Cake-Baking Dynamics: Relation of Flour–Chlorination Rate to Batter Expansion and Layer Volume[1]

L. T. KISSELL and W. T. YAMAZAKI,[2] Soft Wheat Quality Laboratory, Ohio Agricultural Research and Development Center, Wooster, OH 44691

Cereal Chem. 56(4):324-327

ABSTRACT

Physical behavior of cake batters made with the Wooster research formula and the AACC full-formula was observed by a cathetometer during baking and cooling cycles. The maximum height of the batter-air interface of each cake was recorded at 1-min intervals. The effects of 14 levels of chlorination on baking performance were determined, using 0–1.0 ml of Cl_2 per gram of flour (pH 5.7–3.8). Batter expansion was greater for treated flours, even at the lowest chlorination rate, than for untreated flour. For AACC batters, thermal expansion and final volume were maximum at 20–30% of the normal chlorination rate (0.5 ml of Cl_2 per gram) and for Wooster batters, at 50% of normal. With both methods, batter expansion and final layer volume reduced gradually with increasing chlorine dosage. In informal organoleptic tests, the crumb texture of AACC cakes was acceptable over a chlorination range of 20–100% of normal and was optimum over a range of 40–80%.

Behavior of doughs and batters during the heating cycle of baking has been of interest to researchers studying soft wheat quality. A finished baked product is the result of many factors and forces, both internal and external, that act on the batter during baking. Data on the kinetic phase of baking—such as thermal and leavening expansion, structure setting, onset of contraction while baking, and shrinkage during cooling—are usually not available because of the difficulties in measurement.

Miller et al used a mechanical device to monitor the height of baking cake (1964) and measured time-lapse photographs in order to study cake expansion (1967). Our interest in baking dynamics dates to 1956, when we made time-lapse photographs contrasting the performance of good and poor quality flours during baking in the Wooster cookie test (Yamazaki and Lord 1971). In 1966 and 1971 we made time-lapse films of layer cakes baked in steel and glass pans.[3] Although the films visually contrasted the rate of movement of different batters, direct measurements were not possible.

This paper, based on techniques developed and observations made during the filming, describes the use of a cathetometer to record the effect of chlorination rate on the extent of batter expansion, on crumb setting, and on contraction during cooling, using two different cake tests. Cathetometer measurements may be used to study other quality differences in cake, such as the effects of wheat variety and class, milling variables, reduction of flour particle size, and formulation changes in batters.

MATERIALS AND METHODS

We used two baking tests—the Wooster research cake method (Kissell 1959), which excludes milk and egg albumen, and the AACC white layer cake method 10-90 (1969). With the Wooster method, batters were divided in half and 240 g was weighed into a special glass pan, 15.2 cm (6 in.) in diameter and 3.8 cm (1.5 in.) deep, fabricated from sections of heat-resistant industrial-grade glass tubing cemented to glass discs. The pan was centered on an asbestos-covered shelf in a modified wall oven. Temperature was maintained at 163 ± 0.5°C (325 ± 1.0°F) by a thermocouple and proportioning electronic control unit. We observed the baking process through a large single-pane heat-resistant glass window. The layer was baked for 25 min, until maximum vertical expansion was reached and for 2–7 min thereafter. Then without disturbing the cake, power was cut, the door opened, and a 10-min cooling cycle begun. During the entire baking-cooling period, the height at the center of the batter-air interface was monitored by a cathetometer, and measurements to the nearest 0.01 cm were recorded at 1.0-min intervals. Figure 1 shows the relationship of observer to the testpiece.

As a control, the second half of each batter (240 g) was deposited in a conventional 15.2 cm (6 in.) diameter steel pan and baked concurrently with the counterpart in glass at 190°C (375°F) for 21 min in an electric reel oven capable of temperature control to ± 0.5°C.

In a similar sequence by the AACC method 10-90, 425 g of batter was weighed into glass or steel pans, 20.3 cm (8 in.) in diameter and 3.8 cm (1.5 in.) deep, and baking time was increased to 23 min for layers in steel. The volume of layers from all baking treatments was determined by weighing the quantity of rapeseed displaced.

