Effect of steaming, freezing, and re-steaming on the texture properties of non-glutinous rice cakes

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Abstract The effects of steaming time (6, 8, and 10 min), freezing storage period, and re-steaming for thawing on the textural properties of non-glutinous rice cakes (*baekseolgi*) were investigated. As the steaming time increased, the rice cakes softened. In particular, the sample that was steamed for 10 min showed lower hardness than those steamed for shorter periods. A short period of steaming was insufficient for water bound to the surface of the starch granules to penetrate the granules in the dough. During the re-steaming process of the frozen non-glutinous rice cake samples, the retrogradation of starch and water syneresis contributed to the increased hardness of non-glutinous rice cakes.

Keywords: non-glutinous rice, cake, water, steaming, texture

Introduction

Non-glutinous rice cakes (*baekseolgi*) are basic, white steamed rice cakes that are prepared with non-glutinous rice flour and sugar and served as a dessert. Although the recipe is described in many Korean culinary manuscripts, these methods are based on experience, rather than a scientific process, and there is little unity in the manufacturing of non-glutinous rice cakes. The quality of non-glutinous rice cakes is based on various properties, including the rice cultivar (1), particle size (2), soaking, and drying conditions (3). The critical factors that influence the quality of non-glutinous rice cakes were examined using non-glutinous rice cakes that were prepared using various processes and ingredients, including different steaming times and water contents.

To make non-glutinous rice cakes, non-glutinous rice flour, sugar, salt, etc. are combined and steamed, and this process results in the gelatinization of starch in the non-glutinous rice flour. Owing to the rapid retrogradation of the starch in non-glutinous rice cakes after preparation, they require processing for long-term storage. Freezing is a well-known technique to retard retrogradation in rice cakes. In the preparation and storage of non-glutinous rice cakes, various phases of water (i.e., water, ice, and vapor) are involved, and each affects the gelatinization and retrogradation behavior of starch, which determines the quality of non-glutinous rice cakes. During non-glutinous rice cake preparation, water is used as an ingredient to

prepare dough, as vapor during steaming, and as ice within the cakes during freezing storage. Therefore, in the processes of dough-making, cooking, freezing, and thawing of non-glutinous rice cakes, the mass transfer of water and energy transfer from within and outside of rice cakes affect the relative contribution of water, vapor, and ice to the quality of rice cakes. Therefore, understanding the phase changes of water and physical processes that occur during non-glutinous rice cake preparation and storage can provide fundamental information related to their mechanical properties and texture.

One of the techniques used to characterize the textural properties of rice cakes is the large-strain compression test. Stress and strain are common parameters derived from large-strain measurements and may be determined based on sample breakdown (fracture). Texture profile analyses (TPAs) have been used to analyze textural properties of foods, such as hardness, compressive behavior, and deformation (4,5). Two successive compressions to measure the hardness and cohesiveness of various foods imitate the destructive process that occurs in the mouth. A TPA under large deformation provides more direct information on textural properties and can be readily adopted as a routine method owing to its simplicity and discriminative ability (6,7). The fracture properties of foods are highly correlated with some sensory texture attributes (8). Hardness and adhesiveness as estimated by a TPA test are indicators of the textural properties of rice cakes (9). In addition, changes in these parameters are useful to

evaluate and compare the textural properties of rice cakes that are prepared at different conditions.

The objectives of this study were to investigate the effects of steaming time (6, 8, and 10 min) and water content (60 and 65%) on the textural characteristics of non-glutinous rice cakes (*baekseolgi*). In addition, the effect of the freezing storage period on the textural properties of non-glutinous rice cakes after thawing by re-steaming was studied.

Materials and Methods

Materials Non-glutinous rice flour was obtained from Nongshim Flour Mills Corporation (Asan, Korea) and was stored at -20°C . Other ingredients, such as salt (CJ Corp., Shinan, Korea) and sugar (Samyang Corporation, Ulsan, Korea), were purchased from local markets.

