湿熱処理が強力小麦粉のタンパク質の消化性および粘性特性に及ぼす影響

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Effect of Heat-Moisture Treatment on the Digestibility and Viscous Characteristics of Hard Wheat Flour and Separated Wheat Starch

IKEDA Masayo*, MATSUMORI Shingo*† and AKUZAWA Sayuri*§

* Tokyo University of Agriculture, Faculty of Applied Bio-science, Department of Nutritional Science, 1-1-1, Sakuragaoka, Setagayaku, Tokyo 156-8502

The effects of heat-moisture treatment on the digestibility and viscous characteristics of hard wheat flour and separated wheat starch were examined to obtain basic data and information on texture modifier materials in food. From SEM, starch granules of heat-moisture-treated wheat flour appeared to change so as to have a flattened shape and showed adherence to other starch granules. The protein content and moisture content were not changed by heat-moisture treatment. The rate of protein degradation by pronase and the solubility of flour proteins in 0.5 M sodium chloride and water were markedly lower for the heat-moisture-treated wheat flour than for untreated native flour. The heat-moisture-treated wheat flour and separated wheat starch showed distinct peak viscosities; in particular, native and heat-moisture-treated starch showed considerable differences in their pasting temperature and peak viscosity. The apparent activation energy of native wheat flour paste at 14.7 kJ/mol was greater than that of the heat-moisture-treated wheat flour paste at 13.4 kJ/mol. In terms of starch pastes, the apparent activation energy of the heat-moisture-treated starch sample was 10.5 kJ/mol, whereas that of the native sample was 25.9 kJ/mol.

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Key words: Heat-moisture treatment, Wheat flour, SEM, Viscous characteristic, Apparent activation energy

The texture and rheology of food are very important and influential factors in the evaluation of foods. Food processing companies have been varying mixture proportions and improving processing techniques in response to the demand for food with new textures.

Heat-moisture treatment is a hydrothermal treatment that modifies the physicochemical properties of starch, but does not destroy the granular structure of starch. Many researchers have reported on the physicochemical properties of heat-moisture-treated starch11–15 and on the rheological properties of starch pastes16–19. In a previous study19, we reported that a heat-moisture-treated corn starch gel, which produces a soft-food feeling in the mouth, was suitable for use as a new food material. The physical modification of starch, as a natural material with high safety, is of interest in food applications.

There have been few reports on the properties of heat-moisture-treated tuber, root16, bean17, or wheat flour18; nevertheless, we have been using these materials in cookies, pastry, bread, and breakfast cereals19.

The objective of this study was to assess the effect of heat-moisture treatment on the viscous characteristics of wheat flour and separated wheat starch by comparing native and heat-moisture-treated wheat flour and separated wheat starch to obtain basic data on these useful food materials. We compared the starch granule shape, protein digestibility by pronase, and viscous characteristics of heat-moisture-treated wheat flour and separated wheat starch.

Materials and Methods

1. Materials

Two hard wheat flour samples (Ohtion produced by Nishin Seifun Co., Ltd.), one native and the

§ Corresponding author, E-mail: akuzawa@nodai.ac.jp
† Present address: Komazawa Woman's Junior College, Department Food and Nutrition; 238, Hamasaka, Inagi-shi, Tokyo 206-8511
other treated with heat moisture at 125°C for 20 min by Sanwa Cornstarch Co., Ltd., were used. The starch was separated from each wheat flour sample with 0.5% aqueous NaOH, and then washed and centrifuged with distilled water until a pH of 7 was obtained for the separated wheat starch-water slurry. After purification, the starch samples were centrifuged and dried in a dry-air oven overnight at 40°C. 

2. Microscopic observation

Samples were coated with platinum (about 20nm thick) by magnetron sputtering (JEOL JUC-5000), for 6 7 min and examined with a Hitachi HFS-2 scanning electron microscope at an accelerating voltage of 0.8 kV.

3. Chemical analysis

The water activity was determined using a Testo 650 instrument (Shimadzu Co., Ltd.). A wheat flour sample of 10 g was put into the Testo 650 chamber, and measurements were taken in a constant-temperature oven at 25°C. The protein content was determined by the Kjeldahl method (N × 5.7). The enzymatic digestibility of each wheat flour sample was carried out by adding 40,000 PU of pronase (Merck Co., Ltd. 4,000,000 PU/g EC 3.4.24.4) to a starch slurry of 100mL containing 1 g (w/w on the basis of the anhydride) of wheat flour. Aliquots of 5 mL were removed at specified time intervals, pipetted into 5 mL of 10% trichloroacetic acid (TCA) and centrifuged. Aliquots of the supernatant were analyzed for soluble proteins as TCA-soluble digestion products by the Lowry method.

