Physiochemical Properties of Sweet Potato and Mung Bean Starch and Their Blends for Noodle Production

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Abstract

Physiochemical properties of four types of sweet potato starch (SPS) and mung bean starch (MBS), and their blends for noodle production were accessed. The results indicated that MBS was significantly higher in amylose content (40.69%), gel hardness, hot paste stability and cold paste viscosity, but substantially lower in protein, lipid, ash content, and gel stickiness than those of all sweet potato starches. Among all sweet potato varieties, the white skin and yellow-red flesh color sweet potato variety (SP1_W_YR) was the most suitable for noodle production due to its the highest starch yield (17%) and starch purity as well as the best starch color. The MBS noodle quality was superior to SPS noodle quality, and blending SPS with MBS for noodle production resulted in markedly reducing quality. However, the quality of noodles made from mixture of 20% SPS and 80% MBS was not significant difference to that of MBS noodles. The increase of solid content of starch slurry resulted in considerable increasing in cooking time, cooking loss, rehydration and tensile of noodles while aging time only markedly affected cooking loss and tensile. For noodles prepared from mixture of 20% SPS and 80% MBS, the most suitable initial solid content of starch slurry and aging time at 4°C were 35% and 10-20 hrs respectively.

Keywords: Sweet potato starch; Sung bean starch; Cooking quality; Starch noodles

Abbreviation: SPS: Sweet Potato Starch; SPS_N: Sweet Potato Starch Noodle; SP1_W_YR: White skin and Yellow-Red flesh color Sweet Potato variety; SP2_P_P: Purple skin and Purple flesh color Sweet Potato variety; SP3_P_Y: Purple skin and Yellow flesh color Sweet Potato variety; SP4_OP_O: Orange- Purple skin and Orange flesh Sweet Potato variety; MBS: Mung Bean Starch; MBS_N: Mung Bean Starch Noodle; 15_9M_N: Noodles made from 10% SPS and 90% MBS; 2S_8M_N: Noodles made from 20% SPS and 80% MBS; 35_7M_N: Noodles made from 30% SPS and 70% MBS; 4S_6M_N: Noodles made from 40% SPS and 60% MBS; 3565SWN: Noodles made from 35% starch and 65% Water; 4065WON: Noodles made from 40% starch and 60% Water; 4555SWN: Noodles made from 45% Starch and 55% Water

Introduction

Starch noodles or cellophane noodles are popular staple foods in many Asian countries in which China is the largest production and consuming country. Unlike the other types of noodles such as wheat noodles or pasta in which gluten protein is responsible for forming the network to integrate other components to form visco-elastic dough [1], starch noodles are made only from free-gluten starches and water, therefore the starch properties are essential for noodle processing and final product quality. The starch noodles can be produced by dropping, cutting or extruding method. The common characteristics of these methods are heat treatment starch dough or slurry which are boiling and high swelling and a C-type Bra bender viscosity pattern which indicated no pasting peak but rather a very high viscosity which remained constant or else increased during cooking and it provided the favorite texture and appearance of cooked noodles [2,4,5]. However, due to low yield and tediousness in starch isolation procedure, together with expensive price; mung bean starch cannot meet the increasing demand of starch noodles in recently years [4,8]; therefore looking for other starch materials, which are abundant and cheaper price, substitute mung bean starch partially or totally will be valuable. The sweet potato starch is one of the promising substitutes for mung bean starch in noodle production. The sweet potato is relatively easy to grow, high productivity, high starch content (6.9-30.7%) in which amylose content is 8.5-38% depending on variety [4]. The Asian countries contributed more than 80% of total world production of sweet potato. In China, Vietnam, Indonesia, Thailand and India, sweet potatoes are important food crops grown throughout country. However, noodles made from sweet potato starch are not much preferred by customers, and their qualities are significantly inferior to mung bean starch noodle qualities. The sweet potato starch noodles are dull, opaque, moderately elastic, and high cooking loss and swelling as cooking [2,4,5,9]. Therefore, the blending SPS with MBS for noodle production needs to be investigated to combine both advantage characteristics of mung bean and sweet potato starch.

