Compressibility of Baked Goods
After Carbon Dioxide Atmosphere Processing and Storage

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ABSTRACT

Compressibility of baked goods stored in pure carbon dioxide and processed and stored under carbon dioxide or air atmospheres was evaluated. Results from storage tests indicated that carbon dioxide significantly decreased compressibility of French bread, white bread, and lean formula baked goods compared to air-stored samples. Fermentation and baking of enriched white bread dough under carbon dioxide modified atmosphere also resulted in softer breads than air-processed samples, especially when no relative humidity control was maintained during storage. Lower a, values resulted when bread samples were stored in air without humidity control as compared with CO₂-stored goods.

Carbon dioxide is used extensively in food industry applications such as carbonation, freezing, cooling, size reduction, supercritical extraction, and controlled atmosphere storage (Seiler et al 1974, Schultz et al 1982, Stahl 1982, Schmidtko 1984). Storage in an atmosphere rich in carbon dioxide prevents microbial spoilage of baked goods for an extended period of time and is preferable to storage in a nitrogen atmosphere (Brümm er et al 1980, Cerny 1979, Seiler 1983). Recently the relationship between storage in carbon dioxide- or nitrogen-rich atmospheres and compressibility of wheat flour bread and biscuits was examined (Knorr and Tomlins 1985). Packaged baked goods stored in a carbon dioxide-rich atmosphere for up to 15 days showed significantly (P < 0.01) lower regression coefficients than air-stored samples indicating that softer products were obtained during storage in CO₂ atmosphere. The mechanism by which carbon dioxide affects compressibility of baked goods is still unknown. However, it is known that the complex changes contributing to staling are initiated immediately after baking (Kulp and Ponte 1981). Therefore, further studies were done to determine if processing wheat flour doughs in CO₂ atmospheres would delay changes in compressibility that occur during storage.

MATERIALS AND METHODS

Commercially available French bread and white bread were purchased within 1 hr after baking from local bakeries. Research pup loaves (100 g) made available from an industrial research laboratory, labeled as lean formula (white bread) and intermediate formula (donut), were used for storage tests in carbon dioxide-rich atmospheres. Frozen white bread dough (enriched white bread dough, Rich Products Corp., NY) was thawed for 5 hr at 22 ± 1°C before fermentation and was used for the combined fermentation baking and storage tests.

Fermentation and baking were conducted in closed, black cylindrical metal containers (diameter 250 mm, height 275 mm), each containing six 55 × 110 mm bread pans. Copper tubing (6 mm outer diameter) was used to supply gas to the containers; it was wound around the containers, entering at the bottom and exiting at the top, to preheat the gases (Fig. 1). Thermocouples, connected with a Digitrend 200 data logger (Type T, Dorio Scientific Division, San Diego, CA), were placed in the center of each container. Temperature was recorded in 2-min intervals. Gas flow rate (carbon dioxide or compressed air) was 150 cm³/min during fermentation and 300 cm³/min during baking. Six dough samples, placed in 55 × 110 mm bread pans and on wire racks, were processed per container. Fermentation was performed at 40 ± 2°C for 30 min and baking at 150 ± 5°C for 45 min. After baking, the samples were cooled for 1 hour in the fermentation/baking containers at a gas flow rate of 150 cm³/min. They were then transferred to storage containers (120 mm diameter, 230 mm height), which were flushed with gas for 30 min and left at 24 ± 1°C (carbon dioxide incubator, Hotpack, Philadelphia, PA) at a gas flow rate of 150 cm³/min during the duration of the storage tests. Constant relative humidity in storage containers was maintained by bubbling respective gases through saturated salt solutions (Fig. 1). Precooled products were packaged in Nylonsurylin pouches (International Paper Co., New York, NY), evacuated slightly to 400 mmHg, and then heat sealed (Statovac Vacuum Co., Inc., Rochelle Park, NY). Compressibility tests were performed in 5–6 replications on 20 × 20 × 20-mm bread crumb cubes between two uniaxial plates to 50% of initial thickness using a universal testing machine (model 1140, Instron Corp., Canton, MA). Water activity was measured in duplicates on bread crumb center pieces (type SMT-B, Sina AG, Zürich, Switzerland).

