Model Studies of Cake Baking. VI. Effects of Cake Ingredients and Cake Formula on Shear Modulus of Cake

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ABSTRACT

Shear modulus was measured for cakes baked from degassed cake batter containing basic ingredients. Flour, fat, and a foaming agent (emulsifier) increased shear modulus, but sugar, water, and oil decreased the shear modulus of cake. Whole egg either increased or decreased shear modulus, depending on concentration. Variation in ratios of egg and sugar or egg and flour increased the shear modulus under certain conditions. The shear modulus was strongly influenced by a small change in cake formulation of a ternary flour, egg, and sugar system. Shear modulus measurements added to an understanding of the structural roles of cake ingredients and formula balancing.

Cake quality is determined by three major factors: suitability of the individual ingredients for the specific type of cake being made, the proportions or balance in which the ingredients are combined in the cake formula, and the procedures followed in mixing and baking (Pyler 1973).

Many authors have described the role of cake ingredients and formula balance on cake structure from empirical standpoints (Borders 1968, Daniel 1978, Lawson 1970, Lowe 1955, Matz 1960, Pyler 1973, Sultan 1965). In general, cake ingredients may be classified as toughening, tenderizers, moisteners, and driers. In order to make a satisfactory cake, toughening and tenderizers must be properly balanced, as must moisteners and driers. These two systems must then be balanced with a proper amount of leavening. Flour, egg white, milk solids, and salt toughen cakes, whereas sugar, fat, and egg yolks tenderize them (Borders 1968, Coughlin 1947, Lawson 1970). Therefore, cake ingredients and formula balance are important factors in determining final cake qualities, i.e., cake volume, contour, grain, texture, mouthfeel, and flavor.

A great deal of research has been conducted to reveal the effect of cake ingredients and cake formula on cake quality. Davies (1937) demonstrated the effect of formula, sugar, fat, liquid, and baking powder on cake grain, volume, and texture, and reported general rules for formula balance. Kissell and Marshall (1962) and Kissell (1967) studied the effects of various white layer cake ingredients to cake volume, top contour, and internal score by a multi-factor, response-surface technique. Wilson and Donelson (1963, 1965) described the role of water on volume, crumb structure, and top contour of layer cake in another response-surface study. Smith and Rose (1963) applied multiple-factor analysis to study the effect of water, flour, and shortening variables on piecrust consistency and specific volume. Ochi and Yoshikawa (1969) showed the effect of formula balance on sponge cake quality by a simple lattice design method. Johnson and Hoseney (1979) measured the effect of different cake ingredients on the baking properties of chlorine-treated and untreated flours.

It is also apparent that most cake qualities (softness, contour, grain, mouthfeel, and flavor) are affected by cake structure, which consists of an internal and an external phase. Usually, the internal phase consists of gas cells and the external phase is a gel-like material resulting from the heat setting of cake ingredients. We reported that silicone affected gas cell structure (internal phase) and did not affect starch swelling or protein coagulation (external phase) of cake batter (1983a), and that gummy layer formation in cake was caused by foam drainage, which was caused by lack of foam stability (1983b). A companion paper reported (Mizukoshi 1985) that the shear modulus of cake was influenced by its porosity, and that shear modulus was affected by various sugar levels in the external phase when the internal phase was held constant (degassed). That study was based on the hypothesis that the rheological properties of cake batter (such as shear modulus) are functionally related to batter composition. In other words, the rheological properties of cake batter during baking affect final cake quality (cake volume, contour, grain, texture, mouthfeel, and flavor). The purpose of this study was to investigate the relationships among the cake quality parameters and cake formulation using shear modulus measurements of cake containing no cell structure.

MATERIALS AND METHODS

Ingredients used to produce cakes included cake flour, sugar, egg, and a foaming agent, which have been described elsewhere (Mizukoshi 1983a). The shortenings used were refined soybean oil with an iodine value of 130, an acid value of 0.03, and a solid fat index of 0 at 20° C, or a hydrogenated vegetable shortening prepared in our laboratory from rapeseed oil and palm oil that had an iodine value of 75, an acid value of 0.04, a melting point of 34.1° C and a solid fat index of 13.6 at 20° C. The cake formulation is expressed in percentage of total weight, not on a flour basis. Methods for cake batter preparation and shear modulus measurements were the same as previously reported (Mizukoshi 1985). Batter compositions are summarized in Tables I and II, along with mean shear modulus values of triplicate measurements.