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Mung bean starch traditionally was ideal material for noodle production because its starch showed high amylose content, restricted swelling and a C-type Bra bender viscosity pattern which indicated no pasting peak but rather a very high viscosity which remained constant or else increased during cooking and it provided the favorite texture and appearance of cooked noodles [2,4,5]. However, due to low yield and tediousness in starch isolation procedure, together with expensive price; mung bean starch cannot meet the increasing demand of starch noodles in recently years [4,8]; therefore looking for other starch materials, which are abundant and cheaper price, substitute mung bean starch partially or totally will be valuable. The sweet potato starch is one of the promising substitutes for mung bean starch in noodle production. The sweet potato is relatively easy to grow, high productivity, high starch content (6.9-30.7%) in which amylose content is 8.5-38% depending on variety [4]. The Asian countries contributed more than 80% of total world production of sweet potato. In China, Vietnam, Indonesia, Thailand and India, sweet potatoes are important food crops grown throughout country. However, noodles made from sweet potato starch are not much preferred by customers, and their qualities are significantly inferior to mung bean starch noodle qualities. The sweet potato starch noodles are dull, opaque, moderately elastic, and high cooking loss and swelling as cooking [2,4,5,9]. Therefore, the blending SPS with MBS for noodle production needs to be investigated to combine both advantage characteristics of mung bean and sweet potato starch.

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physiochemical properties of starches isolated from four common Thai sweet potato varieties and mung bean starch, (2) to evaluate qualities of noodles prepared from mixture of SPS and MBS and (3) to access effects of processing parameters on noodle quality.

Materials and Methods

Raw materials

Four types of sweet potato varieties namely, white skin and yellow-red flesh color (Kratai cultivar) (SP1_W_Y), purple skin and yellow flesh color (Torpuag cultivar) (SP2_P_P), purple skin and yellow flesh color (Kaset cultivar) (SP3_P_Y) and orange-purple skin and orange flesh color (Khai cultivar) (SP4_OP_O); and mung bean starch produced by SitThiNan Co., Ltd. were purchased from Thailand. All used chemicals and reagents were in analytical grade.

Starch isolation

The sweet potato roots were washed thoroughly, peeled, cut into small pieces (4x4x4mm) that were then soaked in 0.2% sodium metabisulfite solution with ratio of 1.2 (w/w) for 15 minutes and ground in a blender for 5 min. The slurry was filtrated through a fabric filter to remove fibers and other components before passing through a 100 mesh sieve. The filtrate was allowed to undisturbed stand for 3 hrs. The collected starch re suspended with tap water, settled down and removed water. This process was repeated in three times to remove any pigment residue. The obtained starches were dried in hot air oven at 50°C for 12 hrs until about 10% MC (wet basis). Then, it was finely ground and packaged in polypropylene bags and kept at cold room (4°C) until further analysis.

Starch yield (%)

The starch yield (%) obtained from sweet potato root could be calculated by following formula:

\[
\text{Starch yield} = \frac{\text{Extracted starch}}{\text{Total amount of raw sweet potato root}} \times 100
\]  

Proximate compositions of starches

Apparent amylose content (%) was determined by colorimetric iodine assay index method, following Juliano [10]. The moisture, protein, lipid and ash content in starch were determined using procedure of AACC method [11].

Starch color

The color of starches in terms of L*, a* and b* values were measured by Hunter lab Colorimeter (Colorflex, USA). The whiteness value was obtained by following equation:

\[
\text{Whiteness} = 100 - \left[\left(100 - L^*\right)^2 + a^* + b^*\right]^{1/2}
\]  

Light microscopy observation

The shape and size of starch granule were determined by using BX40 Microscope (MBL2100, Germany) interfaced to digital camera (DCM 300, 3M pixels). Placing a drop of starch suspension (0.1g starch in 10ml water and stirring thoroughly) onto the glass plate and cover with cover slit and observing under microscopic. Granule size was measured using a microscope fitted with a calibrated eyepiece to calculate the range and average of the granular size [4].

Gel texture

Gel texture was determined by using Instron TA.XT2 Plus, uniaxial compression (Stable Micro System, USA) as reported by Pons [12].

Starch gel was made by heating and stirring continuously 10% starch slurry at 85°C for 20 minutes. Then, it was poured into in PVC pipe (3/4inch diameter). After sealing with covers at both two ends, the tubes were kept overnight at 4°C. The height of gel obtained was 25mm. The gel was compressed at 1mm/s to distance of 10mm by using stainless steel punch probe (P/35). The gel hardness and stickiness were obtained from the peaks of force-time curve.

