Baking and Coloring Characteristics for Frozen Pizza Dough in a Hot-air and Superheated Steam Oven

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Summary

Pizza dough samples were frozen and stored at different temperature (-5°C, -15°C, -25°C, -35°C and -45°C) and for different storage periods (1 day, 15 days, 25 days and 35 days) to measure the baking characteristics of the samples in a hot air (HA) and superheated steam (SHS) oven. Baked samples were employed for the measurement of surface color and moisture content. The moisture content of the samples frozen at -5°C significantly decreased after 15 days of frozen storage. The surface color of the SHS-dried samples changed more drastically than that of HA-dried samples. Compared with HA, the SHS baking showed the potential to give the frozen pizza dough higher thawing rate, less baking time, and faster browning ability. The combined effect of initial condensation, crust thickness and water redistribution from crumbs to crusts might have played important roles in differentiating the HA- and SHS-baked samples. Different freezing temperatures from -5°C to -45°C did not cause any significant difference in color.

Keywords: baking, frozen pizza dough, hot-air, superheated steam, surface color

1. Introduction

One of the advantages of utilizing superheated steam (SHS) in food processing is to shorten the cooking time due to the increase in heat transfer rate inside food materials\(^1\). Although continuous thawing and heating characteristics of frozen beef have been already investigated using SHS\(^2\), there was no previous studies on the measurement of continuous thawing and heating characteristics of other food materials. This research aims to give a better understanding on the evaluation for the baking characteristics and subsequent quality of frozen pizza, including thawing rate, baking time and crust color. Hot air (HA) was also used as the comparison baking medium for comparison together with SHS throughout the whole research steps.

2. Materials and Methods

2.1 Sample dough preparation

Based on the previous research\(^3\), the following ingredients were used for making sample pizza dough: Rustica pizza flour (100%; Baker’s percent), salt (1.74%), sugar (2%), olive oil (3%), dry yeast (0.5%) and water (58%). All ingredients were slowly mixed for 1 min by a kitchen-aid heavy duty mixer and after the dough stuck together the mixing speed was turned to medium-slow for another 6 min. After mixing was completed, the dough was taken off from the hook of the mixer and was rested for 10 min, with an aluminum paper covered for a short-time pre-proofing (room temperature). Once the dough was pre-proofed, it was divided into 75 g for each piece, and then shaped and rounded by a sample mold (100 mm in diameter and 10 mm in height).

2.2 Experimental Oven and Data Acquisition System

An experimental oven\(^4\) was designed and manufactured to allow continuous measurement of the changes in mass of the samples using an electric balance Shimazu UW-4200H (Shimadzu Corp., Kyoto, Japan) placed on the top of the oven (Fig.1). A sample holder was hung on to the balance, using a wire through a hole made on the top of the oven.

Measurement of temperatures was carried out using K-type thermocouples located at several points, which are the surfaces of top heater inside the oven, the center of the oven, and the samples.

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2.3 Freezing and frozen storage

Pizza dough samples were frozen and stored at different temperature (-5°C, -15°C, -25°C, -35°C and -45°C) and for different storage periods (1 day, 15 days, 25 days and 35 days) before the baking characteristics of the samples were measured during hot air (HA) and superheated steam (SHS) baking. A thermostat chamber (EC-33LTP, Hitachi) was used for freezing process. During freezing, the inner temperature of the samples was measured using K-type thermocouples connected to a data logger (GL220, GRAPHTEC). After the core temperature had reached down to the desired temperature, the samples were kept frozen in a storage refrigerator (SANYO, MDF-U536D).

2.4 Baking

Baking experiment was conducted using the experimental oven shown in Fig.1. The temperature of superheated steam was maintained at 105°C. An electric scale (Shimadzu UW4200H) was placed on the top of the oven and separated from the oven by a heat protection space, where an electric fan was also used for heat dissipation. Heaters were installed both in the upper and lower layers in the oven and heat-durable thermocouples were tied around heaters to check their temperature. Another thermocouple was used to check the air surrounding the sample holder. During preheating, temperature of heaters was adjusted so as to ensure the air temperature surrounding the samples to be approximately same and stable for each trial. In this research, surrounding air temperature was adjusted to around 260°C for both hot air (HA) and superheated steam (SHS) baking methods.

