Compressibility of Baked Goods After Carbon Dioxide Atmosphere Processing and Storage

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ABSTRACT

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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_w values resulted when bread samples were stored in air without humidity control as compared with CO_2-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 1983, Schultz et al 1974, Stahl 1982, Schmidtke 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 (Brümmer 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 CO_2 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 CO_2 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 cm^3/min during fermentation and 300 cm^3/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 cm^3/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 cm^3/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 Nylon-Suryln 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).

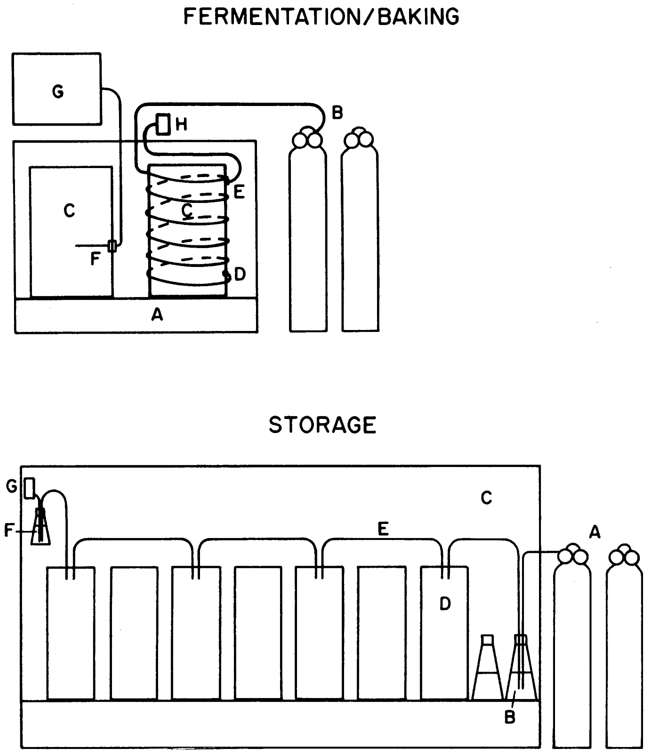

Fig. 1. Simplified experimental set-up of fermentation/baking and storage tests. **Top,** fermentation/baking: temperature-controlled chamber (**A**), gas tanks (**B**), fermentation/baking containers (**C**), gas inlet (**D**), gas outlet (**E**), thermocouple (**F**), temperature data logger (**G**), 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 CO_2-stored breads was identical, breads stored in CO_2 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 white bread in air for 96 hr resulted in compressibility values of approximately 11×10^3 Pa as compared to 6×10^3 Pa for the CO_2-stored samples (Fig. 2). After 192 hr of storage, the compressibility of the CO_2 stored samples was still significantly lower than for the air-stored samples after 96 hr. Continuation of storage up to 504 hr under CO_2 atmosphere resulted in an increase in compressibility to only 14.3×10^3 Pa.

Results on the effect of CO_2 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 retarding 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 CO_2 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 CO_2 stored samples ($a_w = 0.91$) and air-stored samples ($a_w = 0.67$) after 96 hr of storage suggest that the CO_2 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 CO_2 storage on compressibility of the low fat formula products, while the intermediate fat formula was less affected. This indicates that the well-established effects of surfactants on compressibility of bread also apply under CO_2 atmosphere.

Samples packaged in flexible pouches (Fig. 4) remained softest and maintained a_w levels of 0.92–0.94, whereas the CO_2 and air-stored samples without humidity control during the experiments reached lower a_w levels, down to 0.84, indicating a possible relationship between a_w and compressibility of bread samples.

In summary, the effects of controlled carbon dioxide atmosphere storage on compressibility were greater for lean formulas than for intermediate formula baked products. Water activity was lowest at the lowest compressibility of samples, with more distinct effects in the case of air-stored samples. This suggests an effect of carbon dioxide atmosphere on maintainance of initial activity levels of samples while concurrently retarding their spoilage.

