April 5, 1971

To the Graduate Council:

I am submitting herewith a thesis written by Ellen Brasher Willis entitled "Trans Isomers in Relation to Their Effect on the Aeration Function of a Shortening." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science.

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TRANS ISOMERS IN RELATION TO THEIR EFFECT ON THE AERATION FUNCTION OF A SHORTENING

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Ellen Brasher Willis

June 1971

ACKNOWLEDGMENTS

The author wishes to express her appreciation to Dr. Ada Marie Campbell for her patient help and guidance during the planning and development of this study and for her assistance in the preparation of this manuscript. An expression of thanks is also extended to Dr. John T. Smith and Dr. Bernadine Meyer for their suggestions and help provided during the course of this work and to Dr. H. A. Lasater for help in the statistical analysis of the data. The author also wishes to express gratitude for continuous support to her mother, Mrs. H. E. Brasher.

ABSTRACT

Lipid effects on aeration of batters and sensory attributes of cakes were investigated. The shortenings were prepared from lard with elaidinized vegetable oil substituted at the 0, 40, 60 and 80 percent levels. These levels of substitution represented trans isomer contents of 0 to 56 percent of the total monoene. Penetrability of the manipulated lipids decreased with increasing elaidinized lipid substitution.

Viscosity and density determinations were made on the batters. Viscosity increased ($P<0.01$) up to the 60 percent level of substitution, at which level density was the lowest ($P<0.01$).

Volume index was measured as the area (cm^2) of the center-cut cross-section. Cakes made with unsubstituted lard were smallest ($P<0.01$) and those made from lipid at the 80 percent substitution level were largest ($P<0.01$).

The sensory panel judged the cakes made of unsubstituted shortening to be of highest quality ($P<0.01$) and those made with 80 percent substitution to be of lowest quality ($P<0.01$).

Addition of elaidinized lipid to lard up to the 60 percent level of substitution increased aeration during mixing and the cakes produced at the 40 and 60 percent substitution levels had acceptable sensory qualities.

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I. INTRODUCTION

Most shortenings currently are made by conversion of vegetable oils to plastic solids through hydrogenation. Many positional and geometric isomers may be formed during the hydrogenation process (Allen and Kiess, 1955; Eckey, 1954; Swern, 1964). Concentrations of trans fatty acids in commercially available shortenings range from about 20 to 40 percent (Mabrouk and Brown, 1956; Sgoutas and Kummerow, 1970) and contribute to the change in physical state. The formation of trans isomers of unsaturated fatty acids is termed elaidinization. With properly selected catalytic and other reaction conditions, elaidinization of unsaturated lipids may occur without hydrogenation.

Until recently, elaidinized lipid has not been studied in relation to effects it might have on the functional properties of lipids. Ostrander (1968) and Klouda (1969) studied the effect of elaidinized lipid on shortening power. Another function of lipid in foods is batter aeration, the trapping of air in flour mixtures. Hoerr (1967) found aeration of a cake batter to contribute to volume, grain and texture of the baked product. Shortenings of various types have been studied in relation to their aeration ability and consequent effects on cake characteristics. The availability of commercially

prepared elaidinized lipid (Cochran et al., 1961) makes it feasible to study its effect on aeration power of shortening and sensory qualities of the baked cake.

II. REVIEW OF LITERATURE

Elaidinization

Elaidinized lipids have been produced for many years with a variety of catalysts (Allen and Kiess, 1955; Eckey, 1954). Elaidinization results in greater resistance to oxidation than does hydrogenation (Bertram, 1949). Elaidinized lipids have higher melting points than their cis isomers and retain their degree of unsaturation; therefore, a vegetable oil may be converted to a solid without loss of unsaturation.

Cis-trans isomerization also occurs during hydrogenation (Allen and Kiess, 1955; Hoerr, 1967). A shortening with desirable qualities can be produced either from hydrogenated lipids that contain trans fatty acids or from completely hydrogenated lipids that are rearranged with unhydrogenated oils (Zalewski and Kummerow, 1968). Rearrangement adds to the processing steps and the cost; therefore, trans fatty acid formation during hydrogenation is economically advantageous.

Polyunsaturated fatty acids lower the serum lipid levels when used to replace saturated fats in the diet. Some investigators have found that unsaturated shortenings containing trans fatty acids may not lower serum lipid levels as much as shortenings of the same degree of unsaturation

containing no trans fatty acids (McOsker et al., 1962; Weigensberg and McMillan, 1964).

