

Factors Affecting Cake Firmness and Cake Moisture Content as Evaluated by Response Surface Methodology

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ABSTRACT

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Values of initial fat temperature, mixing intensity, mixing time, and mass ratio of fat and sucrose (F/S ratio) were varied in the preparation of fat-sugar cream. The dependence of cake firmness and cake moisture content on these values, the size of sucrose particles, and storage time were studied using response surface methodology. The logarithm of storage time and F/S ratio

proved to be the best predictors for both cake firmness and cake moisture content in the creamed cake. An interaction between fat temperature and F/S ratio had a notable influence and size of sucrose particles had a slight influence on cake firmness. Besides logarithm of time and F/S ratio, mixing intensity was the only factor that affected cake moisture content significantly.

Staling is a generic term used to describe the deleterious chemical and physical changes occurring in bakery products during storage. Cake staling has been related to the intrinsic firming process of the cake crumb and the migration of moisture from the crumb to the drier regions of the cake (Guy 1983). In spite of the great economic importance of cake staling, it seems that a multivariate outlook on the factors affecting cake firmness or cake moisture content is lacking. Therefore, systematical studies are needed to detect the relative importance and interactions of the factors affecting them.

Many factors including moisture content (Guy 1983) and the proportion of sucrose (Ngo and Taranto 1986) and other ingredients affect the firmness of cake crumb. It is generally accepted that sucrose, as well as the water-holding capacity of flour, also accounts for much of the loss of cake moisture during storage. Factors associated with batter making are largely determined by the preparation method used. A creaming, blending, or whipping method or some combination method is normally employed for cake preparation (Sultan 1990).

Finnish confectioneries use mainly creamed batters, whose details are slightly varied according to product type. The present study was undertaken to chart the effects of the creaming conditions and the ratio of fat and sucrose on cake firmness and cake moisture content. The effects of fat temperature and particle size of sucrose were also studied to enlighten their potential role in creaming. The magnitude of the effect of storage time was charted by way of comparison.

MATERIALS AND METHODS

Ingredients

The formula for the cake batter is presented in Table I. The analytical data of the wheat flour used are given in Table II. The fat used was Leipo 8 margarine (Van den Bergh Foods, Finland) which is meant for the preparation of creamed batters. The baking powder (Pimenta Ltd., Finland) contained sodium pyrophosphate E450 (41%), sodium bicarbonate E500 (38%), tartaric acid E334 (10%), and wheat flour. Two sucrose types, granulated sucrose Siro 0.33 and powdered sucrose Tomu 0.100 (Sucros Ltd., Finland), were used in the batters (Table III). Eggs were obtained from a local retailer.

Preparation of Cakes

Fat-sugar creams were prepared using a heavy duty mixer with a beater impeller (K5SS, Kitchen Aid Inc., St. Joseph, MI). The mixer speed was adjusted by input voltage and checked using a tachometer (3404, Hioki E. E. Corp., Nagano, Japan). Initial fat

temperature, mass ratio of fat and sucrose (F/S ratio) and the mixing conditions were varied methodically. Warmed egg (27.0°C) and potassium sorbate were added to the cream first and mixed for 3 min at speed 2. Wheat flour and baking powder were then added. The mixing was continued for a further 2 min at the same speed, and the batter was poured to molds. Each mold (19- × 7.5- × 7-cm) contained 0.370 kg of the batter. The batters were baked for 50 min at 160°C. A stone grate oven was used in the baking (DN 22, Dahlen International AB, Borås, Sweden).

Packaging and Storage of Cakes

The cakes were packed in polypropylene bags 25- μ m thick 2 hr after baking. All the bags were heat-sealed. One cake of each batter was used for the determinations after one day of storage. Two cakes were used in the determinations at seven days and two cakes at 21 days after baking. The cakes were stored at a temperature of 22–24°C.