Pasting properties

Rapid Visco Analyzer (RVA, Mode 1A, Newport Scientific, Australia) was used to determine the starch pasting properties [11]. Amylogram profile showed RVA parameters in terms of pasting temperature (Ptemp), peak viscosity (PV), trough viscosity (TV), breakdown (BD = PV-TV), final viscosity (FV) and setback viscosity (SB = FV-TV).

Noodle preparation

The procedure for starch noodle making was followed according to Lee and Hormdok and Noomhorm [5,13] with a slight modification. The SPS were well mixed to MBS to form starch mixture in which SPS accounted for 0, 10, 20, 30, 40 and 100%. The water was added into starch mixture to obtain starch slurry with solid content of 35, 40 and 45%. The starch slurry was equilibrated at room temperature for 1hr before pouring into stainless plate (150x160mm), then spread to form sheet in 1mm thickness. After steaming at 92.5°C until complete gelatinization, the samples were cooled at room temperature for 10minutes and then covered with aluminum foil and aged in a refrigerator (4°C) for 1, 10 and 20hr. After that, the starch gel was cut into thin-noodle strands (2mm in width) by cutting knife. The noodle strands were dried in an air oven at 40°C until about 12% of final MC. To simplify the experiment, as studying effects of a processing condition on starch noodle quality, other processing conditions were kept constant. The best processing condition from previous step was chosen for the next step. The quality of both dried and cooked noodles was evaluated by following methods.

Color of starch noodles: The color of both dry and cooked starch noodles was determined by Hunter lab Colorimeter (Colorflex, USA) in terms of L*, a* and b* values.

Cooking quality of starch noodles: The cooking time of the starch noodles measured by cooking 5g noodles (2-3cm long) in 200ml distilled water, every 30second the noodle strands were removed and pressed between two pieces of watch glass. Optimum cooking time was achieved when the center of the noodles was fully hydrated [2].

Cooking loss (CL) and % rehydration (RE) starch noodles were determined by the method introduced by Hormdok and Noomhorm [13]. CL was calculated based on the dry weight of noodles. The RE was calculated as the percentage increase in weight of the cooked noodle compared to the weight of dried noodle.

Extension of starch noodles: The extension of a single strand of cooked noodles was measured by using Instron TA.XT2 Plus, (Stable Micro System, USA), following method of Chen [4] with the test speed was 1mm/s. The extension modulus (E,MPa) and the relative extension (r) were calculated from the following equations: E = (F/ΔL)/(L/A) and \( r = \frac{\Delta L}{L} \). Where F is the extension force (g force), A is the cross sectional area of starch noodle (mm²), ΔL is the increased length (mm) and L is the original length of starch noodle (mm).

Sensory evaluation of starch noodles: Multiple comparison tests were used for sensory evaluation the quality of both dry and cooked starch noodles. The cooked noodles were prepared by cooking in
boiling water for 1 minute more than cooking time and cooling in cold water for 5 minutes before evaluation. The twelve panelists (seven men and five women whose age was from 27 to 40 year olds), who were familiar to products, were asked comparing each of all samples to the reference sample made from pure mung bean starch. In terms of appearance, texture, flavor and overall acceptability by using 9-point scale. They were informed the method evaluation and terminology of quality attribute before evaluation.

Data analysis
All experiments and analysis were performed in three replications. The data were subjected to statistical one-way ANOVA test and Fisher’s Least Significant Difference (LSD) test or Duncan Multiple Range Test (DMRT) to compare among treatments at the 5% significant level by using SPSS version 16.

Results and Discussions
Starch yield (%)
The SP1_W_YR variety showed the highest extracted starch with about 17.52%, following by SP2_P_P cultivar with 15.54%. The isolated starch content from both SP3_P_Y and SP4_OP_O roots was not significant difference, holding 12.38% and 12.55% respectively (Figure 1). This may be explained that starch content in SP1_W_YR and SP2_P_P roots was much higher than that in SP3_P_Y and SP4_OP_O roots. However, the roots with higher starch content was not necessarily higher percentage of extracted starch, almost there was no relationship between starch content in roots and isolated starch [14]. The reason for that difference can be the structure of cell wall of SP3_P_Y and SP4_OP_O varieties seem to be much thicker than that of the other sweet potato varieties, resulting in hindering starch isolation from chloroplast, resulting in low starch yield.

