Physico-chemical and rheological properties of modified corn starches and its effect on noodle quality

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Abstract In this study, three different modification methods (pregelatinization, acid-thinning and dextrinization) were used to produce the modified corn starches. Physicochemical and rheological properties of the native and modified corn starch were studied. In addition, the resultant modified corn starches were used at levels 5%, 10% and 15% to replace wheat flour in noodle processing. The crude protein and lipid contents of modified corn starches significantly decreased compared to native ones. Water and oil binding capacity of corn starch increased up to 1.49 and 2.35 g/g, respectively, after modifying by the pregelatinization method. Results also showed that the maximum solubility was given by dextrinized corn starch after heat treatment at 90 °C being 44.85%, which means about 5.9-fold increase in solubility as compared to native starch. However, acid-thinning modified corn starch showed a significant decreased effect on the syneresis of its gel in comparison to those of other modified starches and the native one. The maximum viscosity decreased in pregelatinized starch followed by acid-thinned starch in comparison to native corn starch. The same trend was found in the viscosity after holding at 95 °C for 15 min. The highest noodle weight and volume increases were recorded for noodles containing 5% and 10% of native corn starch followed by 10% of pregelatinized corn starch, as well as, the control. Replacing wheat flour with 5%, 10% and 15% of native or pregelatinized corn starch did not cause any negative effects on sensory attributes of noodles in comparison to the control sample. Finally, it could be
Introduction

Starch is an important ingredient for the food industries, whereas starches with specific properties are necessary to impart functionality desirable attributes to foods. Native starches provide viscous, cohesive and sticky pastes when they are heated and gels when these pastes cool off (Adebowale et al., 2005). In general, native starch presents low shear stress resistance and thermal decomposition, in addition to high retrogradation and syneresis. Native corn starch can be modified to obtain pastes with specific attributes that can resist extreme food processing requirements like heat, stirring and low pH conditions.

Starch modification may be done by physical or chemical methods. Physical modification is made using heat and moisture (pregelatinization); while chemical treatments involve the introduction of functional groups into the starch molecule using reactions of derivatization (etherification, esterification and crosslinking) or decomposition (acid or enzymatic hydrolysis and oxidation) (Singh et al., 2007). Knowledge about physical and chemical modification effects on starch granules structure is necessary to understand their functional properties and allow developing starches with desired properties enhancing their uses especially in food industry. Modification treatment, reaction conditions and starch source are critical factors that govern the pasting behavior of starch pastes (Reddy and Seib, 1999; Gonzalez and Perez, 2002; Singh et al., 2004).

Noodles are widely consumed throughout the world and it is a fast growing sector of the noodle industry. The world instant noodle market is projected to reach 158.7 billion packs by the year 2010 (Anonymous, 2008). This is because noodles are convenient, easy to cook, low cost and have a relatively long shelf-life. It has been estimated that at least 12% of global wheat production is used for processing Asian noodle products (FAO, 2005; Hou, 2001). Market research has typically indicated that consumption of noodles continues to expand rapidly in various countries in Europe, South America, the Middle East as well as, Asia. Of the many types of noodles, instant noodle is the fastest growing sector of these products. The unique processing, involving steaming and deep frying, gives instant noodles a distinctive flavor and texture (Rho et al., 1986). The texture of noodles is expressed as rubbery, firm, or smooth (Kubomura, 1998).

Instant noodles should have a porous spongy structure as well as pregelatinized starch through the steaming process (Wu et al., 1998). During the frying process, many tiny holes are created as water is quickly dehydrated and replaced by oil on the surface of the noodles, serving as channel for water during cooking (Hou, 2001). Frying and steaming processes can enable quick serving compared with other types of noodles, and the processes are important in governing the quality of instant noodles (Kim, 1996).

Therefore, the aim of this study was to investigate the effects of different modification methods on physicochemical properties of corn starch and its application in noodles preparation.

Materials and methods

Materials

Commercial yellow corn (Zea maiz) was kindly obtained from Egyptian starch and glucose company, Cairo, Egypt. Commercial wheat flour (72% extraction) was obtained from 6th October for Milling and Marketing Co., 6th October City, Cairo, Egypt. Salt (sodium chloride), was purchased from the local market Cairo, Egypt.

