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Relative Effects of Ingredients on Cake Staling Based on an Accelerated Shelf-life Test

P. Gélinas, G. Roy, and M. Guillet

ABSTRACT

An accelerated shelf-life test was developed to estimate the texture of devil's food cake stored 21 d at 21 °C, by studying the effects of packaging film water permeability and storage temperature over time. Best results were obtained after 7 d at 34 °C with low water permeability films. The test was used to determine the effects of 28 ingredient combinations on the incidence of cake staling. Staling was greatly reduced by partly replacing shortening with butter and glucose with sucrose. To a lesser extent, replacement of natural cocoa with dutched cocoa and use of high concentrations of fats, sugars, egg whites, or sodium bicarbonate also slowed staling rate.

Key Words: cake, texture, staling, packaging film, water permeability

INTRODUCTION

SHELF-LIFE AND TOLERANCE TO STALing determine the quality of industrial cakes (Dargue, 1975; Jones, 1994). Cakes are usually expected to keep from 1 to 4 wk or more, depending on formulation, packaging, water activity, and storage temperature. High-quality cakes have various attributes, including high volume and tenderness, that result from balanced formulas. In general, cakes with a low specific volume are firm. Ingredients such as sugar and fat have softening effects on cakes, but eggs have firming effects (Hodge, 1977). For example, high sugar-fat ratio reduced cake firmness (Lahtinen et al., 1998), and surfactants are used for shelf-life extension (Birnbaum, 1978). Staling is much slower in cakes than in breads, partly because cakes contain more fat and less flour. Therefore, lower concentrations of unstable starch might slow cake staling rate, and native starches have been proposed as partial replacements for cake flour (Kim and Walker, 1992).

Although we know about the functionality of ingredients, it is difficult to assess their specific contributions in complex systems, such as cakes, because several ingredients interact and affect cake texture (Doerry, 1995). Some information is available on the mechanism of cake staling and the effects of specific ingredients on characteristics of fresh cakes. However, the effects of combined ingredients on texture and staling rate of cakes is not well documented.

Developing new cake formulations and processes is a lengthy process partly because cakes must be stored several weeks before testing for staling. It may be possible to accelerate tests for determining shelf-life of foods (Labuza and Schmidl, 1985). High storage temperatures, up to 45 °C, have been used, and the acceleration process could be modeled. Cake staling rate is accelerated by storage at 20 to 27 °C compared to 1 to 4 °C (Pence and Standridge, 1958; Hodge, 1977). This was confirmed with cakes under modified atmosphere packaging (Guinot and Mathlouthi, 1991). Guy (1983) also showed that staling was more rapid at 40 °C than 30 °C. Besides storage at high temperatures, packaging films with a high water permeability increased cake staling rate (Hodge, 1977). According to Willhoft (1973), dehydration of cake crumb affects staling but initial water content had no effect on staling rate of cakes stored at 20 °C for 42 days (Sych et al., 1987).

Our objective was to determine the effects of storage conditions and ingredients on the extent of texture changes for devil's food cakes, containing cocoa and prepared with a high-sugar ratio formulation (with equal or higher concentrations of sugar than flour). Combined effects of storage temperature and packaging film water permeability were determined over time to accelerate cake staling and design a rapid shelf-life test. Then 16 ingredients were tested (28 combinations) to determine their respective effects on the incidence of staling.

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MATERIALS & METHODS

Cake preparation

Accelerated shelf-life test. A formulation was used to prepare 3 kg of cake batter, containing (ingredient proportions): chlorinated flour (100), sucrose (87), water (67), whole eggs (22), egg whites (17), glucose (16), soy oil (13), cocoa (10), milk replacer (6.4), emulsified shortening (4), baking powder (3.1), salt (2.4), sodium bicarbonate (2), emulsifiers (1.2) and potassium sorbate (0.4).

Sucrose, emulsifiers, and fat were mixed 1 min (Hobart, Model A-120; Groupe Hobart Canada, Île des Soeurs, Quebec). After scraping down the batter, the rest of the dry ingredients (flour, cocoa, milk replacer, baking powder, salt, sodium bicarbonate, potassium sorbate), glucose, and 50% of total water were added and mixed 3.5 min at medium speed. After scraping down, egg products were added and mixed 1.5 min at medium speed. The rest of the water was then added and mixed 3.5 min at medium speed. After scraping down, portions of cake batter (101.6 g) were transferred to a series of aluminum cake pans (14.4 cm diam and 2.5 cm height). Cakes were baked in an electric reel oven at 204 °C for 14 min, cooled 40 min on a grid, and cut vertically in half with a knife.