Chemical compositions
The starches from all SPSs were high in apparent amylose content ranging from 28.06% to 34.52%, but much lower than that in MBS which was 40.36% (Table 1). These results were in agreement with the previous reports, amylose content in SPSs ranged from 8.5% to 37.4% depending on the variety [4,8]. Amylose content in starch was one of important factors influencing to starch pasting and the strength of starch gel due to its quick retrogradation, association and interaction to lipids and amylopectin to form helical complex giving strong gel structures. Starches with high amylose content were desired for manufacture of starch noodles [2,18]. However, Kim [3] found that amylase content was no significant correlation to noodle hardness and suggested that next to amylose threshold level, other starch properties were more important than amylose content. Tam [19] found that high amylose corn starch was not suitable for noodle making because it was not sufficiently gelatinized at atmosphere condition, leading to almost no amylose molecules released to participate into the noodle structure formation. The starch with high amount of protein, lipid and ash content indicated low purity. The protein content in starches from all sweet potato cultivars, which ranged from 0.15 to 0.23% db, were slightly higher than that in mung bean starch which was 0.16% db; while the ash content in SPSs (0.110 - 0.282%) was markedly greater comparing to that in MBS (0.053%) (Table 1). The lipid content in SP2_P_P and SP3_P_Y starches, which was 0.084% and 0.061% respectively, was considerable higher than that in SP1_W_YR, SP4_OP_O and MBS, which was 0.031%, 0.039% and 0.038% respectively. High lipid content can reduce in clarity of starch paste and hinder the swelling of starch granule because of high rate formation of amylose-lipid complex [4,8]. Nevertheless, the protein and lipid played important role in retention of amylose in starch noodles during cooking, resulting in minimizing cooking loss [3].

Light microscopy analyses
The microscopic images of mung bean and sweet potato starch granules are shown in Figure 2. For all sweet potato varieties, the

### Table 1: Comparison of the chemical composition and granule size among all sweet potato starch and mung bean starches.

| Properties                  | SP1_W_YR       | SP2_P_P       | SP3_P_Y       | SP4_OP_O       | MBS            |
|-----------------------------|----------------|---------------|---------------|---------------|----------------|
| Chemical composition, % db (*) |                |               |               |               |                |
| - Moisture                  | 0.097(0.50)    | 0.104(0.29)   | 0.103(0.10)   | 0.079(0.63)   | 0.103(0.09)    |
| - Protein                   | 0.21(0.021)    | 0.19(0.018)   | 0.21(0.017)   | 0.23(0.028)   | 0.16(0.019)    |
| - Lipid                     | 0.031(0.0073)  | 0.084(0.0027) | 0.061(0.0026) | 0.039(0.0079) | 0.038(0.0054)  |
| - Ash                       | 0.137(0.0238)  | 0.282(0.0480) | 0.110(0.0221) | 0.221(0.0535) | 0.053(0.0055)  |
| Apparent amylose content (%) | 31.50(0.81)    | 29.34(0.56)   | 28.06(1.11)   | 34.52(1.18)   | 40.36(0.59)    |
| Granule size (µm) (**)      |                |               |               |               |                |
| - Range                     | 6.27-25.37     | 5.18-24.55    | 6.63-30.47    | 7.11-29.50    | 8.42-38.43     |
| - Average                  | 15.31(0.05)    | 14.88(0.01)   | 17.26(1.02)   | 14.80(0.42)   | 24.04(1.00)    |

(*) All values are means of three replications. Data in the parenthesis are standard deviation. Within the same column, the values with different letters are significant difference at p < 0.05 by LSD test.

(**) All values are means of three determinations. For each determination, the value was average of fifty particles.
starch granule shapes were heterogeneous and no noticeable difference, including small or largely polygonal and circle-shaped particles. It therefore was very difficult to distinguish these sweet potato varieties on the basis of starch granule shapes. The mung bean starch granule shapes were more homogeneous, consisting of small, round-shaped and large, kidney-shaped particles. Some of large granules in both sweet potato and mung bean starches had centered fissures, while small ones almost no had this phenomenon.

The granule size range of all sweet potato starch was not clearly different from that of mung bean starch. Nevertheless, the starch granule average size of all sweet potatoes was significant smaller than that of mung bean. The mean length of SPS granules ranges from 14 to 17µm while granule length of MBS was about 24µm (Table 1). This could be explained that the ratio of large particles to small ones for all sweet potato starches was nearly equal whereas for mung bean starch the large granules account for a larger proportion. Granule size and particle size distribution influenced on water binding capacity, swelling power and paste clarity as well as applicable ability of starches in food processing [4].

