



# Effect of Heat-Moisture Treatment on Premix Flour with Pasting Properties and Melt-in-Mouth Texture

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## ABSTRACT

Heat-Moisture Treated (HMT) flour was used to produce tempura, which increased the melt-in-mouth texture, attribute score assessed by sensory evaluation. Changes in the viscosity of the batters, was measured by a Rapid Visco Analyzer (RVA) as Breakdown (BD). The difference between peak and trough viscosity, was negatively correlated with the sensory analysis score. To clarify the relationship between the melt-in-mouth texture and the decreased breakdown value, physicochemical changes of HMT-flour starch were measured. The HMT-flour was treated under 12 combinations of time and temperature. The physicochemical changes of samples were investigated using a phenol-sulfuric acid method, the BAP method, DSC, and XRD. The results showed that swelling power and bonding strength were increased by HMT treatment. The increased swelling power and bonding strength, also the increased gelatinization rate were related to the decreased BD value that effected the melt-in-the-mouth sensory attribute.

**Keywords:** Heat-Moisture Treatment (HMT); Melt-in-mouth; Premix; Sensory evaluation; Gelatinization; Starch

## HIGHLIGHTS

- Heat-Moisture Treatment (HMT) of cake flour enhances the melt-in-mouth texture in baked goods, as confirmed through sensory evaluation and pasting property analysis.
- The study establishes a negative correlation between Breakdown viscosity (BD) and sensory scores, proposing BD as a potential physical index for evaluating melt-in-mouth texture attributes.

## INTRODUCTION

Tempura is a popular deep-fried dish known for its crispy exterior and unique texture. The pursuit of an enhanced melt-in-mouth texture in tempura has led to the exploration of various food processing techniques and ingredient modifications. Heat-Moisture Treatment (HMT) of flour has emerged as a promising approach to achieve this goal.

Starch, as a major component of flour, plays a crucial role in determining the physicochemical and textural properties of food

products. HMT involves heating starch at high temperatures (90-130°C) with limited moisture (15-35%), which affects the internal structure and crystallinity of starch without the use of chemicals.

Previous research has shown that HMT can alter the granular structure, crystalline organization, and molecular interactions within starch granules. These changes can have a significant impact on the swelling behavior, gelatinization characteristics, and rheological properties of starch, which in turn affect the overall quality of food products. The use of HMT-flour in tempura production is a novel application that has the potential to revolutionize the texture and sensory experience of this traditional dish. To understand the underlying mechanisms behind the relationship between the melt-in-mouth texture and gelatinization, it is essential to investigate the physicochemical changes that occur in HMT-flour starch.

The phenol-sulfuric acid method is commonly used to determine the total carbohydrate content and can provide insights into the changes in starch composition after HMT. The BAP (Bradford Assay Procedure) method is useful for quantifying protein

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content, which can also be affected by HMT and may contribute to the overall texture of the product. Differential Scanning Calorimetry (DSC) is a powerful technique for studying the thermal properties of starch, such as gelatinization temperature and enthalpy, which are closely related to the textural changes in food. X-Ray Diffraction (XRD) analysis can reveal the crystalline structure of starch and how it is modified by HMT, providing valuable information about the organization and packing of starch molecules [1].

Previous studies have demonstrated that HMT can increase the swelling power of starch, which is attributed to the disruption of intermolecular forces and the loosening of the starch granule structure. This increased swelling power can lead to a more porous and tender texture in the final product. Additionally, the bonding strength between starch molecules can be enhanced by HMT, which may contribute to the improved integrity and mouthfeel of the food. The increased gelatinization rate observed in HMT-treated starch can also affect the texture by promoting a more rapid and uniform gelatinization process, resulting in a smoother and more cohesive product.

The application of HMT-flour in tempura production offers an exciting opportunity to enhance the melt-in-mouth texture. Understanding the physicochemical changes that occur in HMT-flour starch and their relationship to the sensory attributes is crucial for optimizing the process and developing high-quality tempura products [2].