Preparation of non-glutinous rice cakes (*baekseolgi*) To prepare non-glutinous rice cakes, 600 g of non-glutinous rice flour and 7.8 g of salt were mixed with water. In this study, 2 levels of water, 360 and 390 g, were tested. In order to adjust water content accurately to the given levels, additional water content was calculated after measuring inherent moisture content in the rice flour. Subsequently, the mixture was passed twice through a 16-mesh sieve, and supplemented with 36 g of sugar. Finally, the mixture was put into a stainless steel tray (45 mm×45 mm×40 mm) and was steamed in an electronic steamer (3 kW; Daechang Stainless, Seoul, Korea). In this study, 3 different steaming times (6, 8, and 10 min) were applied to investigate their effect on the texture properties of non-glutinous rice cakes. Steaming time affects the degree of gelatinization of rice starch molecules, which is a major factor that determines the textural quality of non-glutinous rice cakes. After steaming, the non-glutinous rice cake was removed from the steamer and cooled on a table at room temperature ($25\pm 2^{\circ}\text{C}$) for 30 min. The non-glutinous rice cake samples were stored in an ethylene bag.

Freezing storage and thawing of non-glutinous rice cakes The non-glutinous rice cake samples packaged in an ethylene bag were stored at -40°C in a deep-freezer for 40 min and were subsequently stored at -20°C in a refrigerator for 28 days.

During freezing storage, the non-glutinous rice cake samples were collected periodically (7, 14, and 28 days) for analyzing their texture properties to determine the effect of freezing storage on rice cake quality. Frozen non-glutinous rice cake samples were thawed by re-steaming for 10 min. The re-steamed samples were vacuum-packaged in high-density polyethylene plastic bags and were cooled on a table at room temperature ($25\pm 2^{\circ}\text{C}$) for up to 4 h. The thawed rice cake samples by re-steaming were collected at 1 h intervals to investigate textural changes over time.

Textural profile analysis of non-glutinous rice cakes The TPA was

performed using a texture analyzer (MS-Pro; Food Technology Co., Sterling, VA, USA) equipped with a 25 N load cell and a circular probe of 7.5 cm in diameter to measure hardness and adhesiveness. The non-glutinous rice cake sample (45 mm×45 mm×40 mm) was compressed by up to 50% of its original height at 120 mm/min. TPA parameters, such as hardness and adhesiveness, of the non-glutinous rice cake sample were calculated using the software provided with TMS-Pro. The TPA was replicated for 3 samples.

X-ray diffractometry of non-glutinous rice cakes X-ray diffractometry analyses of the non-glutinous rice cakes prepared using different water contents and steaming times were carried out using a high resolution X-ray diffractometer (X'Pert PRO MPD; PANalytical, Almelo, Netherlands). The X-ray diffractometer was operated at a target voltage of 40 kV and a current of 30 mA. The scanning angle (2θ) was set at a scan rate of $1.5^{\circ}/\text{min}$ between 2.5 and 40° .

Statistical analysis The statistical analysis was performed with SPSS ver. 18.0 for Windows (Statistical Package for the Social Sciences, IBM Corp., Armonk, NY, USA). To analyze the effects of water content (60 and 65%) and steaming time (6, 8, and 10 min) on the textural properties of the non-glutinous rice cakes, the results were expressed as means $\pm$ SD (Standard Deviation) and a two tailed *p*-value of less than 0.05 was considered statistically significant. Differences in continuous variables among groups with different steaming times were tested using one-way analysis of variance followed by post-hoc tests using the Bonferroni method. Differences in the texture properties among rice cakes prepared using different water contents or steaming times were tested using independent *t*-tests.

Results and Discussion

Microstructure and textural profile of non-glutinous rice cakes

Figure 1 shows scanning electron micrographs of the non-glutinous rice cakes prepared using different water contents and steaming times. The gelatinized starch matrixes possessed many pores occupied by water or air, but these were removed during specimen preparation for the scanning electron microscopy analysis. The texture of the rice cakes may depend on the ratio of the starch matrix to the pore area, which is dependent on the water content of the dough as well as the steaming time.

Figure 2 shows the hardness and adhesiveness of the non-glutinous rice cakes prepared using various water contents and steaming times. When a non-glutinous rice cake was tested by TPA, it deformed (compressed) against the stress applied by the probe installed on the texture analyzer and eventually broke into pieces (fracture or collapse). This compressive behavior is generally attributed to structure densification, which is typical of highly cross-linked polymer systems (10). Upon compressing non-glutinous rice cakes, more energy was required for deformation owing largely to the

Fig. 1. SEM micrographs of the non-glutinous rice cakes prepared with (A) 60% and (B) 65% water contents for 10 min steaming.

dense structure of the gelatinized starch matrix.

