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Effects of Water and Gelatinized Starch on the Viscoelasticity of Pizza Dough and the Texture of Pizza Crust

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Abstract: The soft texture of the pizza crust rim is generated by baking at a high temperature for a short period in a stone oven. In the case of baking in an electric oven, the pizza dough is baked at a much lower temperature and for a longer period, resulting in a harder texture. To improve the texture of electric oven-baked pizza crust, the effects of water and gelatinized starch on the viscoelasticity of pizza dough and the texture of pizza crust were investigated. Rheological properties (storage modulus, loss modulus, and yield stress) of pizza dough decreased with an increase in water content. When wheat flour in the dough was partially replaced with pre-gelatinized wheat starch, the rheological properties of the dough were maintained even at a high-water content. These results indicate that water-enriched dough can be prepared with gelatinized starch and baked using an electric oven. There was no significant difference in apparent density between the conventional and modified pizza crusts. Water content of the crumb part of the modified crust was significantly higher than that of the conventional crust. Texture analysis revealed that the modified pizza crust showed significantly lower stress at high strain than the conventional crust. In addition, sensory evaluation showed that the modified pizza crust exhibited greater firmness and stickiness than the conventional crust, which was attributed to the increased water content with gelatinized starch of the dough.

Key words: gelatinized starch, pizza, dough, texture, viscoelasticity

INTRODUCTION

Pizza is a widely favored meal served at traditional pizzerias, exclusive and fast-food restaurants, and home. The cooking process of pizza is simple. First, pizza dough is prepared similarly to bread dough, in which wheat flour, water, and other ingredients (e.g., NaCl, sucrose, oil, and yeast) are combined, kneaded, and fermented. Next, the pizza dough is spread onto a round sheet with a small rim, and topped with sauce and various other food ingredients. Finally, the raw pizza is baked at a high temperature for a short period. To achieve such high temperature baking, a stone oven is used, especially at traditional pizzerias and exclusive restaurants. For more convenient serving at fast-food restaurants and home, frozen dough or semi-baked pizza is used, which is baked in an electric oven.

The rim of the pizza crust, the so-called "*cornicione*", is particularly favored in Naples, Italy. The soft texture of the rim of the pizza crust (hereafter pizza crust) is generated by baking at a high temperature for a short duration in a stone oven. When baked using an electric oven, the raw pizza is baked at a much lower temperature and for a longer period compared to baking with a stone oven, resulting in a harder texture. The difference in baking condition is thought to be the reason for the large texture difference of the pizza crust. However, it is practically difficult to use stone ovens at fast-food restaurants and home. Modification of the physical properties of pizza dough may be an effective way to improve the texture of pizza crust baked in an electric oven.

Water is the most effective plasticizer for foods.[1)] Thus, it is expected that the higher the water content of the pizza dough, the softer the texture of the crust. However, the rheological properties of pizza dough are obviously affected by the addition of water, and thus the kneading and forming properties of the dough are negatively affected. In fact, the viscoelastic parameters such as storage modulus (G') and loss modulus (G'') of dough samples (wheat flour, water, and dry yeast) decrease as the water content increases.[2)3)] To maintain optimum rheological properties of pizza dough, hydrophilic polymers are proposed to be effective as physical modifiers. For example, Sciarini *et al*. (2012) reported that the viscoelasticity of bread dough containing hydrophilic colloids such as xanthan gum did not significantly change, even when the water content of the dough exceeded that of conventional (non-additive) dough.[3)]

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Abbreviations: DM, dry matter; G', Storage modulus; G'', Loss modulus; σ_{yield}, yield stress.

Since pizza dough is comprised of only a few components (mainly wheat flour and water), it is possible that physical modifiers could result in an unnatural pizza crust taste. Wheat starch is the main component of pizza crust, and thus provides a natural taste even if it is added as a physical modifier to pizza dough. When starch is heated with water, the double-helix of amylopectin unfolds, and the amorphous amylopectin hydrates a larger amount of water molecules than its original form. This process is known as starch gelatinization.[4)5)] Starch gelatinization occurs in pizza crust during the baking process. Thus, if wheat flour in pizza dough is partially replaced by pre-gelatinized wheat starch, the pizza dough is expected to maintain its viscoelastic properties even at a higher water content compared to conventional dough. As a result, it is possible that pizza crust baked using an electric oven could be modified to produce a softer texture. Similar approach has been employed for the texture modification of bread[6)7)] and rice bread.[8)9)10)]

The purpose of this study is to clarify the effects of water and gelatinized starch on the viscoelasticity of pizza dough. In addition, the water-enriched pizza dough with gelatinized starch was baked using a household electric oven, and the texture of the modified pizza crust was compared mechanically and sensorially with that of conventional pizza crust.

