

Effect of Shortening Replacement with Oatrim on the Physical and Rheological Properties of Cakes

Suyong Lee,¹ Sanghoon Kim,¹ and George E. Inglett^{1,2}

ABSTRACT

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Oatrim (oat β -glucan amyloextrins) was evaluated as a fat substitute in a cake system. The physical and rheological properties of cakes containing shortening replaced with 20, 40, and 60% by weight of Oatrim were characterized. The increase in the specific gravity of the cakes and the decrease in the viscosity as more shortening was replaced with Oatrim were correlated with the change in the cake volume. The number of air bubbles present in the cake batters varied significantly; however, the size of the observed bubbles did not change. The cakes containing more Oatrim displayed a higher starch gelatinization temperature due to the amyloextrins in the Oatrim. The dynamic rheological properties of the

cakes were investigated during baking and correlated with the differential scanning calorimetry results. The oscillatory shear storage moduli decreased upon initial heating, then increased due to starch gelatinization, and finally reached a plateau value that varied based on the sample composition. Moreover, increased replacement of shortening with Oatrim resulted in higher observed oscillatory shear storage moduli. The cakes prepared with up to 20% by weight of Oatrim did not evidence significant changes in softness ($P < 0.01$) and generally exhibited similar physical properties to the control cake.

As one of the principal and essential nutritional components of diet, fat contributes pleasing flavor and texture to food products, thus providing positive sensory attributes to the consumer. However, it is well recognized that a diet high in fat leads to health problems such as obesity, high blood pressure, and heart disease. The World Health Organization recommends that saturated fat intake should not exceed 10% of the total calories for healthy people and that the total fat intake should be less than 30% of the total calories (WHO 2003). Recently, consumers have shown a concern for the amount of fat in foods and an interest in lower fat, heart-healthy products. With these trends as a driving force, food scientists have a market-driven impetus to develop low-fat or fat-free foods with acceptable taste and texture. This segment of the food market is currently one of the fastest growing areas.

To meet the consumer demand for low-fat or fat-free food products, various sources are being developed and used as fat replacers in foods. Specifically, carbohydrate-based fat replacers have widely been used in baked products such as cookies (Sanchez et al 1995), biscuits (Conforti et al 1997), and cakes (Bath et al 1992). Oatrim is one of carbohydrate-based fat substitutes made from oats and, in its dried state, is a nearly tasteless white powder. It was discovered (Inglett 1990, 1993) and patented by the U.S. Department of Agriculture (Inglett 1992). Preparation of Oatrim involves the conversion of starch in oat flour or bran into amyloextrins by enzymatic hydrolysis. Oatrim consists primarily of amyloextrins and soluble fiber (β -glucan usually at 5–10% by weight) with low amounts of lipids, proteins, and minerals. β -Glucan has shown beneficial physiological effects such as the reduction of blood cholesterol (Wood et al 1989; Braaten et al 1994; Malkki and Virtanen 2001). Furthermore, amyloextrins provide a smooth mouthfeel and reduce the calorie count in foods (Inglett 1993; Giese 1996). Therefore, Oatrim displays great promise as a fat replacer and nutraceutical additive for food products.

Oatrim can be used in most foods as a powder or gel. In a previous study, it was used as a fat substitute in several foods such as cookies, candies, muffins, salad dressings, margarine, and breakfast cereals (Inglett and Warner 1992). For cookies and candies, the sensory evaluation exhibited acceptability of flavor and texture characteristics of up to 50% replacement by weight of shortening. To effectively develop new food products using Oatrim, a more detailed understanding of the role of this material in the processing and functional requirements of foods is needed.

The goals of this study were to evaluate the role of Oatrim as a fat replacer for baked products, specifically, cakes. Shortening was systematically replaced with different levels of the Oatrim and its effect on cake qualities was investigated by using physical and rheological measurements.