RESULTS AND DISCUSSION

Effect of Flour, Egg, and Sugar on Shear Modulus

Effects of three major cake ingredients, flour, egg, and sugar on shear moduli of degassed cakes were examined. Flour consists of starch and proteins and serves as a basic structural element in cakes. Figure 1 shows the dependence of flour content of cake on shear modulus under a constant egg to sugar ratio (1:1). Shear modulus increased with increasing flour content. Gelatinization of starch and coagulation of flour protein have been shown to contribute to the structural development of cakes during baking (Mizukoshi et al 1979).

Egg content at a constant flour to sugar ratio (1:1) has a complicated response to shear modulus of cake (Fig. 2). Approximately 20% egg was necessary to form a measurable gel. A maximum shear modulus was observed at 33% egg content; further increase in egg content decreased the shear modulus. Thus, egg acted as a toughener or a tenderizer depending on its concentration.

Sugar (sucrose) concentration also showed a significant effect on shear modulus. Although sucrose had no effect on the shear modulus below 20% concentration, it markedly reduced the shear modulus between 30–40% concentration (Fig. 3). This suggests a critical range of sucrose content; below this range, cake batter had a very tough texture and above it batter was tender and fragile. One way in which sucrose may act as a tenderizer may be interpreted from the results of Mizukoshi et al (1979) indicating that sugar

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TABLE I
Batter Composition and Shear Modulus

Experiment No.	Batter Composition (%)			Shear Modulus ($\times 10^5$dyne/cm^2)	
	Flour	Sugar	Egg	Mean	SD
1	50.0	···	50.0	12.47	0.23
2	40.0	20.0	40.0	12.71	0.03
3	35.0	30.0	35.0	11.94	0
4	33.3	33.3	33.3	10.40	0.08
5	32.5	35.0	32.5	9.58	0.18
6	30.0	40.0	30.0	3.36	0.12
7	20.0	60.0	20.0	0.80	0.12
8	10.0	80.0	10.0	1.01	0.10
9	40.0	40.0	20.0	1.12	0.15
10	37.5	37.5	25.0	4.77	0.03
11	35.0	35.0	30.0	8.77	0.20
12	30.0	30.0	40.0	9.87	0.48
13	20.0	20.0	60.0	5.39	0.19
14	10.0	10.0	80.0	3.64	0.16
15	···	···	100.0	1.58	0.07
16	···	50.0	50.0	0.24	0.02
17	20.0	40.0	40.0	5.09	0.30
18	40.0	30.0	30.0	14.34	0.12
19	60.0	20.0	20.0	18.05	0.39
20	80.0	10.0	10.0	···	···
21	33.3	···	66.7	6.84	0.10
22	33.3	13.3	53.4	8.85	0.20
23	33.3	26.7	40.0	9.87	0.05
24	33.3	40.0	26.7	2.25	0.21
25	33.3	53.4	13.3	0.59	0.15
26	···	33.3	66.7	1.43	0.14
27	16.7	33.3	50.0	5.72	0
28	26.7	33.3	40.0	8.76	0.42
29	40.0	33.3	26.7	5.86	0.60
30	50.0	33.3	16.7	4.61	0.27
31	66.7	···	33.3	17.45	0.86
32	53.4	13.3	33.3	15.71	0.44
33	40.0	26.7	33.3	13.75	0.21
34	26.7	40.0	33.3	5.71	0.28
35	13.3	53.4	33.3	0.64	0.15
36	···	66.7	33.3	0.18	0.05

retards starch gelatinization and protein coagulation during baking.