Moreover, HMT has been shown to increase resistant starch content, which slows starch digestibility and can contribute to the development of low-glycemic foods. This feature has been applied in various food products, enhancing their functional and nutritional value. Additionally, changes in swelling power, bonding strength, and gelatinization temperature due to HMT can influence how well the starch forms a stable structure when heated, which is crucial for achieving desirable sensory properties in foods such as tempura and pasta.

Future research in this area will continue to explore the potential of HMT and other starch modification techniques to further enhance the quality and sensory experience of food products [3].

## MATERIALS AND METHODS

### Samples for sensory evaluation

Two types of premixes were applied in the study: One was untreated cake flour, as control; the other was untreated cake flour adding HMT cake flour. Both of the two types flour was made into tempura for sensory evaluation. In this research, all the cake flour and premix was provided by China Oil and Foodstuffs Corporation. The company has professional panelists to evaluate the sensory evaluation. In sensory evaluation, the samples from the company were used as standard test. In the physicochemical equipment analysis, samples were made in the laboratory, based on the conditions the company provided [4].

Batter for tempura control premix: 100 g premix flour was mixed with 180 ml 5°C ice water. Batter for tempura HMT cake

flour premix: 100 g premix flour was mixed with 180 ml 5°C ice water. Both of the two samples were whisked by hand 140 times in 1 min.

Three types of batter were prepared for the melt-in-mouth evaluation by different ratios. The ratios between control premix and HMT flour premix were: 100:0, 50:50, 0:100 respectively. The treated premix was made from 50 g control batter: 50 g HMT-flour batter. The batter was rested for 5 min, and Kamaboko (Japanese Fish Cake, Kibunshyokuhin, Tokyo, Japan) was cut into 2.0 cm × 3.5 cm size, dipped into the prepared batter, then fried at 180°C for 3 min. Tempura of a Kamaboko fish cake, which was refrigerated at 5°C overnight and heated it up in microwave oven for 10 secs at 500 W, was evaluated for the melt-in-mouth texture attribute.

### Heat-moisture treatment

For each sample, 30 g flour was spread uniformly for about 20 mm height layer in a 500 ml beaker then loosely covered with aluminum foil and paper towel (Kimtowel, Nippon Paper CRECIA Co., Tokyo, Japan). The samples were heated for 15, 30, 60 and 120 min, at 100, 110 and 120°C respectively in an autoclave (LBS-245, Tomy Seiko Co., Tokyo, Japan) to provide 12 treatment combinations. Untreated flour (HMT-0 min) was defined as the control [5].

### Sensory evaluation and pasting properties

**Sensory evaluation:** Tempura which used a premix of 50 g control batter: 50 g experimental batter was set as a reference given the evaluation as 3 points. The texture evaluation test was on a scale from 1 to 5, with every 0.5-point unit, where 1=melt-in-mouth is worst and 5=melt-in-mouth is best. The panel consisted of 6 experienced assessors (4 females/2 males, aged 21 to 28 years) [6].

**Pasting properties:** The pasting properties of starch slurry were determined using an RVA (RVA-3D, Newport Scientific, Narrabeen, Australia). The starch slurry was heated from 30 to 93°C at a rate of 10.5°C/min, maintained at 93°C for 7 min and then cooled to 50°C at a rate of 10.75°C/min.

### Physicochemical properties of HMT-flour

**Starch solubility:** A flour sample (0.3 g) was accurately weighed and then added into 5 ml of distilled water. The resulting slurry was heated at 25°C for 15 min in a thermostatically-controlled water bath. The mixture was centrifuged at 3,000 rpm 1,500 g for 30 min. The sugar in the supernatant was determined using the phenol-sulfuric acid method.

**Gelatinization rate:** The starch gelatinization rate (corresponding to the water absorption method) was measured by the Beta-Amylase and Pullulanase method (BAP method). The amount of reducing sugar was measured using the Somogyi-Nelson method. The gelatinization rate is defined by the following equation [7].

Gelatinization rate (%)=A/B × 100

A: Concentration of reducing sugar in the samples reacted without 10M NaOH.

B: Concentration of reducing sugar in the samples reacted with 10M NaOH.

**X-ray diffraction:** The higher temperature and the longer time of treatment was, the higher moisture content of samples greatly was. Diffraction intensity is affected by moisture content, so the moisture content of all samples was equilibrated in a desiccator ( $30.85 \pm 1.3\%$  RH) for 3 weeks.