MATERIALS AND METHODS

Based on Approved Method 10-90 (AACC 2000), cake samples in this study were prepared from high-ratio cake flour (14% moisture basis, ConAgra Inc., Omaha, NE), sugar (United Sugars Co., Minneapolis, MN), nonfat dry milk (DairyAmerica, Fresno, CA), dried egg white (Oskaloosa Food Products, Oskaloosa, IA), sodium chloride, baking powder (Kraft Foods, Inc., Rye Brook, NY), distilled water, and shortening (Hunt-Wesson, Inc., Fullerton, CA). The Oatrim used in this study was obtained from Rhodia, Inc. (Cranbury, NJ) and its composition was 82.7% amyloextrins, 5.8% β -glucan, 5.0% protein, 1.4% lipid, 3.1% minerals, and 2.0% pentosans.

Cake Preparation

Cakes with 0, 20, 40, and 60% by weight replacement of Oatrim for shortening were prepared and the formulas are listed in Table I. The shortening and sugar were first blended using a paddle in a mixer (KitchenAid, St. Joseph, MI) for 2 min. Water (60 mL) was then added and mixed for 2 min. Other dry ingredients including the Oatrim were sifted well using a strainer (Oxo International, New York, NY), added with remaining water (190 mL), and mixed for 1 min. The cake batter was scraped down and mixed for an additional 2 min. Then, after scraping down again, the mixing was continued for a further 4 min. The batter (425 g) was transferred to a round cake pan 20 cm in diameter and baked at 170°C in a reel oven (National Mfg. Co., Lincoln, NE) for 35 min.

Physical Property Measurements

Batter specific gravity was determined as the ratio of the weight of a measuring cup filled with batter to that filled with water. A

¹ Cereal Products & Food Science Research Unit, National Center for Agricultural Utilization Research, Agricultural Research Service, United States Department of Agriculture, Peoria, IL 61604. Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to exclusion of others that may also be suitable.

² Corresponding author. Phone: 309-681-6363. Fax: 309-681-6685. E-mail: Inglett@ncaur.usda.gov

layer cake measuring template was used to obtain the volume index of the cake samples (Approved Method 10-91, AACC 2000). The viscosity of the cake batters as a function of shear rate ($3 \times 10^{-4} \approx 10 \text{ s}^{-1}$) was measured by using a strain-controlled rheometer (ARESLS, TA Instruments, New Castle, DE). Measurements were made at 25°C using parallel plates 50 mm in diameter. All measurements were triplicated.

Microscopic Examination of Cake Batters

The number and size distribution of bubbles in the cake batters were investigated using image analysis. A drop of the cake batter was placed on a glass slide, covered by a cover glass, and gently pressed. The slide was placed on a brightfield microscope (Diastar, Reichert, Deerfield, IL) with the objective set at 10 \times . A Nikon digital camera (D100, Tokyo, Japan) was mounted at the top of the microscope using a microscope adapter (Universal Microscopic Adapter, Edmund Industrial Optics, Barrington, NJ). The images were captured in JPEG format at 3,000 \times 2,000 pixels and then transferred to a personal computer for image analysis. Using commercial image processing software (Photoshop, Adobe Systems, Inc., San Jose, CA), the images were converted to gray-scale, and the contrast of each image was enhanced to more clearly outline the boundaries of air bubbles. Following this, the images were exported to image software (Scion Corp., Frederick, MD) and then converted to halftone mode. The number of air bubbles and the size distribution were determined by using the built-in threshold-finding and particle-counting functions of the software. Because the reliability of the particle-counting function depends on the clarity of the images, each image was manually inspected before and after thresholding to avoid possible counting errors. For statistical treatment of the data, five samples were taken from each cake batter and three images were taken from each sample.

The procedure described above is a modified version of video microscopic technique that has been reported for monitoring and analyzing cake batter bubbles during baking on a hot-stage (Pateras et al 1994). In principle, any light microscope equipped with any kind of digital camera can be used for this type of experiment. Because the transmittance of air bubbles is a lot different from that of the matrix, a phase-contrast microscope is not necessary. Once the images are taken from the microscope, the image files can be processed with any kind of software that allows us to evaluate the number of air bubbles and the size distribution in a sample material.