Effect of Sugar to Egg, Flour to Sugar, and Egg to Flour Ratios

To clarify the interaction among the cake ingredients on cake structure the sugar to egg, flour to sugar, and egg to flour ratios were changed. Typical shear moduli of various sugar to egg ratios at various flour contents are shown in Figure 4. Above 30% flour content shear moduli were maximum at a sugar to egg ratio of 50:50. These phenomena indicated that egg and flour interacted to form a tough cake structure at this ratio. A critical region existed in this system which was the area between 50:50 and 70:30 ratio of sugar to egg. In this region, a small increase in the sugar:egg ratio reduced the shear modulus dramatically. An increase in flour content consistently increased the shear modulus. Increasing the

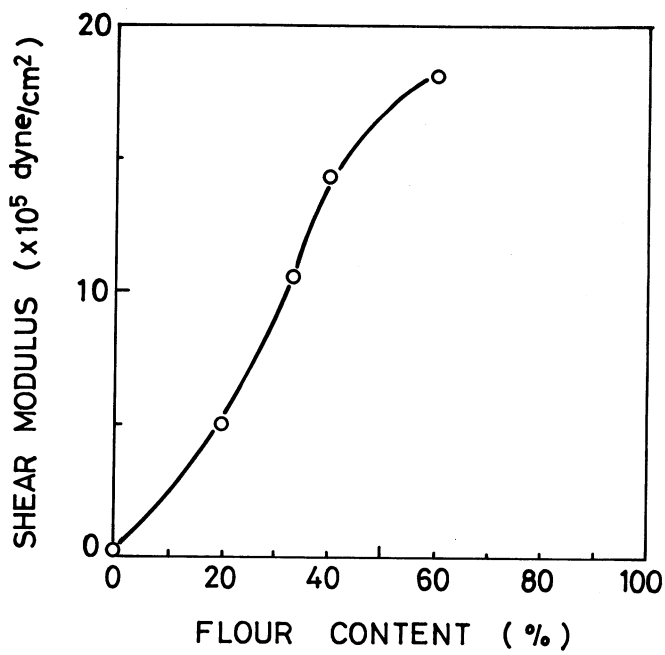

Fig. 1. Effect of flour content on shear modulus in cake (egg:sugar ratio = 1:1).

TABLE II
Batter Composition and Shear Modulus

Experiment No.	Batter Composition (%)							Shear Modulus ($\times 10^5$dyne/cm^2)	
	Flour	Sugar	Egg	Water	Fat	Oil	Foaming Agent	Mean	SD
37	31.2	31.2	31.2	6.4	···	···	···	8.91	0.21
38	29.4	29.4	29.4	11.8	···	···	···	6.24	0.31
39	27.8	27.8	27.8	16.6	···	···	···	5.17	0.09
40	26.3	26.3	26.3	21.1	···	···	···	4.03	0.08
41	25.0	25.0	25.0	25.0	···	···	···	3.24	0.25
42	23.3	23.3	23.3	30.0	···	···	···	1.98	0.01
43	20.0	20.0	20.0	40.0	···	···	···	0.89	0.07
44	31.6	31.6	31.6	···	5.0	···	···	11.16	0.40
45	30.0	30.0	30.0	···	10.0	···	···	12.18	0.15
46	26.6	26.6	26.6	···	20.0	···	···	13.05	0.19
47	23.3	23.3	23.3	···	30.0	···	···	···	···
48	31.5	31.5	31.5	···	···	5.0	···	9.12	0.05
49	30.0	30.0	30.0	···	···	10.0	···	8.23	0.49
50	26.7	26.7	26.7	···	···	20.0	···	5.95	0.34
51	23.3	23.3	23.3	···	···	30.0	···	5.02	0.08
52	29.2	29.2	29.2	11.9	···	···	0.5	7.07	0.12
53	29.1	29.1	29.1	11.7	···	···	1.0	7.19	0.14
54	28.8	28.8	28.8	11.6	···	···	2.0	7.58	0.21
55	28.5	28.5	28.5	11.5	···	···	3.0	7.90	0.02

flour to sugar ratio resulted in increased shear modulus values regardless of the content of egg (Fig. 5). When Figures 1, 3, and 5 are compared, it appears that the toughening effect of flour is greater than the tenderizing effect of sucrose. Shear modulus values reached the maximum at an egg to flour ratio of 70:30 at 40% sugar content (Fig. 6). The influence on shear modulus of ratios of sugar to egg, sugar to flour, and egg to flour suggest the need for further research.

