Effect of Nutrim Oat Bran and Flaxseed on Rheological Properties of Cakes

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ABSTRACT

Cake shortening contents were replaced with Nutrim oat bran (OB) and flaxseed powder, and the effects of these substitutions on the physical and rheological properties of cakes were investigated. Cakes with shortening replaced up to 40% by weight possessed a volume similar to that of the control cake produced with shortening. Replacement using Nutrim OB and flaxseed powder revealed significant color changes in both the cake crust and crumb. At high levels of substitution, the cake crust became lighter, while the crumb darkened. At >40% by weight substitution with either Nutrim OB or flaxseed, the cakes displayed increased hardness; however, cohesiveness and springiness increased gradually with increasing substitution. Increased substitution with Nutrim OB caused an increase in the measured shear viscosity and oscillatory storage and loss moduli of the cakes. Increased substitution with flaxseed caused decreases in these rheological parameters. Additional rheological experiments were performed to elucidate changes in the formulations during the baking process and indicated an increase in the elasticity of the baked batter with decreasing shortening.

The beneficial effects of a healthy diet on quality of life, as well as on the cost effectiveness of health care, are widely recognized. The food industry is facing the challenge of developing new food products with special health-enhancing characteristics. Nutraceuticals are exploding in importance in the natural health and food products industry and represent a multibillion dollar market. The growth of nutraceuticals is due to increasing attempts to develop foods with disease-preventing qualities. These products are in response to an aging population, increasing health care costs, consumer interest in nutrition, and food technology advances. New sources of nutraceuticals and other nutritional materials are needed to meet this growing market. Sources of these materials come from a wide variety of plant-consumable products. Various constituents from agricultural crops provide important nutraceutical additives that may be used in foods. In particular, the soluble fiber in oat bran (i.e., β-glucan) is well recognized as one of the important dietary substances needed for good health (FDA 1997; Malkki and Virtanen 2001). Nutrim OB, developed and patented by the USDA (Inglett 2000), is a hydrocolloid prepared by thermomechanically shearing oats and provides a viable source of β-glucan for use in food products.

Previously, Nutrim OB muffins and several desserts such as frozen yogurt were prepared by replacing fat and cream in these products (Maneepun et al 1998; Warner and Inglett 1998; Inglett et al 2003). These studies indicated that Nutrim OB improved the texture as well as nutritional value and displayed potential as a fat and cream replacer in other food products.

One reason to replace fat or oil is that there is too much consumption of fat, specifically saturated fat, which is not good for health. Therefore, current public concern for the fat present in foods has contributed to the introduction of desirable fat or oil sources. Omega-3 fatty acids have beneficial health effects including antihypercholesterolemic and anticarcinogenic effects (Carter 1993; Cunnane and Thompson 1995), and flaxseed is a good source of the omega-3 fatty acids. Moreover, it contains a large amount of α-linolenic acid, dietary fiber, lignans, and other nutrients. This has led to the rapid growth of flaxseed as an additive in value-added food products (Alpers and Sawyer-Morse 1996; Gilbert 2002). Flaxseed provides thermal and oxidative stability during baking as well as nutritional benefits in some baked products (Carter 1993; Chen et al 1994). However, the effect of flaxseed and Nutrim OB on the physical qualities of baked products has not been previously reported in the literature.

This research was undertaken to examine the effects of using flaxseed and Nutrim OB as shortening substitutes in specific baked products. Different levels of shortening were replaced with Nutrim OB or flaxseed powder and their effects on the physical and rheological properties of the cakes were examined.

MATERIALS AND METHODS

Sample Preparation

The cake formulas are shown in Table I. They included cake flour (14% moisture basis, Congra, Omaha, NE), sugar (United Sugars Co., Minneapolis, MN), nonfat dry milk (DairyAmerica, Fresno, CA), dried egg white (Oskaloosa Food Products, Oskaloosa, IA), NaCl, baking powder (Kraft Foods, Rye Brook, NY), distilled water, and shortening (Hunt-Wesson, Fullerton, CA). Nutrim OB is a thermomechanically sheared commercial oat bran (Van Drunen Farms/FutureCeuticals, Momence, IL). The composition was 8% moisture, 17% protein, 2.8% ash, 6.9% lipid, and 10% β-glucan (Inglett 2000). Flaxseed powder was obtained from golden flaxseed (Roman Meal Milling, Fargo, ND) and ground to pass through 20- and 100-mesh screens in a pin mill. The composition was 6.2% moisture, 26.7% protein, 3.5% ash, and 38.6% lipid.