Methods

Corn starch isolation

Corn starch was isolated according to the method of Takeda et al. (1988) as follows: corn kernels were steeped in 0.5% Na2SO4 solution, pH 4–5 at 50–52 °C for 2 days. The softened kernels were homogenized with cold water (10 °C) for 10 min and then, the homogenate was squeezed through a 100 mesh sieves. The starch was washed three times with cold water followed by centrifugation at 1000g for 15 min and then dried in an air dried oven at 40 °C for 12 h.

Preparation of modified corn starches

Modified starch by pregelatinization. Starch solution 1:1 (750 g starch + 750 ml deionized water) was incubated at 63 °C for 5 min. Gelatinized starch was produced by drying the solution at room temperature (20 ± 2 °C) for 24 h (Knight, 1969).

Modified starch by diluted acid. Three hundred and seventy-five milliliters of 0.1 N HCL solution was added to a mixture of 750 g starch and 375 ml deionized water and mixed for 30 min. Then, the pH was adjusted to 7.0 with 1 N NaOH. Neutralized starch was dried at room temperature (20 ± 2 °C) for 24 h following washing three times and filtration with Filter Paper No. 1 (Caglarirmak and Cakmakli, 1993).

Dextrinized modified starch. A weight of 750 g of corn starch was mixed thoroughly with 600 ml of 0.1 N HCL, and then dried at 50 °C for 32 h to 5% moisture content. The dried starch was dissolved in 750 ml deionized water and pH was adjusted to 7.0 by adding 80 ml of NaOH. The starch was dried at room temperature (20 ± 2 °C) for 24 h (Caglarirmak and Cakmakli, 1993).

Chemical composition

Native and modified corn starches by different methods were chemically analyzed for their moisture, ash, lipids (ether extract), crude fiber and crude protein contents (N × 6.25) according to the methods described in AACC (2000). The nitrogen free extract (NFE) was calculated by difference.
Bulk density and pH determination

Bulk density of native and modified corn starches was determined according to the method of Adeleke and Odedeji (2010) as follows: starch sample (50 g) was put into a 100 ml measuring cylinder. The cylinder was tapped several times on a laboratory bench to a constant volume. Bulk density (g/cm³) was calculated by dividing the weight of sample on its volume after tapping. The pH of the starch samples was measured according to the method of Adeleke and Odedeji (2010) using a pH meter (HANNA, HI 9025) already standardized with buffer solutions of pH 4.0 and 7.0. Each sample (10 g) was homogenized in 50 ml of distilled water and the resulting suspensions were decanted and their pH values were determined.

Water and oil binding capacity

Distilled water (15 ml) was added to 1 g of the corn starch sample in a weighed 25 ml centrifuge tube. The tube was agitated on a vortex mixer for 2 min, and then centrifuged at 1250g for 20 min. The clear supernatant was decanted and discarded. The adhering drops of water was removed and re-weighed. Water binding capacity (WBC) is expressed as the weight in gram of water bound by 1 g dried sample. For oil binding capacity (OBC) determination, 10 ml of refined corn oil was added to 1 g of the corn starch sample in a weighed 25 ml centrifuge tube. The tube was agitated on a vortex mixer for 2 min and then centrifuged at 1250g for 20 min. The volume of free oil was recorded and decanted. Oil binding capacity is expressed as gram of oil (d = 0.9198) bound by 1 g dried sample (Adeleke and Odedeji, 2010).

Swelling power and solubility

Swelling power and solubility determination were carried out at 50, 70 and 90 °C using the method of Leach et al. (1959). A 1% aqueous suspension of starch (100 ml) was heated in a water bath at 90 °C for 1 h with constant stirring. The suspension was cooled for half an hour at 30 °C. Samples were then poured into preweighed centrifuge tubes, centrifuged at 3000g for 10 min and weight of sediments was determined. For the measurement of solubility, the supernatants were poured into aluminum dishes and evaporated at 110 °C for 12 h and weight of dry solids was determined.

Syneresis

The syneresis of the starches was determined according to the method described by Singh et al. (2004). Starch suspension (2%, w/v) was heated at 85 °C for 30 min in a water bath, followed by rapid cooling in an ice-water bath to room temperature. The starch samples were stored for 24, 48 and 120 h at 4 °C. Syneresis was measured as the percentage of water released after centrifugation at 3000g for 15 min.