Ternary Flour, Egg, and Sugar System

To further investigate the combined effects of flour, sugar, and egg on the shear modulus of cake, a study of a ternary system was conducted (Fig. 7). An unexpected observation was the existence of a region of close contour lines. This is a critical region of cake formulation in which the shear modulus of cake is strongly influenced by small changes in cake formula. It is important to note that commercial cakes in Japan are usually formulated in this critical region.

In general, an increased shear modulus reflected stronger cake structure and resistance to cake shrinkage during cooling, but such cakes are inferior in tenderness and mouthfeel. Balancing these two aspects is the most important point in formula balancing. From this standpoint, a most desirable cake formula seems to result in a shear modulus between 5–10 dyne/cm^2.

Effect of Water

The most effective ingredient in decreasing shear modulus was water. As shown in Figure 8, shear modulus decreased almost linearly with increasing water content. Water can be understood as a diluent of materials which contribute to cake structure, and as such tenderizes cake structure.

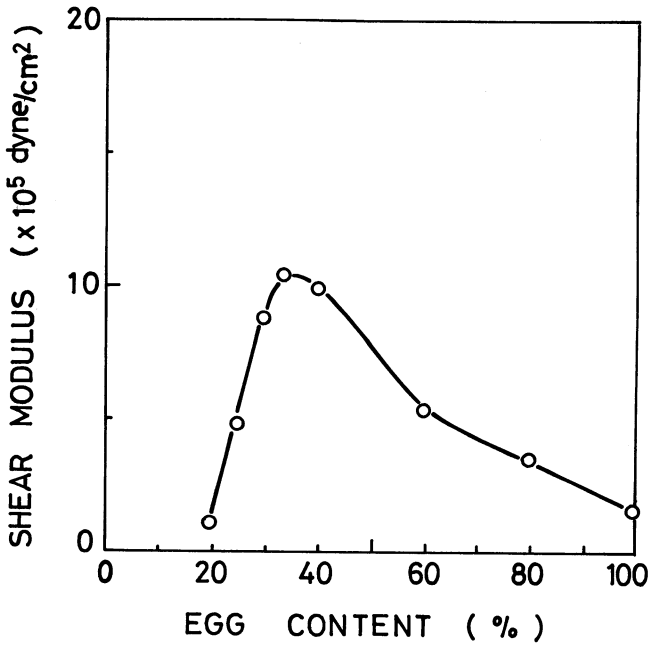

Fig. 2. Effect of egg content on shear modulus in cake (flour:sugar ratio = 1:1).

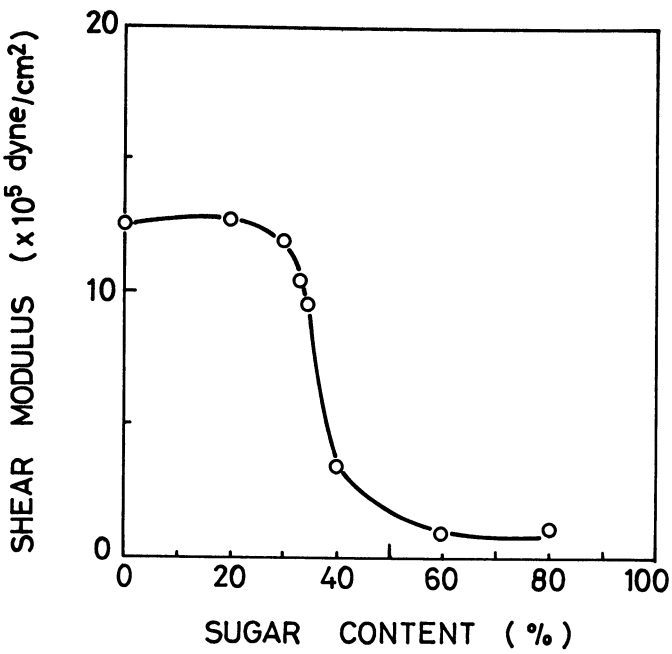

Fig. 3. Effect of sugar content on shear modulus in cake (egg:flour ratio = 1:1).