Thermocouples were inserted approximately into the core part of the samples to measure the inside temperature of samples during baking. To avoid samples under or over baking, baking was stopped immediately when inner temperature reached up to 100°C, which was a threshold because temperature of samples would not rise above it. During baking, weight and temperature of samples were measured simultaneously.

After baking was completed, samples were allowed to cool down till the inner temperature was down to room temperature before wrapped with preservative films to prevent moisture loss. Three samples frozen under each temperature under 1 day frozen storage were baked in this research. Samples frozen over 15, 25 and 35 days were not triplicated due to the availability.
2.5 Color measurement
The surface color of the samples was measured using a handy spectrophotometer NF-333 (Nippon Denshoku, Ind. Co. Ltd, Tokyo, Japan) before and after baking. The color difference ($\Delta E$) between the samples before and after baking was calculated as follows:

$$\Delta E = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2} \quad (1)$$

where $L_1$, $a_1$, and $b_1$ stand for the color values of the samples before baking, and $L_2$, $a_2$, and $b_2$ for those of baked samples.

2.6 Moisture content measurement
Three cylindrical small samples (diameter 6 mm, height 10 mm) taken from the middle part of the samples by cork borer, were dried by an oven (F0-60W, Japan) under 105ºC over 24 h.

2.7 Statistical analysis
R programming language was used for statistical analysis.

3. Results and Discussion
3.1 Freezing characteristics
Fig. 2 shows freezing curves of sample center temperature under different freezing conditions. All the samples were frozen for 4 h. Supercooling was observed in the samples frozen at -5ºC.

Table 1 shows the moisture content of the samples after frozen storage. The moisture content of the samples frozen at -5ºC significantly decreased after 15 days of frozen storage.

3.2 Baking characteristics
Initial condensation had been a unique phenomenon in SHS baking and a weight increase proved this phenomenon in this research (Fig.3). During baking, inner temperature in samples did not transcend 100 ºC due to the phase transition. Compared with HA baked samples, the samples baked by SHS showed significant higher thawing rate in samples frozen under all temperatures, and this was due to higher heat transfer properties in SHS than in HA at the same temperature (Fig. 4; Table 2). Initial condensation might also contribute to this result.

Some apparent correlation was found in HA baked samples such as the longer the lower the freezing temperature, the longer the baking time. However, this did not work the same in SHS baked samples, revealing a more complicated baking method compared with HA.

Table 1 Moisture content of the samples after frozen storage

<table>
<thead>
<tr>
<th>Freezing temperature</th>
<th>Frozen storage duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ºC)</td>
<td>1</td>
</tr>
<tr>
<td>-5</td>
<td>64.7±0.4c</td>
</tr>
<tr>
<td>-15</td>
<td>68.1±0.8a</td>
</tr>
<tr>
<td>-25</td>
<td>68.5±0.1a</td>
</tr>
<tr>
<td>-35</td>
<td>70.0±0.4b</td>
</tr>
<tr>
<td>-45</td>
<td>71.1±0.5b</td>
</tr>
</tbody>
</table>

a,b,c: Means with the same lowercase superscript in the same column are not significantly different at the 0.05 level.

Fig. 2 Freezing curve of sample center temperature under different freezing conditions

Fig. 3 Typical weight loss curves of HA and SHS baked samples during baking

Fig. 4 Typical temperature profiles of HA and SHS baked samples during baking
3.3 Color

In SHS baked samples, L₂ and a₂ values were significantly lower in samples frozen under -25 °C, than samples frozen under -35 °C, while a₂ values was significantly lower in samples frozen under -35 °C (Table 3). This was due to the longer baking time in samples frozen under -25 °C and shorter baking time in samples frozen under -35 °C.

Compared with HA baked samples, SHS baked samples had significantly (p<0.05) lower L values, while higher in a, b total color variance values. This result indicated accelerated surface browning by the combined effect of Maillard reaction and caramelisation, between which the Maillard reaction took more part in coloring than caramelisation did. Previous research had found that the value of L₂ decreased more quickly by SHS than HA in the baking process of sliced bread by using in-situ color measurement.