Thermal Analysis

The gelatinization of the cake batters was studied using a TA Instrument differential scanning calorimeter (DSC) 2920 (TA Instruments, New Castle, DE) with a refrigerated cooling system. The DSC was calibrated with indium (156.6°C, 28.591 J/g) and an empty pan was used as the reference. Each cake batter sample was weighed and sealed in a high-volume stainless steel pan. The samples were heated from 30–170°C at a rate of 10°C/min. All DSC measurements were quadruplicated.

Rheological Measurement During Baking

The changes in rheological properties of cake batters occurring during baking were examined using a rheometer equipped with a forced-air convection oven connected with a mechanical chiller

(ARESLSM, TA Instruments, New Castle, DE). The samples were placed between two 25-mm serrated plates to minimize slippage during measurements and then enclosed by the oven chamber. Before testing, the actual gap between the plates was measured automatically by the instrument. Dynamic temperature ramp tests were conducted at a frequency of 1 rad/sec and a strain of 1%. The instrument was operated from 30–170°C at a heating rate of 10°C/min to obtain the oscillatory shear storage and loss moduli (G' and G'') of the samples. The reported results are mean values of three measurements

Texture Profile Analysis of Cakes

A texture analyzer (Texture Technologies Co., Scarsdale, NY) was used to measure the texture profiles of the cakes from which the hardness, cohesiveness, and springiness of the samples were obtained (Bourne 1978; Kim et al 2001). The samples (2.5 cm height \times 4 cm diameter) were compressed twice to 50% of their original height using a cylindrical probe 2.5 cm in diameter and a test speed of 5 mm/sec.

Statistical Analysis

The data were analyzed by a randomized complete block design for statistical analysis, followed by Duncan's multiple range test to determine significant differences among samples (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

The changes in the specific gravity of cake batters are shown in Table II. There were general increases in the specific gravity as more shortening was replaced with the Oatrim, while no significant difference was observed between the control and 20 OTM (20% Oatrim). The specific gravity is related to the number of air bubbles incorporated into a cake batter. In this study, the increase in the specific gravity, as a result of shortening replacement with Oatrim, indicates less incorporation of air bubbles in the cake batters. It is well known that one of the roles of fats in cake systems is the incorporation and stabilization of air cells (Bath et

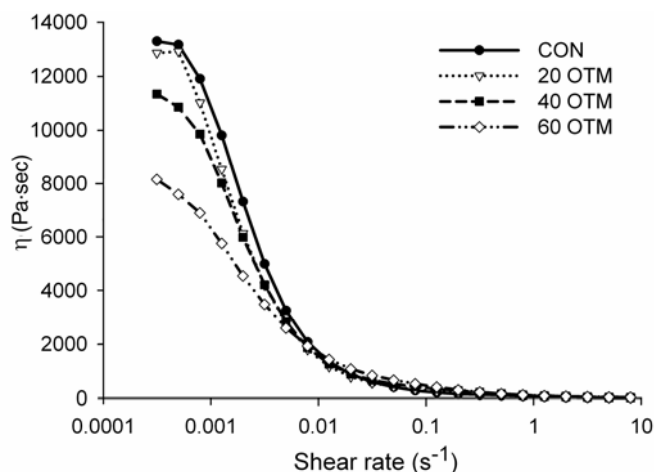


Fig. 1. Plots of cake batter viscosity vs. shear rates of control and Oatrim (OTM).

TABLE I
Formulations (g) of Cakes Prepared with Different Levels of Shortening and Oatrim

	Flour	Sugar	Nonfat Dry Milk	Dried Egg White	NaCl	Baking Powder	Water	Shortening	Oatrim
Control	200	280	24	18	6	11.5	250	100	0
20OTM	200	280	24	18	6	11.5	250	80	20
40OTM	200	280	24	18	6	11.5	250	60	40
60OTM	200	280	24	18	6	11.5	250	40	60

al 1992; Brooker 1993). Therefore, before baking, it was expected that more replacement of the shortening with Oatrim would result in a lower cake volume, which was in agreement with the volume measurements listed in Table II.

