Regular Paper

Improved Functional Properties of Potato Starch through Simultaneous Heat-moisture Treatment and Conjugation with Lysine and Fatty Acylated Saccharide by the Maillard Reaction

(Received February 28, 2013; Accepted July 9, 2013)
(J-STAGE Advance Published Date: July 17, 2013)

Noriki Kohyama,1,† Naomi Soga,2,* Satoko Ohashi,2,† Makoto Hattori,2 Tadashi Yoshida,2 Takanori Hasegawa,1 Yasuyuki Oishi,1 Fumiki Morimatsu1 and Koji Takahashi2

1R & D Center, Nippon Meat Packers Inc. (Midorigahara, Tsukuba 300–2646, Japan)
2Department of Applied Biological Science, Faculty of Agriculture, Tokyo University of Agriculture and Technology (3–5–8 Saiwai-cho, Fuchu, Tokyo 183–8509, Japan)

Abstract: Potato starch (PS), L (+)-lysine hydrochloride (Lys) and glucose/fructose stearic acid monoester (GE/FE) were conjugated by autoclaving them by heat-moisture treatment (HMT) and the Maillard reaction to prepare PS-Lys-GE/FE conjugate with a molar ratio of PS (as glucose residues) : Lys : GE/FE=684 : 1.0 : 0.66. PS-Lys-GE/FE exhibited increased thermal stability in terms of significantly higher gelatinization temperature, lower gelatinization enthalpy, lower solubility than those of native and control PSs. It maintained the state of swollen granules without collapse, even if heated at 110℃ for 30 min. In addition, gelatinized PS-Lys-GE/FE exhibited resistance to digestibility with α-amylase and easy vaporization of water, similar that of free water. Addition of PS-Lys-GE/FE markedly reduced the peak viscosity and breakdown values of wheat flour batter. Simultaneous modification through HMT and the Maillard reaction resulting in conjugation of PS with GE/FE through Lys could provide a conjugated starch material with unique properties in terms of the elevated gelatinization temperature, reduced solubility, swelling and digestibility, easy water vaporization, high thermal resistance, and reduced viscosity of wheat flour batter.

Key words: starch, amino acid, fatty acylated saccharide, Maillard reaction, heat-moisture treatment

INTRODUCTION

Starch is an important component of many foods, and is used to build and control the physical properties and structures of processed foods. Since starch occurs in nature as insoluble granules, gelatinization of starch by heating is essential to reveal its functional properties. However, gelatinization often causes extensive swelling, and easy breakdown under shearing stress, resulting in a decrease in the quality of starchy foods with the development of a sticky and pasty texture. In particular, heating to high temperatures (e.g. by retort treatment) results in drastic deterioration of physical properties through reduced viscosity of the paste due to collapse of the swollen starch granules and/or further breakdown of the starch chains.

Water vaporization from starchy foods, especially fried foods, has become of special interest, because daily consumption of fried foods has increased recently, and frying is a very useful food-processing method; it brings about many beneficial changes in foods through gelatinization of starch, denaturation and coagulation of protein, development of characteristic aromas and browning, and crispy of the fried coatings by dehydration. However, fried coatings rapidly lose their crispness because of transport of water from the food material inside; this results in deterioration in the quality of fried foods and shortening of their shelf life. It is therefore very desirable to control swelling and water vaporization to appropriately maintain such physical properties as viscosity and crispness.

To control viscosity and swelling and improve crispness, many efforts have been made to apply combinations of such substances as salts,1–4 sugars,3,5 alcohols,6 fatty acids,8 surfactants,3,9 organic acids,7 amino acids and peptides10–16 and compound substances17 to influence gelatinization behavior. Moreover, physical treatment such as heat-moisture treatment (HMT) and conjugating or compounding with non-starchy substances by the Maillard reaction have been applied to provide improved starch materials with such properties. For example, charged amino acids and charged amino acid-rich peptides exhibited an excellent ability to control viscosity and swelling, as shown by a marked increase in gelatinization temperature and reduced viscosity and swelling,10–16 as well as easy vaporization of external water in the swollen starch granules.18 It was also revealed that adding charged amino acids could improve the degraded viscosity of retorted starch paste during storage.19 However, the control of starchy food processing with adding modifiers described above is in insufficient, because few materials are available for food use; moreover, control becomes unstable.