![FERMENTATION/BAKING](image)

![STORAGE](image)

Fig. 1. Simplified experimental set-up of fermentation/baking and storage tests. Top, fermentation/baking: temperature-controlled chamber (A), gas tanks (B), fermentation/baking containers (C), gas inlet (D), gas outlet (E), thermocouple (F), temperature data logger (G), and flow meter (H). Bottom, storage: gas tanks (A), salt solutions for humidity (B), temperature-controlled chamber (C), storage containers (D), gas pipes (E), trap (F), and flow meter (G).

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RESULTS AND DISCUSSION

Controlled Atmosphere Storage

The change in compressibility of French bread during 96 hr of storage in air or carbon dioxide atmosphere is presented in Table I. Although the initial compressibility of air and CO₂-stored breads was identical, breads stored in CO₂ for 72 hr were significantly softer than the air-stored counterparts. It is important to note that the differences in compressibility occurred while water activity (a_w) of the stored samples was maintained at a level of 0.95.

Storage (rh 95%) of bread in air for 96 hr resulted in compressibility values of approximately 11 × 10⁵ Pa as compared to 6 × 10⁵ Pa for the CO₂-stored samples (Fig. 2). After 192 hr of storage, the compressibility of the CO₂ stored samples was still significantly lower than for the air-stored samples after 96 hr. Continuation of storage up to 504 hr under CO₂ atmosphere resulted in an increase in compressibility to only 14.3 × 10⁵ Pa.

Results on the effect of CO₂ versus air storage without control of relative humidity on the compressibility of white bread are presented in Figure 3. They indicate a dramatic effect of carbon dioxide storage without relative humidity control on retardating the compressibility of white bread as compared to air storage. Data on the compressibility of enriched white bread presented in Table II suggest that even after discontinuing controlled CO₂ atmosphere storage after 24, 48, or 72 hr, bread samples wrapped in polyethylene wrapping (Cling Wrap, Union Carbide Corp., Danbury, CT) and placed in air atmosphere without humidity control for 24 hr still had significantly lower compressibility compared to air-stored products. The observed differences between water activity of the CO₂ stored samples (a_w = 0.91) and air-stored samples (a_w = 0.67) after 96 hr of storage suggest that the CO₂ atmosphere affected water binding of the bread samples.

A comparison of low and intermediate (fat) formula baked goods of unknown composition stored 3 hr after baking in a carbon dioxide atmosphere, air atmosphere, or air packaged in flexible pouches (Fig. 4), demonstrated a significant effect of CO₂.

| TABLE I | Compressibility of Commercial French Bread During 96 hr of Storage at 24 ± 1°C and at 95% rh in Carbon Dioxide or Air Atmosphere
<table>
<thead>
<tr>
<th>Storage Time (hr)</th>
<th>Compressibility (Pascal × 10⁵)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air⁵</td>
</tr>
<tr>
<td>4</td>
<td>5.8 ± 0.6</td>
</tr>
<tr>
<td>24</td>
<td>11.1 ± 2.2a</td>
</tr>
<tr>
<td>48</td>
<td>15.7 ± 3.9a</td>
</tr>
<tr>
<td>72</td>
<td>24.9 ± 9.1a</td>
</tr>
<tr>
<td>96</td>
<td>...</td>
</tr>
</tbody>
</table>

Data are presented as mean ± standard deviation (n = 10).

Different letters within a row indicate significant differences (P > 0.01).

Mold.

Too moldy to assay.

| TABLE II | Compressibility of Enriched White Bread Baked and Stored at 24 ± 1°C in Carbon Dioxide or Air Atmosphere or Wrapped in Polyethylene Wrapping and Stored at 24 ± 1°C in Air
<table>
<thead>
<tr>
<th>Storage Time (hr)</th>
<th>Compressibility* (Pascal × 10⁵)</th>
<th>Water Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air (Exp. 1)</td>
<td>Air (Exp. 2)</td>
</tr>
<tr>
<td>1</td>
<td>1.6 ± 0.4</td>
<td>2.7 ± 1.8</td>
</tr>
<tr>
<td>24</td>
<td>10.9 ± 5.2</td>
<td>9.1 ± 7.1</td>
</tr>
<tr>
<td>48</td>
<td>33.9 ± 2.9</td>
<td>13.3 ± 6.1</td>
</tr>
<tr>
<td>72</td>
<td>103.6 ± 3.1</td>
<td>93.7 ± 30.4</td>
</tr>
<tr>
<td>96</td>
<td>234.8 ± 8.7</td>
<td>246.6 ± 108.2</td>
</tr>
<tr>
<td>24/48⁵</td>
<td>28.3 ± 3.5</td>
<td>...</td>
</tr>
<tr>
<td>48/72⁵</td>
<td>83.3 ± 3.5</td>
<td>...</td>
</tr>
<tr>
<td>72/96⁵</td>
<td>212.5 ± 54.8</td>
<td>...</td>
</tr>
</tbody>
</table>

Data presented are mean ± standard deviation (n = 5).