Effects of ingredient combinations. Standard cake formulation was prepared as described. Ingredients (16) were tested at various concentrations to give 28 combinations (Table 1). The following ingredients were kept constant: chlorinated flour, water, milk replacer, baking powder, salt, and potassium sorbate. Substitution flour (rye or soy) was used in replacement of chlorinated flour. Four emulsifiers were chosen according to composition and potential synergy of active constituents in cake formulations (Kamel, 1993): emulsifier #1 (sorbitan monostearate + polysorbate 60; Protameen Chemicals Inc., Totowa, N.J., U.S.A.), emulsifier #2 (propylene glycol esters of fatty acids + mono- and diglycerides + lecithin; EC-25; Quest Intl., Lachine, Quebec, Canada), emulsifier #3 (propylene glycol esters of fatty acids + distilled monoglycerides + sodium stearoyl lactylate; Gatodan 1350; Danisco Ingredients, New Century, Kans., U.S.A.) and emulsifier #4 (sorbitan monostearate + monoglycerides + polysorbate 60; Vanall; American Ingredients Co., Kansas City, Mo., U.S.A.). According to specific recommendations of manufacturers, emulsifiers were added with fat during the first mixing step, except #3, which was incorporated with water at the second mixing step.

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Table 1—Variations of ingredients (% flour basis) in a devil's food cake formulation

	Variation							
Ingredient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Fats								
Shortening	15	0	9	0	60	0	36	0
Oil	0	15	0	9	0	60	0	36
Butter	0	0	6	6	0	0	24	24
Sugars								
Sucrose	67	94	107	150				
Glucose	33	6	53	10				
Eggs								
Egg whites	20	0	60	0				
Whole eggs	0	20	0	60				
Cocoa								
Dutched	10	0						
Natural	0	10						
Substitution Flour								
Rye	9	0	12	0				
Soy	0	9	0	12				
Emulsifiers								
#1	1.5	0	0	0				
#2	0	13.5[a]	0	0				
#3	0	0	1.5	0				
#4	0	0	0	3				
Sodium bicarbonate	4	0						

[a]% fat basis according to manufacturers' specifications.

Cake packaging and storage

Accelerated shelf-life test. Immediately after cooling, cakes were placed into films of different water permeability (g ∞ 25μm/m^2 ∞ day ∞ atm): 0.88 (BX 131-080; Applied Extrusion Technologies Inc., Wilmington, Del., U.S.A.), 1.62 (Bicor SPW-L; Mobil Chemicals, Stone Mountain, Ga., U.S.A.), 4.76 (Polypack, Montréal, Quebec, Canada), or 26.81 (BCL Canada Inc., Cornwall, Ontario, Canada). Water transmission rate was determined at 21 °C and 100% r. h. with a water transmission analyzer (Permatran; Mocon Modern Control Inc., Minneapolis, Minn., U.S.A.). Packaging was heat-sealed (Impulse Sealer, Model CD-400, Montréal, Quebec, Canada), then cakes were stored on a metal grid. Standard cakes were stored at 21 °C for 1 or 21 d in a low water permeability film (1.62). Relative humidity in storage rooms was about 25%.

Effects of ingredient combinations. Immediately after cooling, cakes were placed into films with a low water permeability (1.62 g ∞ 25 μm/m^2 ∞ day ∞ atm; Bicor SPW-L; Mobil Chemicals, Stone Mountain, Ga., U.S.A.). Packaging was sealed (Impulse Sealer, Model CD-400, Montréal, Quebec, Canada). Then, cakes were stored for 0 or 7 days on a metal grid at 34 °C. Relative humidity in storage room was about 25%.

Experimental design

Accelerated shelf-life test. Variables were: storage temperature (30, 38, and 45 °C), film water permeability (0.88 and 26.81; 1.62 and 4.76) (g ∞ 25μm/m^2 ∞ day ∞ atm) and storage period (1, 2, 3, and 7 d; 8, 9, 10, and 13 d). Three batters were prepared, each giving 12 cakes or 24 half-cakes. Six half-cakes (2 half-cakes ∞ 3 batters) were used for each storage condition. Texture analyses were performed once on each half-cake. A split-split plot design was used with respect to production day, batch of batter, and position in oven. Each new test was planned based on the results of the preceding test with an adaptation of steepest ascent method (Box and Draper, 1987). In steepest ascent methodology, data analysis provides the definition of an area where the response function seems to be maximal. Our test, however, involved an area where the response function gave values comparable to those under standard storage conditions (21 d at 21 °C).