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[a]

Storage Time (hr)	Compressibility (Pascal × 10^3) Air[b]	CO_2[b]
4	5.8 ± 0.6	5.8 ± 0.6
24	11.1 ± 2.2 a	8.2 ± 1.5 b
48	15.7 ± 3.9 a	15.7 ± 5.0 a
72	24.9 ± 9.1 a[c]	13.6 ± 2.4 b
96	...[d]	20.3 ± 7.0

[a] Data are presented as mean ± standard deviation ($n = 10$).

[b] Different letters within one row indicate significant differences ($P > 0.01$).

[c] Moldy.

[d] Too moldy to assay.

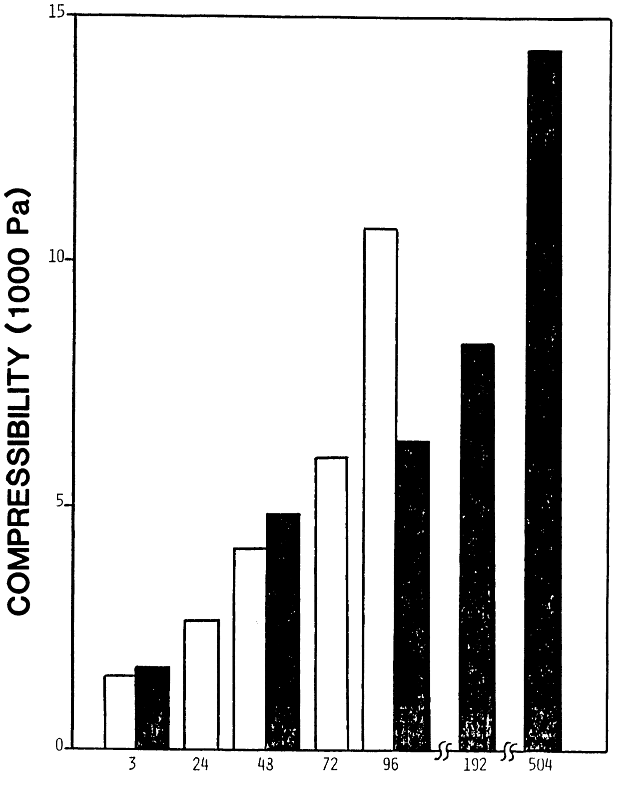

Fig. 2. Compressibility of white bread stored under air (□) or carbon dioxide (■) atmosphere at 95% rh and 24 ± 1°C.

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

Storage Time (hr)	Compressibility[a] (Pascal × 10^3) Air (Exp. 1)	Air (Exp. 2)	CO_2 (Exp. 1)	CO_2 (Exp. 2)	Water Activity Air (Exp. 2)	Water Activity CO_2 (Exp. 2)
1	1.6 ± 0.4	2.7 ± 1.8	1.2 ± 0.5	1.3 ± 0.7	0.96	0.96
24	10.9 ± 5.2	2.8 ± 0.5	4.2 ± 0.5	2.9 ± 0.3	0.95	0.95
48	33.9 ± 2.1	13.3 ± 6.1	5.4 ± 2.0	8.0 ± 3.3	0.95	0.95
72	103.6 ± 3.1	93.7 ± 30.4	16.5 ± 0.3	14.2 ± 7.2	0.82	0.94
96	234.3 ± 8.7	246.6 ± 108.2	117.4 ± 47.0[c]	65.5 ± 25.0	0.67	0.91
24/48[b]	28.2 ± 3.5	...	4.7 ± 1.0	...	...	...
48/72[b]	88.3 ± 3.5	...	16.2 ± 6.6	...	...	...
72/96[b]	212.5 ± 54.8	...	107.7 ± 73.6	...	...	...

[a] Data presented are mean ± standard deviation ($n = 5$).

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

[c] Leakage of CO_2 from storage containers between 72 and 96 hr of storage.