The non-glutinous rice cake samples were fractured when the stress applied was greater than the adhesion or cohesion between the structural elements. Beyond this point, the samples were broken into small pieces during the TPA test (11). The stress value at the collapse point is generally considered a measure of hardness in the TPA test. The gelatinized networks in the rice cake were fractured and compacted again during a second compression, which offered a progressive increase in the resistance of the structure of the non-glutinous rice cake during the TPA test. The hardness and adhesiveness of the non-glutinous rice cakes depended on the water content and the steaming time, as shown in Fig. 2.

Effect of water content on the textural properties of non-glutinous rice cakes The hardness and adhesiveness of the non-glutinous rice cakes prepared using 60 and 65% water contents are shown in Fig. 2. For a dough mixture with a water content of 60%, the hardness values of the non-glutinous rice cakes steamed for 6, 8, and 10 min were 37.72, 34.55, and 33.86 N, respectively. The hardness values of the non-glutinous rice cakes with a 65% water content were 46.93 (6 min), 42.59 (8 min), and 40.10 (10 min). Hardness increased as the

water content increased under our TPA testing conditions. The rice cakes prepared with a water content of 65% needed a higher compression force to breakdown the internal structure during the TPA test. A lack of gelatinization was observed when rice cakes with higher water content were prepared. Dough prepared with higher water content was associated with a less gelatinized structure in the rice cake, resulting in higher hardness. As a result, non-glutinous rice cakes prepared with a relatively higher water content were harder. The observed changes in hardness with respect to water content are in agreement with those of other TA analyses of rice cakes (12).

The adhesiveness values of the non-glutinous rice cakes with 60% water content were 21.83 (after steaming for 6 min), 18.81 (8 min), and 17.71 (10 min) N·s. When the dough was prepared with a 65% water content, the adhesiveness values of the non-glutinous rice cakes steamed for 6, 8, and 10 min were 29.19, 17.81, and 18.43 N·s, respectively. Overall, adhesiveness increased with as the water content of the dough increased for all tested conditions, except 8 min of steaming. Rice cakes prepared with higher water content (65%) were stickier than those prepared with lower water content because the rice cake structure held more water during gelatinization. The internal structure for rice cakes with a higher water content exhibited minimal starch gelatinization, resulting in a larger adhesiveness value. As a result, the rice cakes underwent less expansion and a sticky texture was obtained.

When the dough samples with 60 or 65% water contents were steamed for 8 min, the adhesiveness values of the rice cakes were 18.81 and 17.81 N·s, respectively. The adhesiveness of the non-glutinous rice cakes was inversely related to steaming time; the relationship between adhesiveness and water content was inconsistent. However, the changes in adhesiveness in response to changes in water content were not as pronounced as the observed changes in hardness, but should be taken into account during rice cake processing.

Effect of steaming time on textural properties of non-glutinous rice cakes The steaming time (6, 8, and 10 min) affected the hardness and adhesiveness of the non-glutinous rice cakes, as shown in Fig. 2. For non-glutinous rice cakes prepared with dough containing both 60 and 65% water non-glutinous rice cakes, the hardness increased as the steaming time decreased. In order for rice dough to gelatinize completely, sufficient energy (i.e., heat supplied for a sufficient period) is needed during steaming. In general, the crystalline structure of the starch granules in rice dough is easily softened by heating. Water is absorbed and easily penetrates starch granules upon heating. Under a sufficient energy supply, the crystalline structure of the starch granules changes into an amorphous form. Thus, a sufficient energy supply results in a soft texture of the non-glutinous rice cake.