The viscosity of the cake batters as a function of shear rate is illustrated in Fig. 1. The control cake had the highest viscosity and increasing the levels of shortening replacement with Oatrim caused the decrease in the cake viscosity. It is recognized that the viscosity of a cake batter is a controlling factor in the final cake volume due to its effects on bubble incorporation and movement (Handleman et al 1961; Bath et al 1992; Kim et al 2001). The rate at which bubbles rise due to buoyancy is inversely proportional to the viscosity. Thus, cake volume loss may ensue as a result of the rapidly rising bubbles in a low-viscosity cake batter. Higher cake batter viscosities aid in incorporating more air bubbles in the batter and keeping the bubbles from rising to the surface, which provides more stability for the cake.

The size distribution and number of air bubbles existing in the cake batters were investigated by using brightfield microscopy (Fig. 2). Similarity of size distribution profiles among the cake samples are illustrated in Fig. 2. For all of the samples, the size (cross-sectional area) of 90% of the incorporated air bubbles was $\approx 4.0 \times 10^{-9} \text{ m}^2$ or less. Furthermore, the replacement of shortening with Oatrim did not make any difference in the mean size of the bubbles, which was $\approx 1.5 \times 10^{-9} \text{ m}^2$. During mixing, air bubbles are occluded and the shear stress allows them to be elongated and finally disrupted into smaller bubbles. The lack of differentiation in the size of the incorporated bubbles in the samples may be due, in part, to the similar shear history that the samples

experienced. In contrast, significant changes were observed in the number of air bubbles incorporated in the samples (Fig. 2B). As cakes were prepared with lower amounts of shortening, the number of entrapped air bubbles decreased; the 60 OTM cake had 40% fewer air bubbles than the control. This observation confirms the role of shortening on air bubble entrapment in the cakes and is in accord with volume data reported in Table II and studies from other researchers (Brooker 1993).

The thermodynamic properties of the cakes were investigated using DSC (Fig. 3). Two distinct endothermic transitions were observed at ≈ 50 and 100°C in the DSC curves. The first peak is probably due to melting of the shortening. The intensity of this peak was observed to decrease as the amount of shortening was lessened. The other endotherm is probably due to the gelatinization of the starch in the cake batter. The initial and peak temperatures, as well as the enthalpy for the gelatinization transition for each of the samples, are summarized in Table III. It is interesting to note that the gelatinization temperatures increased with the amount of Oatrim in the samples, although the 20 OTM cake was not statistically different from the control. The higher temperatures for the onset of starch gelatinization may have been due to the lower amounts of shortening or the presence of higher amounts of Oatrim. However, the effect of shortening on the starch gelatinization was already mentioned in several previous studies. Ghiasi et al (1982) reported that shortening does not affect the starch gelatinization temperature from evidence obtained from a study of the effects of dough ingredients such as sugar, salt, and shortening. These observations have been confirmed by other researchers (Shelke et al 1990; Lin et al 1994).

In these studies, Oatrim had a strong effect on the starch gelatinization temperatures. As mentioned previously, the process for the Oatrim production involves the α -amylase hydrolysis of starch in either oat flour or bran. Therefore, Oatrim is composed primarily of soluble fiber (β -glucan) and amylopectins with small quantities of lipid, protein, and minerals. It is well recognized that low molecular weight dextrans and sugars elevate the starch gelatinization temperature (Spies and Hosney 1982; Duran et al 2001). The presence of these materials decreases the water activity, requiring more energy for the reaction with water. In addition, these materials can also act as a stabilizer for the amorphous regions of the starch granules. In either case, the maltodextrins in the Oatrim could push the onset of starch gelatinization to higher temperatures in the cakes.