Controlled Atmosphere Processing and Storage

Enriched white bread samples were fermented and baked in CO_2 or in air atmosphere and then packaged (air atmosphere) in flexible pouches. Storage tests were discontinued for air-stored samples

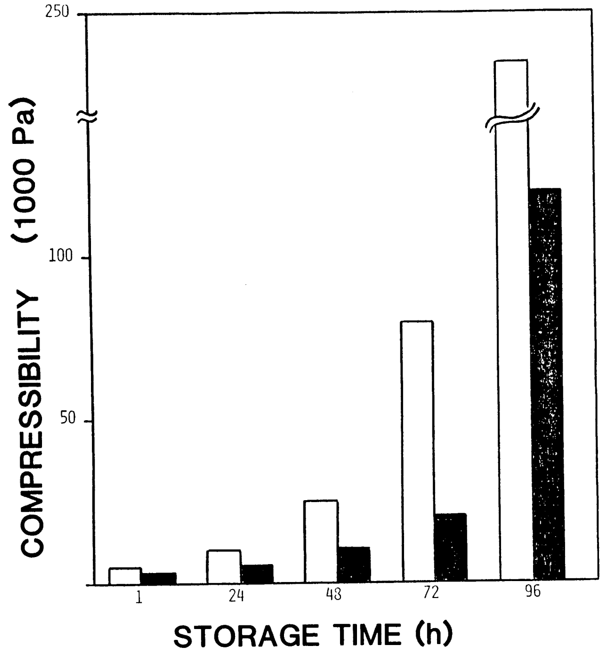

Fig. 3. Compressibility of enriched white bread fermented, baked and stored in air (□) or carbon dioxide (■) atmosphere at 24 ± 1° C without controlling relative humidity of storage environment (overall means of two consecutive experiments).

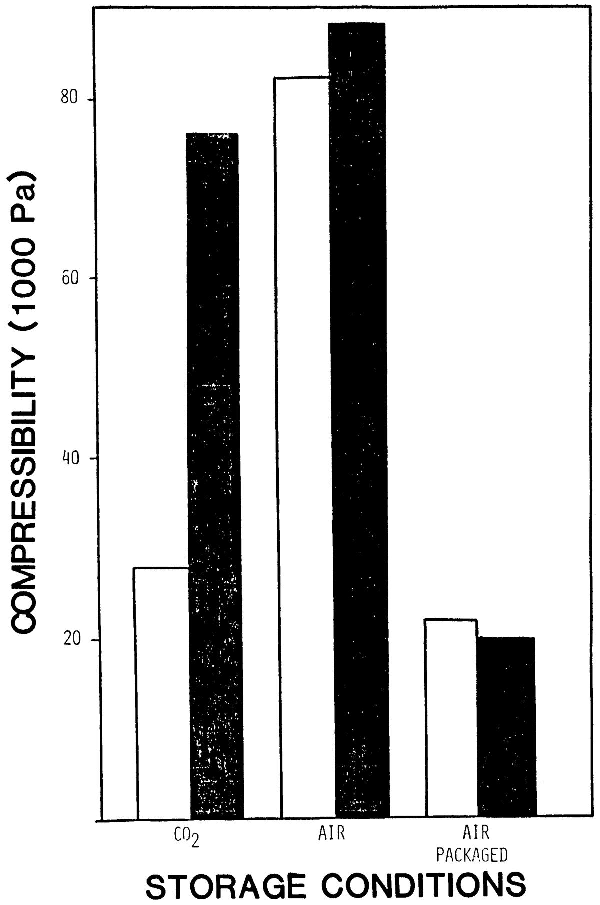

Fig. 4. Compressibility of lean (□) and intermediate (■) formula baked goods stored at 24 ± 1° C for 10 days in CO_2 air atmosphere without relative humidity control or packaged (air atmosphere) in flexible pouches.