Unchlorinated and chlorinated samples of the same commercial patent cake flour obtained from an Ohio mill were used as controls. When calculated to 14% moisture basis, the protein content (N × 5.7) was 9.4% and the ash content 0.33%. The pH was 5.8 for untreated flour and 4.6 for chlorinated. Samples of the untreated flour were treated to various chlorine levels in the Wooster chlorine reactor (Kissell and Marshall 1972). For this study, we defined as

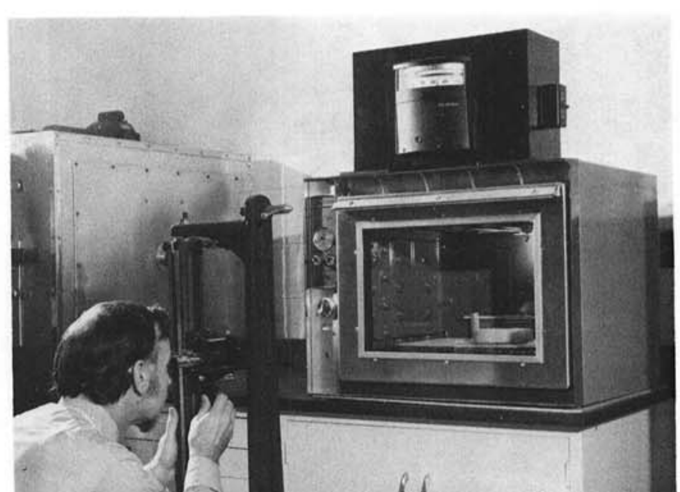

Fig. 1. Relationship of observer and cathetometer to the testpiece.

[1]Presented in part at the 59th Annual Meeting, Montreal, Canada, November 1974. Cooperative investigation of the North Central Region, Agricultural Research, Science and Education Administration, U.S. Department of Agriculture, and Department of Agronomy, Ohio Agricultural Research and Development Center. Approved for publication as Journal Article 181-77 of the Ohio Agricultural Research and Development Center, Wooster, OH 44691.

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[2]Research chemists, North Central Region, USDA-SEA/AR.

[3]One of these films, "Dynamics of Cake Baking," was presented at Technical Movie Session I, the 56th AACC Annual Meeting, Dallas, October 1971.

normal the volume of chlorine gas necessary to change the pH of the unbleached flour from 5.8 to 4.6, which was 0.5 ml Cl_2 per gram of flour or 1,450 ppm. The flours we tested had been treated serially at 14 levels ranging from 2 to 200% of this amount of chlorine. All flours were baked at batter-liquid contents found to be optimum for the normally chlorinated sample; optimum liquid levels were 103% for the Wooster formula and 150% for the AACC method, both on a flour weight basis.

RESULTS AND DISCUSSION

Comparative response curves for batter expansion of unchlorinated control flour and some experimentally chlorinated flours baked in cakes by the Wooster method are shown in Fig. 2. Cathetometer measurements and baking data for the series are given in Table I. In Wooster-formula cakes, baked in duplicate in 15.2 cm diameter glass pans, the various levels of chlorination did not affect batter expansion until after 15 min of baking. Batter from unchlorinated flour (0%) expanded the least; batter from flour chlorinated at half the normal rate (50%), the most. Although batters from flours with low chlorination rates (2–10%) expanded nearly to maximum, their crumb structures were unstable and they subsided precipitously (43–47%) to nearly the minimum height during cooling. The stability of crumb structure and the expansion of the batter increased with the rate of chlorination up to the optimum range (50–100%). Additional chlorination (150–200%) produced batters with restricted expansion, minimal shrinkage, and diminished layer volumes.

