Effect of shortening type on the rheological characteristics of cookie dough

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ABSTRACT

The effect of four types of shortening including a commercially vegetable oil (as control), palm olein (PO), palm stearin (PS), and a blend of the latter two oils with rapeseed oil (BF) on the rheological properties of cookie dough was determined by using dynamic oscillatory measurement testing. All of the obtained dough treatments showed weak liquid viscoelastic behavior. Their storage (G') and loss (G'') moduli were almost the same with a loss tangent (tan δ) value of about 1. G'' was greater than G' in most of the measured frequency range. Both G' and G'' were frequency dependent and decreased with increasing of frequency. Differing oil compositions were found to differently affect on the overall strength of the doughs. The control dough showed the lowest frequency dependence. At lower frequencies, PO dough had the same consistency as the control, but at higher frequencies, its interaction was reduced leading to a weaker system. PS and BF doughs had stronger systems with higher values of G' and G'' at low frequencies; both showed a dramatic drop in the values of G' and G'' at about 1 Hz. After this frequency, they showed similar rheological profile to the control. Baking test showed that the final quality of the baked products was significantly different in both appearance and internal texture.

Keywords: Dough rheology; Viscoelastic properties; Oil composition; Baking quality

INTRODUCTION

Rheological properties of dough have been recognized to have a considerable influence on the final quality of baked products. Relating the flow and deformation behavior of dough to its actual structure and baking quality is difficult since dough has a complex composite and all of its components affect on the rheological behavior to some extent. Wheat flour dough is a viscoelastic composite with more or less nonlinear shear thinning and thixotropic behavior [1].

Dough shows viscose “liquid-like'' behavior at high strain values (>0.1) because of the large deformation of its structure and the breakdown of the interactions between the polymer chains ($G''>G'$) [2]. However, at lower strains, its viscosity increases and dough shows a more viscoelastic “solid-like” behavior ($G'>G''$) [1].

In a traditional rheological analysis of dough systems, instruments such as Farinograph and Extensograph impose large deformations on the samples. These instruments produce data in the nonlinear viscoelastic region. The results are in empirical units, which cannot be used to assess the fundamental rheological behavior of the material. Bloksma and Bushuk (1988) reported that it is difficult to detect the direct rheological effect of added oil on the dough by empirical techniques such as Extensograph and Farinograph [3]. However, by applying fundamental non-destructive methods, physical properties of the samples can be determined over wide range of strain and strain rate, and their absolute values can be obtained, as measurements can be taken in the linear viscoelastic region of the material where the dynamic moduli and tan δ are independent of stress and strain, and stress-strain relationship is linear [4].

The use of dynamic oscillatory technique has allowed considerable progress in the understanding of dough rheology since it can measure both elastic and viscose components of the complex system simultaneously [1]. The rheological properties of dough and its structure development will be influenced by the addition of shortening during mixing. While the effect of adding different quantities of oil on the rheology of dough has been determined by Fu et al. (1997) using dynamic mechanical analysis and stress relaxation tests [5], little is reported on the effect of the composition of the oils used. In this study, the rheological effects of four different compositions of oil added to the cookie dough and their influence on the quality of final product have been investigated. The other factors, which may alter the dough rheology (moisture, etc.) have been held at constant levels during subsequent experiments.

MATERIALS AND METHODS

Cookie dough preparation

Soft plain wheat flour with 10.2% w/w protein content was used to make dough. Four different types of shortening including a commercially available vegetable oil (as control), refined bleached and deodorized palm olein (PO) with the Iodine Value of 65, refined bleached and deodorized palm stearin (PS) with the Iodine Value of 14, and a blend of the latter two oils with rapeseed oil (BF) were used. Dough formulation was a simple cookie dough recipe, consisting of 50% w/w of wheat four, 25% w/w of total sugar, 15% w/w of oil and 10% w/w of water.

Four treatments of dough with different shortening were obtained; the batch of dough (used as control) consisted of 15% w/w of the commercial shortening as oil in formulation, and other three treatments were compared with it. PO and PS were used as shortening in the amount of 15% w/w of dough in two different treatments. The fourth batch, BF (blend of 22% w/w of PO and 22% w/w of PS with 56% w/w of rapeseed oil) was used as 15% w/w total oil content of dough formulation.