Visco-amylograph test

Rheological properties of native and modified corn starch pastes were measured by using Barabender amylograph (OHG Duisburg kulturstra Be S1–55, D-4100 Duisburg, Germany) according to Merco and Juliano (1981) as follows: a slurry of 50 g of starch (10%) was mixed with 450 ml of distilled water in the bowl of the amylograph. The mixture was shaken and the temperature of the sample was increased from 25 to 95 °C at a rate of 1.5 °C per min. The sample was left at 95 °C for 15 min, while stirring and recording the viscosity continuously. The starch paste was then cooled at 50 °C at a rate of 1.5 °C per min and held for 15 min, at this temperature, while stirring and recording viscosity continuously, the viscosity in Barabender Units (B.U.) was calculated from the obtained amyl grams.

Preparation of noodles

Noodle samples were prepared according to the procedure described by Oh et al. (1983). Wheat flour (100 g) and 2 g of salt were mixed with 30 g of water; the proper water absorbent was determined by the appearance and handling properties dough sheet. After mixing, the dough was pressed into an initial dough sheet by passage through the rolls of the laboratory machine (Past Matic 1000 Simac Machine Corporation, Milano, Italy). The final dough sheet had a thickness of 1.5 mm immediately after sheeting; the dough sheet was cut into 5 mm-wide noodles strips. Steaming procedures were carried out according to Baik et al. (1994). Fresh noodles were steamed at atmospheric pressure for 3 min using a steam blancher. The drying temperature was held constant at 45 °C for 14 h then the samples were cooled enough to room temperature (20 ± 2 °C), packed in polyethylene bags for further analysis. The wheat flour used in noodles preparation was replaced at levels of 0%, 5%, 10% and 15% of starches.

Cooking quality of noodles

Noodles cooking quality was determined according to the approved method in AACC (2000). Optimum cooking time was the time required for the opaque central core of the noodle to disappear when squeezed gently between two glass plates after cooking. Twenty five grams of noodles were cooked for optimum time in 300 ml tap water in a beaker rinsed in cold water and drained for 15 min before weighed. Percentage of increased weight was calculated as a cooking yield. Solid contents in the cooking water were determined by drying at 105 °C overnight. The cooking loss was expressed as a percentage of the difference between the solid weight and initial dry matter. Volume increase was calculated by dividing the water displacement of cooked noodles on the water displacement of an equivalent amount of uncooked noodles.

Sensory evaluation of cooked noodles

The cooked noodles were subjected to evaluate their appearance, color, flavor, texture (stickiness) and mouth feel (tenderness) by 10 members of a semi trained preference test panel from the staff of the Food Science Department, Faculty of Agriculture, Ain Shams University as described by Matz (1959).

Statistical analysis

Data were expressed as means ± SD. Statistical analysis was carried out using the PROC ANOVA followed by Duncan’s multiple range test for comparison between means. Different alphabetical letters in the column are statistically differed at 5% level of significant (Snedecor and Cochran, 1980). All procedures were triplicate using Statistical Analysis System program (SAS, 1996).

Results and discussion

Chemical composition of native and modified corn starch

Corn starch was selected as a standard for comparison since its physico-chemical properties are well established. The proximate composition of native, pregelatinized, acid thinned and
Dextrinized corn starches are presented in Table 1. The obtained data indicated that the four studied starches were significantly (P ≤ 0.05) varied in their composition except in ash content of native 0.78% and pregelatinized 0.79% starch were statistically equal, as well as, NFE of pregelatinized and acid-thinned starch had the same value of 98.33%.

The moisture content of analyzed samples ranged between 9.70% and 13.70%, these obtained values were less than 20% and were acceptable (Wolfgang et al., 1999) because it is allowed commercially up to 20% of moisture in starch as raw material. The low moisture content is usually reflects the high stability during storage, the starches are protected from mold growth and give a high yield of dry weight. Regarding the protein, lipid and ash contents, their percentages were less than 1%, the native starch registered the highest protein content (0.73%), while dextrinized starch had the highest ash content (0.90%). On the other hand, acid thinned starch presented the lowest protein and ash values (0.42% and 0.70%, respectively). The amount of protein is usually considered as an index of purity of legume and cereal starches (Lii and Chang, 1981). Generally, starch ash is mainly composed of phosphorus, sodium, potassium, magnesium and calcium. The phosphorus content is seen as the phosphate groups, which are founded to the amylopectin molecules and confer a polyelectrolyte nature to the chains, the ionic nature allows starch dispersions to develop high viscosity. Concerning the content of lipids, the native starch exhibited significantly the highest percentage (0.58%), meanwhile, pregelatinized starch recorded statistically the least lipid content (0.29%) (Beynum and Roels, 1985).