Fig. 5 and Fig. 6 show the intuitive vision of the appearance comparison of crust color between HA- and SHS-baked samples. L, a and b values of samples baked SHS are apparently distributed in a wider range in the colour space, indicating larger total colour change (ΔE) values with darker, yellower and redder outcomes, even within comparatively shorter baking time. In this research, baking temperature was controlled to be around 260 °C in either baking method. Comparatively larger amount of moisture loss to crust of samples baked by SHS might be the reason why the crust colour was more severely tanned (Fig. 6).

The crust and crumb came from the same original dough, but their final properties differed according to a distinct local heat-moisture treatment. As soon as the dough was placed inside the oven, water evaporated from the warmer region, absorbing latent heat of vaporization and the surface layers started baking, resulting in a much lower water content than at the center part. Beneath this baking region, water vapor diffused through the interconnected pores towards the surface. A concomitant liquid water gradient was formed from the core to the surface. As the diffusive flow of liquid water from the core was less rapid than evaporation flow at the surface, a baking zone was developed that slowly increased in thickness and formed the crust. Compared with crumb, the heating rate of crust was higher. Also, the addition of steam reduced the water loss at the onset of baking, as shown in Fig. 4. However, as the surface reached the dew point temperature, steam accelerated temperature rise and water loss for long baking time, which differentiated with HA baked crust, showing a more tanned color.

4. Conclusion

The moisture content of the samples frozen at -5°C significantly decreased after 15 days of frozen storage. The surface color of the SHS-dried samples changed more drastically than that of HA-dried samples. Compared with HA baked samples, SHS baked samples showed higher thawing rate and less baking time. SHS baked samples had darker, yellower and redder crust color.

Initial condensation, baking rate especially at the top layer of pizza crusts crust thickness and water redistribution from crumbs to crusts might have played the most important roles which differentiated HA and SHS baked products. Different freezing temperature from -15°C till -45°C did not seem to produce different outcomes in color of frozen pizza, except for thawing rate due to the temperature difference between frozen pizza dough and baking medium.

5. Acknowledgment

This work was partially supported by JSPS KAKENHI 15K14832.

References

Table 3 Color values of the samples (1 day frozen) before and after baking

<table>
<thead>
<tr>
<th>Baking method</th>
<th>Freezing temperature (ºC)</th>
<th>-5</th>
<th>-15</th>
<th>-25</th>
<th>-35</th>
<th>-45</th>
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</thead>
<tbody>
<tr>
<td>L1</td>
<td>-</td>
<td>85.2±0.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>88.9±1.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>87.5±1.9&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>87.5±1.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>a&lt;sub&gt;1&lt;/sub&gt;</td>
<td>-</td>
<td>4.0±0.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.9±0.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9±0.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.1±0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.0±0.7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>b&lt;sub&gt;1&lt;/sub&gt;</td>
<td>-</td>
<td>14.5±1.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.9±1.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.5±0.9&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>14.4±1.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.4±1.0&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
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<td>HA</td>
<td>80.9±2.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>82.5±4.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>82.2±1.7&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>SHS</td>
<td>77.8±1.3&lt;sup&gt;c&lt;/sup&gt;</td>
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<td>65.7±5.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>60.8±7.7&lt;sup&gt;ab&lt;/sup&gt;</td>
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<tr>
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<td>HA</td>
<td>3.0±0.4&lt;sup&gt;ab&lt;/sup&gt;</td>
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<td>2.7±1.2&lt;sup&gt;ab&lt;/sup&gt;</td>
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<tr>
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<tr>
<td>b&lt;sub&gt;2&lt;/sub&gt;</td>
<td>HA</td>
<td>14.6±0.5&lt;sup&gt;ab&lt;/sup&gt;</td>
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<td></td>
<td>SHS</td>
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<td>35.0±3.4&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>ΔE</td>
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<tr>
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<td>SHS</td>
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<td>35.6±8.2&lt;sup&gt;b&lt;/sup&gt;</td>
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</tbody>
</table>

<sup>a,b,c</sup>: Means with the same lowercase superscript in the same row are not significantly different at the 0.05 level.

![Fig. 5 Three-dimensional plot for color distribution of the samples baked by (a) HA and (b) SHS](image1)

![Fig. 6 Appearance of the samples (1 day frozen at -15ºC) baked by (a) HA (13 min) and (b) SHS (10.7 min)](image2)