Dough treatments were obtained by mixing the components in a minor pin mixer with the bowl capacity of 50 g at room temperature (~ 23°C) for 6 min until the constancy and full development of the doughs were achieved. After sheeting, the doughs were covered by clear plastic film to prevent moisture loss and rested for 45 min in room temperature. Then, a round cutter was used to cut pieces of the doughs from the prepared sheets. The samples were placed between two serrated parallel plates used to prevent any slippage [6]. Then they were compressed to reach the gap size of 2 mm.

Edge treatment by using silicone oil is a common method to prevent dehydration of the sample; however, the problem is that the oil can penetrate into the sample and cause error in the experiment [7]. As a result, this study did not make use of it. Subsequent analysis of the treatments showed no evidence of moisture loss. The samples were allowed to rest 5 min before measurement to remove any stress induced into them during the loading. The rheologiacal and baking tests were carried out at 15°C.

Rheologiacal measurement

Dynamic oscillatory measurement were carried out with Rhometrics Dynamic Spectrometer (RDS-7700, Rheometrics, Inc., Piscataway, N.J.) to determine the storage modulus (G'), loss modulus (G''), complex modulus (G^*) and loss tangent (tan δ).

G' shows the solid or elastic characteristics of the sample and the energy stored in and recovered per cycle, whereas G'' is the measurement of energy lost per cycle and it indicates the liquid or viscose character of the material [8]. Loss tangent is the ratio of G'' (or viscose) and G' (or elastic characteristic) of the material. So in the linear viscoelastic region, when the tan δ is less than 1, it illustrates that the material behaves more like solid and deformation is recoverable, but when G'' exceeds G', the tan δ will be more than 1, implying that liquid or viscose characteristic of the material is predominant over the elastic or solid behavior [4].

In order to determine the linear viscoelastic region of the samples, strain sweep test in the range of 0.1–10% at the frequency of 1 Hz was conducted. Frequency sweep test was performed in the frequencies range of 0.1 to 100 Hz at 1% strain. The mean and standard deviation (±SD) of the moduli were then determined (n of control=24, n of other samples=18).

Baking method

In order to determine the effect of different added shortening compositions on the quality of final baked product, the dough treatments were baked at 170°C for 30 min in oven. Then the treatments, which contained PO, PS and BF were compared in appearance and texture with the control.

RESULTS AND DISCUSSION

Rheological measurement

The G**'**, G**''** and G* values of the four treatments of cookie dough made using different types of shortening are shown in Figures 1–4.

Figure 1 shows the values G**'** and G**''** as a function of frequency (0.1–100 Hz) for the commercial (control) shortening. There was a gradual fall in the logarithmic values of G**'** and G**''** with increasing of frequency from 6.7 to 6.1 (Pa) for G**'** and from 7.2 to 6.2 (Pa) for G**''**. No indication of any sudden changes in the rheological behavior of the control treatments has been observed.

As can be seen in Figure 2, which shows the dynamic moduli for the treatments containing PO, there is again a steady fall in the logarithmic values of G**'** and G**''** as a function of frequency from 6.4 to 5.2 (Pa) for G**'** and from 7.2 to 5 (Pa) for G**''**. However, PO shows a greater reduction in G**'** and G**''** as a function of frequency than the control. The overall behavior is, once again, a weak viscoelastic system, suggest in that similar interactions are responsible for both types of dough structure.

The dynamic moduli (G**'** and G**''**) as a function of frequency for the treatments containing PS are shown in Figure 3. Both of these moduli are similar in value and decrease from 7.9 to 6.2 (Pa) in the measured frequencies range. This overall reduction was seen for of the control treatments; however, in this case, the decrease in the moduli from 7.9 to 6.2 (Pa) is somewhat larger for the PS treatment and about 7 to 6.2 (Pa) for the control and seems to have a "discontinuity" at about 1 Hz. This suggests a sudden decrease in the degree of interactions present in the dough treatments at higher frequencies. These reduced values were similar to those of the control treatments at equivalent frequencies. It seems that the increased interactions and the initial "high" moduli values observed at the lower frequencies (from 0.1to 1 Hz) for the PS treatments were caused by the inclusion of the PS.