4. Pasting properties

The gelatinization and pasting properties were determined with a Rapid Visco Analyzer (RVA; Newport Scientific Pty., Ltd.). Samples of 2.5 g of wheat flour or starch (10% w/w on the basis of the anhydride) were each transferred into a canister and approximately 25 mL of distilled water was added (corrected to compensate for 10% concentration). The slurry was heated from 30 to 95°C at 1.5°C/min, held at 95°C for 20 min, and finally cooled to 30°C at 1.5°C/min. The gelatinization and pasting properties were calculated from the obtained pasting curves showing the apparent viscosity in units of cp. RVU was calculated by multiplying what by the coefficient of 8.33 × 10⁻².

5. Viscous characteristics of wheat flour and separated starch pastes

Wheat flour and separated starch pastes for measurement of apparent viscosity were prepared as follows. Six percent (w/w on the basis of the anhydride) suspensions of wheat flour and separated starch were allowed to swell for 15 min, after which they were heated for 20 min in an autoclave (ES-215, Tomy Co., Ltd.) at 105°C. Each wheat flour sample and separated starch paste sample was allowed to stand at 20°C for 30 min before shear-thinning behavior was measured by a Rotovisco CV-20 instrument (Hakke Co., Ltd.) with an ME-30 sensor consisting of a coaxial cylinder and beaker. The measurement conditions were applied at each temperature of 10, 20, 30, 40 and 50°C at a fixed shear stress of 50 (s⁻¹). The point at which the rate of change of stress was under 1% was selected as the apparent viscosity at a specific shear rate. The effect of temperature on apparent viscosity can be described by the Andrade relationship as the apparent activation energy as follows:

\[ \eta = A e^{(E_a/R)(1/T)} \]

where \( \eta \) is the apparent viscosity, \( A e \) is a constant, \( E_a \) is the apparent activation energy (J/mol), \( T \) is the absolute temperature (K) and \( R \) is the gas constant (J/mol K).

RESULTS and DISCUSSION

1. Microscopic observation

Fig.1 shows scanning electron microscope (SEM) of the surfaces of wheat flour and separated starch samples. The native wheat flour has two types of granule with the shape of a swollen ellipse and a smooth surface, the diameters of the two types of granule being about 5 7 µm and 15 30µm. In the case of heat-moisture-treated wheat flour, however,
the surface of the granules shows cracks and the elliptical shapes are distorted. In addition, the starch granules of heat-moisture-treated wheat flour are flattened and contain a hollow portion at the center, and seem to adhere to several other starch granules. This deviation from the native spherical shape seems to have been caused by the effects of the heat-moisture treatment. These observations thus suggest that the internal structure of the starch granules and the formation of proteins have disintegrated.

2. Chemical analysis of wheat flour samples

The water content, water activity, protein content, and degradation rate of the protein of the native and heat-moisture-treated wheat flour samples are shown in Table 1. The moisture and protein content of the wheat flours were not changed by heat-moisture treatment; thus, this treatment seems to have changed the structure of the components without changing their content.

The degradation rate of protein in the native and the heat-moisture-treated wheat flour samples increased with time. The degradation rate of the native sample was about 30% after 5 minutes and almost reached a plateau after 30 minutes. In contrast, the degradation rate of the heat-moisture-treated flour was 2.3% after 5 minutes, and this rate increased only slightly after 30 minutes. However, these values were considerably lower than the native ones. HANSEN et al.\(^1\) have reported that albumins, globulins, and some gliadins aggregate, forming large urea-insoluble complexes as indicated by a decrease in protein solubility in urea. The content of salt-soluble protein was decreased from about 50.9% to 13.8% by heat-moisture treatment (data not shown). The degradation rate of flour protein by pronase was decreased by heat-moisture treatment. This observation suggests that the number of sites for degradation of wheat protein decreased because of aggregation resulting from the treatment. This aggregation was apparent from the combination of protein and starch granules that is shown in the SEM, and the degradation rate seems to have been decreased by these changes.