The observed-respone curves for the same flour samples baked in the AACC formulation are shown in Fig. 3. Corresponding data for cathetometer measurement of the resultant cakes baked in glass and steel are given in Table II. The moisture condition (mouth feel) of representative cakes baked in steel is indicated. In the AACC cake series, baked in three to six replications in 20.3-cm glass pans, the differential chlorination rates did not affect batter expansion for the first 10 min of baking. Although batters from the low rates of chlorination (2–10%) did not expand as much, nor shrink as rapidly, as batters with the same flours in Wooster cakes, those flours did show baking behavior that was noticeably better than that of

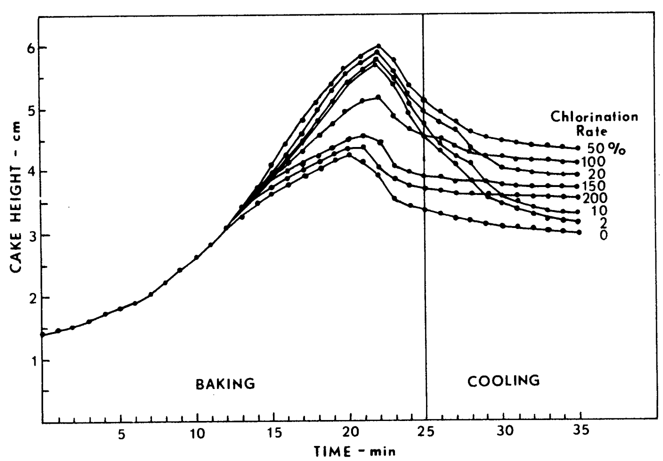

Fig. 2. Baking-response curves for patent cake flour treated with 0–200% of normal chlorination rate and baked in 15.2 cm diameter glass pans according to the Wooster formula. For clarity, some curves have been altered slightly; see Table I for exact data.

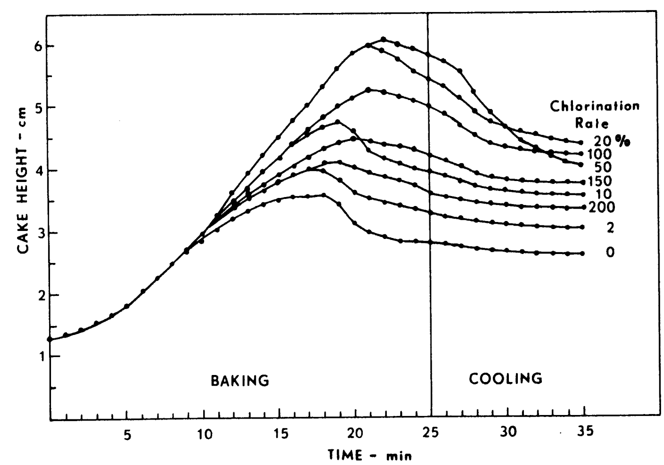

Fig. 3. Baking-response curves for patent cake flour treated with 0–200% of normal chlorination rate and baked in 20.3 cm diameter glass pans according to AACC method 10-90.

TABLE I
Mean Cathetometer Measurements and Baking Data for Experimentally Chlorinated Patent Flours Baked at 163°C in 15.2 cm Diameter Pans According to the Wooster Cake Formulation[a]

Flour Chlorination (% of 0.5 ml of Cl_2 per gram)	Flour pH	Time to Maximum Height (min)	Layer Height[b] Max (cm)	Baked (cm)	Cool (cm)	Final (cm)	Vertical Shrinkage[c] (%)	Final Layer Volume Glass (cc)	Steel (cc)
0	5.76	20	4.36	3.34	3.04	2.90	30.3	404	459
2	5.71	22	5.73	4.15	3.06	2.93	46.6	393	454
5	5.67	22	5.71	4.12	3.25	2.93	43.1	409	471
10	5.59	23	5.78	4.08	3.17	2.86	45.2	402	438
20	5.44	22	5.96	4.67	3.73	3.18	37.4	456	491
30	5.39	23	5.98	4.67	3.81	3.55	36.3	500	537
40	5.26	23	5.96	4.80	3.90	3.60	34.6	508	559
50	5.13	22	5.83	4.77	4.30	4.08	26.2	552	609
60	5.02	22	5.65	4.80	4.22	3.99	25.3	539	581
70	4.99	21	5.45	4.70	4.14	3.89	24.0	542	575
80	4.87	22	5.49	4.68	4.27	4.02	22.2	532	558
90	4.77	23	5.26	4.50	4.16	3.89	20.9	535	582
100	4.61	22	5.16	4.44	4.09	3.83	20.7	526	562
150	4.19	21	4.53	3.90	3.72	3.37	17.9	499	540
200	3.81	21	4.35	3.68	3.53	3.18	18.9	475	513
Commercial	4.60	21	4.76	4.06	3.81	3.56	20.0	520	556