Physical properties of native and modified corn starch

Food eating quality is often connected with the relation of water and oil in swollen starch granules (Richard et al., 1992). The physicochemical properties of native and modified corn starch are listed in Table 2. No significant difference (P ≤ 0.05) could be recorded for bulk density between native and acid-thinned corn starch, meanwhile, significant difference was observed between the aforementioned samples and pregelatinized, as well as dextrinized corn starches (Table 2). No significant difference (P ≤ 0.05) in water binding capacity (WBC) g/g of native, acid-thinned and dextrinized corn starches could be recorded, it ranged between 1.18 and 1.22 g/g, it was noticed that the hydrophilic capacity of the native, pregelatinized and dextrinized corn starches was impaired after heat treatment, the low WBC of starch samples may be due to the reduction of amorphous region in the starch granules. This reduces the number of available binding sites for water in the starch granules (Lawal, 2004).

Contrarily, water and oil binding capacity (WOBC) increased after pregelatinization, which may be attributed to the fact that hydrophilic tendency of starch increases after heat-moisture treatment (Singh et al., 2009). From the same Table 2 the obtained pH values ranged between 5.43 for pregelatinized corn starch and 6.73 for dextrinized corn starch.

Swelling power and solubility of native and modified corn starch

The semi-crystalline structure of the starch granules is responsible for their low solubility even at high temperatures (Ferrini et al., 2008). The swelling power and solubility of native and modified corn starches at different temperatures 50, 70 and 90 °C are illustrated in (Figs. 1 and 2). It could be noticed that the native starch had statistically the highest swelling power; it was 2.70, 10.74 and 12.81 g/g at 50, 70 and 90 °C, respectively. The dextrinized corn starch showed significantly the lowest swelling power being 2.32, 3.70 and 4.66 g/g at 50, 70 and 90 °C, respectively. The swelling power of the starch decreased after acid thinning and pregelatinization having ordinary values being 2.44, 9.34, 10.31 and 2.52, 9.50 and 9.28 g/g, respectively at 50, 70 and 90 °C. Generally, significant (P ≤ 0.05) differences in the swelling power were observed between native and modified corn starches at 50, 70 and 90 °C. The low swelling power of the corn starch could be attributed to the presence of lipids in corn starch which may reduce the swelling of the individual granules by forming a complex with amylose (Galliard and Bowler, 1987). A maximum solubility (44.85%) was allowed commercially up to 20% of moisture in starch as raw material. The low moisture content is usually reflects the high stability during storage, the starches are protected from mold growth and give a high yield of dry weight. Regarding the protein, lipid and ash contents, their percentages were less than 1%, the native starch registered the highest protein content (0.73%), while dextrinized starch had the highest ash content (0.90%). On the other hand, acid thinned starch presented the lowest protein and ash values (0.42% and 0.70%, respectively). The amount of protein is usually considered as an index of purity of legume and cereal starches (Lii and Chang, 1981). Generally, starch ash is mainly composed of phosphorus, sodium, potassium, magnesium and calcium. The phosphorus content is seen as the phosphate groups, which are founded to the amylopectin molecules and confer a polyelectrolyte nature to the chains, the ionic nature allows starch dispersions to develop high viscosity. Concerning the content of lipids, the native starch exhibited significantly the highest percentage (0.58%), meanwhile, pregelatinized starch recorded statistically the least lipid content (0.29%) (Beynum and Roels, 1985).

**Table 1** Proximate chemical composition of native and modified corn starch (% on dry weight basis).

<table>
<thead>
<tr>
<th>Starch samples</th>
<th>Moisture</th>
<th>Crude protein (N × 6.25)</th>
<th>Lipids</th>
<th>Ash</th>
<th>Nitrogen free extract (NFE)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native</td>
<td>11.40 ± 0.14&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.73 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.58 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.78 ± 0.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>97.91 ± 0.91&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pregelatinized</td>
<td>11.65 ± 0.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.58 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.29 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.79 ± 0.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>98.33 ± 0.11&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Acid-thinned</td>
<td>13.70 ± 0.10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.42 ± 0.01&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.54 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.70 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
<td>98.33 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dextrinized</td>
<td>9.70 ± 0.14&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.54 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.47 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.90 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>98.09 ± 0.13&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Data are the mean ± SD; n = 3, values followed by the same letters in the same column are not significantly different (P ≤ 0.05).