Determination Methods

Cake moisture content was determined as loss of mass after heating for 1 hr at 130°C. Cake firmness was measured with a universal testing machine (MK5, Lloyd Instruments Ltd., Southampton, England) as the area under the distance-force curve. Approved Method 74-09 was followed in the firmness measurements except

TABLE I
Recipe for Cake Batter

Ingredient	Mass (g)
Medium-coarse wheat flour	695
Fat and sucrose together ^a	1,590
Egg	625
Baking powder	7
Potassium sorbate (8% solution in water)	27

^a Mass ratio of fat and sucrose ranging from 0.50 to 1.50 with 0.25 intervals.

TABLE II
Analytical Data of Wheat Flour

Property	Value
Moisture content	15.0%
Falling Number	311 sec
Gluten content	28.3%
Ash content	0.70%
Farinogram	
Absorption	61.5%
Peak time	1.5 min
Stability	14.6 min
20-min drop-off	40 BU
Extensigram (using absorption 58.1%)	
Curve area	44 cm ²
Resistance to extension/extensibility	3.3

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that 20- × 25- × 25-mm cubes were used instead of slices of cake (AACC 1995). Several determinations from the same points of the cakes were made to obtain representative mean values for computations.

Collection of Data

Fat and sucrose were creamed according to a uniform precision rotatable central composite design (Table IV). All the experiments in the design were performed using both of the sucrose types. The ranges were: 18.0 and 26.0°C, fat temperature; 89 and 129 rpm, mixing intensity; 4.0 and 12.0 min, mixing time; and 0.50 and 1.50, F/S ratio. Each of these factors was used at five levels within these limits. The experiments were completed in a randomized order.

Computation of Second-Order Polynomials

The coefficients of the polynomials were computed by linear regression analysis. The outliers were removed from the data on the

basis of studentized residuals during the computation. The significance of the model coefficients was tested by *t*-test. Coded values of the input variables in the range -2 to 2 were used in the computation. The value -2 corresponded to powdered sucrose and the value 2 corresponded to granulated sucrose in the coding of sucrose type. All the analyses were made using the SAS 6.08 software (SAS Institute Inc., Cary, NC).

The effect of sucrose type was tested using paired *t*-test before regression analysis. This factor proved to be insignificant in the case of cake moisture content but not in the case of cake firmness. Means of the paired moisture contents obtained from the first 24 experiments by the two sucrose types were used in the modeling. The corresponding 14 repetitions from the remaining seven experiments were all included in the computation.

Cake firmness and cake moisture content both changed following nonlinear kinetics during storage (Fig. 1). Therefore, the natural logarithm of storage time was used as a predictor in the polynomials computed. Due to this transformation, the lack-of-fits of the polynomials became insignificant. The transformation also enhanced the coefficients of determination of these models.

TABLE III
Particle Size Analysis of Sucrose

Measurement	Sucrose Type	
	Granulated	Powdered
Mean particle size	0.320 mm	0.100 mm
Sieving (mm)		
0.500	0.0%	
0.400	5.7%	
0.315	44.6%	
0.200	40.0%	
0.160	7.4%	
0.125		26%
0.063		57%
0.000	2.3%	17%

TABLE IV
Experimental Design for Cake Batters

No.	Fat Temperature (°C)	Mixing Intensity (rpm)	Mixing Time (min)	F/S Ratio ^a
1	20.0	99	6.0	0.75
2	24.0	99	6.0	0.75
3	20.0	119	6.0	0.75
4	24.0	119	6.0	0.75
5	20.0	99	10.0	0.75
6	24.0	99	10.0	0.75
7	20.0	119	10.0	0.75
8	24.0	119	10.0	0.75
9	20.0	99	6.0	1.25
10	24.0	99	6.0	1.25
11	20.0	119	6.0	1.25
12	24.0	119	6.0	1.25
13	20.0	99	10.0	1.25
14	24.0	99	10.0	1.25
15	20.0	119	10.0	1.25
16	24.0	119	10.0	1.25
17	18.0	109	8.0	1.00
18	26.0	109	8.0	1.00
19	22.0	89	8.0	1.00
20	22.0	129	8.0	1.00
21	22.0	109	4.0	1.00
22	22.0	109	12.0	1.00
23	22.0	109	8.0	0.50
24	22.0	109	8.0	1.50
25	22.0	109	8.0	1.00
26	22.0	109	8.0	1.00
27	22.0	109	8.0	1.00
28	22.0	109	8.0	1.00
29	22.0	109	8.0	1.00
30	22.0	109	8.0	1.00
31	22.0	109	8.0	1.00