1Equal contributor.
*Corresponding author(Tel.: +81–29–847–7817, Fax: +81–26–847–7824, E-mail: n.kohyama@nipponham.co.jp).
during practical food processing, because the effects of additives change with changes in the environment of the starch granules resulting from the production process. HMT provides a starch material with low viscosity and swelling, indicative of high structural stability, whereas the swollen starch granules would collapse during retort treatment after all. Recently, it has been reported that conjugation or compounding with charged amino acids, by the Maillard reaction or by autoclaving the mixture of starch and amino acids, exhibited fragile granules without substantial changes in appearance and crystallinity, and with greatly decreased viscosity and swelling and easy vaporization of water, similar that of free water. However, changes in the viscosity and swelling of the conjugate or composite through retort treatment have not been reported in these papers, indicating that the satisfactory improvement is still unknown at all in this way.

Emulsifiers such as sucrose fatty acid ester (SE) are frequently used as modifiers to control such thermal behavior as gelatinization and retrogradation. Emulsifiers such as sucrose fatty acid ester (SE) are unknown in this way. GE/FE was prepared by hydrolyzing SE according to a previously described method that achieved compounding with amino acids. In brief, PS (1 kg) and Lys (0.3 mol/kg of PS), were well mixed in a polyethylene bag, and then 200 g of the mixture was packed in a retort pouch. The pouch was tightly heat-sealed, and then autoclaved at 120°C for 90 min to perform simultaneous modification with heat-moisture treatment of PS and the Maillard reaction resulting in conjugation with Lys. After being cooled to room temperature, the reaction mixture was washed with DW to eliminate the unreacted Lys, and then air-dried to obtain the conjugate (PS-Lys). PS-Lys (100 g) was added to 70 mL of ethanol warmed at about 40°C containing GE/FE (0.6 mol/0.3 mol Lys and 1 kg of PS) and mixed. The amount of GE/FE giving significantly higher gelatinization temperature than that of Lys-PS from some conditions (0.3 mol/0.3 mol Lys, 0.6 mol/0.3 mol Lys and 1.5 mol/0.3 mol Lys) was selected. After being thoroughly air-dried, the reaction mixture was once again autoclaved at 115°C for 60 min in the manner just described to perform heat-moisture treatment of PS-Lys and conjugation with the free amino group of the Lys moiety of PS-Lys by the Maillard reaction. The autoclaving condition giving the highest gelatinization temperature and lowest gelatinization enthalpy from several conditions (110, 115 and 120°C for 30–120 min) was selected. The reaction product was extracted with warm ethanol to eliminate the unreacted GE/FE, and then washed with DW. The PS-Lys-GE/FE conjugate was recovered after air-drying.

**Differential scanning calorimetry (DSC).** The gelatinization behavior of PS-Lys and PS-Lys-GE/FE was studied by a SSC-5020 DSC 100 apparatus (SII NanoTechnologies Inc., Chiba, Japan) as previously described. For DSC analysis, Muse software (SII NanoTechnologies Inc.) was used. About 5 mg of sample and 10 μL of DW were sealed in an anodized aluminum sample capsule. DSC was carried out to determine the gelatinization temperatures [onset temperature (T<sub>n</sub>), peak temperature (T<sub>p</sub>), and conclusion temperature (T<sub>c</sub>)] and enthalpy change (ΔH) of gelatinization in the range of 5 to 100°C at a heating rate of 2°C/min. DW (15 μL) was used as a reference, and five measurements were performed.

**Measurement of pasting property of wheat flour with added PS-Lys-GE/FE.** The viscosity of wheat flour mixture containing 30% PS-Lys-GE/FE on a wheat flour basis was evaluated by an RVA Super 3 Rapid Viscoanalyzer (Newport Scientific Pty. Ltd., NSW, Australia), as described previously. Three measurements for PS in our previous experiment had shown a high degree of reproducibility, the coefficient of variation of the peak viscosity being evaluated as only 0.19% (159.2 ± 0.3 RVU, mean ± SD). Each measurement in the present study was therefore taken only once.