The rheological properties of the cakes were studied during heating to mimic the baking process. Samples were heated from 30 to 170°C , and the oscillatory shear storage moduli were monitored (Fig. 3). Correlations between the oscillatory shear storage

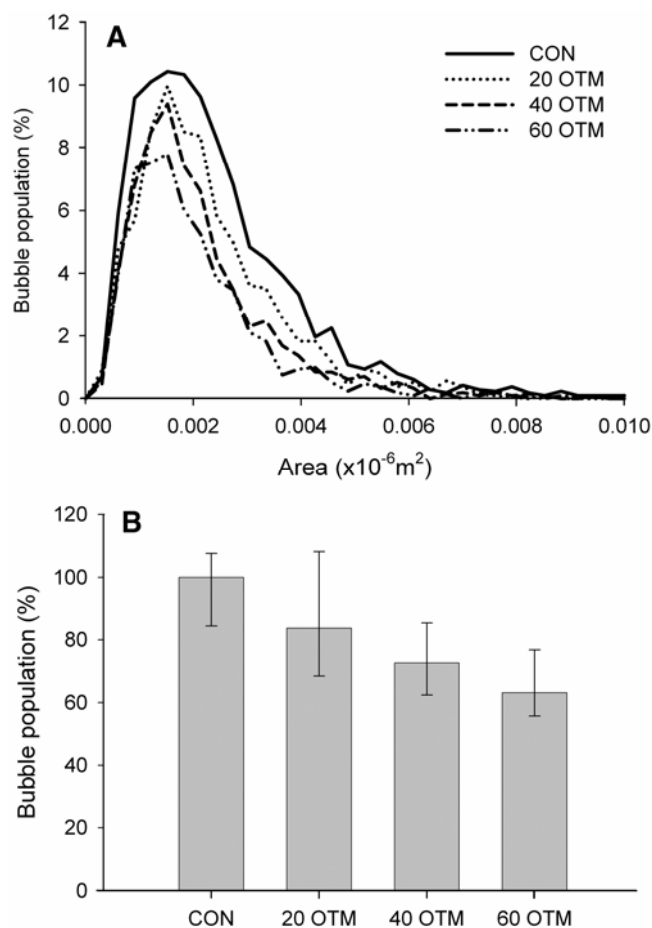


Fig. 2. Size distribution (A) and relative number (B) of air bubbles in cake batters (control, con; Oatrim, OTM). Bubble population represented as a percentage of the number of bubbles in the control; mean was set equal to 100%.

TABLE II
Comparison of Specific Gravity of Cake Batters and Volume Index of Cakes^a

	Control	20 OTM	40 OTM	60 OTM
Specific gravity	0.86c	0.87c	0.90b	0.96a
Volume index	111.40a	108.00b	99.80c	91.80d

^a Means with the same letter in the same row are not significantly different at the 1% level.

TABLE III
Changes in Temperature and Enthalpy of Starch Gelatinization of Cakes^a

	Control	20 OTM	40 OTM	60 OTM
Initial temp. ($^\circ\text{C}$)	99.2c	99.6c	100.4b	101.1a
Onset temp. ($^\circ\text{C}$)	105.1c	105.7c	106.4b	107.4a
Enthalpy (J/g)	2.53a	2.50a	2.44ab	2.37b

^a Means with the same letter in the same row are not significantly different at the 1% level.

moduli and the DSC thermograms were investigated. Overall, the storage moduli were higher for the cakes with decreased amounts of shortening, indicating more elastic behavior. The oscillatory shear storage moduli were observed to decrease with increasing temperatures up to 70–80°C, then increase with increasing temperature up to ≈130–150°C, after which the moduli reached a plateau. In a previous investigation, the storage/loss modulus of a cake batter was studied from 25 to 125°C to examine the effect of sucrose on the rheological properties of the cake batters (Ngo and Taranto 1986). Pernell et al (2002) investigated the dynamic viscoelastic properties of angel food cakes made with whey protein or egg white protein from 34 to 150°C. Their results compare favorably with ours. As the samples were initially heated, the shortening in the cake batters melted and trapped air bubbles expanded, which increased the cake volume. The closed-cell foam formed would possess a less elastic character, which would be evidenced by a decrease in the oscillatory shear storage modulus; this would occur at the same temperature as the first observed peak in the DSC. As the temperature was increased and reached the starch gelatinization temperature, the oscillatory shear moduli were observed to increase. During gelatinization, starch granules take up water and swell progressively, releasing soluble starch. This increase in the volume fraction of the starch granules produces a close packed structure, elevating the chance of intergranular interactions (Lii et al 1995, 1996). This, in turn, leads to increased rigidity in the system, which is manifest in the increase in the oscillatory shear storage modulus.