^a Mass ratio of fat and sucrose.

RESULTS AND DISCUSSION

Main Characteristics of the Models

The model type used predicted cake moisture content successfully. However, the predicted values of cake firmness agreed with the data only passably (Table V). The logarithm of storage time

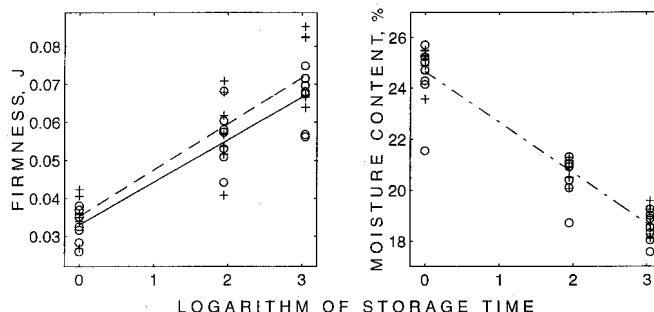


Fig. 1. Cake firmness and cake moisture content as a function of storage time using granulated sucrose (O, —), powdered sucrose (+, ---), and combined data (- · - · -). Points are from experiments 25-31 (Table IV).

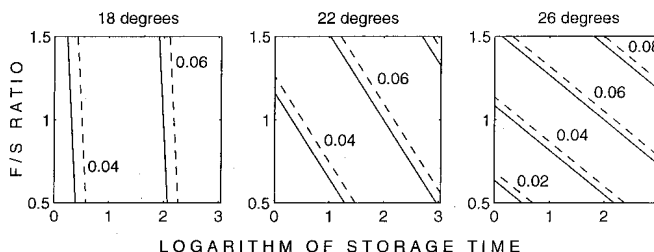


Fig. 2. Contour lines of cake firmness at three temperatures (°C) using granulated sucrose (—) and powdered sucrose (---). Firmness values refer to the paired lines.

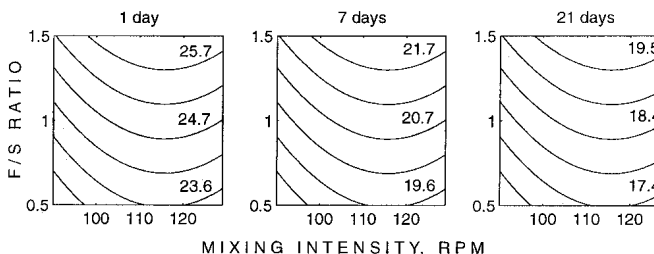


Fig. 3. Contour lines of cake moisture content (%) at one, seven, and 21 days after baking.

proved to be the best predictor for both cake firmness and cake moisture content (Table V). F/S ratio and time had the greatest influence on both the cake properties studied.

Factors Affecting Cake Firmness

An increasing F/S ratio increased cake firmness at each of the fat temperatures (Fig. 2). This was probably due to the decrease of sucrose concentration and the subsequent lowering of gelatinization temperature of starch (Ngo and Taranto 1986). The tenderizing of cake crumb, due to fat disrupting the gluten and starch structure (Pyler 1988), did not appear when F/S ratio was scrutinized. The rising influence of fat on the gelatinization temperature (Tamstorf et al 1986) also did not dominate over the effect of the low sucrose concentration.