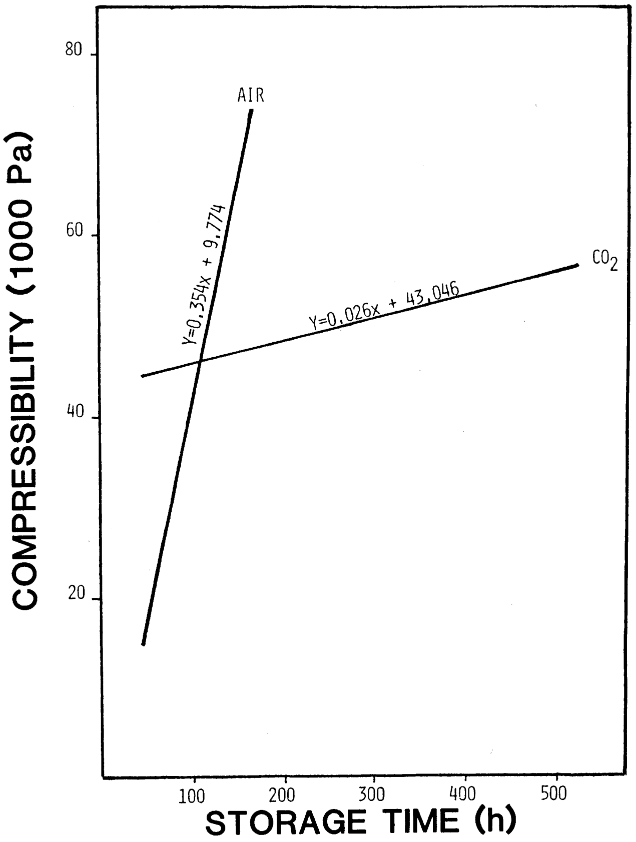

Fig. 5. Compressibility of enriched white bread fermented and baked in air or carbon dioxide atmosphere and stored in flexible pouches (air atmosphere) at 24 ± 1° C.

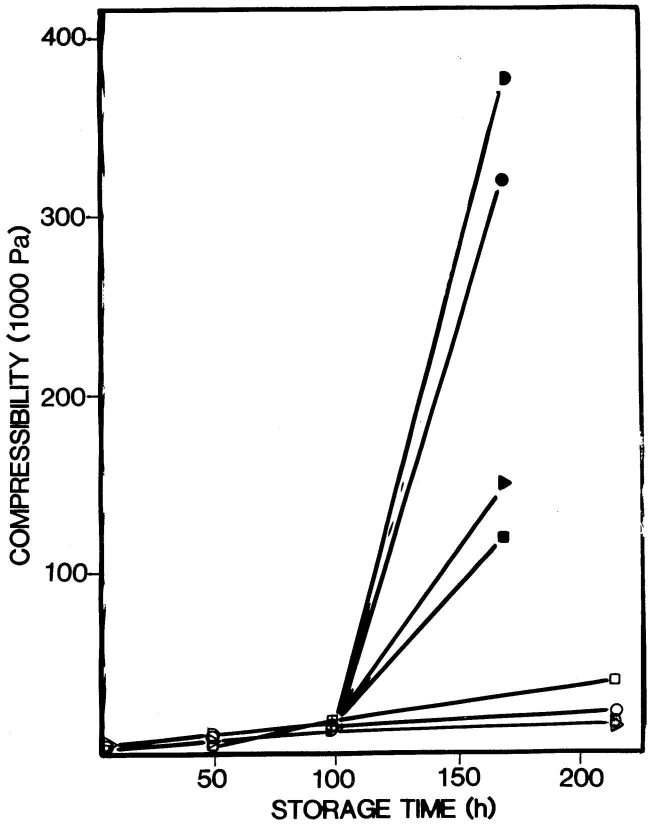

Fig. 6. Compressibility of enriched white bread fermented, baked, and stored in air or carbon dioxide atmosphere at 24 ± 1° C with relative humidity control (rh > 0.95) for 216 hr (open symbols) or without rh control from 96 to 168 hr of storage (solid symbols). Baked in air/stored in air (o, ●), baked in air/stored in CO_2 (D, ◗), baked in CO_2/stored in air (Δ, ▲), baked in CO_2/stored in CO_2 (□, ■).

after 192 hr because of mold growth but maintained for CO_2 samples until 504 hr. Results from regression analyses (Fig. 5) show that compressibility under CO_2 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 CO_2-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 CO_2 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 CO_2 fermented/baked samples (Fig. 6). After storage for 168 hr, the samples processed under CO_2 averaged 120×10^3 and 150×10^3 Pa, respectively, as compared to 320×10^3 and 380×10^3 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 CO_2 fermented/baked samples maintained a_w values of 0.92. This again suggests an effect of the CO_2 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 CO_2 environment was not kept constant (Knorr and Tomlins 1985). The data presented suggest that processing of bread under CO_2 environment and creating an "internal" CO_2 environment where CO_2 diffuses to the surface of the breads might be more beneficial than using an "external" CO_2 environment where air diffuses to the bread surface and affects the controlled environment. An internal CO_2 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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