**Starch color**

The desired starches for noodle production should be high value for lightness and low value for chroma [2]. The color of starches extracted from SP1_W_YR and SP3_P_Y varieties was no significant difference to that of MBS in terms of lightness (L*), yellowness (b*). However, due to slight difference in greenness (a*) resulted in small difference in whiteness (Table 2). While the SP2_P_P and SP4_OP_O

**Figure 2:** Light microscopy (40X) of starch granules of sweet potatoes and mung bean.

| Note: |
|-------|
| SP1_W_YR: White skin and yellow-red flesh color |
| SP2_P_P: Purple skin and purple flesh color |
| SP3_P_Y: Purple skin and yellow flesh color |
| SP4_OP_O: Orange-purple skin and orange flesh |
| MBS: Mung bean starch |
varieties contained a higher amount of pigments, polyphenol oxidase and phenolic compounds which are easily undergo denaturalization or browning during starch isolation and drying process, lead to inferior starch color [4].

Gel texture

The gel texture of MBS was significant higher in hardness, which was about 1.2 kg forces, than that of all SPSs which ranged from 0.13 to 0.26 kg force depending on varieties, but markedly lower in gel stickiness. The gels obtained from SP1_W_YR and SP4_OP_O starches were more firmness than the other SPSs although there were no considerable differences in stickiness (Table 3). The mechanical properties of starch gel depended on the amylose content and amylopectin structure. The starches which exhibited higher gel firmness seem to have higher amylose content and longer amylopectin chains [2,20]. The soluble starches which exhibited higher gel firmness seem to have higher amylose restricted the starch granules swelling, resulting in low peak viscosity have negative correlation with amylose content because the degree of bonding within the crystalline region [25]. The very high phosphorous content [4] differences in size and shape of starch granules required longer time to gelatinize than mung bean starch. The pasting temperature and peak time could have implications for the stability of components in formulated food, and also indicated energy costs [14].

The peak viscosity of all sweet potato starches ranged from 403.06 RVU for SP1_W_YR starch to 473.63 for SP4_OP_O starch that of mung bean starch was in the middle of that range about 427.31 RVU (Table 4 and Figure 3). The peak viscosity found in this research for sweet potato starches appeared in the range with the findings of Collado and Corke [15], in which the peak viscosity of sweet potato starches were from 377 RVU to 428 RVU. They also reported that peak viscosity have negative correlation with amylose content because the amylose restricted the starch granules swelling, resulting in low peak viscosity. This seems to be not comparable to the results in this study. The differences in peak viscosity may partly result from differences in phosphorous content [4] differences in size and shape of starch granules [14] or difference in size and branching chain length of amylopectin [20,24]. Starches with higher in phosphorous content exhibited a higher peak viscosity due to increasing hydration of starch by weakening the degree of bonding within the crystalline region [25]. The very long branch chains of amylopectin mimiced amylose to form helical complexes with lipids and interlink with other branch chains to hold the integrity of starch granules during heating and shearing, resulting in low peak viscosity [18]. Larger granules had a lower surface area to volume ratio and therefore the association between hydrogen bond and granules were very weak, hence enhanced swelling [26].

The results in Table 4 indicated that mung bean starch withstands shear much better and higher temperature than all sweet potato starches due to very low breakdown value, which was about 94.97 RVU.
comparing to that for sweet potato starches, ranging from 203.69 RVU (SP1_W_YR) to 237.28 RVU (SP3_P_Y). Among sweet potato starches, SP1_W_YR starch was the most stable to temperature and shear treatment, followed by SP4_OP_O, SP2_P_P and SP3_P_Y starches in descending order.

The tendency of starch retrogradation can be predicted by using setback ratio obtained from RVA curve. Higher setback value indicates higher rate of retrogradation. Setback value in Table 4 indicated that the retrogradation rate of mung bean starch was higher approximately three times than that of all sweet potato starches. The starches with higher amylose content exhibited higher setback value, more hardness and less stickiness. Therefore, the setback was considered as another important criterion for starch selection for many food industries such as noodles [14,22].

The pasting profiles can be used for evaluation of suitability for starch noodles. The firmness of starch noodles was positively significant correlation to final viscosity [15]. This final viscosity for mung bean starch was about 599.69 RVU, much higher than those for all sweet potato starch (240.06-349.29 RVU). Starches with high trough viscosity generally exhibited superior eating quality and low cooling loss while that with high final viscosity related to high shear resistance [22].