**Measurement of the swelling index and solubility.** The

---

**MATERIALS AND METHODS**

**Materials.** Potato starch (PS; Hokuren Research Institute, Sapporo, Japan) was used after being repeatedly washed with distilled water (DW) before air-drying (water content, 12.8%). L-(+)-Lysine hydrochloride (Lys) was supplied by Ajinomoto Co. (Tokyo, Japan). Sucrose stearic acid diester (SE; S-570) was supplied by Mitsubishi-Kagaku Foods Co. Ltd. (Tokyo, Japan). Wheat flour (Violet: protein, 7.1%; ash, 0.33%) was obtained from Nisshin Flour Milling Co., Ltd. (Tokyo, Japan). All other reagents were commercially available.

**Preparation of glucose/fructose stearic acid monoester (GE/FE).** GE/FE was prepared by hydrolizing SE according to the previously described method. In brief, SE was hydrolyzed in acidic 80% ethanol (0.54 M HCl) at 62°C for 30 min. After being cooled to room temperature with running water, the reaction product was neutralized with 0.6 M NaOH, and then cooled further in an ice bath. The resulting precipitate was collected by centrifuging, and then washed thoroughly with 50% ethanol until no more precipitated silver chloride could be detected by the addition of a silver nitrate solution to the supernatant. After replacement of the solvent with ethanol, the precipitate was air-dried to obtain the GE/FE preparation.

**Preparation of potato starch-Lys-GE/FE conjugate (PS-Lys-GE/FE).** Lys-conjugated starch (PS-Lys) was prepared according to a previously described method that achieved compounding with amino acids. In brief, PS (1 kg) and Lys (0.3 mol/kg of PS), were well mixed in a polyethylene bag, and then 200 g of the mixture was packed in a retort pouch. The pouch was tightly heat-sealed, and then autoclaved at 120°C for 90 min to perform simultaneous modification with heat-moisture treatment of PS and the Maillard reaction resulting in conjugation with Lys. After being cooled to room temperature, the reaction mixture was washed with DW to eliminate the unreacted Lys, and then air-dried to obtain the conjugate (PS-Lys). PS-Lys (100 g) was added to 70 mL of ethanol warmed at about 40°C containing GE/FE (0.6 mol/0.3 mol Lys and 1 kg of PS) and mixed. The amount of GE/FE giving significantly higher gelatinization temperature than that of Lys-PS from some conditions (0.3 mol/0.3 mol Lys, 0.6 mol/0.3 mol Lys and 1.5 mol/0.3 mol Lys) was selected. After being thoroughly air-dried, the reaction mixture was once again autoclaved at 115°C for 60 min in the manner just described to perform heat-moisture treatment of PS-Lys and conjugation with the free amino group of the Lys moiety of PS-Lys by the Maillard reaction. The autoclaving condition giving the highest gelatinization temperature and lowest gelatinization enthalpy from several conditions (110, 115 and 120°C for 30–120 min) was selected. The reaction product was extracted with warm ethanol to eliminate the unreacted GE/FE, and then washed with DW. The PS-Lys-GE/FE conjugate was recovered after air-drying.

**Measurement of pasting property of wheat flour with added PS-Lys-GE/FE.** The viscosity of wheat flour mixture containing 30% PS-Lys-GE/FE on a wheat flour basis was evaluated by an RVA Super 3 Rapid Viscoanalyzer (Newport Scientific Pty. Ltd., NSW, Australia), as described previously. Three measurements for PS in our previous experiment had shown a high degree of reproducibility, the coefficient of variation of the peak viscosity being evaluated as only 0.19% (159.2 ± 0.3 RVU, mean ± SD). Each measurement in the present study was therefore taken only once.

