn starch noodle scored significantly higher for elasticity than control corn starch noodle, but not significantly different from mung bean starch noodle. The result of overall acceptability was similar to elasticity (Yuan et al., 2008).

The above results indicated that fermentation can greatly improve the eating quality of corn starch noodle, and the quality of fermented corn starch noodle was comparable to that of mung bean starch noodle. Spontaneous fermentation is an effective and safe way to produce corn starch noodle with satisfactory quality. It will contribute to promoting the utilization of corn starch (Yuan et al., 2008).

7.5. Using additives

Generally, the quality problem from non-mungbean starches noodles is normally partially overcome by using additives and other treatments. The formulation of non-mungbean starch noodles often includes the used of potash alum or polysaccharide gums to improve the quality in China. Many researchers are looking for new additives to improve the quality of non-mungbean starch noodles.

7.5.1. Adding soybean protein

To discuss the effect of addition of isolated soybean protein (ISP) on physical properties of starch noodle (Harusame), Takahashi, Hirao, and Watanabe (1986) made the noodles from potato, mung bean or broad bean starch mixed with ISP using pressure extruder at 80 °C. The extruded starch were heated in boiling water for 3 min, washed with water, and dried immediately, or frozen, thawed, drained and dried. The noodles were cooked in boiling water for 3 min, washed. Their transparency, swelling power, solubility and texture were measured and there also subjected to organoleptic test. The results indicated that the noodles from potato starch added 5% ISP are transparent, have higher tensile strength and elongation elastic modulus, less adhesiveness, lower solubility and be non-sticky than the noodles of potato starch only. By raising extrusion temperature from 80 °C to 120 °C, cooked noodle from potato starch only was extremely hard and sticky, difficult to separate each other, however, the addition of ISP made the noodle more elastic and chewy, and even in the case of ordinary drying, the noodles were not sticky and easy to separate each other. Effects of freezing of noodle before drying on physical properties of cooked noodles were evident in potato starch noodles with higher value in compression and tension test. But the effect is not obvious in mung bean starch and mixture of potato and sweet potato starch (1:1). However, by adding ISP, physical properties of noodles from these starches were improved compared with frozen noodles from potato starch (Takahashi et al., 1986).

7.5.2. Adding fatty acid esters

Fatty acid esters (abbreviated as FAE) had a facilitating effect on the separation of frozen starch noodle (abbreviated as FSN). The separating effect of FAE increased in proportion to the length of the alkyl chain of FAE. Further, the separating effect was found to be closely related to the HLB (Hydrophilic Lypophilic Balance) value of FAE. Mohri (1980) studied the relation between the separating effect of FAE on FSN and the interaction of FAE with starches to verify the connection with complex-formation, syneresis, iodine affinity, viscosity and adhesive force of starch in the presence of FAE and also the adsorption of FAE on starch surfaces.

The amount of FAE adsorbed on starch was highly dependent on the molecular weights of FAE—the greater the adsorption amount of FAE, the longer the alkyl chain length of FAE. Further, as the degree of esterification increases, the adsorption ability of glycerin fatty acid ester decreases. Because of the steric hindrance, the trioleate will not adsorb on starch surface easily. The influence of FAE on syneresis of starch gel was that as the water-solubility of FAE, namely, HLB-value increased, the starch gel containing FAE showed remarkable syneresis. This syneresis is caused by the decrease of hydration power of starch owing to the occurrence of a strong hydrogen bond between FAE and starch. FAE was also effective in lowering the viscosity of starch paste and in decreasing the adhesive force of starch. The higher the HLB of FAE, the higher the viscosity of starch paste containing them. The effect decreasing adhesive force of FAE heavily depends on the molecular weight of FAE and, in general, increases with the molecular weight. In fact, weakening the adhesive force of starch disturbing the separation of FSN was an important factor to promote the separation of FSN (Mohri, 1980).