Steaming time affects the textural properties and degree of gelatinization of the non-glutinous rice cakes which are made of the lumps of the gelatinized particles in the dough. The formation of the

Fig. 2. Effect of water content and steaming time on hardness and adhesiveness of the non-glutinous rice cakes: (A) hardness of the rice cakes with 60% water content, (B) hardness of the rice cakes with 65% water content, (C) adhesiveness of the rice cakes with 60% water content, and (D) adhesiveness of the rice cakes with 65% water content.

lumps of the gelatinized particles are affected by water content and water distribution in the dough during steaming. For water contents of both 60 and 65%, the hardness values were higher for the non-glutinous rice cakes steamed for 6 min than for those steamed for 8 or 10 min, as shown in Fig. 2. Six minutes was insufficient for the development of a completely gelatinized structure in the rice cakes, resulting in a large hardness value. The textures of the non-glutinous rice cakes prepared with insufficient steaming times were relatively hard compared to those prepared with sufficient steaming times. These results agree with those of previous studies related to rice cakes (13).

The adhesiveness of the non-glutinous rice cakes with water contents of 60 and 65% that were steamed for 6 min were 21.83 and 29.19 N·s, respectively; these represented the highest adhesiveness values observed in this study. Adhesiveness was high when the non-glutinous rice dough was steamed for a short period. Similar to the hardness results, 6 min of steaming was insufficient to develop a fully gelatinized structure in the rice cake. A short steaming time did not enable water bound to the surface of starch granules to penetrate the granules in the dough. Therefore, the surfaces of starch granules had relatively high amounts of bound water, resulting in a stickier

rice cake. As a result, severe gelatinization occurred on the surface of the starch granules owing to highly localized water, but gelatinization inside the rice cake was incomplete. The observed effects of heating (steaming) time on the adhesiveness of rice cakes were in agreement with the results of previous reports (14).

Effect of water content and steaming time on crystalline properties of non-glutinous rice cakes

Figure 3 shows the crystalline patterns of the non-glutinous rice cakes determined by X-ray diffraction. Specifically, the X-ray diffraction patterns of non-glutinous rice cakes showed peaks at 15, 17, 22, and 24°, which are often observed in retrograded starches with B-type crystallinity. In general, retrograded starches are characterized by a B-type diffraction pattern, which is different from the A-type diffraction pattern with strong peaks at 13 and 21°. An increase in crystallinity results in a hard texture and phase separation between the gelatinized starch matrix and water in the non-glutinous rice cakes. Retrogradation of rice cakes is associated proportionally with content of amylose which plays an important role in the formation of rice cake structure (15).

The non-glutinous rice cakes prepared using dough with a water content of 60% showed lower peak intensities than rice cakes with a

Fig. 3. X-ray diffraction pattern of non-glutinous rice cakes prepared with (A) 60% and (B) 65% water contents steamed for 6, 8, and 10 min.

water content of 65%, and these intensities were significantly dependent on the steaming time, as shown in Fig. 3. For SRs with 60% water content, crystallites of SRs increased with decreasing steaming time where the XRD angle was low. For the non-glutinous rice cakes with 65% water content, steaming time did not significantly affect the crystalline patterns since the rice cakes were prepared with sufficient water content (65%) which resulted in higher crystallinity owing to

the relatively large amount of free water (unbound water). This is in agreement with previous studies showing that diffraction patterns over time depend on the amount of water present in the food matrix (15). In a previous study of examining gluten-free bread production, bread prepared with water contents exceeding 43% showed a B-type crystalline structure, while those prepared with water contents of lower than 29% formed an A-type pattern (16).

Effect of freezing storage period on textural properties of non-glutinous rice cakes The hardness and adhesiveness of the non-glutinous rice cakes after freezing storage for up to 28 days are listed in Table 1. The effect of the freezing storage period on hardness and adhesiveness was examined for samples prepared with 60% water content owing to the superior quality relative to those prepared with 65% water content based on the above mentioned analysis. However, the effect of steaming time was studied across the same range (6, 8, and 10 min) as that used for rice cake preparation.

When the non-glutinous rice cakes prepared with 6, 8, and 10 min of steaming were stored for 1 day, their hardness values after thawing were 37.583, 36.417, and 32.580 N, respectively. In particular, the sample steamed for 10 min showed lower hardness than that steamed for shorter periods. As storage time elapsed in the freezer at -20°C , the hardness of the non-glutinous rice cake samples increased slightly up to 7 days, but increased considerably up to 28 days. The hardness values of the non-glutinous rice cakes prepared with 6, 8, and 10 min of steaming after 7 days of storage were 38.237, 36.847, and 32.973, respectively, and after 28 days storage were 39.330, 39.070, and 37.947, respectively. These results demonstrated that the thawed non-glutinous rice cakes were of poorer quality than the fresh rice cakes. Although freezing is recognized as the best method to retard the retrogradation of bakery and rice cake products, hardness increases during long-term freezing storage, e.g., storage for 28 days. The retrogradation of the non-glutinous rice cakes might be accelerated during the thawing process by re-steaming.