Incorporation of trans fatty acids into tissue lipids has been studied (Sgoutas and Kummerow, 1970). The trans fatty acids were found to be metabolized as easily as the cis form, but their biological utilization does differ.

Aeration of Cake Batters

The role of shortening in cake was described by Carlin (1944), who considered the aeration of batter to be due to incorporation of air into the plastic shortening phase during mixing. According to Kearney (1969), the air bubbles in a cake batter are enclosed in globules of fat and contribute to volume and grain. Other workers reported that the air cells either are trapped in the fat or collect at the oil-water interface (Carlin, 1944; Dunn and White, 1939; Greethead, 1969). Pohl and co-workers (1968), using freeze-dried cake batters, found that air bubbles are not incorporated primarily in the fat particle, but are dispersed throughout the batter. Many types of shortenings were used with similar results. These workers postulated that air is incorporated during mixing and trapped at the dough cleavage planes at the oil-water interface. They also observed greater aeration and increased viscosity of batters with fat in the formula. Matthews and Dawson (1966) found that the fat ingredient affects incorporation of air into the batter.

Hoerr (1967) and Greethead (1969) reported the size and number of air bubbles in cake batter to differ markedly with different shortenings and to affect volume, grain and texture. The greater the volume of air, the more uniform its distribution and the smaller the individual air cells, the greater was the volume and the finer the texture of the baked cake.

Hoerr (1967) stated that the degree of aeration of bakery products is primarily a mechanical action dependent on the crystal characteristic of the fat. Fats are polymorphic, i.e., they can exist in more than one crystal form. It is possible for two fats to have the same melting point but exist in different crystal forms, resulting in markedly different performance in some applications, such as batter aeration.

Batter structure changes during baking (Carlin, 1944). Handleman et al. (1961) studied the bubble mechanics in thick foams and their effect on quality of cake made with liquid shortenings. They found increased air incorporation in single-stage batters with lactoylated glycerides as shortening additives. Wootton and co-workers (1967), also using liquid shortenings, found alpha-tending additives to enhance air incorporation. In both of these studies, the additives were necessary to keep the liquid shortenings from inhibiting the foaming ability of protein dispersions.

Factors Related to Aeration and Cake Quality

Matthews and Dawson (1966), investigating the performance of five shortenings in white cakes, related batter properties to cake quality. Batter viscosity was positively related to volume index and to sensory scores.

Howard and co-workers (1968) measured density of batters containing different liquid shortenings. Batter density was affected by the lipid used and was relatively low for cake of relatively high volume. Donelson and Wilson (1960) used volume as the primary measure of cake quality.

Kissell (1959) developed a lean-cake formula requiring only flour, sugar, shortening, baking powder and water. Volume and internal appearance of the cakes were evaluated and the formula was found to be capable of showing experimental differences with little replication error. This lean formula has been used successfully by other workers (Donelson and Wilson, 1960; Hoerr et al., 1966; Yamazaki, 1962).

III. EXPERIMENTAL PROCEDURE

Cakes containing four different lipid samples were prepared in a randomly selected sequence for each replication. Eight replications were completed, each on a different day. Physical measurements were made on the lipids, batters and cakes. The cakes were subjected to sensory evaluation.

Preparation of Lipid Samples

Lard was obtained from a local packing company.* Elaidinized vegetable oil was obtained from a commercial source.† Four samples representing substitution of elaidinized lipid for lard at the 0, 40, 60 and 80 percent levels were mixed for 10 minutes in a Hobart N-50 mixer at speed one under a nitrogen atmosphere. Individual portions were weighed and stored in glass jars at -20°C until used.

Analysis of Lipid Samples

Methyl esters were prepared by the method reported by Ostrander (1968). Gas-liquid chromatography (GLC) was used to determine the fatty acid composition of the methylated lipids (Klouda, 1969). GLC does not separate cis and trans isomers. The proportion of trans fatty acids in the methylated

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*East Tennessee Packing Company, Knoxville, Tennessee

†Durkee Famous Foods, Chicago, Illinois

samples was calculated from data obtained by using argentation thin-layer chromatography (TLC) as described by Ostrander (1968).

Physical Measurements of Lipid Samples

Melting points were determined by the AOCS official capillary tube method (AOCS, 1963). Penetrability of the lipid samples was measured by a modification (Klouda, 1969) of the method of Hornstein et al. (1943) involving a series of passages through a sieve.