The formulation used to make the cake samples in this study was based on Approved Method 10-90 (AACC 2000). The shortening was replaced with Nutrim OB and flaxseed powder at 20–60%, by weight. All the cakes had the same overall solid contents. The shortening and sugar were first blended in a mixer (KitchenAid, St. Joseph, MI) for 2 min. Water (60 mL) was then added and mixed for 2 min. Other dry ingredients were sifted well, added with the remaining water, and mixed for 1 min. The resulting cake batter was scraped down and mixed for 2 min. After a second scraping, mixing was continued for a further 4 min. The batter was poured into a round cake pan (20 cm diameter) and baked at 170°C in an oven (National Mfg. Co., Lincoln, NE) for 35 min.

Rheological Measurements

The rheological properties of cake batters before baking were assessed by using a strain-controlled rheometer (ARES-LS, TA

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Instruments, New Castle, DE) operating under Rheometrics Orchestrator software. All the measurements were made at 25°C using 50-mm diameter parallel plates and a sample was surrounded by a humidity cover with wet pads to prevent dehydration. Before testing, the actual gap could be measured automatically and immediately by the instrument. The viscosity of samples was measured as a function of shear rate ($10^{-4} \approx 10$ sec^{-1}) under steady shear conditions. At each shear rate, the sample was sheared for 15 sec to reach steady-state. The dynamic oscillatory-shear storage and loss moduli (*G'* and *G"*) were measured at 0.1% strain over a frequency range of 0.1–20 Hz. Before conducting these investigations, strain sweep experiments were used to ensure that the applied strain was within the linear viscoelastic regime of each of the samples. To examine the evolution of the rheological properties of the samples during baking, a second strain-controlled rheometer equipped with an oven and connected to a refrigerator cooler (ARES-LSM, TA Instruments, New Castle, DE) was used. The oven was a forced-air convection environmental chamber that enclosed the sample with two resistive heaters mounted in the oven. During testing, air was input to the heaters and the oven temperature was controlled by the thermometer connected to the low fixture. To minimize slip of the samples during the experiments, 25-mm serrated parallel plates were utilized. *G'*, *G"*, and tan δ (*G"/ G'*) were monitored from 25 to 170°C at 1 rad/sec and a heating rate of 10°C/min. Rheological measurements were performed in duplicate and the reported results are mean values of two measurements.

The texture profile analyses of the baked cakes (Bourne 1978; Kim et al 2001) were performed by using a texture analyzer (Texture Technologies Co., Scarsdale, NY). The texture profile parameters (hardness, cohesiveness, and springiness) were determined from force versus time curves. Samples from the baked cakes were cut into cylindrical shapes (2.5 cm height × 4 cm diameter), placed on the flat stage, and subjected to two successive compressions to 50% of the original height. For all the experiments, a 25-mm cylindrical probe was used. The cross-head speed was set at 5 mm/sec and all the experiments were conducted at ambient temperature (23°C).

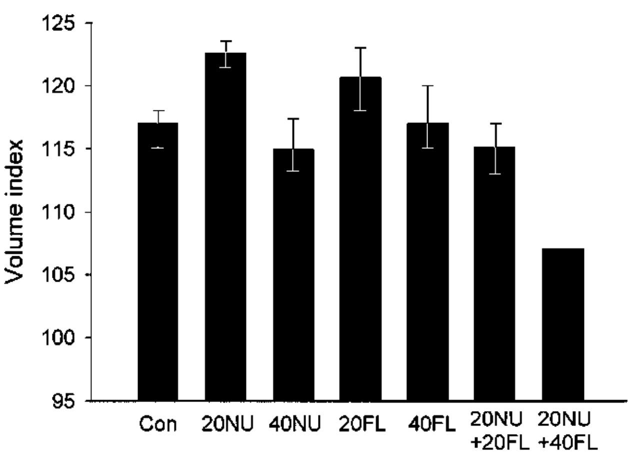

Fig. 1. Comparison of cake volume measurments. Con, control; NU, Nutrim oat bran; FL, flaxseed powder.