MATERIALS AND METHODS

Materials. High gluten wheat flour (Nissin Seifun Group Inc., Tokyo, Japan), sucrose (Pearl Ace Co., Ltd., Tokyo, Japan), NaCl (Hakata Salt Co., Ltd., Ehime, Japan), olive oil (Nisshin OilliO Group, Ltd., Tokyo, Japan), and dry yeast (Nissin Seifun Group Inc., Tokyo, Japan) were purchased at a local market. Wheat starch was purchased from Wako Pure Chemical Industries, Ltd. (Osaka, Japan). The water content of the wheat flour and wheat starch was determined preliminarily to be 14.0 ± 0.3 g/100 g-DM (dry matter) and 11.9 ± 0.2 g/100 g-DM, respectively, by oven-drying at 105 °C for 24 h. For sensory analysis of pizza crust, commercially available wheat starch (Pioneer Planning Co., Kanagawa, Japan) was used as a food stuff. The water content of the commercially available wheat starch was 11.8 ± 0.1 g/100 g-DM.

Preparation of pizza dough models and samples. The experimental procedure is shown in Fig. 1. The ingredients of pizza dough models (mixture of wheat flour and water with and without pre-gelatinized starch) and samples (mixture of wheat flour, water, sucrose, NaCl, and dry yeast with and without pre-gelatinized starch) are shown in Table 1. For the preparation of pizza dough models and samples without pre-gelatinized starch, the ingredients were placed into the container of the bread maker (Home Bakery SD-BMS106; Panasonic Corp., Osaka, Japan). For the preparation of pizza dough models and samples with pre-gelatinized starch, gelatinized wheat starch was prepared in advance; water was added to the starch in a glass beaker containing a magnetic stir bar according to Table 1, and

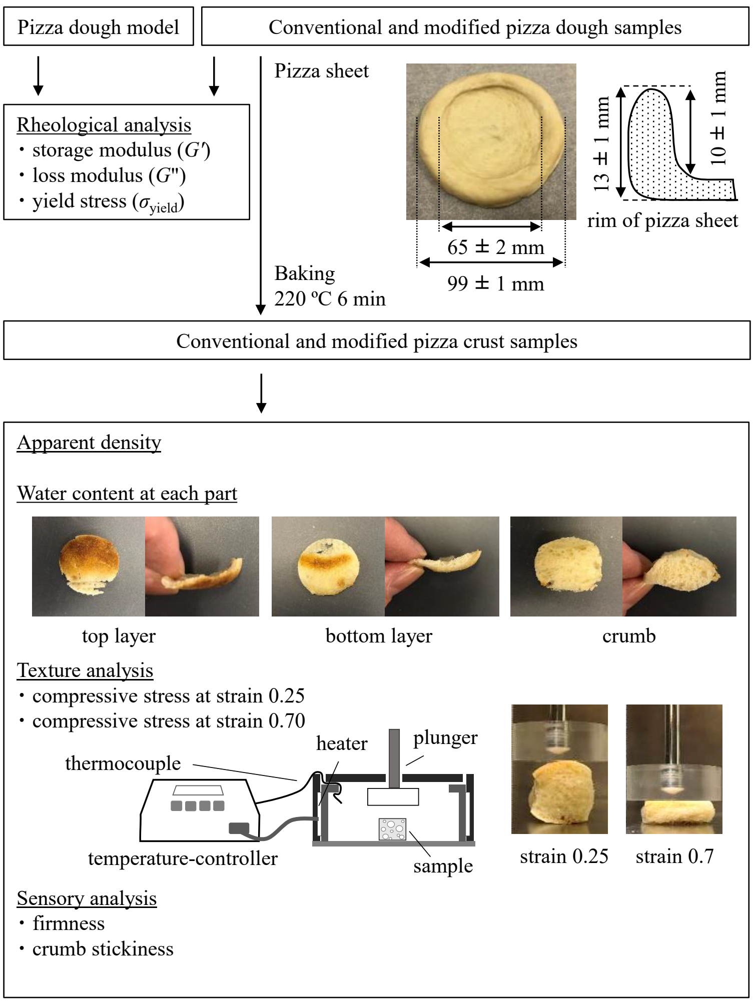

Fig. 1. Experimental procedure.