<sup>a</sup> NFE calculated by difference.

**Table 2** The physical properties of native and modified corn starch.

<table>
<thead>
<tr>
<th>Starch samples</th>
<th>Bulk density (g/cm&lt;sup&gt;3&lt;/sup&gt;)</th>
<th>WBC (g/g)</th>
<th>OBC (g/g)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native</td>
<td>0.766 ± 0.009&lt;sup&gt;e&lt;/sup&gt;</td>
<td>1.20 ± 0.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.60 ± 0.21&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.47 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pregelatinized</td>
<td>0.790 ± 0.006&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.49 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.35 ± 0.07&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.43 ± 0.01&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Acid-thinned</td>
<td>0.770 ± 0.003&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.22 ± 0.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.98 ± 0.21&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.72 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dextrinized</td>
<td>0.850 ± 0.008&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.18 ± 0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.21 ± 0.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.73 ± 0.00&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Data are the mean ± SD; n = 3, values followed by the same letters in the same column are not significantly different (P ≤ 0.05). WBC, water binding capacity; OBC, oil binding capacity.
was recorded for dextrinized corn starch after heat treatment at 90 °C, which means a 5.9-fold increase in solubility as compared to its native counterpart. The increase in solubility following dextrinization is a result of depolymerization and structural weakening of the starch granules. A significant (P ≤ 0.05) difference between native and modified corn starches in solubility at 50, 70 and 90 °C was seen. The results are in accordance with Jyothi et al. (2006), Ferrini et al. (2008) and Singh et al. (2009).

Syneresis of native and modified corn starch

The syneresis of gels prepared from native and modified corn starches measured as amount of water released from gels during storage for up to 120 h at 4 °C is shown in Fig. 3. Syneresis of native and modified corn starch pastes increased with the increase in storage duration. Significant (P ≤ 0.05) differences in syneresis could be observed between native and modified corn starch gels, except for pregelatinized and acid-thinned ones after 72 h of storage period. Higher syneresis values: 76.75%, 77.75%, 79.30% and 80.30% were recorded in dextrinized corn starch gels after storage for 24, 48, 72 and 120 h, respectively. The retrogradation properties of starches are indirectly influenced by the structural arrangement of starch chains, which in turn, influence the extent of granule breakdown during gelatinization and the interaction that occurs between starch chains during gel storage (Perera et al., 1997). Acid-thinning had a decreasing effect on the syneresis of starch gels in comparison to the native counterpart. The low amylose content might have caused lowering syneresis of the starch during the gel formation and resulted in weaker gel structure (Singh et al., 2009).

Visco-amylograph measurements of the native and different modified corn starch are presented in Table 3. The gelatinization temperature of the corn starch samples ranged from 70.25 °C for pregelatinized and acid-thinned starch to 71.00 °C for native corn starch. The decrease in maximum viscosity of modified corn starch was observed for pregelatinized starch (940 B.U.) followed by 1050 B.U. for acid-thinned starch in comparison to 1080 B.U. for native corn starch. The dextrinized corn starch did not produce an amylograph curve. The general trend for the viscosity of samples under research pasting at 95 °C and after holding at 95 °C for 15 min was 1050, 840 B.U. for native corn starch to 875, 750 and 835, 695 for pregelatinized and acid-thinned corn starch, respectively. On the other side, increases in viscosity at 50 °C, as well as by holding at 50 °C for 15 min were noticed for pregelatinized corn starch 1595, 1780 B.U., native starch 1590, 1730 B.U. and acid-thinned corn starch 1355, 1555 B.U., respectively.