Physical Property Measurements

The volume index of the cake samples was obtained using the layer cake measuring template according to Approved Method 10-91 (AACC 2000). The colors of the crust and crumb in the cakes were measured using a HunterLab spectrocolorimeter (Labscan XE, Hunter Associates Laboratory, Reston, VA) standardized with black and white tiles. The samples were placed in a glass cup on a 1-in. port and then *L** (lightness/darkness), *a** (redness/greenness), and *b** (yellowness/blueness) were measured. The measurements of the cake physical properties were made in triplicate.

Statistical Analysis

A randomized block design was utilized for this study. Using the SAS system (SAS Institute, Cary, NC), analysis of variance (ANOVA) was performed to determine a significance of difference among samples. When the analysis of variance indicated a significant effect, Duncan's multiple range test was used to discover which treatment means differed.

RESULTS AND DISCUSSION

One of the most important physical qualities in cakes is volume, which has a strong influence on consumer preferences and is related among other factors to the type and amount of shortening used. Shortening has many different functions in baked products including flavor and tender mouthfeel. In addition, shortening helps incorporate and retain air, which improves the fine air cell structure and expansion of cakes. Specifically, cakes are highly dependent on shortening for desirable aeration. The volume index of cakes is presented in Fig. 1. Bath et al (1992) indicated that cakes without fat became flat and had low volume. A similar trend was observed in other bread systems (Junge and Hoseney 1981). The 20 NU cake exhibited higher volume indices compared with the control, even though it contained 20% less by weight of shortening and the (20 NU + 40 FL) cake showed the lowest volume index. These results indicate that cakes could be produced with up to 40% by weight substitution with similar volumes to the control cake.

The cake batter viscosity is one of the factors controlling the final volume of a cake. Because the rising rate of bubbles in the cake is in inverse proportion to the viscosity, the high viscosity aids in incorporating and retaining more air bubbles, providing more stability of the cake (Handleman et al 1961). Therefore, the observation related to the volume of the NU cakes may be due to the better stability of the cake batter imparted by the increased viscosity, which would help retain gas cells in the batter.

TABLE I
Formulations (g) of Cakes Prepared with Different Levels of Shortening, Nutrim (NU) Oat Bran, and Flaxseed (FL) Powder

Component	Control (g)	20 NU (g)	40 NU (g)	20 FL (g)	40 FL (g)	20 NU + 20 FL (g)	20 NU + 40 FL(g)
Flour	200	...	...	...	...	...	...
Sugar	280	...	...	...	...	...	...
Nonfat dry milk	24	...	...	...	...	...	...
Dried egg white	18	...	...	...	...	...	...
NaCl	6	...	...	...	...	...	...
Baking powder	11.5	...	...	...	...	...	...
Water	250	...	...	...	...	...	...
Shortening	100	80	60	80	60	60	40
Nutrim OB	–	20	40	–	–	20	20
Flaxseed powder	–	–	–	20	40	20	40