covered with plastic film. The beaker was placed in a water bath (98−100 °C) and heated for 10 min with stirring to prevent sedimentation of the starch granules. The gelatinized starch paste was cooled to room temperature and mixed with the other ingredients in the container of the bread maker. For the preparation of pizza dough samples with and without pre-gelatinized starch, the dry yeast was set in a separate compartment of the bread maker.

The pizza dough models and samples were prepared using the bread maker on 'pizza dough mode'. The ingredients in the container of the bread maker were kneaded over a 45 min period. It was previously confirmed that the dough temperature was increased up to 25 °C within 5 min. Then the temperature was maintained for 10 min, increased up to 34 °C within 10 min, and maintained for 20 min during processing.[11] The pizza dough models and samples were used within the same day.

Viscoelasticity of pizza dough models and samples. The G', G'', and yield stress (σ_{yield}) of the pizza dough models and samples were evaluated using a dynamic mechanical thermal analyzer (Haake Mars III system; Thermo Fisher Scientific K.K., Tokyo, Japan). The dough was set on the sample stage, and a parallel plate (diameter 20 mm and gap 1.0 mm) was used.[12] The G', G'', and σ_{yield} were evaluated at 1 Hz in the shear stress range between 1 Pa and 10,000 Pa at 25 °C (see detailed explanation below). The measurements were performed in triplicate and the results were averaged.

Preparation of pizza crust samples. For the preparation of pizza crust samples, conventional and modified pizza dough samples were used as listed in Table 1. Pizzas were formed according to our previous study[11] with a minor modification. In brief, the dough (50 g) was rolled out in a circular mold and pressed manually using a circular stamp. Then, a circular recess (diameter 65 ± 2 mm and depth 10 ± 1 mm) in the center of the pizza dough (diameter 99 ± 1 mm and height 13 ± 1 mm) was formed (Fig. 1). To prevent expansion in the center of the crust sample during baking, pin holes were randomly made in the dough. The dough samples were immediately baked using a household electric oven (NB-DT50; Panasonic Corp.) according to the manufacturer's instructions. The dough sample was placed on an aluminum plate and baked at 220 °C (set temperature) for 6 min in the electric oven. As a reference, the time courses of air, plate, and sample temperatures during the baking are shown in Fig. S1 (see J. Appl. Glycosci. Web site).

Water content at each part of pizza crust samples. The pizza crust was removed from the oven, and immediately the rim of the pizza crust was cut out with a circular mold (diameter of 30 mm) on a cutting board. In addition, the rim was divided into three parts with a knife; top and bottom layers and crumb (Fig. 1). To prevent water evaporation during analysis, the samples were enclosed into a plastic bag immediately after sampling and cooled down to ambient temperature. Water content of the samples was evaluated gravimetrically by oven-drying 105 °C for 24 h. The measurements were performed in triplicate and the results were averaged.

Apparent density of pizza crust samples. The pizza crust was cooled to ambient temperature, divided into half using an electric knife, weighed, and the volume was determined using a 3D-scanner (MFS1V2 3D SCANNER; Matter and Form, Inc., Toronto, ON, Canada). The measurements were performed in triplicate and the results were averaged.

Texture of the crumb part of pizza crust samples. Immediately after baking, the pizza crust sample was held at 60 °C for 8−11 min in an incubator before using for the texture measurement. It had been preliminarily confirmed that there was no significant change in the water content of pizza crust crumb samples during the holding period. The rim of the pizza crust was cut with a knife, and the crumb part formed a cube (10−15 mm) in the incubator. The size of samples was measured using a caliper. The sample was set on the sample stage surrounded by a heating system and compressed with a plate plunger (diameter 30 mm) at 100 mm/min at 60 °C (Fig. 1) using a rheometer of which digital force recorder (ZTA-100N, Imada Corp., Aichi, Japan) was equipped with a cylinder system (Nissin Seiki Co., Ltd., Hiroshima, Japan). From the stress-strain curve, compressive stress at strains 0.25 and 0.70 was evaluated. The measurements were performed in triplicate and the results were averaged.