From the increase observed from DSC in the starch gelatinization temperature in the cake batters with Oatrim substitution, it would be expected that similar observations could be made in the rheological properties; however, this was not clearly observed. Results indicate that the oscillatory shear storage moduli reached a maximum at 130–150°C where the formation of the cake crust may have started. The maximum storage modulus of the 60 OTM was almost an order of magnitude higher than that of the control. At ≈130°C, the storage modulus of the control cake became con-

stant, whereas that of the 60 OTM became constant at 150°C. The onset temperature for observation of the modulus plateau was pushed to higher temperatures as more shortening was replaced with Oatrim. This observation could be explained by the increased water binding activity of Oatrim, which would retard the evaporation of the water in the cake, even at higher temperatures.

Texture profile analysis was performed to obtain the textural parameters (hardness, cohesiveness, and springiness) of the cakes, as shown in the Table IV. The cake hardness had a tendency to increase as more shortening was replaced with Oatrim although no significant difference between the control and the 20 OTM was observed. The same trends were observed for cohesiveness and springiness. This observation followed the trends discussed above with an increase in the elastic nature of the cakes as the amount of Oatrim was increased (Fig. 3).

CONCLUSIONS

The utility of Oatrim as a fat substitute for baked products, specifically a cake, was focused on the physical and rheological effects on the cakes before, during, and after baking and compared with those of the control. The replacement of shortening with Oatrim influenced the specific gravity, volume, and rheology of the cakes. Significant differences, however, were not observed between the control and 20 OTM, indicating that shortening in a cake can be replaced with Oatrim up to 20% by weight without loss of the cake quality.

The shortening reduction using Oatrim can provide health effects by reducing calories and blood cholesterol levels. Moreover, β-glucan, soluble fiber from Oatrim provides more health-enhancing benefits to the cakes. To obtain the health benefits allowed by FDA for oat products, it would be necessary to consume 0.75 g of β-glucan in a serving portion (FDA 1997). Based on the composition of Oatrim mentioned previously, 20% shortening replacement with Oatrim contributes 1 g of β-glucan to a cake prepared with 100 g of shortening. Consequently, by consuming an Oatrim-substituted cake, we expect the health benefits provided by β-glucan, as well as a reduced calorie count.

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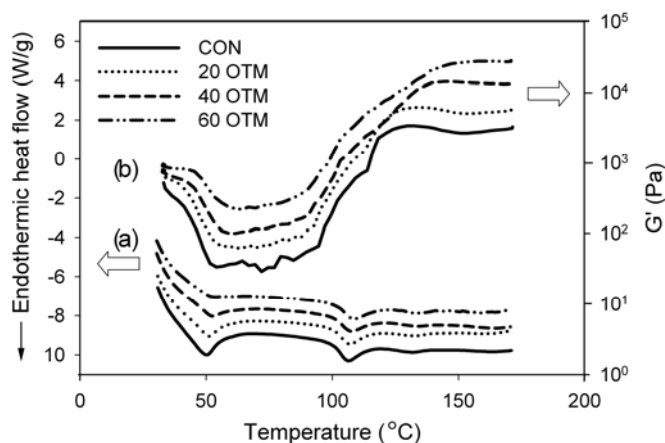


Fig. 3. Comparison of thermal and rheological properties of cakes (control, con; Oatrim, OTM) during baking. DSC thermograms (a) and storage modulus (G') (b).

TABLE IV
Effect of Shortening Replacement with Oatrim on Texture Properties of Cakes^a

	Control	20 OTM	40 OTM	60 OTM
Hardness (N)	14.65c	15.61c	16.84b	19.88a
Cohesiveness	0.60d	0.61c	0.65b	0.67a
Springiness	0.96c	0.97bc	0.97a	0.97ab

^a Means with the same letter in the same row are not significantly different at the 1% level.

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