From the above discussion, Mohri (1980) understand that separating effect of FAE has a close relationship to the interaction of FAE with starch. The following factors are at least important in the separating effect of FAE: (a) adsorption of FAE on starch surface and (b) the subsequent action of FAE to reduce the viscosity and adhesive force of starch paste. The reason for FAE, especially sorbitan stearate or glycerin stearate, being effective in the separating of FSN probably lies in the FAE ability to satisfy the above requirements.

7.5.3. Adding glycerol monostearate

Kaur et al. (2005) studied the effects of glycerol monostearate (GMS) on the physico-chemical, thermal, rheological, textural and noodle making properties of corn starch and potato starches from four different cultivars. The presence of lipids in the corn starch may be another influencing factor that delayed the swelling of individual starch granules within the noodle strands (Singh et al., 2002). The addition of GMS increased cooking time of corn and potato starch noodles. The helical inclusion complexes formed between the GMS and the amylose may possibly affect the cooking time of the noodles. After the addition of GMS, potato starch noodles showed the maximum increment in cooking time, with Jyoti and Sindhuri at the highest. The addition of GMS reduced the cooked weight as well as cooking loss for corn and potato starch noodles. The presence of GMS may prevent the swelling of starch granules to their full extent and transport of water that resulted in lower cooking weight. Lower cooking losses with GMS indicated its complexation with amylose within the cooked noodles (Kaur et al., 2005).

The addition of GMS decreased the hardness values of corn and potato starch noodles, however the effect was slightly pronounced. Delayed swelling of starch granules in the presence of GMS may affect the hardness values of noodles. The cohesiveness values decreased with the addition of GMS in corn and potato starch noodles. GMS may provide the stability to the starch granules that reduced the cohesiveness by decreasing granule interaction and association within the starch noodles. The gumminess, chewiness and springiness values of cooked starch noodles containing GMS were also lower than those without GMS. The addition of GMS brought substantial changes in physico-chemical, thermal, rheological, textural and noodle properties. The presence of GMS decreased swelling power and solubility of starch, while gelatinization temperatures and enthalpy of gelatinization were increased. Cooked starch noodles containing GMS showed lower values for texture profile analysis parameters such as hardness, cohesiveness, gumminess, chewiness and springiness. The starches with large granule populations comparing with potato starches with small granules or corn starch brought greater changes of starch and noodle properties subsequently (Kaur et al., 2005).

7.5.4. Adding chitosan

Chitosan is a linear polysaccharide of anhydrous β-D-glucosamine units joined by (1→4) linkages. It is obtained by deacetylation of chitin, a natural polymer, manufactured from shrimps or crab shell. Chitosan has three types of functional groups in monomeric unit, an amino group as well as primary and secondary hydroxyl groups (C-6, C-2, and C-3, respectively). Chitosan has already been used as a functional ingredient to improve food functionality and quality in the food processing industries (Baek et al., 2001). While alum has strong ionic properties in aqueous solution and increases starch gelatinization temperature, starch dough strength, and bleaching effect. Since it is a chemical ingredient, natural substances are more favored. Baek et al. (2001) investigated the effect of chitosan addition on quality of sweet potato starch noodles, and to evaluate the possibility of chitosan as an alum replacement for sweet potato starch noodles preparation.

Solubility of sweet potato starch noodle increased with the increasing of cooking time and decreased as the amount of added chitosan increased. When the sweet potato starch noodles containing alum (0.3%) was cooked for 6 and 12 min, the solubility values of sweet potato starch noodle were 0.80% and 0.98%, respectively, which were less than the values for chitosan-added noodles (0.81–0.90%, and 1.13–1.29%, respectively). Alum was more effective in holding the noodle structure stable during cooking. At 6 min of cooking, the difference between the alum- and chitosan content increased, the noodles tended to become more stable (Baek et al., 2001).

Alum acted as a chelating agent, resulting in a more rigid and stable network formation compared to chitosan, but solubility was not significantly different with increasing amounts of alum addition. On the other hand, in the case of chitosan, the ionic-dipole interaction between chitosan ($-NH_3^+$) and starch hydroxyl groups (–OH) might facilitate intermolecular interactions that resulted in a more rigid and stable network formation. Consequently, the increased addition of chitosan caused decreasing of solubility of sweet potato starch noodles (Baek et al., 2001).