Sensory analysis. Sensory analysis of the conventional and modified samples was carried out by ten panelists consisting of 4 men and 6 women between the ages of 22 and 29 years (mean age, 23.1 ± 2.4 years). The samples were served to the panelists within 5 min after preparation, and the firmness and crumb stickiness of the samples were evaluated using a scale from –2 (firm or not sticky) to +2 (soft or sticky). The evaluation index was in accordance with the literature on the sensory evaluation of bread.[13]

Statistical analysis. Statistical analysis was performed with

Table 1. The recipe for pizza dough models and samples.

Pizza dough	Notation	Wheat flour	Wheat starch	Water	Oil	Sucrose	NaCl	Yeast
Model	WS0	100	0	50 60 70 80	0	0	0	0
	WS10	90	10	60 70 80	0	0	0	0
	WS20	80	20	70 80	0	0	0	0
Sample	Conventional	100	0	60	3	2	2	2
	modified	80	20	80	3	2	2	2

Unit is gram.

a *t*-test and the Tukey-Kramer test ($p < 0.05$) using Microsoft Excel and R 4.0.2 for Windows.

RESULTS AND DISCUSSION

Rheological properties of pizza dough models.

As a typical result of dynamic mechanical thermal analysis, the effect of shear stress on the G' and G'' of a pizza dough model (wheat flour-water mixture without pre-gelatinized starch, water content of 0.82 g/g-dry wheat flour) is shown in Fig. 2A. The G' and G'' indicate elastic and viscous properties of the sample, respectively. With an increase in the shear stress, the G' and G'' showed a constant value up to approximately 100 Pa (linear stress region), and then largely decreased (non-linear stress region). The G' was slightly higher than the G'' in the linear stress region, but they showed crossover at a certain stress in the non-linear stress region. From the rheological behavior, G' and G'' values at around 10 Pa (linear stress region for every sample) were determined. In addition, shear stress at the crossover-point between G' and G'' was determined as σ_{yield}. The σ_{yield}, which is the minimum shear stress required for flow (irreversible deformation) of the sample, corresponds to the kneading property of dough.[14] It should be noted that the σ_{yield} evaluated by this approach is slightly higher than that determined from the shear stress-strain curve.[15] The σ_{yield} for a portion of the samples could not be determined because the crossover-point was not in the measured stress range.

The effect of water content on the G', G'', and σ_{yield} of pizza dough models is shown in Figs. 2B, 2C, and 2D, respectively. The values with the results of statistical analysis are also listed in Table S1 (see J. Appl. Glycosci. Web site). The water content in the figures was described as the total amount of water per total amount of dry wheat flour and wheat starch. The water content of the conventional pizza dough model (WS0) was 0.82 g/g-dry wheat flour. The G', G'', and σ_{yield} for the conventional pizza dough model were 21,020, 8,514, and 4,167 Pa, respectively. These reference values are indicated as horizontal dotted lines in the figures. The G' was approximately 1.8–3.0 times higher than G'' for all models, and the tangent loss (G''/G') values ranged between 0.3 and 0.6. The parameter tan δ characterizes the viscoelasticity of the sample between solid-like (tan $\delta < 1$) and liquid-like (tan $\delta > 1$). Gelatinized starch tended to reduce slightly the tan δ of the dough models. Water content, on the other hand, did not affect tan δ.[16]

The G', G'', and σ_{yield} decreased logarithmically with an increase in water content because of water plasticization.[2,16] When wheat flour was partially replaced with gelatinized starch, the G', G'', and σ_{yield} of the pizza dough models increased with the increase in replaced content at each water content. In other words, the rheological properties could be maintained by the addition of gelatinized starch even at a higher water content. The water content of the pizza dough model could be elevated up to 1.04 g/g-dry wheat flour-starch when wheat flour was replaced with 20 % gelatinized starch. Gelatinized starch is an amorphous polymer; thus, much greater intermolecular hydrogen bonding with water molecules is expected compared to non-gelatinized starch.[16,17,18] Since wheat flour was replaced with wheat starch, wheat protein (mainly gliadin and glutenin) content decreased. Effect of wheat protein on the rheological properties of pizza dough is discussed below.