**Measurement of the swelling index and solubility.** The
swelling indexes and solubility of native PS, control PS, PS-Lys and PS-Lys-GE/FE were evaluated according to the previous paper.\textsuperscript{51} In brief, the starch sample (0.1 g) in a polypropylene centrifuge tube (15 i.d. \times 60 mm) with a lid was suspended in 5 mL of distilled water, and then heated in an aluminum block bath (Scinics Corporation, Tokyo, Japan) at 70°C for 30 min while stirring at 500 rpm. After quickly cooling to room temperature, the sample was centrifuged at 31,000 \times G for 30 min at 20°C. The resulting supernatant was completely removed, and the dissolved saccharide was determined by the phenol-sulfuric acid method\textsuperscript{101} to evaluate its solubility. The precipitate was weighed (\(W_w\)) and then dried at 110°C for 16 h to obtain a constant weight (\(W_d\)). The swelling index was represented as the ratio (\(W_w/W_d\)) of the wet starch sample weight to that of the dried one. Triplicate measurements were carried out.

**Microscopic observation.** The starch sample suspension (50 mg of sample/5 mL of DW) in a screw-capped test tube was heated at 110°C for 30 min while being stirred at 500 rpm. After being stained with iodine solution, the swollen starch granules was observed at a magnification of 100 times under a PM-10AD polarizing microscope (Olympus Corporation, Tokyo, Japan) as described previously.\textsuperscript{23} Brightness of PS-Lys and PS-Lys-GE/FE was evaluated by a CM-3600D spectrophotometer (Konica Minolta, Inc., Tokyo, Japan) as the \(L^*\) value.

**Measurement of vaporized water.** Water vaporization from PS-Lys or PS-Lys-GE/FE was measured by a previously described method.\textsuperscript{24} In brief, PS-Lys or PS-Lys-GE/FE (0.1 g) was suspended in 0.7 mL of DW in a polypropylene centrifuge tube, and then heated in an aluminum block bath at 100°C for 45 min while being stirred at 100 rpm. The water vaporized from the resulting paste was quantified at every 15-min intervals from the reduced weight of each sample. Duplicate measurements were carried out.

**Digestibility with \(\alpha\)-amylase.** The digestibility of each starch sample with \(\alpha\)-amylase (EC 3.2.1.1; 10,000 U, Sigma-Aldrich Co., St. Louis, USA) was measured as described previously.\textsuperscript{25} A sample (2 mg) dispersed in 1 mL of a 0.8 M acetate buffer (pH 6.0) was heated at 100°C for 10 min while being stirred at 100 rpm. After the mixture had cooled to room temperature, 0.2 U of \(\alpha\)-amylase was added, and the reaction mixture was incubated at 30°C for 120 min. Digestibility was evaluated by determining the saccharide concentration of each filtrate passing through a membrane filter with a 0.45-\(\mu\)m pore size (cellulose nitrate A045A025A; Advantec Co., Ltd., Tokyo, Japan) according to the phenol-sulfuric acid method.\textsuperscript{10} Duplicate measurements were carried out.

**Statistical analysis.** Tukey-Kramer test was used to compare means at the 1\% significance level.

**Analytical methods.** Moisture content was determined by heating a sample at 110°C until constant weight had been obtained. The nitrogen content of PS-Lys and PS-Lys-GE/FE was measured by an automatic high sensitivity NC analyzer (Sumigraph Model NC 22A; Sumika Chemical Analysis Service Ltd., Osaka, Japan) with acetonilide as the standard, according to a method previously described.\textsuperscript{33} The stearic acid content of PS-Lys-GE/FE was determined by gas-liquid chromatography with a GC 4CM apparatus (Shimadzu Corporation, Kyoto, Japan) and a DEGS Chromosorb WAW column (GL Science Inc., Tokyo, Japan) after fatty acid methyl esters had been prepared from the PS-Lys-GE/FE by methanolysis according to a method previously described.\textsuperscript{34}