[a]Liquid level was 103% (flour weight basis) to give rounded contour at 100% Cl_2 dosage.
[b]Heights measured at: max = highest point during baking; baked = 25 min; cool = 10 min after power cut-off, door open; final = 2–4 hr after depanning.
[c]Vertical shrinkage % = $\frac{\text{max} - \text{cool}}{\text{max}} \times 100$.

unchlorinated flour. Crumb stability increased progressively in flours chlorinated at 60% or more of the normal rate. Batters had optimum baking performance and produced acceptable crumb if made with flours chlorinated at 20–100% of the normal rate. In our judgment, optimum crumb texture ("moist") was restricted to cakes made with flours chlorinated at 40–80% of normal.

Height and volume measurements differed slightly for cakes from flours chlorinated at the laboratory at the 100% level and at the flour mill (commercial), although flour pH levels were almost identical (Tables I and II). These data indicated that at this pH level, flour treated commercially and flour treated in the laboratory at a level higher than 100% responded comparably. Differences in the source (or purity) of chlorine, in mode of application, and in the flour environment during and after chlorination may have contributed to this variable response. Moreover, pH is an index of hydrogen-ion activity in solution, and its relation to chemical effects of chlorine on flour is somewhat indirect.

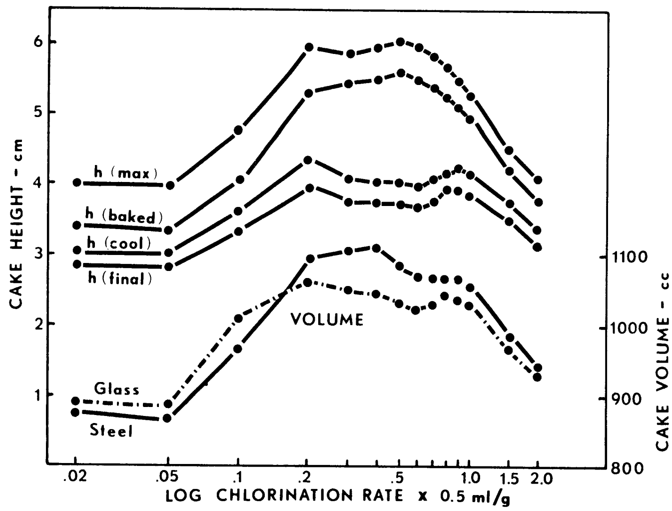

Fig. 4. Response of maximum height and final volume of AACC-formulation cakes, baked in 20.3-cm pans, to the logarithm of the chlorination rate × 0.5 ml per gram. Curves represent: maximum height during baking, h(max); height at 25 min, h(baked); height after 10 min cooling, h(cool); and height at the time of volume measurement, h(final). Comparative volumes for layers are indicated on the right ordinate.

Comprehensive data on batter expansion and layer volume for chlorinated flours in AACC cakes were plotted against the logarithm of the chlorination rate in Fig. 4. All response curves reflect the rapid increase in expansion and volume at low rates of chlorination (5–20% of normal), representing treatment with 75–300 ppm of chlorine gas. The relatively stable expansion over the mid-range (20–50%) was followed by reduced expansion and failure to achieve satisfactory volume at progressively higher treatment rates (60–200%). With the exception of the lowest chlorination levels employed (2–10%), layers in glass were lower in volume and less rounded in contour than the counterpart baked conventionally in steel. Above the 50% chlorination rate, volumes appeared to converge and were not significantly different at corresponding treatments. Overall LSD values for the experiment (5% level) were 24 cc for Wooster formulation and 48 cc for AACC 10-90 cakes.