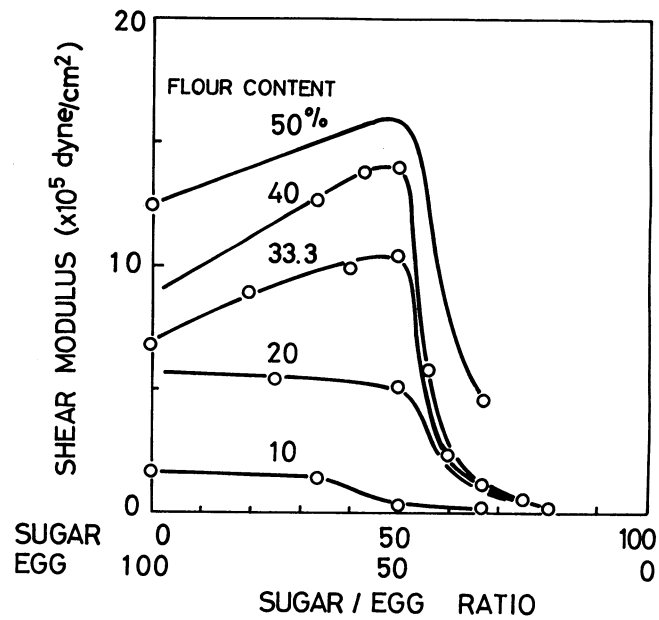

Fig. 4. Effect of varying sugar:egg ratio on shear modulus in cake at constant flour content.

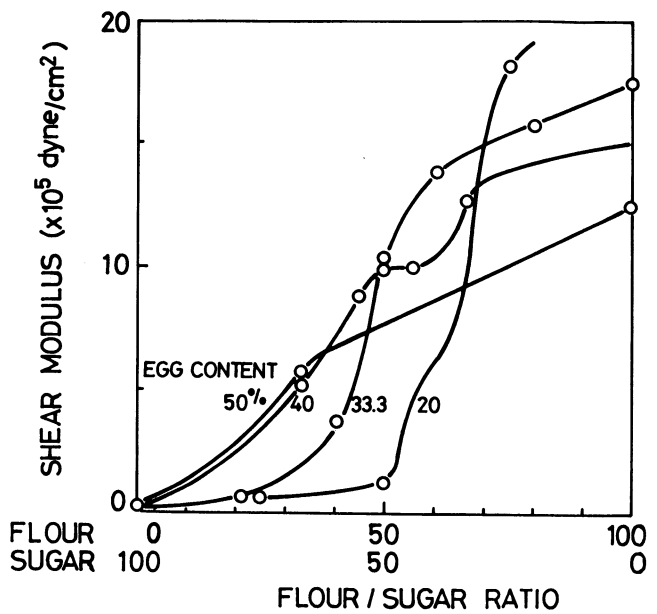

Fig. 5. Effect of varying flour:sugar ratio on shear modulus in cake at constant egg content.

Effects of Fat and Oil

Many fats and oils are used by cake manufacturers to enhance cake qualities such as appearance, volume, texture, mouthfeel, and flavor. In this study, two typical cake shortenings, a vegetable shortening and soybean oil, were used (Fig. 9). The fat increased the shear modulus, but soybean oil decreased it; thus, fat and oil acted oppositely in structural development. When formulas contained above 30% fat or 40% oil, fat and oil were not emulsified, and shear modulus was not measured. Fats and oils are mixtures of triglycerides, and each triglyceride has a different chemical structure and physical properties. Chemical structure is defined by fatty acid composition, the 1-, 2-, and 3- position of glycerine, and cis or trans content, etc. Physical properties include solid fat content, and size and shape of the fat crystal. Further investigation is necessary to clarify the effect of chemical structure and physical properties of triglycerides on the shear modulus of cake.

Effect of a Foaming Agent (Emulsifier)

In recent years, food emulsifiers have become ingredients essential to the cake industry. They improve emulsion stability of cake batter and thus improve cake crumb structure, staling, cake volume, and other qualities. Figure 10 shows that in this study the foaming agent functioned as a cake crumb toughener. Shear modulus increased slightly with increasing emulsifier content. The foaming agent used in this research, contained three kinds of food emulsifiers: monoglycerides, propylene glycol fatty acid esters, and sorbitan fatty acid esters.