Swelling power of sweet potato starch noodle increased with increasing of cooking time and decreased with increasing amount of chitosan addition. Swelling power showed same trend of solubility, but the difference in swelling power caused by different chitosan contents was smaller than the variation of solubility. In the case of sweet potato starch noodles containing chitosan, swelling power of noodles with greatest amount of chitosan (1000 ppm) was 4.37 and 5.80 at 6 and 12 min of cooking, respectively. Therefore, the chitosan was not as affective as the alum in reducing swelling and soluble loss of the noodles. The interaction between starch and chitosan increased while water adsorption decreased as the amount of chitosan addition increased. These changes in the interactions resulted in the decreased swelling of starch noodle with increasing amounts of the residual chitosan (Baek et al., 2001).

Hardness of starch noodle rapidly decreased with increasing cooking time, but increased with increasing amount of chitosan addition. The starch noodle containing alum showed greater hardness than those containing chitosan. The alum-added noodle cooked for 12 min showed a similar hardness to that of starch noodles containing chitosan (1000 ppm) cooked for 8 min. Therefore, the starch noodle containing chitosan became soft readily. However, as the amount of chitosan addition increased, the noodles became harder. Gumminess and chewiness showed similar trends too. From preference test of alum- or chitosan-added starch noodles cooked for 10–12 min, starch noodle containing 750 ppm chitosan or 0.3% alum showed the highest preference with similar scores. There was no significant difference between the two starch noodles added with alum or chitosan in the texture properties and acceptability. However, the color of the cooked noodle appeared stronger for the alum-noodle (Baek et al., 2001).

Chitosan is widely used in food industries as texture controlling agent, food mimetic, thickening and stabilizing agent, and a nutritional quality enhancer (dietary fiber, hypocholesterolemic effect) (Shahidi, Arachchi, & Jeon, 1999). From the sensory evaluation, it can be concluded that chitosan can be used as a replacement of alum for sweet potato starch noodles quality (Baek et al., 2001).

7.5.5. Adding polysaccharide gums

Tan (2007) studied the effect of additives (including polysaccharide gums and alum) on the short-term and long-term retrogradation of sweet potato starch (SPS) in order to provide a theory foundation on improving the quality of its starch noodles. She measured the variety trend of viscosity of mixture of SPS and additives during heating and cooling using Rapid Viscosity Analysis (RVA) and its gel firmness using Texture Analysis and the T_o, T_p, T_c, $\triangle H$ of the mixture system after crystallization using Differential Scanning Calorimetry (DSC), evaluated the quality of sweet potato starch noodles (SPSN) after added additives. The results indicated the RVA parameters of sweet potato starch paste and texture quality indexes increased with adding of additives in a certain extent, especially alum, *Artemisia sphaerocephala* Krasch (ASK), konjak glucomannan (KGM), and xanthan. The DSC thermogram of retrograded sweet potato starch with polysaccharide gums showed two peaks, one was melted amylopectin, another one was a radiative peak (87–105 °C), which resulted from recombination of polysaccharide gums and SPS. The melting temperature of retrograded SPS increased or decreased with addition of polysaccharide gums, but the enthalpy increased. There were radiative peaks owing to the conjecture that polysaccharide gums re-melted and became free at this temperature, and then competed with a few lipids in SPS, preferentially recombined with amylose in SPS, formed a firm system. The quality of SPSN added 1% (on the basis of total starch weight) of KGM and ASK (0.95:0.05) was similar to that of mung bean starch noodles and SPSN containing alum. Combining the measurement of the glass transition temperature using DSC, leached amylose, interaction test and infrared spectrum analysis of mixture systems, Tan (2007) also analyzed the mechanism of interaction between additives and sweet potato starch. The results illuminated that these mixture systems contained CMC, carrageenan and SPS was inconsistent, while those mixture systems contained alum, salt, soybean protein, glycerol, other polysaccharide gums and SPS was consistent. The mixture systems contained KGM, ASK and SPS were more steady than others. Additives combined with amylose in SPS. These interactions were strong or weak. The NaCl can weaken faintly the interactions between polysaccharide gums and SPS, while carbamid can weaken their interactions strongly. The –OH peaks in these infrared spectrum peaks of SPSN contained additives were displaced and other peaks were not displaced comparing to the original SPSN in these infrared spectrum figures. She confirmed that the mechanism of interaction between KGM, ASK and SPS was described as follows: the mixture system contained KGM, ASK and SPS was consistent. There was no new functional group in this mixture system. Their amylose and exterior chains in amylopectin juxtaposed each other by hydrogen bond, which existed inner and exterior chains, and then formed minicrystal zone, which acted as junctures. The net in mixture system was held together by countless junctures so that sweet potato starch gel contained KGM and ASK had strong texture. The interaction between SPS and alum was mainly static electricity.