The above presented properties indicated that the mung bean starch was the best material for noodle production, the SP1_W_YR and SP4_OP_O starches were more suitable for making noodle than the SP2_P_P and SP3_P_Y starches. However, the isolated starch of SP4_OP_O variety had low starch yield and purity of starch, together with output limitation; the SP1_W_YR starch was chosen for blending with mung bean starch in noodle production.

### Correlation among sweet potato starches properties

The results of correlation among property parameters of sweet potato starches shown in Table 5 that the ash content was well negative correlated to starch whiteness (r = -0.94, P < 0.01). This indicated that starches with high ash content had low in whiteness because ash expressed the fine fibers or pigments remaining in starch after isolation which could be browned after drying. A significantly positive correlation was observed between amylose content and trough viscosity (r = 0.91, P < 0.01), final viscosity (r = 0.92, P < 0.01), setback viscosity (r = 0.89, P < 0.05) and gel hardness (r = 0.82, P < 0.05). Moreover, highly positive relationship also was found between peak and final viscosity (r = 0.91, P < 0.01). These relations can be explained that higher amylose content led to higher rate of amylose leaching into free water, resulting in greater peak viscosity. This associated with greater degree of starch swelling could be to increase in final viscosity, more viscous network and high rate of retrogradation upon cooling [7,22].

### Effects of substituted ratios of SPS for MBS on starch noodle quality

**Noodle colors:** For both forms of dry and cooked noodles, the MBS_N were much more lightness and greatly less yellowness and greenness than SPS_N (Table 6). The different color between MBS_N and SPS_N could be due to difference of starch color (Table 2) or due to difference of degree integrity and association of starch chain after pasting [4]. The transparency was the most important appearance attribute of noodles. The transparent noodles were perceived as high quality product by customers [2]. The increase of substituted ratio of SPS for MBS resulted in reducing in lightness but increasing in yellowness and greenness of noodles, resulting in decrease of noodle quality. Nevertheless, the color of both dry and cooked noodles with 20% SPS was not significantly different to that of MBS_N.

### Table 5: Correlation among property parameters of sweet potato starches

| Samples | Dry Noodles | Cooked Noodles |
| --- | --- | --- |
| L* | a* | b* | L* | a* | b* |
| MBS_N | 57.99(0.67) | -1.35(0.21) | 5.41(0.20) | 55.67(0.02) | -1.84(0.02) | -3.97(0.24) |
| 1S_9M_N | 57.19(0.41) | -1.26(0.06) | 5.39(0.06) | 55.49(0.28) | -1.87(0.06) | -3.89(0.16) |
| 2S_8M_N | 57.05(1.18) | -1.25(0.05) | 8.39(0.35) | 54.95(0.41) | -1.92(0.07) | -1.86(0.47) |
| 3S_7M_N | 56.80(0.15) | -1.22(0.09) | 11.18(0.30) | 53.64(0.70) | -2.21(0.06) | 0.62(0.46) |
| 4S_6M_N | 54.13(0.04) | -1.18(0.04) | 12.44(0.53) | 53.12(0.59) | -2.49(0.10) | 0.24(0.15) |
| SPS_N | 48.62(0.44) | 0.72(0.08) | 15.83(0.40) | 51.62(0.28) | -2.78(0.03) | 3.93(0.33) |

All values are mean of three replications. Data in the parenthesis are standard deviation. Within the same column, the values with different letters are significant difference at p < 0.05 by LSD test.

### Table 6: The color of dry and cooked noodles at different ratios of SPS and MBS
Cooking quality: Three important factors standing for cooking quality namely cooking time, cooking loss and rehydration shown in Table 7 indicated that cooking quality of MBS_N was superior to that of SPS_N, and the blending SPS with MBS would reduce cooking quality of noodles in the ways of increasing in cooking loss and rehydration but reducing in cooking time. The differences in cooking time and rehydration between MBS_N (10.33 min and 21.22% respectively) and SPS_N (8.67 min and 285.99% respectively) could be differences in swelling and solubility of starch, and noodle inside structures. The starchy with higher swelling power resulted in higher rehydration and shorter cooking time of noodles [3]. The MBS noodles had a compact structure while inside structure of SPS noodles was loose and porosity. Therefore, SPS_N absorbed more water and faster than MBS_N, leading to shorter cooking time [2]. The slow water absorption of MBS_N in the first 0.5 hr was good eating quality because cooked noodles were usually consumed within 0.5 hr [4].