### RESULTS AND DISCUSSION

**Features of PS-Lys-GE/FE conjugate.**

PS was autoclaved in a dry state with Lys to perform simultaneous modification with HMT and conjugation by the Maillard reaction, and then thoroughly washed with DW to eliminate unreacted Lys. The reaction product was pale brown, with a slight decrease in brightness (\(L^*\) value) to 93.9\% of that of native PS. This suggests that conjugation of PS and Lys occurred by the Maillard reaction. The resulting conjugate (PS-Lys) was added to a GE/FE ethanol solution, and then air-dried. The dried reaction mixture was re-autoclaved, and then washed with ethanol to eliminate unreacted GE/FE. The \(L^*\) value of this reaction product decreased to 85.3\% of that of native PS, suggesting further conjugation of PS-Lys and GE/FE by the Maillard reaction. The resulting conjugate (PS-Lys-GE/FE) had the structural composition of PS : Lys : GE/FE = 99.6 : 0.13 : 0.26 (weight ratio). The weight ratio was converted to the molar ratio [PS (as glucose residues) : Lys : GE/FE = 684 : 1.0 : 0.66], where the glucose residue content was estimated from the PS content. Since preparation of the PS-Lys by the Maillard reaction through heating of the PS and Lys mixture at 60°C for 3 weeks at a relative humidity of 79\% gave a composition of PS (as glucose residues) : Lys = 742 : 1.0 (molar ratio),\textsuperscript{35} the simultaneous modification just described gave a conjugated Lys content and reaction time that were superior to those obtained with the conventional Maillard reaction. Control PS was prepared by autoclaving at 120°C for 90 min and successively at 115°C for 60 min, according to respective experimental condition in the preparation of the PS-Lys conjugate and PS-Lys-GE/FE conjugate.

**Improved gelatinization behavior.**

Gelatinization for PS-Lys and PS-Lys-GE/FE was investigated by DSC. Control PS autoclaved without Lys and GE/FE \([i.e.\ simple heat-moisture-treated PS (HMT-PS)]\) showed significantly lower \(T_o\) and \(T_p\) but higher \(T_c\) than those of native PS (\(p<0.01, \text{Fig. 1(A)}\)). This broadened gelatinization temperature range of HMT-PS has been already reports by several researchers,\textsuperscript{21,35-36} indicating occurrence in destabilization and stabilization of the ordered structure of the starch granules, whereas Varatharajan \textit{et al.}\textsuperscript{22} has reported that HMT-PS showed some increases in all gelatinization temperatures (\(T_o, T_p\) and \(T_c\)) of HMT-PS in this study is presumably caused by some distortion of the ordered structure with relatively low thermal stability through the warm ethanol treatment corresponding to extraction with warm ethanol to eliminate the unreacted GE/FE during the preparation of PS-Lys-GE/FE conjugate. In contrast, PS-Lys showed significantly higher gelatinization temperatures (except in the case of \(T_o\)) than those of the native PS and control PS, well corresponding to a previous result obtained by the conventional Maillard reaction.\textsuperscript{23} Thus conjugation with Lys gave improved thermal stability, probably through reduced hydration of starch chains.
PS-Lys-GE/FE exhibited significantly higher gelatinization temperatures than those of PS-Lys, because of hydrophobicity endowed by the GE/FE moiety. Gelatinization enthalpy significantly decreased by simple HMT as compared with native PS, and conjugation with Lys and GE/FE reduced it further (Fig. 1(B)). PS-Lys-GE/FE exhibited the lowest gelatinization enthalpy. These results suggest that PS-Lys-GE/FE acquired higher rigidity than that of native PS through simultaneous modification by HMT and conjugation with Lys and GE/FE by the Maillard reaction, probably resulting in endowment of thermal resistance in terms of swelling and water vaporization of the paste, as autoclaving tapioca starch containing monosodium glutamate has resulted in the reduced swelling and improved water vaporization of the paste.24,25)