Preparation of Batters and Cakes

The lean formula developed by Kissell (1959) was used because it essentially eliminates sources of fat other than the experimental samples (Table 1). Cake flour and baking powder were pre-weighed and stored in bags in a covered container until used. The pre-weighed lipid samples were brought to room temperature for use. Sufficient sugar solution was prepared for all replications and stored at room temperature in a glass carboy with an attached siphon.

Kissell's method, involving machine mixing of flour, baking powder and shortening during gradual addition of sugar solution and water, was followed with these exceptions: (1) a Hobart N-50 mixer was used, (2) sugar solution and water were poured from a graduated cylinder during the 30 sec of mixing at speed one, (3) 300 gms of batter in a 6 X 6 X 1-1/2-inch layer pan were used for each cake and (4) a Despatch rotary oven was used for baking.

Table 1. Cake Formula

Ingredient	Quantity	Composition on percent flour basis
Cake Flour, g	150	100
Sugar Solution, ml	212	130[a]
Shortening, g	41.8	27.9
Sulfate-phosphate Baking Powder, g	7.1	4.7
Distilled Water, ml	75	109[b]

[a]Sugar only. Sugar solution contained 0.92 g sucrose and 0.42 g water per ml at 24-25°C.

[b]Percent total water, including water in sugar solution.

Measurements

Batters. Apparent viscosity of the batters at room temperature was determined with the Brookfield viscometer (Model LVF) with spindle 4 and speed 12. Tall-form beakers of 250 ml capacity were filled with batter. After stabilization, three readings were taken 30 sec apart and averaged. For the batter density determinations, pre-weighed crystallizing dishes were over-filled and leveled. Density was calculated as the weight of batter required to exactly fill the crystallizing dish divided by the predetermined volume of the dish.

Baked cakes. Volume index was determined as the area of a center-cut slice measured with a compensating polar planimeter (Halliday and Noble, 1943). A six-member panel evaluated each of the cakes for cell size, cell wall thickness, uniformity of cell distribution, tenderness and mouthfeel. Each judge also indicated his overall preference on the scorecard (Figure 1, Appendix).

Statistical Design and Analysis

Friedman's two-way analysis of variance by ranks was applied to the objective and sensory data by the method of Siegel (1956). The statistic χr^2 is computed* to determine if any significant differences occur, but the location of the significance is determined by the differences in the rank totals. If the qualities being measured are independent of the variable, the ranks appear randomly, yielding similar rank totals. If the quality measured is dependent on the variable, the ranks tend to fall similarly for each replication, yielding different rank totals.

$$*\chi r^2 = \frac{12}{Nk\ (k+1)} \sum_{j=1}^{k} (R_j)^2 - 3\ N(k+1)$$

N = number of rows (eight replications)
k = number of columns (four lipid samples)
R_j = sum of ranks in the j^{th} column

IV. RESULTS AND DISCUSSION

Lipids

Composition. Table 2 presents the composition of the four lipid samples. The total monoenes increased only from 51 to 63 percent as the level of substitution of elaidinized lipid increased, but the trans monoenes increased from 0 to 56 percent. The C18:2 levels decreased inversely to the increase in total monoenes.

Physical measurements. Penetrability and melting points of the four lipid samples are shown in Table 3. With increased levels of elaidinized lipid, penetrability decreased. Samples tended to increase in penetrability with manipulation, but their penetrability ranking remained unchanged. The melting point of the unsubstituted lipid was higher than those of the lipids containing elaidinized oil, which were similar and only slightly above the melting point of the elaidinized lipid used in substitution (36°C).

Batters

Viscosity. Mean viscosity of the batters at room temperature increased significantly ($P<0.01$) as the level of substitution increased until the 80 percent level, at which it decreased to a value similar to that for the unsubstituted

Table 2. Fatty Acid Composition of Lipid Samples, percent[a]

Percent of Elaidinized Lipid	Fatty Acids[b]						Total Monoene	Trans Monoene[c]
	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2		
0	2.4	24.3	1.3	11.4	49.8	11.8	51.1	0
40	1.2	22.8	1.2	12.6	55.6	6.7	56.8	22
60	1.0	20.8	0.4	13.9	59.8	3.9	60.2	36
80	0.6	19.7	trace	14.4	63.4	1.8	63.4	56

[a]Data collected in collaboration with Klouda (1969).