From the data in Table 3, it was noticed that, the acid-thinned and pregelatinized corn starches were strengthened as a result of modification and resisted the breakdown of paste, the relative breakdown ranged between 1.7-fold for acid-thinned corn starch to 8.0-fold for native corn starch (untabulated data). The bonding forces within the granules of starch affect its swelling power (Fig. 1). The high final viscosity and relatively low breakdown viscosity of modified corn starch by acid-thinning and pregelatinization are desirable properties because the native starch paste has a non-cohesive texture suitable for many food and industrial applications.
### Table 3  Visco-amylograph parameters of native and modified corn starches.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Native</td>
<td>71.00</td>
<td>91.25</td>
<td>1080</td>
<td>840</td>
<td>1590</td>
<td>1730</td>
<td>30</td>
</tr>
<tr>
<td>Pregelatinized</td>
<td>70.25</td>
<td>90.50</td>
<td>940</td>
<td>875</td>
<td>1595</td>
<td>1780</td>
<td>65</td>
</tr>
<tr>
<td>Acid-thinned</td>
<td>70.25</td>
<td>83.75</td>
<td>1050</td>
<td>835</td>
<td>1355</td>
<td>1555</td>
<td>215</td>
</tr>
<tr>
<td>Dextrinized</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
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</table>

Breakdown (1) = maximum viscosity – viscosity at 95 °C.
Breakdown (2) = maximum viscosity – viscosity after 15 min at 95 °C.
Setback (1) = viscosity at 50 °C – viscosity at 95 °C.
Setback (2) = viscosity at 50 °C – viscosity after 15 min at 95 °C.

* B.U., Barabender Unit; –, not recorded.

### Table 4  Cooking quality of cooked noodles prepared by substitution of wheat flour with different levels of native and modified corn starch.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Level of substitution (%)</th>
<th>Optimum cooking time (min)</th>
<th>Weight increase (%)</th>
<th>Volume increase (%)</th>
<th>Cooking loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat flour 100%       (control)</td>
<td>0</td>
<td>16.50 ± 0.50b</td>
<td>100.00 ± 1.00b</td>
<td>125.32 ± 1.00b</td>
<td>12.60 ± 0.30f</td>
</tr>
<tr>
<td>Native</td>
<td>5</td>
<td>16.50 ± 0.50b</td>
<td>100.00 ± 3.00b</td>
<td>125.00 ± 2.00a</td>
<td>13.50 ± 1.00f</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>15.50 ± 0.50b</td>
<td>111.00 ± 1.50a</td>
<td>125.00 ± 1.00a</td>
<td>15.80 ± 0.20f</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>15.50 ± 0.50b</td>
<td>98.50 ± 0.50bc</td>
<td>121.50 ± 1.50b</td>
<td>17.50 ± 0.50d</td>
</tr>
<tr>
<td>Pregelatinized</td>
<td>5</td>
<td>14.50 ± 0.50c</td>
<td>96.00 ± 1.00b</td>
<td>125.00 ± 1.00a</td>
<td>18.40 ± 0.40c</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>14.50 ± 0.50c</td>
<td>98.50 ± 0.50bc</td>
<td>125.00 ± 1.00a</td>
<td>13.50 ± 1.00f</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>16.50 ± 0.50c</td>
<td>78.50 ± 1.00d</td>
<td>125.00 ± 2.00a</td>
<td>19.00 ± 1.00f</td>
</tr>
<tr>
<td>Acid-thinned</td>
<td>5</td>
<td>15.50 ± 0.50b</td>
<td>74.00 ± 2.00b</td>
<td>100.00 ± 2.00d</td>
<td>20.50 ± 0.50b</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>14.50 ± 0.50c</td>
<td>81.00 ± 1.00b</td>
<td>105.10 ± 2.00c</td>
<td>21.30 ± 0.35a</td>
</tr>
<tr>
<td>Dextrinized</td>
<td>5</td>
<td>15.50 ± 0.50b</td>
<td>81.00 ± 1.00b</td>
<td>100.00 ± 1.00d</td>
<td>21.00 ± 0.20b</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>14.50 ± 0.50c</td>
<td>74.00 ± 2.00b</td>
<td>100.00 ± 3.00f</td>
<td>22.00 ± 0.00b</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>13.50 ± 0.71d</td>
<td>75.00 ± 1.41f</td>
<td>96.20 ± 0.85f</td>
<td>22.50 ± 0.35a</td>
</tr>
</tbody>
</table>

Data are the mean ± SD; n = 3, values followed by the same letters in the same column are not significantly different (P < 0.05).
The tendency of corn starches toward setback or gel formation are presented in Table 3, the relative calculated setback was ranged from 1.2-fold for native and pregelatinized corn starches to 1.3-fold for acid-thinned corn starch (untabulated data), probably due to the presence of functional groups that prevent starch chains from associating, as also reported by Moorthy (2002).