Rheological properties of pizza dough samples.

According to the rheological properties of the pizza dough

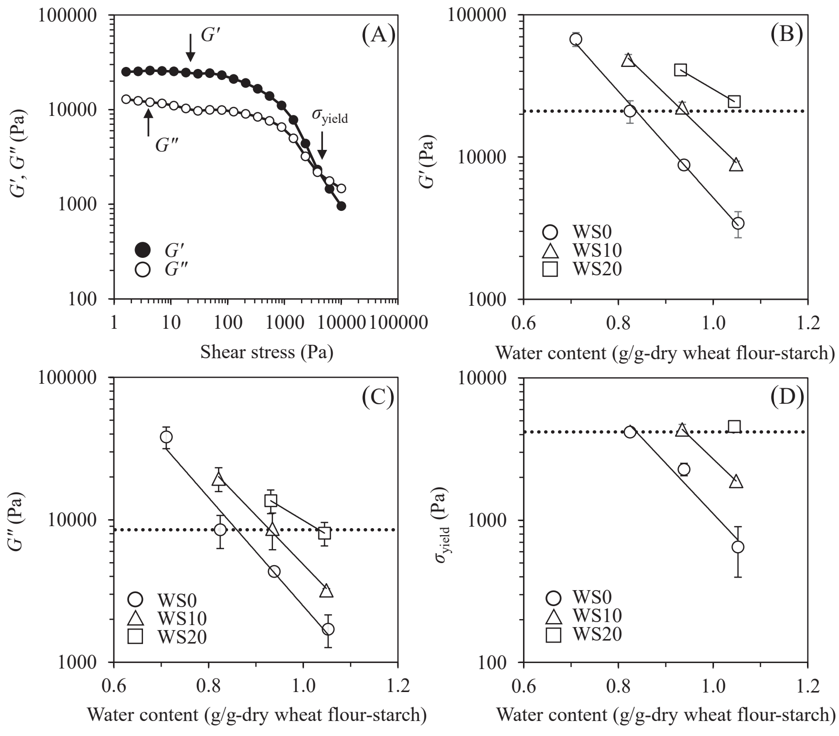

Fig. 2. Rheological properties of pizza dough models.

(A) Typical viscoelastic measurement result, and the effect of water content on the (B) storage modulus (G'), (C) loss modulus (G''), and (D) yield stress (σ_{yield}) of pizza doughs. The values are expressed as the mean ± SD ($n = 3$).

models, the conventional and modified pizza dough samples (Table 1) were used in the subsequent experiments. The rheological properties (G', G'', and σ_{yield}) are shown in Fig. 3. For comparison, pizza dough models having the same contents of water and replaced gelatinized starch (WS0 and WS20) are also shown. There was no significant difference in the rheological properties between WS0 and the conventional pizza dough sample (water content = 0.82 g/g-dry wheat flour) (Table S2: see J. Appl. Glycosci. Web site). This suggests that the minor ingredients (sucrose, NaCl, oil, and dry yeast) had a negligible effect on the rheological properties of the wheat flour-water mixture.

In a comparison between WS20 and the modified pizza dough (water content = 1.04 g/g-dry wheat flour-starch), the modified pizza dough exhibited slightly lower rheological properties. This suggests that the rheological properties of gelatinized starch are more sensitive to the minor ingredients. It is known that the structure of gas cells generated by yeast affects the viscoelasticity of dough. For example, Upadhyay *et al.* (2012) reported that G' increased with increasing yeast concentration and resulted in smaller gas cells.[2] When wheat flour was replaced with 20 % wheat starch, 2.16 % wheat protein content (per pizza dough) is lost. As is well known, gliadin and glutenin form the gluten network during dough making, and gas generated by yeast is trapped in this network. Since the reduction of gluten content will have resulted in an increase in the size of gas cells because of the loose gluten network, the rheological properties of modified pizza dough were lower than those of the model dough.

Apparent density and water content of pizza crust samples.

Conventional and modified pizza dough samples were baked at 220 °C for 6 min in the electric oven, and conventional and modified pizza dough crust samples were obtained. The apparent density of the conventional and modified pizza dough crust samples was 0.44 ± 0.22 and 0.43 ± 0.20 g/cm^3, respectively, and the values were not significantly different.