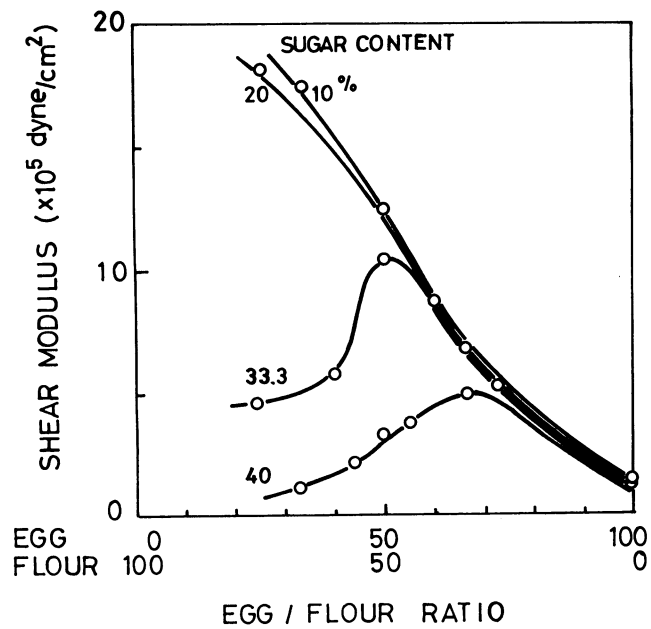

Fig. 6. Effect of varying egg:flour ratio on shear modulus in cake at constant sugar content.

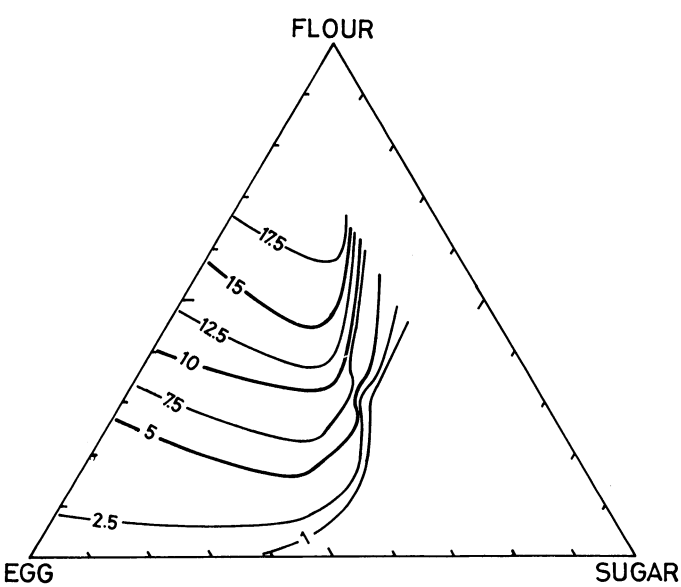

Fig. 7. Ternary system of flour, egg, and sugar on shear modulus in cake.

CONCLUSIONS

Shear modulus measurements of cakes containing no foam structure were used to study the effect of variation in ingredient

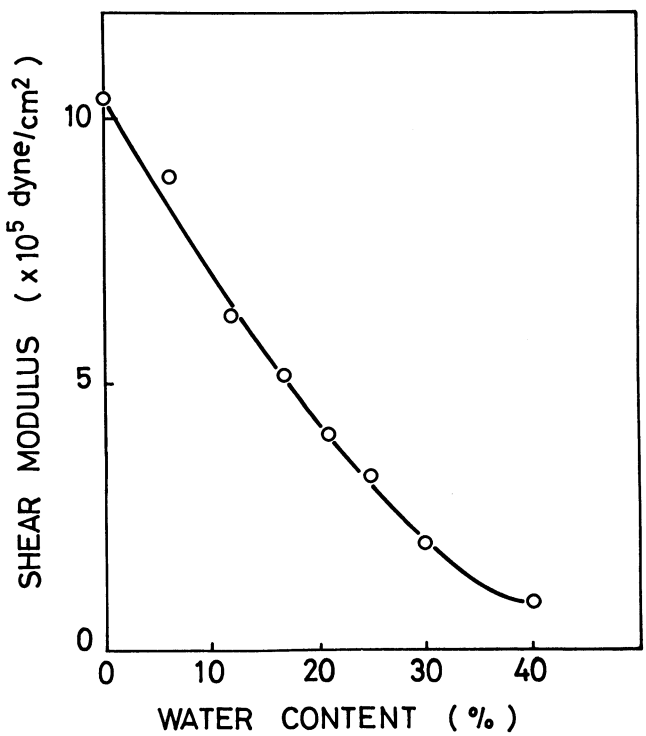

Fig. 8. Effect of water content on shear modulus in cake (flour:egg:sugar ratio = 1:1:1).