Although amylose content in SPS was significant lower than that of MBS (Table 1), the cooking loss for SPS_N (3.68%) was nearly threefold than that for MPS_N (1.44%). These results were in agreement with findings of Chen [4] and conclusions of Kim [3] in which there was negative significant correlation between cooking loss of starch noodles and amylose content. The desired noodles should have short cooking time and less cooking loss [13]. The cooking loss of all noodles was still accepted according to Chinese Agriculture Trade Standards and Thai Standards for starch noodles in which cooking loss should be less than 10 and 9% respectively [2]. The cooking quality of the 20% SPS containing noodles could be comparable to that of MBS noodles.

Noodle Texture: The extension modulus (E), which is a measurement of stretch-hardness of cooked noodles, and the relative extension (ε), which expresses the stretch-ability of cooked noodles, shown in Table 7 revealed that the extension modulus and relative extension of MBS_N (51.40 MPa and 1.80 respectively) were markedly higher than those of SPS_N (28.42 MPa and 1.21 respectively). These results were in the line with the findings reported by Chen and Kasemsuan [4,8]. The tensile strength of MBS_N in this study which was 51.40 MPa was slight lower than that of mung bean starch noodles prepared from 50% dry starch and 50% gelatinized starch by dropping method which was about 54 MPa [8]. The differences in cooked noodles texture between MBS_N and SPS_N could be different about the leaching-out amylose content, swelling power and solubility of starch [6]. Besides, the inside structure of SPS_N was loose and existed many small pores, resulted in low tensile strength comparing to that of MBS_N which was compact structure. The desired starch noodles should be high tensile strength [2,3,9]. They should remain in a noodle strand and withstand to turbulences and mixing during cooking or frying. The addition of SPS to MBS affected significantly the noodle extension. However, the extension of noodles prepared from 30% SPS and 70% MBS was not significant in comparison to that of MBS_N.

Sensory evaluation: The results of sensory evaluation shown in Table 8 indicated that appearance of both dry and cooked SPS_N, which was yellowish, were lower than that of reference sample. High transparent noodle was considered as high quality product by customers [2]. The transparency of noodles highly depended on starch physiochemical properties and phosphorus content [3]. In some extent, there was no significant change in appearance as until 20% SPS replaced for MBS in dry noodles and 40% SPS replaced for MBS in cooked noodles in comparison to that of reference (Figure 4). The off-flavor of noodles could be as results of adding bleaching chemicals or degradation by microorganism, etc. Therefore, the starch noodles should be no off-flavor. From the results of sensory evaluation, all samples were absence of off-flavor. Among noodle properties, texture could be the most important property. The dry SPS_N was high hardness and easy to break during transportation and delivery; while cooked SPS_N was high stickiness, and the adhesiveness each other among strands, together with low in elasticity, resulted in breaking into small strands during mixing or other mechanical impacts. The changes in texture of dry and cooked noodles were not recognized by panelists as about 30% of SPS replaced for MBS in comparison to pure MBS noodles. Although there was high deviation in results evaluation among panelists, the evaluation results for appearance and texture of noodles were well correlation with the results of color and texture measured by instruments (Table 6 and 7).

Overall, the blending MBS with 20% SPS for noodle production almost did not cause any significant changes in appearance, cooking quality, texture and sensory evaluation in comparison to those of pure MBS noodles.

Effects of solid content of starch slurry on noodle quality

The transparency was the most important appearance attribute.
of starch slurry resulted in markedly increasing of extension modulus and cooking loss [2,3]. The excessive presence of incompletely gelatinized starch granules in noodle matrix promoted starch solubility into cooking water during aging and effectively stabilized the starch chains in the gel matrix [15]. Therefore, as prolong aging time of gelatinized starch, there was more amylose or short-chain amylopectin molecules participated to cooking loss and noodle texture. The starch retrogradation occurred in sheet formation, reducing in cooking quality of noodle, raising retrogradation rate which was believed to highly impact on gel formation [7]. Moreover, solid content greatly affected to retrogradation rate which was determined by high impact on gel formation and strength. As increasing of solid content, retrogradation rate might continuously increase, resulting in more stretch hardness noodle texture [3].

From all above results, at 45% of solid content resulted in difficulty in sheet formation, reducing in cooking quality of noodle, raising noodle color and very high extension modulus or stretch hardness. Therefore, solid content of 35-40% was found to suitable for producing good quality noodles. However, with aims to reduce noodle cost, 35% of solid content was chosen for next experiment in which effects of aging time at 4°C were evaluated.