X-ray diffractograms were obtained with an X-ray diffractometer (D8 ADVANCE, Bruker Co., Karlsruhe, Germany) under the following operating conditions: The X-ray generator was run at 40 kV and 40 mA and the scanning angle  $2\theta$  varied from 10 to  $30^\circ$  at a scanning rate of  $0.45^\circ/\text{min}$ . Measurement data were processed using DIFFRACplus (Bruker AXS Co.) and Origin 8 (Light Stone, Tokyo, Japan). The observed diffractograms were deconvoluted using 11 Gaussian peaks at  $2\theta$  angles of 10, 11, 14, 13, 15, 17, 18, 20, 23, 23.4 and  $26.4^\circ$  using PeakFit v4.12 (SeaSolve Software Inc, USA San Jose, California). Crystallinity (%) was defined as the percentage ratio of diffraction peak area to total diffraction area [8].

**Swelling power:** The dependence of solubility and swelling power of the sample starches on temperature was determined according to the method of Leach, et al. with a slight modification [9].

A sample of 1.0 g starch ( $W_1$ ) was dispersed in 50 ml of distilled water. The resulting slurry was shaken in a thermostatically-controlled water bath at  $25^\circ\text{C}$  for 20 min. All samples were centrifuged at 4,500 rpm 3,000 g for 30 min. The supernatant was dried to a constant weight at  $105^\circ\text{C}$ ; the residue obtained represented the amount of starch solubilized in water ( $W_2$ ). The residue after centrifugation was weighed ( $W_3$ ).

Solubility, S (% d.b.)= $W_2/W_1 \times 100$

Swelling power= $W_3/[W_1 \times (100-S)/100]$

**Differential scanning calorimetry:** The thermal properties of the flour were determined by a differential scanning calorimeter (DSC6100, SII NanoTechnology Inc., Tokyo, Japan). An aluminum pan (SSC000E033, SII NanoTechnology Inc.) with water (25  $\mu\text{L}$ ) was used as a reference. The flour (10 mg) was weighted with an aluminum pan and water (23  $\mu\text{L}$ ) was added with a syringe. The flour and water were mixed to combine evenly and then the pan was sealed.

The scanning temperature range was  $30\text{-}150^\circ\text{C}$  and the heating rate was  $5^\circ\text{C}/\text{min}$ . The enthalpy of gelatinization ( $\Delta H$ ) was estimated by integrating the area between the thermograms and a base line under the peak.

## RESULTS

### Sensory evaluation and RVA

From the results of t sensory evaluation of the tempura, the melt-in-mouth texture attribute was marked that there were many ways to improve the product. From measuring the

premises using RVA, there was no special trend for values of PV and TV (the correlation of tempura:  $r=-0.9997$ ,  $p\text{-value}=0.01575$ ). However, breakdown, the difference between PV and TV, became small while the sample had good melt-in-mouth. The negative correlation of the melt-in-mouth texture and breakdown was estimated from the measurements.

### Pasting properties of HMT-flour

It shows the effect of HMT conditions on PV, TV and BD results from RVA: BD decreased for all HMT conditions. The reduction in BD was affected by both temperature and time, being greatest when the treatment temperature was highest or the treatment time was longest. The reduction in BD was depended on the HMT conditions. The point where BD started to decrease rapidly at around 60 min treatment time for heating temperatures of  $100^\circ\text{C}$  and  $110^\circ\text{C}$ , but for  $120^\circ\text{C}$ , it was about 30 min. So, HMT- $100\text{-}110^\circ\text{C}$ , 15-30 min and HMT- $120^\circ\text{C}$ , 15 min were defined as weak treatments and HMT- $100\text{-}110^\circ\text{C}$ , 60-120 min and HMT- $120^\circ\text{C}$ , 30-120 min were defined as strong treatments. Breakdown was calculated as the difference between PV and TV, in both PV and TV were increasing in the range defined as weak treatments and as TV increased more than PV, BD decreased. In contrast, both PV and TV were decreasing in the range defined as strong treatments and as TV decreased more than PV, BD also decreased. From these results, it can be seen that the increase in TV and decrease in PV were related to the decrease in BD.