Wrapped in polyethylene wrapping after storage time indicated in first number until hours of storage given in second number.

Leakage of CO₂ from storage containers between 72 and 96 hr of storage.

Fig. 2. Compressibility of white bread stored under air (■) or carbon dioxide (□) atmosphere at 95% rh and 24 ± 1°C.
Controlled Atmosphere Processing and Storage

Enriched white bread samples were fermented and baked in CO₂ or in air atmosphere and then packaged (air atmosphere) in flexible pouches. Storage tests were discontinued for air-stored samples.

Fig. 3. Compressibility of enriched white bread fermented, baked and stored in air (■) or carbon dioxide (□) atmosphere at 24 ± 1°C without controlling relative humidity of storage environment (overall means of two consecutive experiments).

Fig. 4. Compressibility of lean (■) and intermediate (□) formula baked goods stored at 24 ± 1°C for 10 days in CO₂ air atmosphere without relative humidity control or packaged (air atmosphere) in flexible pouches.

Fig. 5. Compressibility of enriched white bread fermented and baked in air or carbon dioxide atmosphere and stored in flexible pouches (air atmosphere) at 24 ± 1°C.

Fig. 6. Compressibility of enriched white bread fermented, baked, and stored in air or carbon dioxide atmosphere at 24 ± 1°C with relative humidity control (rh > 0.95) for 216 hr (open symbols) or without rh control from 96 to 168 hr of storage (solid symbols). Baked in air/stored in air (○, ●), baked in air/stored in CO₂ (Δ, ▲), baked in CO₂/stored in air (△, ■), baked in CO₂/stored in CO₂ (□, □).
after 192 hr because of mold growth but maintained for CO₂ samples until 504 hr. Results from regression analyses (Fig. 5) show that compressibility under CO₂ environment after 504 hr was comparable to storage of 130 hr under air environment. Water activity of all samples ranged from 0.94 to 0.95, and specific loaf volume was higher for CO₂-stored samples than for air-stored samples.

No substantial decrease in compressibility was observed when enriched white breads were fermented, baked, and stored for 216 hr in CO₂ or air environment at 95% relative humidity (Fig. 6). However, removing the samples from the controlled humidity environment after 96 hr of storage resulted in significant differences between the compressibility of air fermented/baked and the CO₂ fermented/baked samples (Fig. 6). After storage for 168 hr, the samples processed under CO₂ averaged 120 × 10⁻⁷ and 150 × 10⁻⁷ Pa, respectively, as compared to 320 × 10⁻⁷ and 380 × 10⁻⁷ Pa for the air-processed samples. The a_w of air fermented/baked samples decreased from 0.92 at 96 hr to 0.69 at 168 hr, whereas CO₂ fermented/baked samples maintained a_w values of 0.92. This again suggests an effect of the CO₂ environment on water-binding properties of the bread samples, which also slightly reduced the pH values from 5.4 to 5.2. Overall, the results indicate a significant effect of carbon dioxide-modified atmosphere processing as well as storage on compressibility of commercial white breads, especially when stored without humidity control. This is in agreement with earlier findings on modified environment storage where the initial CO₂ environment was not kept constant (Knorr and Tomlins 1985). The data presented suggest that processing of bread under CO₂ environment and creating an “internal” CO₂ environment where CO₂ diffuses to the surface of the breads might be more beneficial than using an “external” CO₂ environment where air diffuses to the bread surface and affects the controlled environment. An internal CO₂ environment might extend low compressibility of unpackaged breads for longer periods of time. The observed effects of controlled atmosphere processing storage on water adsorption and desorption of baked goods that have been neglected so far, warrant further attention and indepth analysis. In addition, the role of surfactants in controlled gas environments should be studied in detail.

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LITERATURE CITED


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