Effects of ingredient combinations. Because ingredients could interact, it was essential to test them simultaneously. However, it was impossible to do all possible variations (more than 8,000 formulations), and the number of formulations tested (110) was determined as follows. A fractional factorial design allowed the testing of all main effects and second order interactions so a quasi-orthogonal design was used based on specific optimality criteria called A- and D-optimality (Sado and Sado, 1991). It permitted enough degrees of freedom (d.f.) to test all chosen effects (80 d.f.) and simultaneously keep a sufficiently large number of d.f. for the error term (29 d.f.). It was constructed with PROC OPTEX of the SAS System (SAS Institute Inc., 1989).

Each of the 110 formulations was tested once, giving 6 cakes or 12 half-cakes. The half-cakes were divided into three groups: 3 half-cakes for tests at day 0 (volume, texture, and brief sensory evaluation); 3 half-cakes for pH and a_w; and 3 half-cakes for each of the two storage tests (7 days at 34 °C or 14 days at 21 °C), involving texture analysis and brief sensory evaluation.

Statistical analyses

Response surface modeling was used to analyze results of the experiments of accelerated shelf-life tests. Quadratic and/or linear effects of the factors and interactions were estimated. Significance of differences was defined at $P \leq 0.05$.

Overall, 34 ingredient combinations were considered. In addition to the 28 (Table 1), 6 others were used to determine specific effects of the following: total fats, total sugars, total eggs, total substitution flours, solid fat (shortening or butter) instead of oil, and butter instead of shortening. Incidence of staling for each ingredient combination was determined on cakes stored 0 or 7 days at 34 °C. Ingredient combinations were placed into 16 homogenous and independent groups of cake formulations; cluster analysis was performed within each group based on incidence of staling expressed as hardness and cohesiveness dynamics. Further analyses such as cross-tabulations of clusters by ingredient and computations of chi-square tests led to the characterization of clusters (Box and Draper, 1987).

Batter and cake analyses

Specific volume and outflow rate on a graduated surface (Consistometer) were determined on cake batters. Volumes of fresh cakes were measured with the layer cake measuring template (Method 10-91; AACC, 1995). The pH was determined in solution in a 100-mL beaker containing 10 g of crumbled cake previously homogenized twice for 30 s with an Oster mixer; 90 mL of water were added and mixed for 10 min with a magnetic stirrer, and the mixture settled for 5 min before measurements. Water activity (a_w) was determined with an Aqua Lab CX-2 (Decagon Devices Inc., Pullman, Wash., U.S.A.).

Packaged cakes were left for 3 to 4 h at room temperature. After removal of a 5 mm-portion from the center of the half-cake, portions of 900 mm^2 were cut vertically from the centers and used for texture analysis. Cake texture analyses were performed with a 5-kg Model (accelerated test) or a 25-kg Model (effects of ingredients) of the TA.XT2 (Stable Micro Systems, Godalming, Surrey, England), using a 5.84 mm dia plunger. For the 5-kg-Model, the following conditions were used: crosshead speed 1 mm/s; 50% compression; 4 s between compressions. For the 25-kg Model, the following conditions were used: crosshead speed 0.8 mm/s; 40% compression; 4 s between compressions.

To briefly confirm the accuracy of the accelerated shelf-life test, freshness of cakes was scored by pooling joint-evaluations of two panelists on cakes submitted to accelerated storage (34 °C for 7 d) or standard storage conditions (21 °C for 14 d). Results were compared with fresh cakes (day 0). A scale from 0 to 4 was used throughout the study (0 = stale; 4 = very fresh).

RESULTS & DISCUSSION

Accelerated shelf-life test

Best textures were obtained when data showed the following trends: low hardness and high cohesiveness. Under standard storage conditions (21 °C for 21 d), cake hardness doubled and cohesiveness was reduced by about one third of its original value (Table 2); the other texture parameters were more constant. Among the six texture parameters, hardness, cohesiveness, and springiness contributed to about 90% of total variation (data not shown). Thus, adhesiveness, gumminess, and chewiness data were omitted from subsequent analyses.