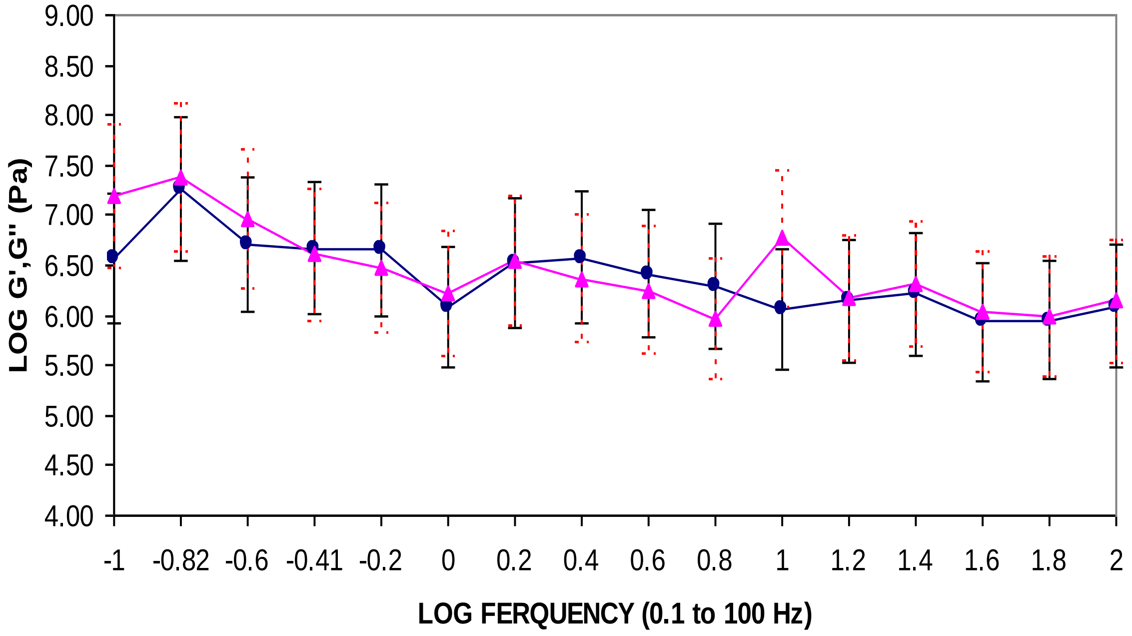


Figure 1. Frequency dependence of dynamic moduli (G**'**, circles; G**''**, triangles) for the control vs. log frequency sweep from -1 to 2 (Hz), measured at 1% strain (n=24, Mean±SD).

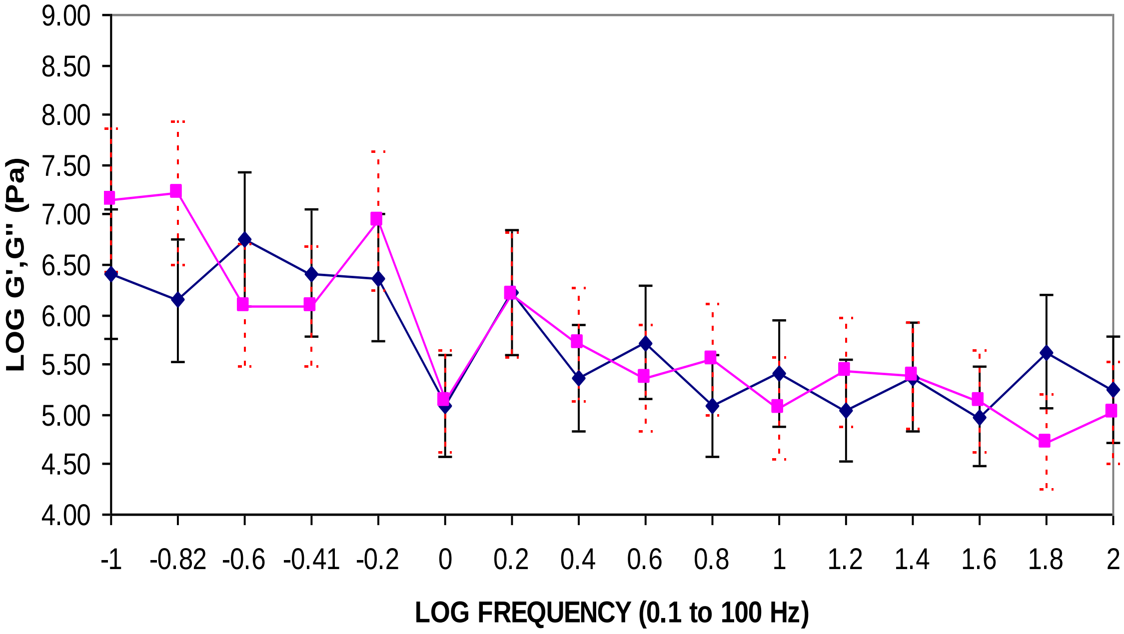


Figure 2. Frequency dependence of dynamic moduli (G', circles; G'', triangles) for the PO treatment vs. log frequency sweep from -1 to 2 (Hz), measured at 1% strain (n=18, Mean±SD).