During the freezing process, water molecules in the rice cake matrix coalesce to form ice crystals, and subsequently migrate and are separated from the rice cake matrix. During the re-steaming

Table 1. Effects of freezing storage period on the non-glutinous rice cake texture

Texture properties ¹⁾	Freezing storage period (days)	Steaming time (min)		
		6	8	10
Hardness (N)	1	37.583±0.496 ^{a2)}	36.417±0.717 ^a	32.580±0.434 ^b
	7	38.237±0.478 ^a	36.847±0.511 ^a	32.973±0.506 ^b
	28	39.330±0.705 ^a	39.070±0.26 ^a	37.947±0.451 ^a
	<i>p</i> -value	0.171	0.025	<0.001
Adhesiveness (N·s)	1	15.261±0.377 ^c	17.738±0.177 ^b	19.579±0.168 ^a
	7	8.448±0.858 ^a	6.643±0.022 ^{ab}	5.416±0.320 ^b
	28	9.148±0.372 ^b	10.916±0.417 ^a	12.084±0.297 ^a
	<i>p</i> -value	<0.001	<0.001	<0.001

¹⁾Data indicate hardness and adhesiveness of the rice cake samples which were vacuum-packaged in a high density polyethylene (HDPE) plastic bag and were cooled on a table at room temperature ($25\pm 2^{\circ}\text{C}$) for 1 h after thawing by re-steaming prior to texture measurement. Data are mean±SD.

²⁾Sharing the same alphabet indicates no significant difference ($p\geq 0.05$) in mean values tested by ANOVA with the Bonferroni method.

Fig. 4. Effect of freezing storage period and after-thawing elapsed time on (A) hardness and (B) adhesiveness of the non-glutinous rice cakes with 60% water content at different steaming time. Symbols represents the freezing storage period of the non-glutinous rice cakes at different steaming time: ○ 6 min steaming and 1 day freezing storage, ▽ 8 min steaming and 1 day freezing storage, □ 10 min steaming and 1 day freezing storage, ● 6 min steaming and 7 days freezing storage, ▼ 8 min steaming and 7 days freezing storage, ■ 10 min steaming and 7 days freezing storage, ● 6 min steaming and 28 days freezing storage, ▼ 8 min steaming and 28 days freezing storage, and ■ 10 min steaming and 28 days freezing storage.

process, the retrogradation of the rice cake matrix occurs and is associated with syneresis, which is the separation of water from the rice cake matrix. Upon thawing, ice is converted into water, which is released in bulk from the matrix (17). In addition, thawing (corresponding to a change in the water phase from ice to water) is a slower process than freezing (a change in the water phase from water to ice) because the thermal diffusivity and thermal conductivity of water are smaller than those of ice (18). During the thawing process, the retrogradation of starch and water syneresis contributed to increased hardness of the non-glutinous rice cakes.

When the non-glutinous rice cakes prepared via 6, 8, and 10 min of steaming were stored for 1 day, their adhesiveness values after thawing were 15.261, 17.738, and 9.579 N·s, respectively. The adhesiveness of the non-glutinous rice cakes was lower after freezing

storage compared to that of the fresh rice cakes (i.e., no freezing). During freezing storage and subsequent thawing, water was separated from the rice cake matrix over time. The water syneresis in the rice cake matrix lowered the adhesiveness. In addition, the non-glutinous rice cakes that were prepared using a longer steaming time showed lower adhesiveness. These phenomena were similar with the samples stored for 7 days. Interestingly, the adhesiveness increased again slightly for the non-glutinous rice cake samples stored for 28 days. The adhesiveness values of the non-glutinous rice cakes prepared with 6, 8, and 10 min of steaming after 28 days of storage were 9.148, 10.916, and 12.084, respectively. As a result, the retrogradation of non-glutinous rice cakes might be accelerated during thawing process.

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