Water content at each part of the pizza crust samples is shown in Fig. 4. For comparison, the water content of the dough samples is also shown. There was no significant difference in the top and bottom water content between conventional and modified pizza crust samples. The top and bottom areas are exposed to the high-temperature condition during baking; thus, the water content in these parts will have been obviously diminished, irrespective of the initial water content.[19)20)] The crumb water content of the modified pizza crust, on the other hand, was much higher than that of the conventional crust. Notably, the crumb water content of the pizza crust samples was equivalent to the water content of each dough. Since the surface layer is formed at the early stage of baking, water evaporation from the crumb part will have been prevented.[20)] Thus, the water content was completely maintained in the crumb part after baking.

Texture of pizza crust samples.

A typical stress-strain curve for the pizza crust sample is shown in Fig. 5A. The stress gradually increased at the low-strain region, and largely increased at the high-strain region. As texture parameters, compressive stress at strains 0.25 and 0.70 was evaluated. The measurement was carried out according to the texture analysis of bread[21)22)] with minor modifications. Since bread is commonly served at room temperature,[23)24)] the texture of bread has been investigated at 25 °C. Pizza, on the other hand, is served piping hot, and thus the texture was investigated at 60 °C. In the case of texture analysis for bread, compressive force at strain 0.25 is evaluated for the classification of bread as being hard or soft. On the other hand, it has been reported that the texture

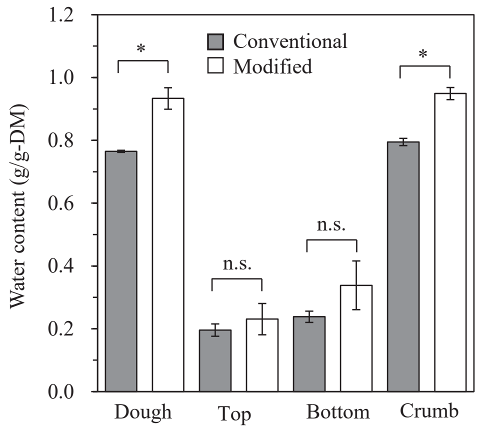

Fig. 4. Water content of conventional and modified pizza dough and crust samples.

The pizza crust samples were divided into top and bottom layers, and crumb. The values are expressed as the mean ± SD (n = 3). An asterisk indicates a significant difference at $p < 0.05$.

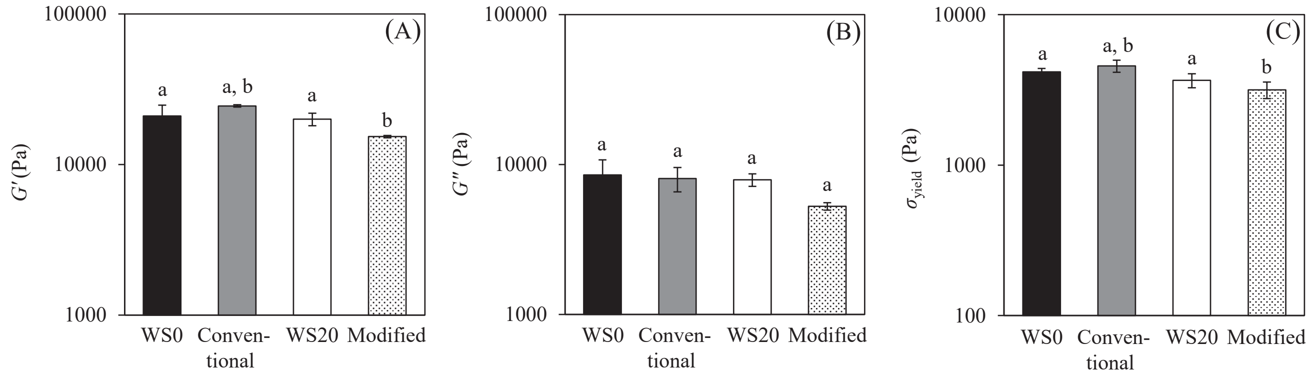

Fig. 3. Rheological properties of conventional and modified pizza sample doughs and pizza model doughs.

The model doughs (WS0 and WS20) have the same water and gelatinized wheat starch contents as the sample doughs. (A) Storage modulus (G'), (B) loss modulus (G''), and (C) yield stress (σ_{yield}) of doughs. The values are expressed as the mean ± SD (n = 3). Values with different letters are significantly different at $p < 0.05$.