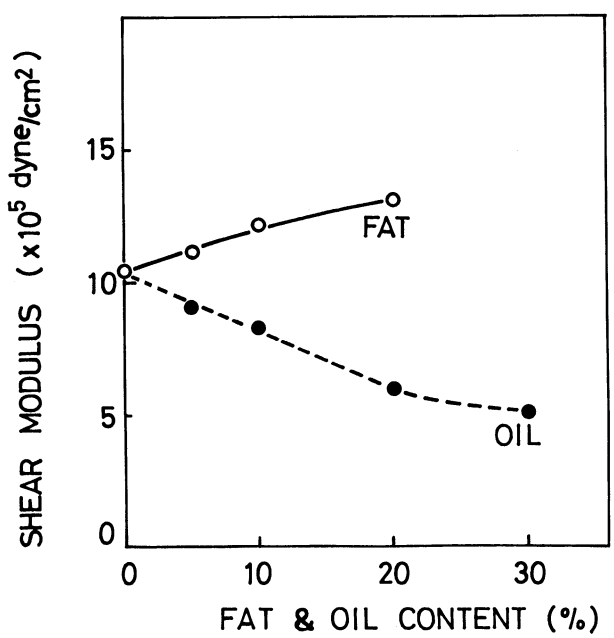

Fig. 9. Effect of fat and oil content on shear modulus in cake (flour:egg:sugar ratio = 1:1:1).

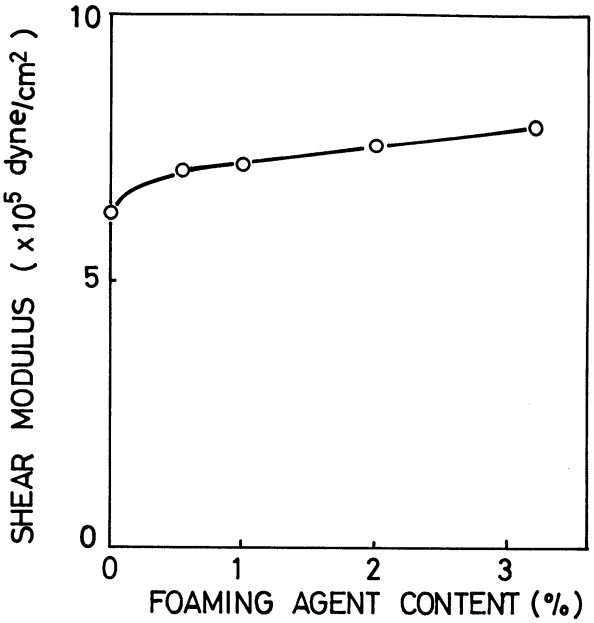

Fig. 10. Effect of foaming agent (emulsifier) content on shear modulus in cake (flour:egg:sugar:water ratio = 1:1:1:0.4).

formulation on mechanical properties of baked cakes. The following results were obtained: 1) flour, fat, and foaming agents acted as cake crumb tougheners, that is, increased the shear modulus; 2) sugar, water, and oil acted as cake crumb tenderizers, that is, decreased the shear modulus; 3) whole egg acted as a cake crumb toughener depending upon the amount in the formula; and 4) a critical region of cake formulation existed in which the shear modulus of cakes was strongly affected by a small change in cake formulation.

Shear modulus measurements were useful to observe the effects of cake ingredients and formulation on cake structure. Further studies should clarify the more detailed role of cake ingredients, their components and interaction, in addition to the methods of mixing cake batter and baking operations. Finally, more study is needed to clarify the relationship between shear modulus and cake qualities, such as softness, mouthfeel, texture, and flavor.

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