The viscosities of the cake batters as a function of shear rate are shown in Fig. 2. All of the samples displayed shear-thinning behavior over the shear rate used in this work, which was consistent with a previous study (Shelke et al 1988). The viscosities of the samples containing differing amounts of Nutrim OB and flaxseed powder also were compared with that of the control cake in Fig. 2. Slightly higher viscosities were observed in batters containing Nutrim OB than in the control while the replacement of shortening with flaxseed powder reduced the viscosity of the control cake. In a previous study, it was shown that the rheological properties of Nutrim OB suspensions (5–15% by weight solids) exhibited high shear viscosities at ambient temperatures (Carriere and Inglett 1998, 2000). The increased viscosity imparted to the batter by Nutrim OB yielded similar viscosities for the 20 NU + 20 FL and 20 NU + 40 FL cakes relative to those of the 20 FL and 40 FL cakes, even though the former had lower levels of shortening. In addition, previous studies (Handleman et al 1961; Bath et al 1992; Kim and Walker 1992) have noted that increased batter viscosity had a tendency to retain air incorporation in the cake batter. The lowest volume index of the 20 NU + 40 FL cake could be because of the low viscosity as well as insufficient shortening, which gave rise to the improper aeration of the cake and produced a dense structure. In the 20 FL cake, the cause of the increase in the cake volume by flaxseed could not be established exactly in spite of its viscosity decrease. However, one possible explanation might be that the lipid present in the flaxseed powder appeared to effectively replace the lower level of shortening in the sample. More studies on the functionality of the ingredients will be needed.

Several studies on the color changes by replacing shortening have been reported. The replacement of shortening with medium chain triglycerides and corn oil did not affect cake color (Schmall and Brewer 1996). Kim et al (2001) investigated the crumb color of the cakes where the shortening was replaced with corn dextrins. The cakes displayed greater darkness and yellowness with the addition of maltodextrin. The color changes in the cake crust and crumb by Nutrim OB and flaxseed powder are shown in Fig. 3. Significant effects of the addition of Nutrim OB and flaxseed powder on cake color were found ($P < 0.01$). As more shortening was replaced, the crust of cakes had a higher L^* values, indicating more lightness, whereas the crumb became darker. That is, the crust and crumb of the control cake were darker and lighter than those of the other samples, respectively. Furthermore, the b^* (yellowness) of the crumb became higher as more Nutrim OB and flaxseed