The main problem with accelerated staling was to find conditions giving satisfactory results for the main texture parameters. Data were compared on hardness (Fig. 1) and cohesiveness (Fig. 2) of cakes stored up to 7 d at 30, 38, or 45 °C in two films with low (a) or high (b) water permeability. Target data for hardness were rapidly attained within 1 to 3 d, but cohesiveness decreased more slowly whatever the film wa-

Table 2—Texture parameters of standard devil's food cake packaged in a low water permeability film (1.62 g ∞ 25 μm/m² ∞ day ∞ atm) according to storage period at 21 °C[a]

	Storage period (days)	
Texture parameter	1	21
Hardness (kg)	0.482 (0.054)	0.962 (0.098)
Cohesiveness	0.697 (0.020)	0.459 (0.030)
Springiness	0.879 (0.026)	0.743 (0.038)
Gumminess (kg)	0.337 (0.030)	0.441 (0.047)
Chewiness (kg)	0.296 (0.026)	0.327 (0.035)
Adhesiveness	–0.048 (0.028)	–0.104 (0.012)

[a]Data are means of 12 data (3 batters ∞ 4 half-cakes). Standard errors are presented in parentheses.

ter permeability (Fig. 2a compared to Fig. 2b). Especially at 45 °C, storage temperature had a larger effect on cake hardness than film water permeability (Fig. 1a compared to Fig. 1b). Data for springiness were more erratic so that almost any storage condition gave results not significantly different from those under standard conditions (data not shown).

In a separate series of experiments and according to results of response surface modeling with films with a low to intermediate water permeability, trends were similar at 34 °C (Fig. 3) or 30 °C (data not shown). Best results were obtained with a low water permeability film (1.62) because the intermediate water permeability film (4.76) accelerated cake firmness too rapidly (Fig. 3a), and they did not enable enough loss of cohesiveness during the same storage period (Fig. 3b). Cake cohesiveness equivalent to standard cakes (stored 21 d at 21 °C) could not be reached even after 13 d. However, after 8 d, 90% of target data were obtained at 34 °C with a low water permeability film (1.62), as in the standard storage condition. Given that both hardness and cohesiveness were necessary to characterize cake texture, it was impossible to select storage conditions under which data for texture parameters were exactly the same as those under standard storage conditions. However, a good compromise was to select conditions minimizing a global distance aggregating the two variables, whether or not significant differences still existed for any of the parameters. Confirmatory assays showed that cake storage after 7 d at 34 or 38 °C in two low water permeability films (0.88 or 1.62) gave similar results (data not shown).

Effects of ingredients on incidence of staling

Using the ingredient combinations described (Table 1), the 110 formulations submitted to accelerated storage were tested statistically for capacity to limit texture changes during storage between 0 and 7 d at 34 °C. Batter viscosity as well as cake pH or a_W were not correlated with cake volume, hardness, or cohesiveness (data not shown). Thus, acceptable cake volume and texture could be obtained from batters with high or low viscosity, although water was kept constant for all formulations. Brief sensory evaluation of the cakes described (Table 1) confirmed trends of the accelerated shelf-life test (data not shown). Cluster analysis gave four major groups characterized by levels of texture variables. These groups were described (Table 3) as % distribution of cake formulations according to low, medium, or high incidence of staling, that is changes for hardness and cohesiveness over time. Within each of the 16 ingredient groups, those combinations marked "b" slowed cake staling rate, as shown by the corresponding % distribution.

Whatever the cake texture and volume, incidence of staling was reduced to some extent by fats, sugars, egg whites, cocoa, and sodium bicarbonate (supplement), but not by whole eggs, substitution flours, or emulsifiers. The following combinations had the

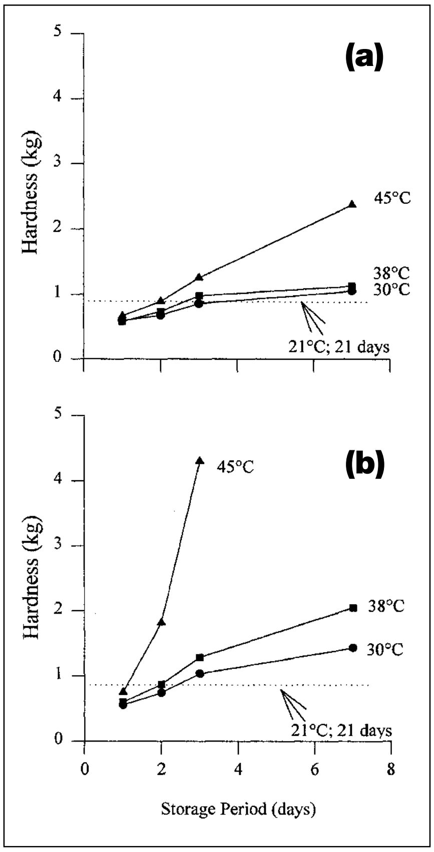

Fig. 1—Effect of storage temperature on hardness of cakes packaged in films with (a) low (0.88 g ∞ 25 μm/m² ∞ day ∞ atm) or (b) high (26.81 g ∞ μm/m² ∞ day ∞ atm) water permeability. Arrow shows target data obtained for standard cakes.