F/S ratio had no appreciable effect on cake firmness at the lowest fat temperature (18°C). The importance of this factor to cake firmness increased notably with increasing fat temperature (Fig. 2). The higher the initial fat temperature, the larger the firmness region attained within the limits of the F/S ratio used. Because of the strong interaction between fat temperature and F/S ratio observed (Table V), these factors should not be scrutinized separately when evaluating cake firmness.

The use of powdered sucrose instead of granulated sucrose decreased cake firmness slightly (Fig. 2). That was preceded by an enhanced foaming of fat in the preparation of fat-sugar cream (S. Lahtinen, unpublished data). Sucrose type did not affect cake moisture content (Table V), so those observations support the mechanical softening influence of sucrose in the creaming (Shepherd and Yoell 1976). The influence of the small particle size would be simply traceable to the number of sucrose particles in the cream.

Factors Affecting Cake Moisture Content

The logarithm of storage time explained 92.2% of the variation observed in cake moisture content. The remaining 4.4% was due to

the variations in mixing intensity and F/S ratio (Table V). The relative importance of the latter variables was greatest in a the fresh cake and decreased in the course of storage time. The proper combination, however, could affect moisture content almost as much as storage time did up to seven days after baking (Fig. 3).

Increasing the mixer speed up to ≈116 rpm increased the moisture content regardless of the F/S ratio used. Use of mixer speeds higher than that optimum value lowered the moisture content of the cakes (Fig. 3). That lowering was not due to over whipping because one of the overall best cakes was obtained using the highest mixer speed (129 rpm, experiment 20 using granulated sucrose). This evaluation was based on the cake's appearance and specific volume, as well as its firmness and moisture content. It was carefully performed under control of an experienced confectioner. The lowered moisture content was possibly connected with coalescing of the entrapped air due to drainage of batter during baking.

CONCLUSIONS

Factors affecting cake firmness and cake moisture content were studied using response surface methodology. The statistical tests performed allow reliable conclusions to be drawn of the relative importance and interactions of these factors. Initial fat temperature, F/S ratio, and mixing intensity proved to be the primary factors that retarded cake staling. Mixing time and size of sucrose particles either did not affect the cake properties studied, or their influence on them was weak.

ACKNOWLEDGMENTS

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TABLE V
Second-Order Polynomials Computed Using Coded and Actual Data^a

Predictor	Coefficient			
	Firmness × 10 ³		Moisture Content	
	Coded	Actual	Coded	Actual
Intercept	51.86	11.90	21.768	1.423
x ₁ (fat temperature)	-0.31		-0.034	
x ₂ (mixing intensity)	0.39		0.201	0.3626
x ₃ (mixing time)	0.14		-0.005	
x ₄ (F/S ratio) ^b	5.83	22.19	0.654	2.609
x ₁ × x ₂	-0.46		0.088	
x ₁ × x ₃	-1.14		0.109	
x ₁ × x ₄	2.66	45.85 × 10 ⁻³	-0.068	
x ₂ × x ₃	0.53		0.075	
x ₂ × x ₄	0.19		0.067	
x ₃ × x ₄	-0.33		0.039	
x ₁ × x ₁	0.59		0.001	
x ₂ × x ₂	1.10		-0.157	-1.571 × 10 ⁻³
x ₃ × x ₃	0.25		0.015	
x ₄ × x ₄	-0.15		-0.019	
Sucrose type	0.59	0.5745		
ln(time) ^c	9.07	11.92	-1.561	-2.050
R ²	0.832**** ^d	0.812***	0.968***	0.966***
RSE ^e	7.2 × 10 ⁻³	7.6 × 10 ⁻³	0.48	0.50
F _{LOF} ^f	0.962 ^g		0.813 ^g	
No. of data points	182		111	

^a Only significant ($P < 0.05$) predictors were included in the actual models.

^b Mass ratio of fat and sucrose.

^c Natural logarithm of storage time.

^d *** = significant at $P < 0.001$.

^e Root mean square error.

^f F ratio for lack-of-fit.

^g Not significant.

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