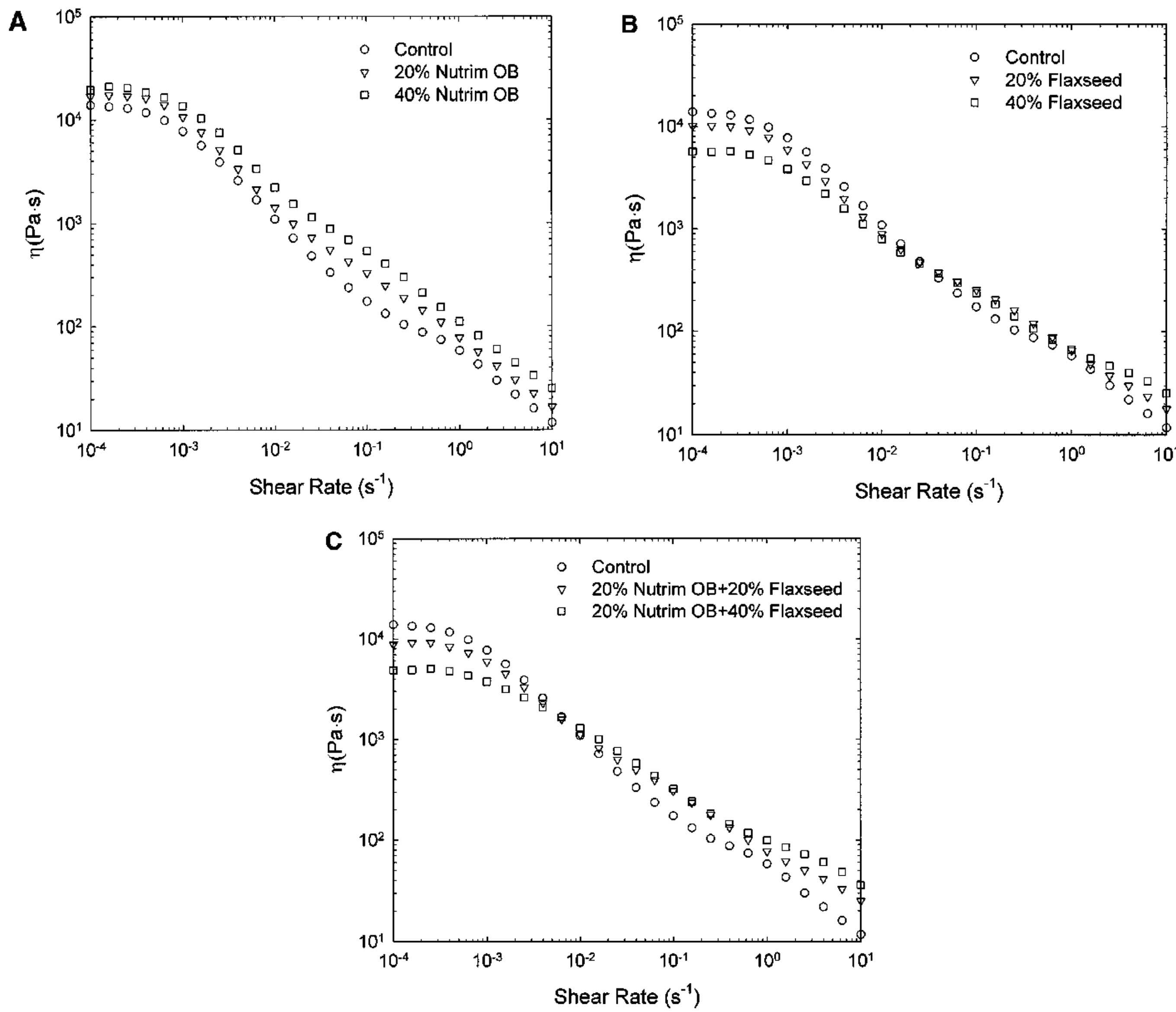

Fig. 2. Plots of batter viscosity for cake batters containing differing amounts of Nutrim OB (NU) and flaxseed powder (FL) compared with that of the control cake batter. 20 NU and 40 FL (**A**); 20 FL and 40 FL (**B**); 20 NU + 20 FL and 20 NU + 40 FL (**C**).

were added because of the intrinsic yellowish colors of these additives. The effect of the substitution of shortening by Nutrim OB and flaxseed powder on the texture profile of cakes was investigated using texture profile analysis. The texture parameters of the cakes are shown in Table II.

No significant differences were observed in hardness among the samples except for the 20 NU + 40 FL cake. This result indicates that the replacement of shortening with Nutrim OB and flaxseed powder would not have a negative effect on the hardness of cakes up to 40% by weight. The fact that the 20 NU + 40 FL cake became harder could be attributed to its dense structure due to the reduced level of shortening. The results displayed a gradual increase in the cohesiveness as more shortening was replaced. The same trend was observed for springiness.

The dynamic oscillatory shear viscoelastic properties of cake batters were investigated as a function of frequency (Fig. 4). *G'*, *G"*, and tan δ of the batters containing Nutrim OB and flaxseed powder were obtained and compared with those of the control batter in the Fig. 4. *G'* and *G"* increased with increasing frequency. There is a general agreement of an inverse relationship between both oscillator shear moduli and water content in dough (Navickis et al 1982; Faubion and Hoseney 1990). In the 20 NU cake, water may interact with some components in the Nutrim OB, such as the β-glucans, as well as starch and proteins. This interaction would lead to lower amounts of available water, making the batter harder to deform. Conversely, the replacement of shortening with flaxseed powder caused both *G'* and *G"* to decrease. The tan δ is a rheological parameter often used in food rheology that shows the relative contributions of elastic and viscous components to the rheological properties of the material being tested. The 20 NU + 40 FL cake had a high tan δ, indicating more viscous behavior compared with other cake batters.