**Improved heat-stability.**

The heat-stability of PS-Lys-GE/FE was evaluated in terms of swelling index, solubility, and resistance to retort treatment. Native PS markedly swelled at 70°C, whereas the swelling index of the control PS was markedly lower, at about 1/5 of the native value (Fig. 2(A)) corresponding to previous results.22) PS-Lys also had a significantly lower swelling index than that of native PS, probably because replacement of hydrated water with Lys reduced the hydration of the starch chains. PS-Lys-GE/FE showed a tendency to more reduce lower swelling index than that of PS-Lys due to hydrophobicity with the steryl residues of the GE/FE moiety. The solubility of the control PS was about 67% of that of the native PS, suggesting an increase in cohesion of the starch chains with HMT (Fig. 2(B)). Conjugation with Lys reduced the solubility to significantly lower than that of the control PS, corresponding to that of the PS-Lys preparation previously prepared by the conventional Maillard reaction.23) PS-Lys-GE/FE exhibited the lowest solubility, probably due to inhibition of hydration by...
the Lys and stearyl residues of GE/FE moieties; it therefore had improved heat-stability.

The PS-Lys-GE/FE suspension was heated at 110°C for 30 min with stirring for observation of morphological change. Native PS heated under such condition lost its swollen starch granules, and completely dissolved, whereas the control PS was incompletely dissolved, with large amounts of collapsed granules and smaller amounts of large irregularly swollen granules (Fig. 3); this was probably due to an increase in cohesion of the starch chains as a result of the HMT. PS-Lys showed many irregularly swollen granules and some collapsed granules. In contrast, PS-Lys-GE/FE exhibited elongated, swollen granules with no collapse presumably due to somewhat weak intermolecular cohesion toward the line of apsides, corresponding with the previous microscopic observation for heat-moisture-treated potato starch.33 This result demonstrated that conjugation with Lys and GE/FE completely inhibited collapse of starch granules, even if they were heated at 110°C for 30 min. It is thus conclude that simultaneous modification by HMT and conjugation with Lys and GE/FE gave a high level of thermal resistance to the starch granules because of an increase in cohesion of the starch chains and inhibition of hydration as just described.

**Improved water-vaporization behavior.**

Water vaporization of the PS-Lys-GE/FE suspension was evaluated by determining the suspension’s weight loss during heating at 100°C with stirring. In this system, the external water of the swollen starch granules could be preferentially vaporized as compared with the internal water of the swollen starch granules. The amount of water vaporized from each sample paste increased with the heating time. Since the relationship between the vaporized water (%Y) and heating time (min, X) could be expressed by linear regression equations with a high determination coefficient (Table 1), the slope of the regression equation was chosen as the vaporization rate. Vaporization rate (%/min) of DW in the same condition as this experiment showed 26.3 ± 1.1 (mean ± SD, n=3). Measured values obtained by many measuring show a normal distribution, and 95% of the whole measured values are contained in a range within mean ± 2 SD. This suggests that lower values of vaporization rate than 24.1%/min could be different from that of DW. Native PS paste showed a lower vaporization rate (23.7%/min) than did DW (Table 1) because of the high hydration ability of starch. The control PS paste and the PS-Lys paste showed vaporization rates similar to that of the native paste, probably because of hydration ability associated with starch chain dispersion through collapse of the swollen starch granules, as occurred with starch itself (Fig. 3). However, the PS-Lys-GE/FE paste exhibited higher vaporization rate than that of DW. PS-Lys-GE/FE could thus provide a paste with easy vaporization of water external to the swollen starch granules owing to the reduced swelling and lack of collapse of the starch granules. This behavior was developed by simultaneous modification with HMT and conjugation with Lys and GE/FE, and it should be valuable as a giving a dry texture to fried coatings by easy vaporization of water from starchy batters when fried in hot oil, or recovering crispness of fried foods lost due to transport of water from the food material inside when re-heated in microwaves.

**Reduced digestibility with α-amylase.**

The digestibility of the native PS, control PS, PS-Lys and PS-Lys-GE/FE with α-amylase was investigated by measuring the saccharides released after gelatinization at 100°C for 10 min. The released saccharides (%) from each sample increased with the digestion time (min). Since the relationship between the two parameters could be expressed by a linear regression equation with a relatively high determination coefficient (Table 2), the slope of the regression equation was chosen as the digestion rate. Digestion rate (%/min) of native PS showed 0.075 ± 0.0092 (mean ± SD, n=3). This suggests that lower values of digestion rate than 0.057%/min are probably different from that of native PS. Control PS showed lower tendency of digestion rate than that of native starch (Table 2), corresponding to previous results for gelati-