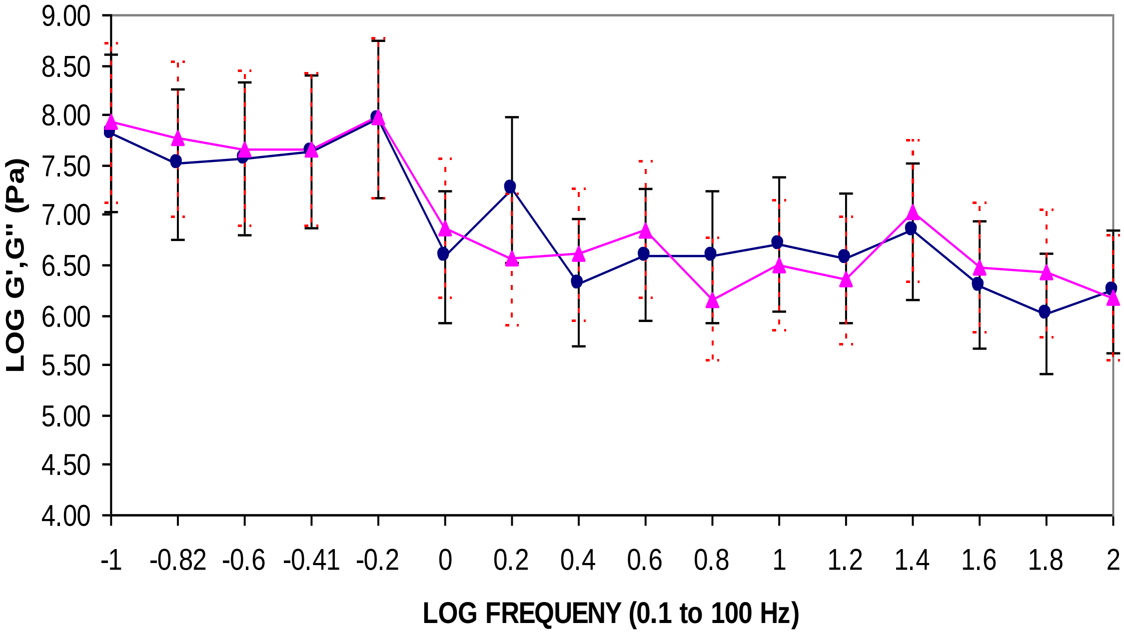


Figure 3. Frequency dependence of dynamic moduli (G', circles; G'', triangles) for the PS treatment vs. log frequency sweep from -1 to 2 (Hz), measured at 1% strain (n=18, Mean±SD).