Lee, Baek, Cha, Park, and Lim (2002) also compared nine polysaccharide gums (sodium alginate, carboxymethyl cellulose, curdllan, gellan, guar gum, gum Arabic, k-carrageenan, locust bean, and xanthan) for their stabilizing effects in sweet potato starch gel against repeated freeze–thawing (FT) treatments. They found that the gums were added in starch gel at 0.3 or 0.6% (w/w, based on total gel weight), and total solid content in the gel was adjusted to 7% (w/w) with starch. The gels containing starch and gum were repeatedly freeze–thawed up to five times by storing at −18 °C for 20 h and then at 25 °C for 4 h. Water release (syneresis) was measured by vacuum-filtering the freeze–thawed gels. Among the gums tested, alginate, guar gum, and xanthan were highly effective in reducing the syneresis. For example, guar gum, at 0.6%, showed the least syneresis (33.0%, w/w based on initial water content) after five FT cycles, which was less than half value of pure starch gel. At 0.3%, however, xanthan was more effective than guar gum in reducing syneresis. Xanthan reduced paste viscosity significantly, whereas guar gum and alginate increased the viscosity, but there was little relation between pasting viscosity and syneresis. The gums remained in the gel matrix during the syneresis without a significant loss. Recrystallization of starch (retrogradation) induced by FT treatment was also retarded by the presence of gums, and sodium alginate was more effective in retarding the retrogradation than xanthan or guar gum (Lee et al., 2002).

Funami et al. (2005a) studied the retrogradation behavior of corn starch in an aqueous system in the presence or absence of various guar gum samples with different molecular weights. Dynamic mechanical loss tangent for starch system with 26% amylose (5 w/v%) was increased by the addition of guar (0.5%) after storage at 4 °C for 24 h, which indicated the reduction of gelled fraction in the system, leading to the retardation of short-term retrogradation of starch. This rheological change of the system related to the amount of amylose leached out the starch granules during gelatinization. The higher the molecular weight of guar, the lower the amount of amylose leached, but this effect of guar became less dependent on its molecular weight at above 15.0×10^5 g/mol. The rate constant determined from the relationship between storage time (for 14 days at 4 °C) and creep compliance for the starch system (15% starch) was decreased in the presence of guar (0.5%), suggesting the retardation of long-term retrogradation of starch. This effect of guar became marked at above 30.0×10^5 g/mol, which was apparently higher than the critical molecular weight value determined from short-term retrogradation. Syneresis for the starch system (5% starch) was increased adversely by the addition of guar (0.5%) with relatively low molecular weight values (e.g., 5.0×10^5 g/mol) after storage at 4 °C for 14 days, suggesting the promotion of long-term retrogradation. Functions of guar on the retrogradation behavior of starch were hypothesized considering interactions between guar and starch components; amylose and amylopectin (Funami et al., 2005a).