These results suggest that cake flours treated to higher than normal pH levels (less chlorine) would be satisfactory in high sugar-shortening ratio cakes. Our close observation of heating batters revealed the increase in batter expansion associated with relatively low levels of chlorine dosage. Batters made with chlorinated flour are capable of retaining leavening gases to a greater extent and for a longer time than those prepared from unchlorinated flour. The improved functionality may result from enhanced foam stability imparted by changes associated with the increase in solubility of flour proteins (Kissell 1971) and/or from the improvement in emulsification properties of flour lipids (Kissell et al 1977) as partial results of chlorination. The full baking potential of flours chlorinated at low rates may not be realized because the gelatinization and hydration properties of starch (Bean and Yamazaki 1974) have not been improved sufficiently to give a product with acceptable mouth feel, even though satisfactory volume and appearance are obtained.

ACKNOWLEDGMENT

We acknowledge the contributions of our late friend and co-worker Doyle H. Donelson to the antecedent film studies and the early phases of this project.

TABLE II
Mean Cathetometer Measurements and Baking Data for Experimentally Chlorinated Patent Flours Baked at 163°C in 20.3 cm Diameter Pans According to AACC method 10-90[a]

Flour Chlorination (% of 0.5 ml Cl_2 per gram)	Flour pH	Time to Maximum Height (min)	Layer Height[b] Max (cm)	Layer Height[b] Baked (cm)	Layer Height[b] Cool (cm)	Layer Height[b] Final (cm)	Vertical Shrinkage[c] (%)	Final Layer Volume Glass (cc)	Final Layer Volume Steel (cc)	Crumb Condition[d]
0	5.76	18	3.57	2.84	2.64	2.48	26.1	771	754	G
2	5.71	18	3.99	3.41	3.06	2.86	23.3	890	877	G
5	5.67	19	3.95	3.28	3.00	2.78	24.1	887	867	G
10	5.59	19	4.74	4.02	3.60	3.33	24.1	1014	965	G
20	5.44	21	5.97	5.34	4.33	3.92	27.5	1061	1096	SG
30	5.39	21	5.84	5.48	4.07	3.72	30.3	1050	1107	SG
40	5.26	22	5.91	5.38	4.02	3.72	32.0	1043	1108	M
50	5.13	22	6.06	5.58	4.03	3.73	33.5	1027	1086	M
60	5.02	22	5.97	5.48	3.95	3.64	33.8	1019	1068	M
70	4.99	22	5.83	5.30	4.09	3.77	29.8	1030	1072	M
80	4.87	22	5.66	5.14	4.19	3.93	26.0	1046	1065	M
90	4.77	22	5.48	5.01	4.24	3.93	22.6	1036	1070	SD
100	4.61	21	5.23	4.69	4.15	3.89	20.7	1029	1054	SD
150	4.19	20	4.46	4.21	3.75	3.50	15.9	969	986	D
200	3.81	19	4.06	3.71	3.39	3.12	16.5	936	937	D
Commercial	4.60	21	4.75	4.45	3.96	3.67	16.6	1009	1007	SD

[a]Liquid level was 150% (flour weight basis) to give rounded contour at 100% Cl_2 dosage.
[b]Heights measured at: max = highest point during baking; baked = 25 min; cool = 10 min after power cut-off, door open; final = 2–4 hr after depanning.
[c]Vertical shrinkage % = $\frac{\text{max} - \text{cool}}{\text{max}} \times 100$.
[d]Consensus of eight individuals' judgments of mouth feel. G = gummy, SG = slightly gummy, M = moist, SD = slightly dry, D = dry.

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[Received April 26, 1978. Accepted January 15, 1979]