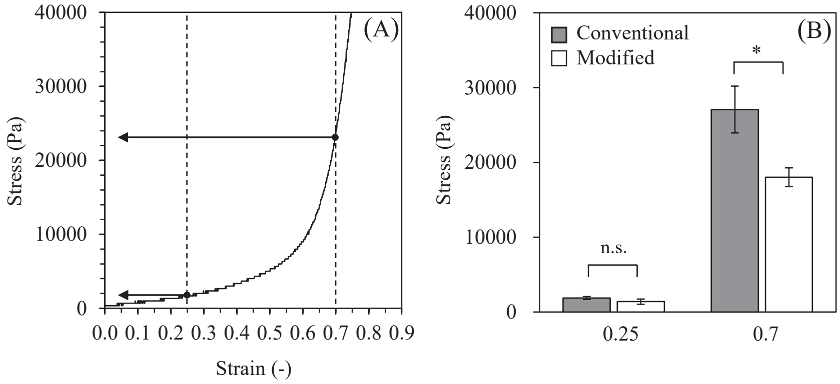

Fig. 5. Texture analysis of conventional and modified pizza crust samples.
(A) Typical stress-strain curve for the conventional pizza crust. (B) Compressive stress at strains 0.25 and 0.70. The values are expressed as the mean ± SD ($n = 3$). An asterisk indicates a significant difference at $p < 0.05$.

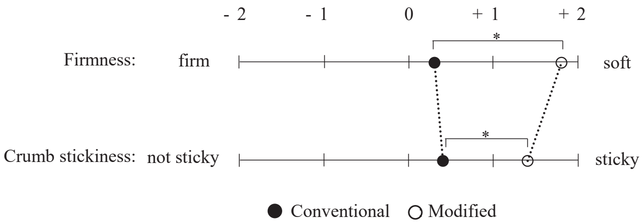

Fig. 6. Sensory evaluation score.
The values are in the range between –2 (firm or not sticky) and +2 (soft or sticky). The values are expressed as the mean ($n = 10$). An asterisk indicates a significant difference at $p < 0.05$.

parameters of rice noodles are evaluated at strain 0.70.[25)]

Compressive stress at strains 0.25 and 0.70 for conventional and modified pizza crust samples is shown in Fig. 5B. There was no significant difference in the stress at strain 0.25 between conventional and modified pizza crusts. Similar to bread,[22)] pizza crust has a gas cell structure. Samples are compressed reversibly at low strain because of the low elasticity originating from the gas cell structure. When wheat flour was replaced with 20 % wheat starch, 2.32 % wheat protein content (per pizza crust) is lost. The reduction of protein (gluten) content will have resulted in an increase in the size of gas cells because of the loose gluten network. However, there was no significant difference in the apparent density between conventional and modified pizza crusts. This suggests that the gas cell structure is developed in the modified pizza crust similar to the conventional crust. It was demonstrated that the stress at strain 0.70 for the modified pizza crust was significantly lower than that for the conventional crust. A value of 0.70 for strain is useful to characterize differences in the texture of pizza crusts.[11)]

The results of sensory analysis are shown in Fig. 6. The modified pizza crust exhibited higher firmness and crumb stickiness compared to the conventional crust. As mentioned above, the higher the water content, the softer the bread texture.[26)] Compressive stress at low and high strain is expected to correspond to firmness and stickiness, respectively. Although there was no significant difference in compressive stress at low strain, the firmness was perceived to be significantly different between the samples. This is considered to originate from the sensitivity of this method, as the compressive stress at low strain was much lower than that at high strain. To physically characterize the sensory firmness, other rheological techniques such as creep measurement will be effective.[27)]

CONCLUSION

The G', G'', and σ_{yield} of the pizza dough decreased as the water content increased. However, the rheological properties of the pizza dough with gelatinized starch were maintained even at a high-water content. In addition, it was demonstrated that the water-enriched pizza crust with gelatinized starch was softer and stickier than the conventional crust. When pizza is baked in an electric oven, the texture of the pizza crust is harder than when baked in a stone oven. The results of this study suggest that the texture of electric oven-baked pizza crust can be improved to a more favorable texture. These findings are of practical importance, especially for the convenient serving of pizza such as by fast-food restaurants and at home.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

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