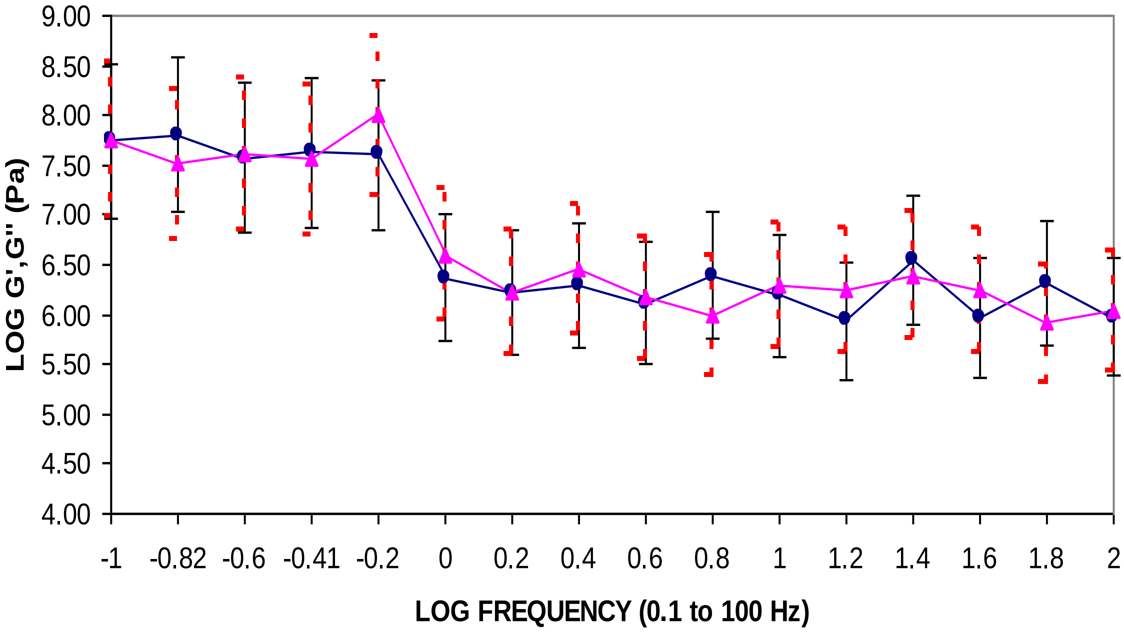


Figure 4. Frequency dependence of dynamic moduli (G**'**, circles; G**''**, triangles) for the BF treatments vs. log frequency sweep from -1 to 2 (Hz), measured at 1% strain (n=18, Mean±SD).

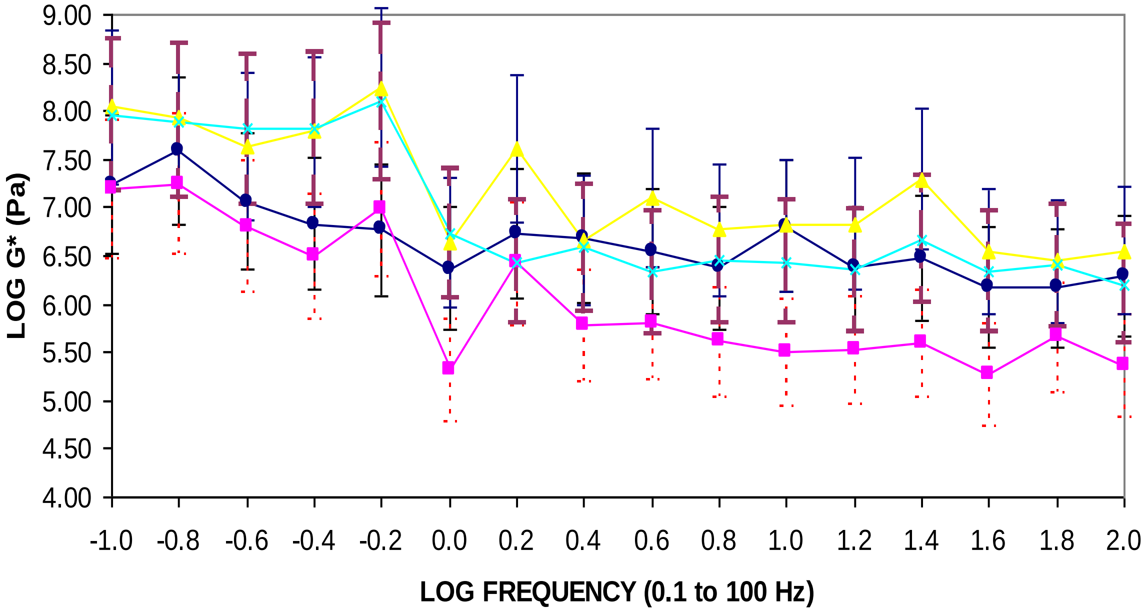


Figure 5. Frequency dependence of complex modulus (G*) for the control (circles), PO (squares), PS (triangles) and BF (crosses) treatments vs. log frequency sweep from -1 to 2 (Hz), measured at 1% strain (control n=24, other treatments n=18, Mean±SD).

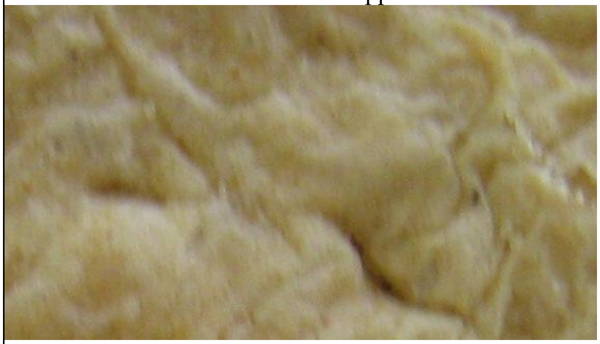
Control cookie's surface appearance 	Control cookie's internal texture 
BF cookie's surface appearance 	BF cookie's internal texture 
PS cookie's surface appearance 	PS cookie's internal texture 
PO cookie's surface appearance 	PO cookie's internal texture 

Figure 6. Surface appearance and internal texture of the cookies formulated with the control, BF, PS, and PO.