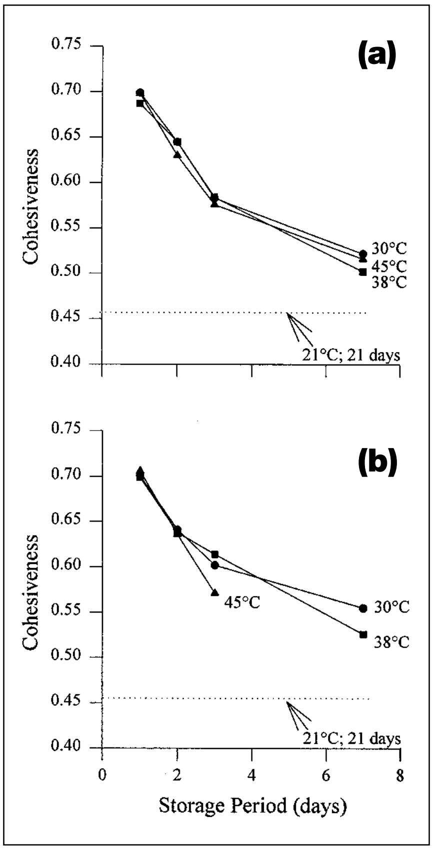

Fig. 2—Effect of storage temperature on cohesiveness of cakes packaged in films with (a) low (0.88 g ∞ 25 μm/m² ∞ day ∞ atm) or (b) high (26.81 g ∞ μm/m² x day x atm) water permeability. Arrow shows target data obtained for standard cakes.

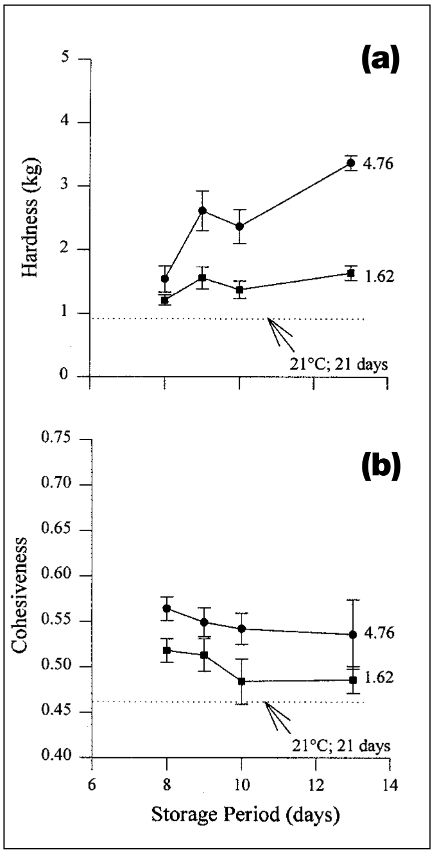

Fig. 3—Effect of water permeability of packaging film on hardness (a) and cohesiveness (b) of cakes stored at 34 °C (duplicates). Arrow shows target data obtained for standard cakes.

best anti-staling properties: (1) partial replacement of shortening by butter in a high solid fat system and (2) a low glucose/ sucrose ratio in a high sugar system. Thus, shortening and glucose accelerated staling, but their effect was only clear in high fat or high sugar systems. Butter is characterized by the presence of smaller β′ crystals and lower melting polymorphs compared to β crystals found in vegetable shortenings (Podmore, 1994). Small crystals are very efficient to incorporate air in cake batters (Brooker, 1993). Although it is higher in cost and had a limited resistance to mixing partly because it contains 20% water (compared to 0% for shortening), butter could be blended with other fats in cake formulations. Butter has a very positive effect on flavor and entraps moisture in cakes (Smith, 1993). The latter effect might slow staling, a process involving several physicochemical changes other than starch retrogradation (Kamel and Ponte, 1993). In high-sugar ratio cakes systems, our results suggest that the composition of plastic fats could be optimized to extend cake shelf-life.