[b]Trace of C_{12} in all samples.
Number of carbons:number of double bonds.

[c]Percent of total monoenes.

Table 3. Penetrability and Melting Points of Lipid Samples[a]

Percent of Elaidinized Lipid	Penetrability, mm/10 in 5 sec			Melting Point, °C
	1	5	9[b]	
0	110	119	124	46
40	83	79	79	38
60	52	54	54	40
80	15	22	22	38

[a]Data collected in collaboration with Klouda (1969).

[b]Number of passages through a 16-mesh sieve.

shortening (Table 4). Visual observation indicated that the emulsions remained smooth while becoming increasingly thick up to the 60 percent level of substitution. Batters made with 80 percent substituted shortening appeared curdled except in one replication. Data for all replications are in the Appendix, Table 6.

Density. Table 4 also gives mean batter density values. Batters made with shortening substituted at the 60 percent level were the least dense ($P<0.01$). The density of the other three batters differed only between the 40 and 80 percent levels of substitution, the 40 percent sample being the less dense. Data for all replications are in the Appendix, Table 7.

Cakes

Volume index. Cakes made from unsubstituted shortening were smallest ($P<0.01$) as indicated by mean volume index (Table 4). Those made with 80 percent substituted shortening were largest ($P<0.01$). The cakes made from shortenings of the 40 and 60 percent substitution levels did not differ; both were larger than the unsubstituted sample ($P<0.01$) and smaller than the 80 percent sample ($P<0.01$). Volume index for all replications is given in the Appendix, Table 8.

Table 4. Apparent Viscosity and Density of Batters and Volume Index of Baked Cakes

Percent of Elaidinized Lipid	Mean Viscosity, cps	Mean Density, g/cc	Mean Volume Index, cm^2
0	9,721[a]	1.0279[a]	41.2[a]
40	10,833[b]	1.0191[ab]	44.8[b]
60	15,548[c]	0.9330[c]	44.6[b]
80	9,075[a]	1.0754[ad]	46.8[c]

[abcd]Means in a single column not having the same superscript differ at the level $P<0.01$.

Sensory data. Rank totals of judges' scores for sensory attributes (Table 5) indicate that the cakes prepared from unsubstituted shortening were most desirable ($P<0.01$) and those prepared from 80 percent substituted shortening were least desirable ($P<0.01$) on every attribute scored. Overall acceptability ratings agreed with the score data. Between the cakes made with 40 and 60 percent substituted shortening, the visual attributes received different scores ($P<0.01$), but those dependent on tactile judgments did not differ.

Discussion

A positive relationship between batter viscosity and volume index has been reported (Matthews and Dawson, 1966). Density measurements have been related negatively to cake volume (Howard et al., 1968). These relationships were found to exist in the present study at the 0, 40 and 60 percent levels of substitution. At the 80 percent substitution level the cake volumes were greatest ($P<0.01$), but the batter viscosity and density did not differ from those of batters made with unsubstituted shortening. Failure of batter viscosity to increase and of density to decrease at the 80 percent substitution level indicates that the large cake volume was influenced by a factor other than air incorporation during mixing. The explanation might lie in the nonhomogeneous nature of the mixed shortenings. The elaidinized lipid

Table 5. Rank Totals for Sensory Data

Sensory Attribute Scored[a]	Percent of Elaidinized Oil			
	0	40	60	80
Cell Size	23.0[b]	12.0[c]	19.0[d]	6.0[e]
Cell Wall Thickness	29.5[b]	17.0[c]	24.0[d]	8.5[e]
Uniformity of Cell Distribution	27.5[b]	16.5[c]	25.5[b]	10.5[d]
Tenderness	30.5[b]	20.0[c]	21.5[c]	8.0[d]
Mouthfeel	30.5[b]	19.5[c]	20.0[c]	10.0[d]
Acceptability[f]	59.9	12.9	24.2	3.3

[a]For every attribute, the most desirable state received the highest score.

[bcde]For each attribute rank totals not having the same superscript differ at the level $P<0.01$.

[f]Values given are the percentages of the total number of preference checks.

remained in visible flakes. The large number of flakes present in the shortening at the 80 percent substitution level possibly increased the number of dough cleavage planes. Melting of the flakes during baking then might have provided pockets in which steam expanded readily, resulting in a product of large volume but unsatisfactory grain.