Effects of aging time of gelatinized starch on starch noodle quality

The aging time was not significantly influence on color of dry noodle, except to yellowness which was decrease with increasing aging time; cooking time; rehydration and relative extension (Table 11 and 12). However, it was considerable effect lightness, cooking loss and extension modulus of cooked noodles. These results could be comparable to those of Kim [3] in which aging time was markedly effect to cooking loss and noodle texture. The starch retrogradation occurred during aging and effectively stabilized the starch chains in the gel matrix [15]. Therefore, as prolong aging time of gelatinized starch, there were more amylose or short-chain amylopectin molecules participated in retrogradation process, resulting in highly impact to noodle strength and cooking loss [2,3].

Conclusions

The results of this study revealed that MBS was the ideal material of noodles. The transparent noodles were perceived as high quality product by customers [2]. The color of noodles at various solid contents was significant difference (Table 9). As increasing solid content of starch slurry, it was likely to reduce lightness (L*) of noodles, especially for dry noodles. The high solid content of starch slurry could lead to insufficient water for starch completely gelatinization, the presence of incompletely gelatinized starch granules in noodles could affect noodle color or transparency.

The cooking time, rehydration and cooking loss of starch noodles considerable increased with increasing of solid content of starch slurry (Table 10). The water content in starch slurry can become inadequate for starch gelatinization as starch concentration in starch slurry was too high [3,15]. The excess presence of incompletely gelatinized starch granules in noodle matrix promoted starch solubility into cooking water, resulting in high cooking loss and long cooking time.

The results in Table 10 indicated that as increase of solid content of starch slurry resulted in markedly increasing of extension modules (E) and relative extension (re) of cooked noodles. These findings were similar to results obtained for rice and mung bean starch vermicelli produced by extrusion method [7,27] and sweet potato starch noodles produced by cutting method [3]. The amount of swollen starch granules and leaching-out amylose could be not enough for forming a continuous matrix at low starch concentration. The slurry starch with higher solid content offered sufficient leaching-out amylose amount to speed up gel formation [7]. Moreover, solid content greatly affected to retrogradation rate which was believed to highly impact on gel formation and strength. As increasing of solid content, retrogradation rate might continuously increase, resulting in more stretch hardness noodle texture [3].

All values are mean of three replications. Data in the parenthesis are standard deviation. Within the same column, the values with different letters are significant difference at p < 0.05 by LSD test.

Table 9: The color of dry and cooked noodles at different solid content .

| Samples    | Dry noodles | Cooked noodles |
|-----------|-------------|----------------|
|           | L*          | a*            | b*            | L*          | a*            | b*            |
| 35S55WN   | 57.53(0.14) | -1.54(0.06)   | 9.68(0.13)    | 56.95(0.88) | -2.23(0.18)   | -0.43(0.20)   |
| 40S60WN   | 57.05(1.18) | -1.20(0.03)   | 8.84(0.35)    | 54.95(0.41) | -1.92(0.07)   | -1.80(0.47)   |
| 45S55WN   | 55.98(0.33) | -1.68(0.03)   | 9.44(0.03)    | 55.79(0.40) | -2.05(0.15)   | -0.54(0.04)   |

All values are mean of three replications. Data in the parenthesis are standard deviation. Within the same column, the values with different letters are significant difference at p < 0.05 by LSD test.

Table 10: The cooking quality and tensile characteristics of noodles at different solid content.

| Aging Time(hr) | Dry Noodles | Cooked Noodles |
|---------------|-------------|----------------|
|               | L*          | a*            | b*            | L*          | a*            | b*            |
| 1             | 57.53(0.14) | -1.54(0.06)   | 9.68(0.13)    | 56.95(0.88) | -2.23(0.18)   | -0.43(0.20)   |
| 10            | 57.92(0.45) | -1.44(0.03)   | 7.67(0.22)    | 59.37(0.27) | -1.91(0.06)   | -0.48(0.16)   |
| 20            | 57.90(0.45) | -1.44(0.01)   | 5.83(0.03)    | 57.93(0.3)  | -2.22(0.02)   | -1.82(0.17)   |

All values are mean of three replications. Data in the parenthesis are standard deviation. Within the same column, the values with different letters are significant difference at p < 0.05 by LSD test.

Table 11: The color of dry and cooked noodles at different aging time.
3. References

4. Acknowledgements

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