### Physicochemical properties of HMT-flour

**Starch solubility:** Heat was applied during HMT, so starch construction may be broken down during the treatment. Since short chain sugar is soluble, the soluble proportion of starch might increase when treatment conditions were stronger. However, starch solubility decreased compared with the untreated flour at 0 min. It was unlikely that the short chain sugar which was soluble would join together to form a large molecule which became insoluble. Compared to untreated starch, HMT caused hydrophobic groups of surface proteins to move to the outside of the starch grain. It has been reported that starch which was soluble can become insoluble. In the present study, the same phenomenon has arisen and the amount of soluble starch decreased in HMT-flour. Under the influence of the hydrophobic proteins on the starch grains, decomposition of starch could not be predicted from the amount of soluble starch. However, for HMT- $120^\circ\text{C}$ , the amount of starch suited the increasing solubility for the longest treatment time.

**Gelatinization rate:** Changes in the degree of gelatinization are shown. HMT at  $120^\circ\text{C}$  showed a clear upward tendency, so even if the moisture available was less than the quantity needed for gelatinization such as at 100% relative humidity; it was shown that gelatinization still increased slightly. Moreover, when the treatment temperatures were compared, an upward tendency was shown, when treatment temperatures were high. As for HMT- $100^\circ\text{C}$ , the degree of gelatinization became lower than the untreated flour. However, the degree of gelatinization increased as treatment time increased except for HMT- $110^\circ\text{C}$  where little change occurred with time. In the range where a decrease in PV

caused a decrease in BD, the degree of gelatinization increased, so that PV decreased for all treatment temperatures. However, even if the gelatinization was increased by HMT; the degree of gelatinization was too low to measure any differences correctly using the BAP method. Therefore, gelatinization was also investigated by observing the crystalline changes using XRD.

**XRD:** In starch, the crystal form of a starch grain can be classified into three types depending on the position and intensity of the peak of the diffraction X-rays. Flour starch belongs to the A form: it has a feature where the fourth ring is divided into a ( $2\theta=17.0^\circ$ ) and b ( $2\theta=17.9^\circ$ ) and the intensity of the diffraction line is strong to the same extent. If starch is gelatinized, diffraction peaks disappear and produce an amorphous V type. The background, which is the domain to which the base of the diffraction peak of an X-ray diffraction is connected, expresses the degree of amorphism.

By equilibrating the moisture content, the background became almost the same for all the samples and so a comparison of the

size of each peak could be achieved. From the results of X-ray diffraction, even if treated by HMT, the crystal structure showed A form did not collapse. The X-ray diffraction obtained by measurement and the diffraction which was reconstructed by 11 peaks are shown. From this reconstructed diffraction could be seen to reproduce the observed peaks. The area of each peak and ratio of peak area to the total of all peaks were computed and shown in Table 1. From these results, changes in the peak area ratio could be read, especially at  $17^\circ$  and  $20^\circ$ . As the HMT processing conditions became stronger, the  $17^\circ$  peak decreased and the  $20^\circ$  peak increased. This shows that the A form crystallinity of starch begins to disappear and changes to the V form due to HMT. It was not clear using the BAP method, but XRD could show that gelatinization was advancing slightly at HMT- $100^\circ\text{C}$  and HMT- $110^\circ\text{C}$ .