The temperature dependence of the rheological properties of cakes was used to examine changes in the samples during the baking process. *G'* and *G"* were measured at 1 rad/sec during a continuous temperature ramp (10°C/min) from 25 to 170°C and are displayed in Fig. 5. All of the cake samples displayed similar types of viscoelastic behavior during the temperature ramp (note that to prevent confusions among samples, the 40 NU and 40 FL cakes are not shown). Several distinct features were observed in

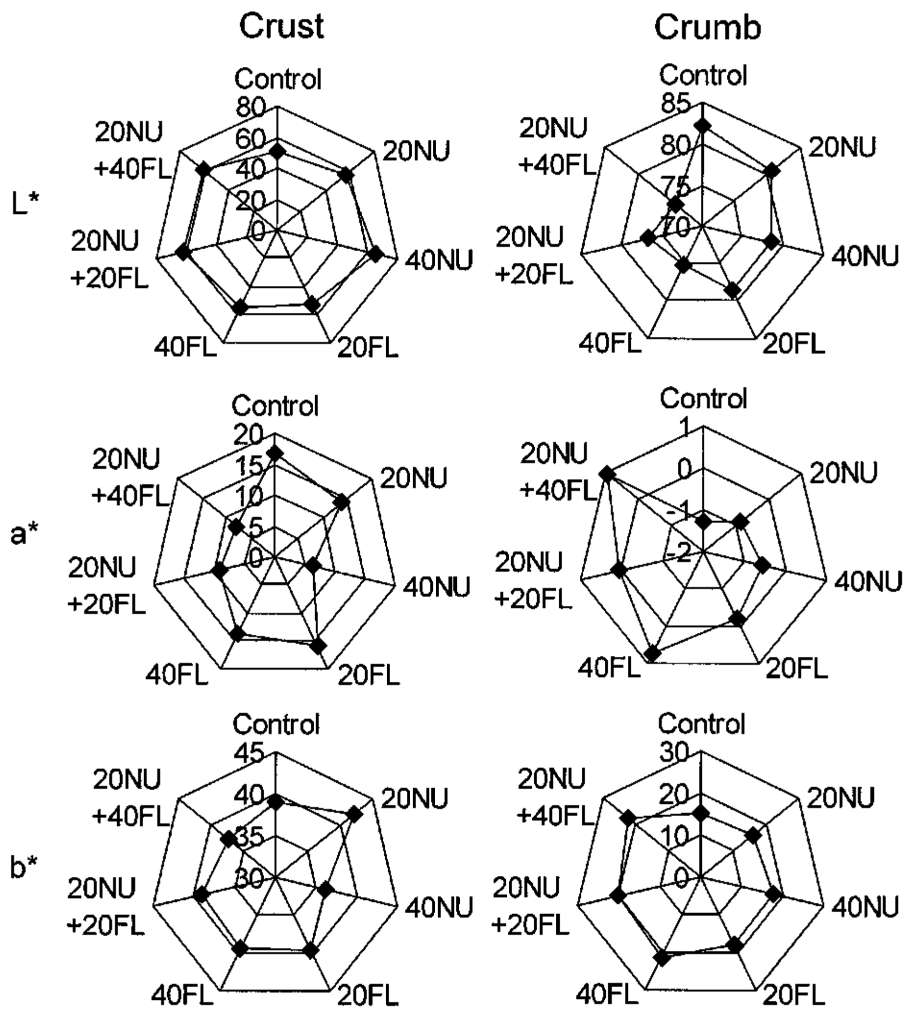

Fig. 3. Color changes in crust and crumb of cake containing Nutrim oat bran and flaxseed powder. NU, Nutrim oat bran; FL, flaxseed powder.

TABLE II
Effect of Nutrim (NU) Oat Bran and Flaxseed (FL) Powder on Cake Texture Properties

Property	Control	20 NU	40 NU	20 FL	40 FL	20 NU + 20 FL	20 NU + 40 FL
Hardness (N)	12.57b	13.24b	13.29b	12.13b	12.48b	12.78b	16.61a
Cohesiveness	0.61d	0.64c	0.73a	0.63cd	0.65c	0.70b	0.72ab
Springiness	0.97c	0.97bc	0.98a	0.97a–c	0.98ab	0.98a	0.98a

[a] Values followed by the same letter in the same row are not significantly different ($P < 0.01$).