The negative effects on cake texture associated with sucrose replacement by glucose have been stressed by Kulp et al. (1991), but its clear effect on incidence of cake staling has not been reported before. To a lesser extent, the following ingredients showed anti-staling properties: high fat content (60% instead of 15%), partial replacement of oil by butter (the only solid fat tested) in a high fat system, high sugar content (160% instead of 100%), high egg whites content (60% instead of 20%; effect enclosed in total eggs), use of dutched cocoa (instead of natural cocoa), and supplementation with sodium bicarbonate. The positive effects of fats, sugars, and surfactants (lecithin in egg whites) on cake texture have been documented (Hodge, 1977). However, compared to other ingredients, the positive effects of dutched cocoa and supplements of sodium bicarbonate on texture of stored cakes have not been reported. Dutched cocoa is produced by alkalization, which is known to improve cake color and flavor (Matz, 1987). Devil's food cake formulations are often supplemented with sodium bicarbonate to raise crumb pH above 8 and to give acceptable color development by cocoa (Doerry, 1995). These results on devil's food cakes (high sugar ratio) remain to be confirmed on other cake types.

Table 3—Distribution (%) of cake formulations within 16 groups of ingredient combinations according to incidence of staling based on cake hardness and cohesiveness[a]

		Staling rate			
Group	Ingredient combination	Low	Medium	High	Effect[b]
I	Total fats 15%	21	38	41	a
	Total fats 60%	36	36	28	b
II	Shortening 15%	8	62	30	a
	Shortening/butter 9/6%	20	20	60	a
III	Shortening 60%	33	44	23	a
	Shortening/butter 36/24%	73	18	9	b
IV	Oil 15%	17	42	41	a
	Oil/butter 9/6%	39	23	38	b
V	Oil 60%	15	31	54	a
	Oil/butter 36/24%	27	55	18	b
VI	Total sugars 100%	21	26	53	a
	Total sugars 160%	38	52	10	b
VII	Sucrose/glucose 67/33%	22	17	61	a
	Sucrose/glucose 94/6%	20	33	47	a
VIII	Sucrose/glucose 107/53%	20	64	16	a
	Sucrose/glucose 150/10%	71	29	0	b
IX	Total eggs 20%	21	38	41	a
	Total eggs 60%	36	36	28	b
X	Egg whites 20%	12	38	50	a
	Egg whites 60%	42	42	16	b
XI	Whole eggs 20%	29	38	33	a
	Whole eggs 60%	30	30	40	a
XII	Cocoa (dutched)	35	28	37	b
	Cocoa (natural)	22	46	32	a
XIII	Total substitution flour 9%	23	36	41	a
	Total substitution flour 12%	34	38	28	a
XIV	Rye flour	26	38	36	a
	Soy flour	31	37	32	a
XV	Emulsifier #1	41	30	29	a
	Emulsifier #2	28	28	44	a
	Emulsifier #3	21	50	29	a
	Emulsifier #4	22	39	39	a
XVI	Sodium bicarbonate 4%	44	40	16	b
	Sodium bicarbonate 0%	14	35	51	a

[a]Cake storage was performed at 34 °C for 7 d in a low water permeability film (1.62 g ∞ 25 µm/m^2 ∞ day ∞ atm).
[b]Within the same group only, ingredients followed by the same letter are not different ($p > 0.05$).

CONCLUSIONS

AFTER 7 D AT 34 °C IN A LOW WATER permeability film, devil's food cake texture was about equivalent to 21 d at room temperature. To accelerate cake staling, this simple test could be used in the development of cake formulations and processes. Higher hardness and lower cohesiveness were the two main texture changes during cake storage but cohesiveness changed more slowly. Storage temperature had a greater effect on cake texture than did film water permeability. Anti-staling effects were shown by type and concentration of sugar, fat, or egg product, cocoa type, and sodium bicarbonate concentration. Butter and sucrose were the best ingredients to slow cake staling compared with shortening and glucose, respectively. Especially at high concentrations, the composition of solid fats and sugars could be optimized to extend cake shelf-life.

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Ms 0329 received 1/21/99; revised 4/30/99; accepted 5/29/99.

Thanks to C. McKinnon (FRDC) for assistance during preparation of the manuscript. This research was supported by the Matching Investment Initiative (Agriculture and Agri-Food Canada).