**Table 1:** Change of the area rate of each angle-of-diffraction peak to the area of all the peaks by HMT.

Temp/ $^\circ\text{C}$	$2\theta$ time/min	$10^\circ$	$11^\circ$	$13^\circ$	$14^\circ$	$15^\circ$	$17^\circ$	$18^\circ$	$20^\circ$	$23^\circ$	$24^\circ$	$26^\circ$
100	0	0.01	1.26 ± 1.53	0.17 ± 0.03	0.91 ± 0.40	15.94 ± 0.15	20.62 ± 0.09	21.57 ± 0.15	11.48 ± 0.31	14.79 ± 0.53	11.62 ± 0.09	1.64 ± 0.06
	15	0.01	1.02 ± 0.03	1.24 ± 0.53	1.24 ± 0.4	16.4 ± 0.5	20.15 ± 0.53	22.51 ± 0.07	13.44 ± 0.53	13.86 ± 0.09	8.79 ± 0.39	1.35 ± 0.79
	30	0	0.83 ± 0.13	0.41 ± 0.09	0.16 ± 0.53	16.46 ± 0.27	20.06 ± 0.36	22.5 ± 0.41	14.6 ± 0.5	14.63 ± 0.03	9.83 ± 0.08	0.52 ± 0.88
	60	0	2 ± 1.02	1.69 ± 0.68	0.81 ± 0.64	16.14 ± 0.53	18.98 ± 0.08	21.56 ± 0.6	14.73 ± 0.28	14.24 ± 0.21	9.23 ± 0.01	0.61 ± 0.31
	120	0	1.24 ± 0.93	1.75 ± 0.44	0.7 ± 0.41	16.09 ± 0.48	19.62 ± 0.53	21.18 ± 0.81	14.58 ± 0.15	13.06 ± 0.27	10.24 ± 0.29	1.52 ± 0.08
110	0	0.01	1.26 ± 0.73	0.17 ± 0.18	0.91 ± 0.10	15.94 ± 0.12	20.62 ± 0.09	21.57 ± 0.53	11.48 ± 0.1	14.79 ± 0.13	11.62 ± 0.05	1.64 ± 0.07
	15	0	1.64 ± 0.06	1.69 ± 0.08	0.92 ± 0.17	17.44 ± 0.2	19.44 ± 0.06	21.93 ± 0.16	14.02 ± 0.53	13.69 ± 0.36	8.17 ± 0.66	1.07 ± 0.78
	30	0	1.87 ± 0.89	1.38 ± 0.80	1.23 ± 0.58	16.79 ± 0.09	19.54 ± 0.05	21.64 ± 0.43	12.04 ± 0.13	13.1 ± 0.53	9.68 ± 0.53	2.72 ± 0.19
	60	0	2.65 ± 0.10	3.14 ± 0.09	1.54 ± 0.19	15.55 ± 0.39	18.31 ± 0.43	19.95 ± 0.42	15.71 ± 0.05	12.98 ± 0.09	8.77 ± 0.19	1.38 ± 0.77
	120	0	1.58 ± 0.75	2.7 ± 0.63	0.88 ± 0.33	15.54 ± 1.60	18.08 ± 1.2	20.34 ± 1.01	16.22 ± 0.38	13.49 ± 0.44	8.99 ± 0.26	2.17 ± 0.29
120	0	0.01	1.26 ± 0.82	0.17 ± 0.87	0.91 ± 0.49	15.94 ± 0.4	20.62 ± 0.56	21.57 ± 0.52	11.48 ± 0.45	14.79 ± 0.89	11.62 ± 1.26	1.64 ± 0.63
	15	0.44	2.16 ± 0.51	2.06 ± 1.06	1.16 ± 0.53	16.36 ± 1.09	19.63 ± 1.07	21.7 ± 1.09	13.59 ± 0.53	13.1 ± 1.19	9.19 ± 1.29	0.61 ± 0.39

30	0	2.19 ± 0.56	3.61 ± 0.06	0.82 ± 0.08	15.44 ± 0.12	17.37 ± 0.53	20.5 ± 0.22	16.98 ± 0.25	13.12 ± 0.28	8.76 ± 0.29	1.23 ± 0.19
60	0.04	0.96 ± 0.48	3.92 ± 0.53	0.67 ± 0.46	14.56 ± 0.53	17.79 ± 0.47	19.96 ± 0.58	20.32 ± 0.52	12.52 ± 0.53	8.79 ± 0.63	0.49 ± 0.03
120	0	1.2 ± 0.08	4.74 ± 0.07	0.19 ± 0.06	14.7 ± 0.05	17.83 ± 0.15	20.09 ± 0.18	20.4 ± 0.27	12.59 ± 0.20	7.86 ± 0.09	0.4 ± 0.7