Fig. 5. First, *G'* and *G"* decreased until the temperature reached ≈70°C and then increased with increasing temperature up to ≈130°C, depending on the specific sample. At higher temperatures, *G'* and *G"* were independent of temperature. This effect can also be observed from the changes in tan δ during the temperature ramp (Fig. 5B). As the temperature increased up to 70°C, both *G'* and *G"* decreased. However *G'* dropped more rapidly leading to an increase in tan δ, indicating more viscous behavior. This could be due to melting of shortening and bubble growth in the sample. In this temperature range, CO_2 is produced and diffused into the air cells through the aqueous phase of the cake batter, increasing its volume. The cake becomes a soft foam, which is evidenced by the viscous behavior displayed in Fig. 5B. As the temperature is increased further, starch gelatinization begins at ≈80°C, and the cake crumb forms. This increases the rigidity of the cake, which results in a decrease in the measured tan δ as shown in Fig. 5B. There are also some other aspects to be taken into account such as the effect of temperature-time history as well as temperature. Viscosity always decreases with temperature. However, it increases above the gelatinization temperature because the temperature-time history plays an important role in the gelatinization. Consequently, the heating rate of a sample can influence the gelatinization and rheological properties (Hsu et al 2000; Sopade et al 2004). However, it would not influence comparison of the overall viscoelastic patterns obtained under the same conditions.

Several rheological studies on the effects of baking on cake batter have been reported. Ngo and Taranto (1986) studied the changes in the dynamic rheological properties of cake batters with differing amounts of sucrose at 25–125°C. In addition, the dependence of cake shrinkage and oscillatory shear moduli on sugar concentration were investigated at 70–100°C (Mizukoshi 1985). Even though the range of baking temperatures used was limited in these studies, similar trends to those reported herein were found. *G'* and *G"* of the cakes increased up to ≈130°C and then remained constant. These observations were posited to be due to the formation of cake crust, which could be observed through the glass window on the oven. The studies indicated higher oscillatory shear moduli were observed for cakes with lower amounts of shortening. In addition, samples containing lower amounts of shortening showed more elastic behavior at >120°C. This agrees with results in Table II, which show the gradual increase in the springiness (elasticity) of the cakes with decreased shortening.

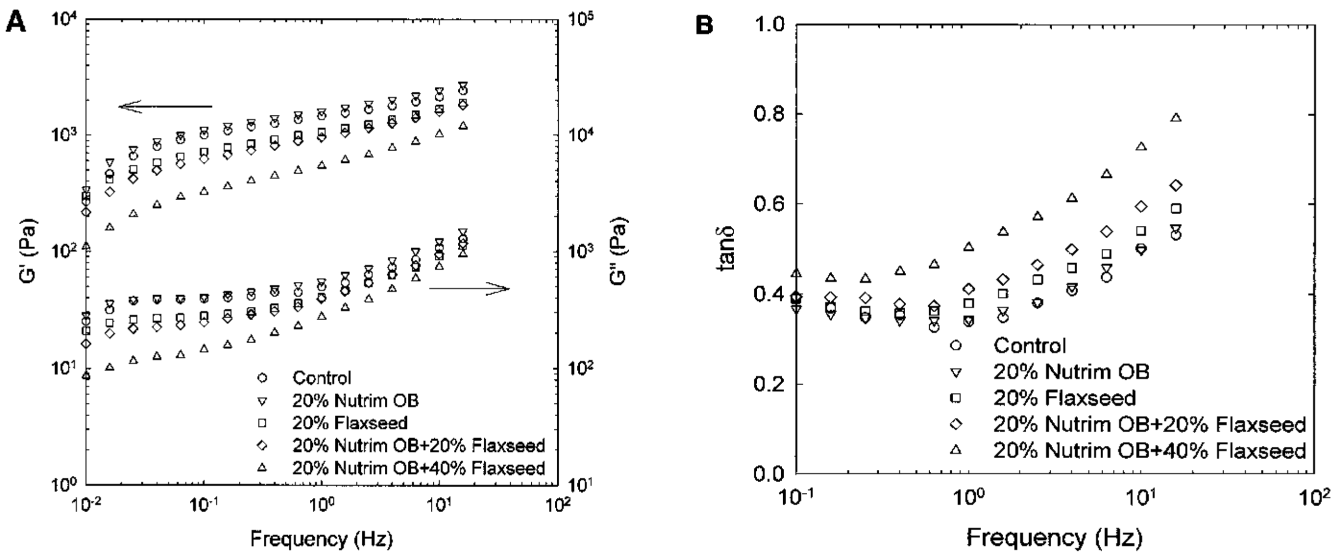

Fig. 4. Effect of Nutrim oat bran and flaxseed powder on viscoelastic moduli of cake batters. *G′* and *G′′* (**A**) and tan δ (**B**).