**Cooking quality of noodles**

Mean values of optimum cooking time (min), weight increase (%), volume increase (%) and cooking loss (%) of noodles prepared by substitution of wheat flour with different levels (5%, 10% and 15%) of native and modified corn starch are listed in Table 4. Cooking weight increase of noodles was significantly \( (P \leq 0.05) \) affected by the type and level of substitution. Noodles containing 10% native corn starch showed the highest cooking weight increase (111%) followed by that containing 5% of native corn starch, as well as the control one, being 100%, being statistically equal to those of noodles that contained 15% native starch and 10% pregelatinized starch having the same weight increase value (98.50%), this increase in cooked noodles weight was significantly equal to that obtained for noodles that contained 5% pregelatinized starch. However, cooked noodles containing more pregelatinized starch (15%), 10% and 15% acid-thinned starch or 5% dextrinized starch exhibited intermediately weight increase values, being statistically equal. While, cooked noodles contained 10% and 15% dextrinized starch recorded the least weight increase.

Concerning the volume increase (%), the cooked noodles prepared by substitution of wheat flour with 5% and 10% native starch, 10%, 15% pregelatinized starch were in the first order having significantly the same highest volume increase being equal to that of the control cooked noodles. However, cooked noodles containing 15% native starch was in the second order, followed by noodles that contained 15% acid-thinned starch, then those that contained 10% acid-thinned starch, and 5%, 15% dextrinized starch. The cooked noodles that contained 5% pregelatinized starch, 10% dextrinized starch and 5% acid-thinned starch showed the lowest volume increase values. Similar observations are in accordance with Kim and Wiesenborn (1996).

Cooking loss of the control noodles was 12.6%. However, the cooking loss for all modified corn starch–wheat flour blends was significantly higher than that of the control noodles, ranged from 15.8% to 22.5% except those containing 10% and 15% pregelatinized corn starch, their cooking loss was the same (13.5%), being statistically equal to that of the control noodle. Noodles containing 10% and 15% dextrinized corn starch had the most significant cooking loss being 22.00% and 22.50%, respectively. The undesirable effect on cooking loss may be due to the dilution of the gluten by increasing the substitution levels of starch. The data are in agreement with Lii and Chang (1981).

**Sensory attributes of noodles**

Sensory characteristics are an important indicator of potential consumer preferences. Differences in sensory quality attributes of all wheat noodles (control) and noodles prepared with native, pregelatinized, acid-thinned and dextrinized corn starch at 5%, 10% and 15% replacement levels are presented in Table 5.
Table 5. Noodles containing 5%, 10% and 15% of native and pregelatinized corn starch did not show any significant (P ≤ 0.05) difference in appearance, color, flavor, texture, mouth feel and total acceptability. Meanwhile, noodles containing 10% and 15% of dextrinized corn starch were rated lower in the aforementioned sensory characteristics. Generally, the all noodle samples containing 5%, 10% and 15% of native and pregelatinized corn starches were more acceptable in comparison to control ones and other samples containing acid-thinned and dextrinized corn starch which exhibited lower sensory characteristic scores. These findings are close to those of Kim et al. (1996).

Conclusions
An integral analysis of the physicochemical and functional properties of native and modified corn starch was performed using different techniques. The moisture content of analyzed samples ranged between 9.70% and 13.70% which are acceptable. The protein and lipids content was higher for native corn starch. No significant difference in bulk density and water binding capacity of native and acid-thinned corn starch could be observed. Water and oil binding capacity increased after pregelatinization method. Significant differences in swelling power could be recorded between native and modified corn starches at 50, 70 and 90°C. A maximum solubility was recorded for dextrinized corn starch after heat treatment at 90°C, which means a 5.9-fold increase in solubility as compared to native starch. Higher syneresis was recorded in dextrinized corn starch gels after storage for 24, 48, 72 and 120 h. The viscosity of samples pasting after holding at 95°C for 15 min was decreased in pregelatinized and acid-thinned corn starch. Noodles containing 5% and 10% of native corn starch showed the highest cooking weight increase comparing to the control. It could be concluded that the addition of native and pregelatinized corn starches to noodles formulation were recommended to enhance noodles quality.

References