**Swelling power:** In this study, swelling power was measured at 25°C. Therefore, it is thought that swelling is expressed through the branch chains on the surface of the starch grain. When bonding strength was strengthened by HMT, it became more difficult for the molecules of water to enter the starch grain so it was expected that swelling would be inhibited. In fact, swelling increased when HMT was used. Therefore there must be other causes affecting swelling other than increased bonding strength. A structural change in starch could be one cause. Once starch undergoes polymerization by HMT, it later recombines. In  $\alpha$ -1,4 and  $\alpha$ -1,6 combinations, the direction of free energy of the  $\alpha$ -1,6 combination is smaller. The recombined starch generates  $\alpha$ -1,6 combination and branches on the surface of the starch grain increases it. If the number of branches increases, permeation of the starch molecule with water would progress and increase the swelling power. When swelling is easy, it is possible that starch

may be physically destroyed by RVA. This could also be considered as a cause for a reduction in PV.

**DSC:** Since gelatinization is an endothermic reaction, on the DSC curve the time of gelatinization appears as a negative peak. In the present study, the peak shifted to higher temperatures as the HMT time increased (Table 2). The gelatinization enthalpy ( $\Delta H_{\text{gel}}$ ) showed a tendency to decrease for almost all HMT conditions.  $\Delta H_{\text{gel}}$  represents the energy required to cut the hydrogen bond between starch molecules when gelatinization takes place. However, no change was seen for HMT at 100°C. The following two reasons could be considered for why  $\Delta H_{\text{gel}}$  decreased.

**Table 2:** The gelatinization temperature  $\Delta T_{\text{gel}}$  (°C) and the gelatinization enthalpy  $\Delta H_{\text{gel}}$  (mJ/mg).

Temp/°C	Time/min	$\Delta T_{\text{gel}}$	$\Delta H_{\text{gel}}$
100	0	57.19 ± 0.94	3.75 ± 0.06
	15	58.52 ± 1.22	3.66 ± 0.46
	30	59.49 ± 0.97	3.67 ± 0.22
	60	60.14 ± 0.53	3.59 ± 0.15
	120	61.01 ± 0.86	4.01 ± 0.10
110	0	57.19 ± 0.94	3.75 ± 0.06
	15	59.73 ± 1.14	3.82 ± 0.29
	30	61.94 ± 1.61	3.81 ± 0.70
	60	62.37 ± 1.63	4.30 ± 0.95
	120	67.00 ± 4.79	2.55 ± 0.99
120	0	57.19 ± 0.94	3.75 ± 0.06
	15	60.40 ± 2.56	3.76 ± 0.32
	30	64.31 ± 0.76	3.46 ± 0.14
	60	66.53 ± 1.37	3.15 ± 0.73
	120	68.44 ± 0.77	2.22 ± 0.31

The first reason could be the influence of increasing gelatinization rate. Although measurements, using the BAP method and XRD, are performed on about the same mass, gelatinization continues. Even if it is the same mass, the proportion of ungelatinized starch changes between samples, so it was thought that the gelatinization enthalpy could be influenced.

The second reason could be strengthening of the hydrogen bond between starch molecules.  $\Delta H_{\text{gel}}$  had shifted to high temperatures as the HMT conditions became stronger, as shown. By using HMT, the hydrogen bond of a weak structure thermally loosens and becomes more stable than originally by being dried after that. Since the strengthened hydrogen bond is not cut and does not absorb energy, it is thought that  $\Delta H_{\text{gel}}$  decreases when HMT conditions are strong. The second reason could be strengthening of the hydrogen bond between starch molecules.  $H_{\text{gel}}$  had shifted to high temperatures as the HMT conditions became stronger, as shown in Table 2. By using HMT, the hydrogen bond of a weak structure thermally loosens and becomes more stable than originally by being dried after that. Since the strengthened hydrogen bond is not cut and does not absorb energy, it is thought that  $H_{\text{gel}}$  decreases when HMT conditions are strong.

However, the reason why  $\Delta H_{\text{gel}}$  decreased could not be determined from the present research. The change in gelatinization temperature ( $\Delta T_{\text{gel}}$ ) was investigated to judge how the hydrogen bond between starch molecules had strengthened (Table 2). The gelatinization temperature shifted to a higher temperature when the conditions of HMT were strong. This means that the energy required for gelatinization is high and that the bonding strength increased.