Unsubstituted shortenings produced the most acceptable product according to sensory scores (Table 5). Although any substitution of elaidinized lipid for lard decreased sensory scores, only at the 80 percent substitution level was the product completely unacceptable. The intermediate amounts of elaidinized lipids substituted for lard increased aeration without yielding an unacceptable product.

V. SUMMARY

Lipid effects on aeration of batters and sensory attributes of cakes were investigated. The shortenings were prepared from lard with elaidinized vegetable oil substituted at the 0, 40, 60 and 80 percent levels. These levels of substitution represented trans isomer contents of 0 to 56 percent of the total monoene. Penetrability of the manipulated lipids decreased with increasing elaidinized lipid substitution.

Viscosity and density determinations were made on the batters. Viscosity increased ($P<0.01$) up to the 60 percent level of substitution, at which level density was the lowest ($P<0.01$).

Volume index was measured as the area (cm^2) of the center-cut cross-section. Cakes made with unsubstituted lard were smallest ($P<0.01$) and those made from lipid at the 80 percent substitution level were largest ($P<0.01$).

The sensory panel judged the cakes made of unsubstituted shortening to be of highest quality ($P<0.01$) and those made with 80 percent substitution to be of lowest quality ($P<0.01$).

Addition of elaidinized lipid to lard up to the 60 percent level of substitution increased aeration during mixing and the cakes produced at the 40 and 60 percent substitution levels had acceptable sensory qualities.

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APPENDIX

Score from 0 to 5. For Mouthfeel and Acceptability, score in the order given.

	Sample Code			
Cell Size the smaller the cells, the higher the score.				
Cell Wall Thickness the thicker the wall, the lower the score.				
Uniformity of Cell Distribution the more evenly distributed, the higher the score.				
Tenderness optimal tenderness receives the higher score.				
Mouthfeel optimal velvetiness and moistness receives the higher score.				
Acceptability Check preference based on all sensory attributes (Possible to have 2 or more equally acceptable.)				

Judge_____

Date_____

Figure 1. Scorecard for Cakes

Table 6. Viscosity of Batters, cps[a]

Replication	Percent of Elaidinized Vegetable Oil			
	0	40	60	80
1	9,065	9,100	11,730	10,215
2	8,400	9,500	11,700	8,600
3	9,050	12,015	14,650	8,785
4	9,050	12,100	14,050	10,750
5	8,950	9,100	14,300	11,450
6	10,450	10,500	23,850	5,550
7	9,800	10,850	16,550	9,050
8	13,000	13,500	17,550	8,200
Mean	9,721	10,833	15,548	9,075
Rank Total	12	22	32	14

[a]Each value is average for three readings.

Table 7. Density of Batters, g/cc

Replication	Percent of Elaidinized Vegetable Oil			
	0	40	60	80
1	1.0358	1.0507	0.9682	1.0442
2	1.0373	1.0332	0.9415	1.0314
3	1.0115	0.9547	0.9625	1.0603
4	1.0450	1.0589	0.9679	1.0828
5	1.0312	1.0293	0.9343	1.0217
6	1.0259	1.0395	0.8797	1.1718
7	1.0496	1.0185	0.9451	1.0713
8	0.9872	0.9677	0.8644	1.1199
Mean	1.0279	1.0191	0.9330	1.0754
Rank Total	23	21	9	27

Table 8. Volume Index, cm^2

Replication	Percent of Elaidinized Vegetable Oil			
	0	40	60	80
1	42.2	41.6	43.9	47.6
2	44.7	46.1	47.9	46.5
3	37.0	44.3	43.7	47.4
4	40.5	45.7	45.0	46.6
5	41.4	44.2	42.9	47.1
6	41.8	46.0	44.0	46.7
7	41.0	45.2	47.6	46.4
8	41.4	45.0	41.5	46.3
Mean	41.2	44.8	44.6	46.8
Rank Total	9	20	21	30

VITA

The author is Ellen Elizabeth Brasher Willis. She was born July 3, 1946 in Murray, Kentucky. She received her B.S. degree from The University of Tennessee at Martin in 1967. She is a member of the American Home Economics Association and Omicron Nu. She has worked as a dietitian at Monmouth Medical Center in Long Branch, New Jersey, and at St. Thomas Hospital in Nashville, Tennessee. She received her M.S. degree from The University of Tennessee at Knoxville in June, 1971.