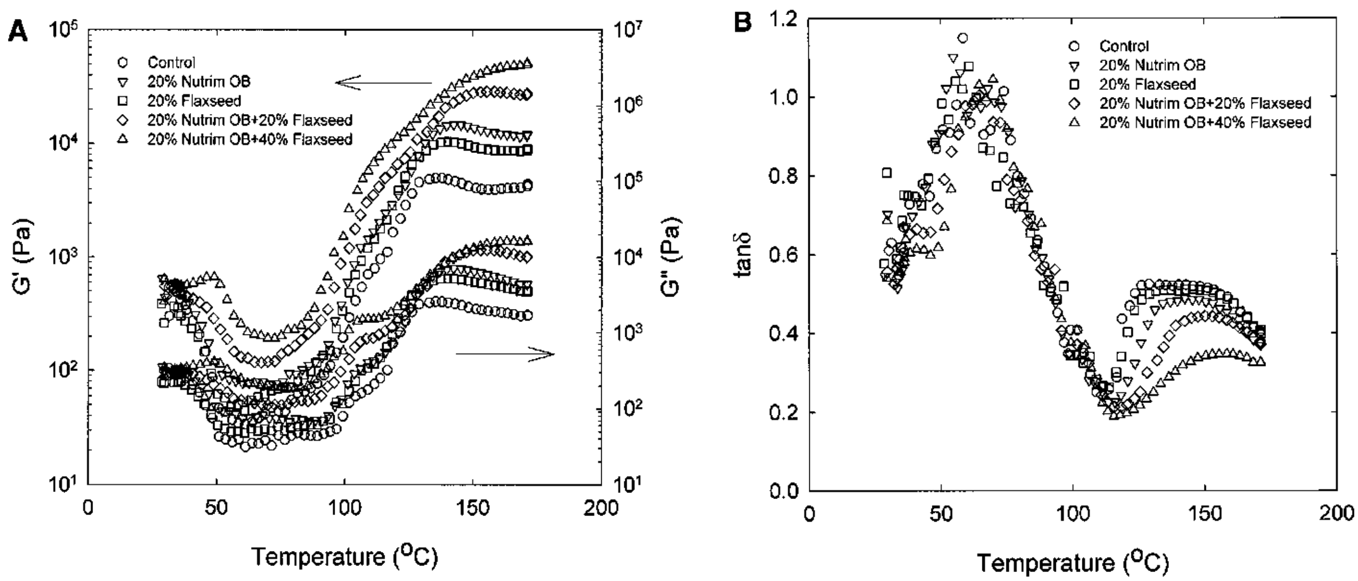

Fig. 5. Changes in viscoelastic properties of control, Nutrim oat bran, and flaxseed powder cakes during baking. *G′* and *G′′* (**A**) and tan δ (**B**).

CONCLUSIONS

In this study, Nutrim OB and flaxseed powder were evaluated as fat replacers in cakes. The replacement of shortening with Nutrim OB and flaxseed powder affected the physical and rheological properties of cake batters. In particular, Nutrim OB caused the viscosity increase in the cake batter, which would be helpful to prevent the volume loss of the cake. Moreover, the dynamic oscillatory testing showed that Nutrim OB and flaxseed powder cakes had viscoelastic patterns similar to those of the control during baking, even though dynamic shear moduli increased with increasing replacement of shortening. Hence, the shortening in a cake could be successfully replaced with Nutrim OB and flaxseed powder up to 40% by weight without quality loss of cakes. Sensory evaluation will be necessary to provide a more practical evaluation of Nutrim OB and flaxseed powder as fat replacers in baked products.

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