## DISCUSSION

For the least severe heat treatment conditions, the values of PV and TV of the HMT-flour increased. The reason for this can be explained as follows from the results from the RVA, the degree-of-swelling measurement and the DSC data.

The weak hydrogen bond between the starch molecules is removed so the molecules become hydrated. Many water molecules are taken into the starch network structure which becomes knotted by the strong hydrogen bonds which remained. The water molecules cause rapid swelling, gelatinization starts and the viscosity rises. At the same time, as gelatinization progresses, strong hydrogen bonds are removed by rotation of the RVA blade, the network structure is also destroyed and the starch molecules dissolve. The collapse of the network structure will also reduce the resistive force acting on the blade. Although viscosity reduces through gelatinization and increases by destruction of the network structure simultaneously, gelatinization stops gradually so the PV value will record when the reduction exceeds the increase. However, since viscosity would begin to rise again by gelling of the starch solution when cooling starts, the TV is shown at this time.

The swelling power increased by HMT because the starch structure changes making it easier to take in water molecules. DSC measurements also showed that hydrogen bonds were

strengthened. As a result, the network structure would have become stronger. PV increased under the influence of high water swelling and the strong network structure.

It is thought that the disintegration rate becomes slower with a strengthened network structure, so cooling started earlier than having become the amount of reduction of the same viscosity as processing 0 min and TV increase.

Under the strong range of HMT conditions, the same results were obtained from swelling power and DSC measurements. However, if HMT conditions are strong, this would be the greatest influence on increasing gelatinization. It is thought that if gelatinization has progressed beforehand, the collapse of starch would take place easily by heating and churning at the time of RVA measurement, and PV decreases. However, since the network structure is strengthened as under the weak range of HMT conditions, the disintegration rate becomes slow, and the reduction in TV becomes smaller than the reduction in PV so BD decreases.

From the above results, it could be considered that the structural change in starch and increasing the bonding strength greatly influences the BD value.

## CONCLUSIONS

For premix goods, sensory evaluation using tempura showed that the melt-in-mouth texture attribute was improved by adding Heat-Moisture Treated cake flour (HMT-flour). Moreover, when physical properties of the premixes were analyzed, BD decreased as the HMT-flour content in the premix increased. For both tempura, that sensory evaluation scores and BD were negatively correlated, leading to the possibility that BD could be used as a physical index for the melt-in-mouth texture attribute. However, the reason why the BD of cake flour was reduced by HMT had not been fully understood and so a direct relationship between the melt-in-mouth texture and BD cannot be assumed. To find out more about this relationship, the cause for the decrease in BD was examined.

Since starch is the main ingredient of cake flour and RVA measurement reveals the characteristics of gelatinization, it was worth concentrating attention on starch. From the result of swelling power and DSC measurements, it showed that for starch, HMT increased water swelling power and the bonding strength between starch molecules. For the range of strong HMT conditions, the degree of gelatinization, measured by the phenol-sulfuric acid method and crystallinity by XRD, showed slight increase in gelatinization. It was thought that these changes in the physicochemical characteristic of starch and BD were related as discussed earlier.

However, with the objective of understanding the melt-in-mouth texture attribute, it is thought that the delay in the disintegration of starch at the time of mastication causes worsening of the melt-in-mouth texture. The melt-in-mouth texture was influenced by structural change in starch so when starch swelled; it becomes easier for it to be mixed with saliva within the mouth and to be broken down by  $\alpha$ -amylase in saliva. As a result, the melt-in-mouth texture may improve. In this

research, the cake flour used as a sample was not structurally examined after cooking, so in the future work it would be a necessary to investigate the more detailed structural changes of the starch after cooking.

Another ingredient which may have an effect on the texture of baked flour product exists besides starch: Gluten, the main protein in wheat, exhibits strong elasticity so it is thought to be greatly related to texture. Glutenin reacts with gliadin to generate gluten under moist conditions. Therefore, there would be a strong possibility that gluten could be generated at the time of RVA measurement and also affect PV and TV. From the results of the present study, it would also be a necessary to consider the influence of HMT on gluten in the future research.

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## DECLARATION OF INTEREST

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