3. Change in viscosity with temperature during gelatinization of wheat flour samples

The shape of the pasting curve differed for the native and heat-moisture-treated samples, as showed in Fig. 2. Significant differences were observed, between native and heat-moisture-treated wheat flour or separated starch, during both heating and cooling in an excess of water. The pasting temperature of separated starch was increased by about 20.8°C by heat-moisture treatment. The heat-moisture-treated wheat flour and separated starch showed distinct peak viscosities; in particular, the native and heat-moisture-treated starch samples differed in their pasting temperature and peak viscosity. However, the trough viscosity and final viscosity values were similar for the native and heat-moisture-treated flour. These results could indicate that heat-moisture treatment led only to the formation of wheat flour granules covered with aggregated protein; thus, there were few differences in RVA properties between heat-moisture-treated wheat flour and native flour. In contrast, we previously reported\(^{13-15}\) that viscosity properties change markedly with this treatment, although the difference between the trough viscosity and final viscosity of each separated starch was

![Fig. 2 RVA pasting curves of 10% wheat flour and separated wheat starch samples](image)

N-S: native starch, HMT-S: heat-moisture-treated starch
N-F: native wheat flour,
HMT-F: heat-moisture-treated wheat flour

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture content (%)</th>
<th>Water activity</th>
<th>Protein content (%)</th>
<th>Protein Digestibility (%)</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Native</td>
<td>11.45</td>
<td>0.538</td>
<td>14.12</td>
<td>31.4</td>
</tr>
<tr>
<td>HMT</td>
<td>11.47</td>
<td>0.615</td>
<td>14.11</td>
<td>2.3</td>
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Table 1 Moisture content, water activity, protein content, and protein digestibility by pronase of the native and heat-moisture-treated wheat flours
negligible. We speculate that the separated starch of this heat-moisture-treated wheat flour was not modified significantly by the treatment, because the effect of heat-moisture treatment was reduced by the existence of protein.

4. Temperature dependence of the apparent viscosity of each wheat flour and separated starch paste

The change in quality, particularly, the viscosity of fluid foods, is very important during the processing and storage of food products. The effect of temperature on the apparent viscosity at a specified shear rate of the power law model of a fluid often can be described by the Andrade relationship. The apparent viscosity versus temperature plots for both wheat flour and separated starch pastes are shown in Fig. 3. From a plot of ln $\eta$ versus (1/T), the apparent activation energy of each 6% wheat flour and separated starch paste was calculated in the temperature range of 10–50°C by using the Andrade equation, and the resultant values are shown in Table 2.

The apparent activation energy of the native wheat flour paste was 14.7 kJ/mol, and that of the heat-moisture-treated one was 13.4 kJ/mol. The apparent activation energy of the heat-moisture-treated wheat flour was slightly lower than that of the native one, but the difference was not significant. In the case of the separated starch pastes, the apparent activation energy of the heat-moisture-treated starch paste was 10.5 kJ/mol, and that of the native one was 25.9 kJ/mol. From these results, we can infer that the RVA viscosity behaviors are not related to the apparent viscosity, and the influence of temperature on viscosity was reflected in the apparent viscosity over the range of temperature. The apparent activation energy is indicative of thermal stability because the viscosity change that occurs at the temperature of the paste was converted into energy. Heat-moisture treatment is a more useful modification method of controlling the viscous properties of starches than wheat flours. We propose that replacing the amount and type of wheat cereal with starch would be a good way to obtain new textures of foods; for example, replacing part of the wheat flour with heat-moisture-treated wheat starch would result in a change in the apparent viscosity and thermal stability in a mixture of foods.

![Graph showing temperature dependence of apparent viscosity](image)

**Table 2** Apparent activation energy of 6% wheat flour and separated wheat starch pastes

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<th>Sample</th>
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<tr>
<td>Native</td>
<td>14.7 ± 0.7</td>
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<tr>
<td>HMT</td>
<td>13.4 ± 1.0</td>
</tr>
<tr>
<td>Starch</td>
<td>25.9 ± 0.1</td>
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References


変化していた。平衡粘度から見かけの活性化エネルギーを算出し、小麦粉および澱粉ペーストの温度安定性を検討したところ、小麦粉ペーストは有意な差はみられなかったが、澱粉ペーストは湿熱処理10.5 kJ/mol、未処理25.9 kJ/molであり熱安定性が著しく向上していた。
（平成20年1月9日受付、平成20年3月18日受理）