Funami et al. (2005b) studied the gelatinization and retrogradation behavior of wheat starch in an aqueous system by rheological and thermal techniques in the presence or absence of non-ionic polysaccharides, including guar gum, tara gum, locust bean gum, and konjac glucomannan. Macromolecular characteristics of each polysaccharide, including weight-average molecular weight M_w and radius of gyration R_g; were determined by static light-scattering, resulting in $(1.0–3.2) \times 10^6$ g/mol for M_w and 104–217 nm for R_g; respectively. During gelatinization, addition of each polysaccharide (0.5–1% w/v) increased peak viscosity for the starch system (13%): 163–231 units larger than the control at 0.5%, whereas 230–437 units larger at 1%. Among the galactomannans tested, the order of this effect (locust > tara > guar) was contrary to that of the molecular size (guar > tara > locust). During short-term retrogradation, addition of polysaccharide (0.5%) increased dynamic mechanical loss tangent ($\tan\sigma$) for the starch system (5%) after storage at 4 °C for 24 h: $(16.5–26.9) \times 10^{-2}$ unit larger than the control. During long-term retrogradation, addition of polysaccharide (0.5%) decreased the rate constant expressing the relationship between storage time (for 14 days at 4 °C) and creep compliance for the starch system (15%): $(0.9–1.5) \times 10^{-2}$ unit smaller than the control. Functions of polysaccharide to starch were hypothesized considering structural compatibility and molecular interactions between polysaccharide and starch components; amylose and amylopectin.

8. Future of starch noodles

The starch noodles on the market today may use other starch materials like broad bean, and other starches besides mung bean, or just plain starch only (corn starch, tapioca starch, or potato starch). Making high-quality starch noodles involves intensive labor and liquid waste disposal which are bottlenecks in the process. The liquid waste is fairly rich in nutrients as it contains all the vitamins, minerals, and proteins in the starchy materials and can be used as animal feed. Attempts have also been made to recover the protein from this liquid waste. For example, a great deal of wastewater was produced during the sweet potato starch production in China. The wastewater will pollute environment because there are a large number of organics in it. Most of organics of wastewater are glycoprotein, which have excellent immunodulating and antitumor biological activity. If the glycoprotein can be extracted from the waste water, not only the polluting problem can be resolved, but also can obtain a kind of biological activity product (Cheng, 2005). Ultrafiltration was used for extracting glycoprotein from wastewater of sweet potato starch production and the structure, biological activities of the glycoprotein were studied by Cheng (2005). He found that glycoprotein of sweet potato has no acute toxicity certified by mice acute toxicity experiment, but has excellent immunomodulating activity. Exploring new product unceasing also is very important for the evolution of starch noodles industry. For example, Zhou, Wu, Lu, Shi, and Li (2004) designed audaciously and successfully the recipe of starch noodle with vegetables as supplements based on the alum-free one. Raw materials were selected for nutrients and colors from seven vegetables. The results showed that amaranth, spinach and China squash could be used as supplement a raw materials in vegetable glass noodle processing. In addition, ascorbic acid could be used as color-protecting agent.

In conclusion, starch noodles became an important and special food and their consumers are not only in Asia but spread around world. There are different ways of consuming starch noodle as well as different recipes in different countries. Also, there are numerous types of starch noodles that depend on the raw materials, product shapes, processing methods and the way of preparation and serving. However, they have also undergone changes driven by technical innovations and consumer demands. Actual process for manufacturing a particular type of starch noodle may differ from country to country, the basic principles involved are practically the same. The processing technology, such as vacuum mixing, auto-extruding, intelligentized freezing, in the production of starch noodle during the 1990s, had rapidly been developing. Although noodles are traditional foods, the technical and technological innovations are continuously evolving to adapt them to global consumers of all ages. Recipes have been modified and continuously adjusted to suit the taste of the consumers in many countries. Production equipments have been improved, modernized, and upgraded to guaranty efficient productivity. Production costs have been optimized to make it affordable also for people in the developing nations. Product size has been modified and continuously being adjusted to the tradition of the western world. New packaging designs, new recipes and new way of preparation continuously appear on the market to satisfy the eternal desire of consumers particularly the younger generation for something new, something fulfilling and something good.

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