---

**Table 1.** Linear regression equations and determination coefficients for water-vaporization of PS-Lys-GE/FE and related starch samples.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Linear regression equation</th>
<th>Determination coefficient (r²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Y = 26.4X − 17.7</td>
<td>0.920</td>
</tr>
<tr>
<td>Native PS</td>
<td>Y = 23.7X − 15.7</td>
<td>0.916</td>
</tr>
<tr>
<td>Control PS</td>
<td>Y = 24.1X − 19.4</td>
<td>0.975</td>
</tr>
<tr>
<td>PS-Lys</td>
<td>Y = 23.8X − 19.3</td>
<td>0.975</td>
</tr>
<tr>
<td>PS-Lys-GE/FE</td>
<td>Y = 26.1X − 18.9</td>
<td>0.952</td>
</tr>
</tbody>
</table>

The sample suspension was heated at 100°C while being stirred at 100 rpm. The relationship between vaporized water (%, Y) and heating time (min, X) was analyzed.
Reduced viscosity of wheat batter with PS-Lys-GE/FE.

Since PS-Lys-GE/FE prepared in this study exhibited remarkably low swelling without collapse, it is expected that this material can be applied to control physical properties of starchy food materials, in particular, wheat batter often used to fried coatings. Lowering viscosity of wheat batter, and increasing in water vaporization caused by low swelling without collapse would result in increased crispness of fried coatings, being one of most important properties. The pasting behavior of the wheat batter was thus investigated by RVA in the presence of PS-Lys-GE/FE. Adding 30% PS-Lys-GE/FE on a wheat flour basis markedly reduced the peak viscosity (PV) and breakdown (BD) compared with those of wheat flour alone (Fig. 4), probably because of the extremely low solubility and swelling of PS-Lys-GE/FE. To analyze the effect of PS-Lys-GE/FE on the viscosity of the mixed wheat batter in terms of PV and BD, it is postulated that the calculated viscosity values (PV, BD and SB) of the mixed wheat batter [composition (wt%); 70% of wheat flour and 30% of PS-Lys-GE/FE] could be estimated with the following simple summation: [calculated viscosity value (PV, BD or SB) of the mixed wheat batter] = [70% of the viscosity value (PV, BD or SB) of wheat flower alone] + [30% of the viscosity value (PV, BD or SB) of PS-Lys-GE/FE alone]. This material would be valuable as a basis for controlling water vaporization from starchy dressing materials such as batters during frying in hot oil or re-heating in microwaves, thus giving a dry texture to starch-dressed foods.

CONCLUSION

PS, Lys and GE/FE were conjugated by simultaneous modification by HMT and the Maillard reaction through autoclaving to prepare a PS-Lys-GE/FE conjugate. PS-Lys-GE/FE had a composition of PS (as glucose residues): Lys: GE/FE=684:1:0.66 (molar ratio). PS-Lys-GE/FE exhibited elevated thermal stability in terms of significantly higher gelatinization temperature, lower gelatinization enthalpy, lower solubility than those of the native and control PSs, and it maintained elongation of swollen granules even when heated at 110°C for 30 min. The gelatinized PS-Lys-GE/FE exhibited resistance to digestibility with α-amylase. The peak viscosity and breakdown of wheat batter containing 30% PS-Lys-GE/FE on a wheat flour basis were markedly decreased, being lower than the values calculated from the respective viscosities of wheat flour and PS-Lys-GE/FE. These results suggest that simultaneous modification by HMT and the Maillard reaction effectively endowed the starch with reduced digestibility with α-amylase whereas the conjugation with the Maillard reaction effectively endowed the GE/FE moiety. These results indicate that simultaneous modification by HMT and conjugation with the Maillard reaction effectively endowed the starch with reduced digestibility with α-amylase.
HMT and the Maillard reaction resulting in conjugation of GE/FE through Lys could provide a conjugated starch material that will help improve the paste texture of starchy foods, the texture of starch-dressed foods, and the physical properties of retorted foods.

REFERENCES