Figure 4 illustrates G′ and G″ values for the treatments containing BF versus frequency (from 0.1 to 100 Hz). Again similar values of dynamic moduli were recorded for both G′ and G″ are decreasing over all of the measured frequency range (from 7.5 to 6 (Pa)). However, there is a sharp decrease in the dynamic moduli at the same frequency (1 Hz) at which the PS treatments also showed a similar discontinuity in their rheological profile. At higher frequencies, the BF treatments showed similar reduced values of dynamic moduli to those of the control and PS treatments. It seems that the BF treatments containing PS showed rheological profiles very similar to those of the PS treatments, suggesting that the same interactions, which caused high modulus values in the PS treatments, are also present in the BF treatments, probably because both have stearin in their composition. The dramatic fall of the dynamic moduli in both the blend and the PS treatments suggests that these interactions are destroyed at higher frequencies (greater than 1 Hz).

Figure 5 shows the values of G* as a function of frequency (0.1–100 Hz) for the control, PO, PS and BF treatments. As was expected, all four types of dough treatment showed the profiles of weak viscoelastic materials (G* are decreasing over the measured frequency range). However, complex modulus of each set of treatments shows a different response as frequency increases from 0.1 to 100 Hz.

Complex modulus of the control treatments drop from 7.2 to 6.3 (Pa) (0.9 difference); and it showed a gradual reduction with increasing of frequency from 0.1 to 100 Hz. No dramatic change in the rheological profile was observed. However, the dough treatments containing PO showed the lowest overall values of G* versus the steady reduction of complex modulus from 7.2 to 5.3 (Pa) (1.9 difference) over of the measured frequency range of 0.1 to 100 Hz.

Initial values of G* at the lower frequency of 0.1 Hz for both the control and the PO treatment, indicate that when the above treatments were initially prepared, their overall consistency was the same, suggesting that if they were baked immediately after mixing without any further processing, the same consistency would be expected in the final products. However, the frequency profile of the PO treatments (at the frequency of 100 Hz final value of G* for PO treatment is lower than final value of G* for the control) suggests that if further high speed (frequency) operations were carried out, the PO treatments would suffer more mechanical damage that the equivalent control. Processes such as sheeting or rolling would be expected to produce softer and sticker doughs.

The complex moduli values of the PS treatments drop from an initially higher value of 8 to a final value of about 6.4 (Pa) (2.4 difference) over the frequency range of 0.1–100 Hz. The PS treatments showed the highest values of G* over the measured frequencies. Moreover, there is a sudden drop in the complex modulus in 1Hz. At higher frequencies, once again, the complex modulus shows a steady reduction with frequency. It seems that a treatment containing significant quantities of PS after initial mixing (without any further processing) would show a stronger overall system. But when the frequency is increased (e.g. at higher mixing speed or sheeting), the complex modulus again will be decreased (dough becomes softer and more sticky), and this reduction is similar to the control.

Complex modulus of the commercial BF treatments decreases from 7.9 to 6.2 (Pa) (1.7 difference) over the measured frequency range. The complex modulus of the treatments as a function of frequency shows two different regions of behavior in the frequency range of 0.1–100. The complex modulus values of BF treatments are similar to those of the PS treatments, confirming the presence of strong doughs with probably the same kind of interactions and cross linkages. There was a significant drop in the complex modulus of BF treatments which occurred at the frequency of 1 Hz. This suggests that when such a treatment containing blended oil is subjected only to lower frequencies, it will exhibit the characteristics of a strong dough system, but when the frequency increases (for example, when it is mixed with a more powerful mixer, high shear rate rolling or sheeted after mixing for molding), then softer and weaker structure dough with less interactions will be produced.

Overall, all values of G′ and G″ for four dough treatments are close to each other, indicating that tan δ is close to 1. This shows a weak viscoelastic system. In addition, G″ exceeds G′ in most of the frequencies, which indicates a viscoelastic liquid like behavior of dough in all treatments. Both G′ and G″ are frequency dependent; that is they decrease when frequency increases. However, they show different responses with different compositions. This may occur as a result of decreasing of the effective cross-linking in the treatments. These results are in agreement with previously reported plasticizing effects of shortening on dough rheology [9]. It can also due to this fact that, before full gluten hydration can occur, oil can "coat" the material and prevent the formation of gluten network, producing less elastic dough. This effect makes the dough suitable for confectionary products since doughs with high elastic properties tend to shrink after lamination [10].

Comparison of the G* values of four treatments indicates that PO treatments were the weakest dough with lowest values of G* over all frequencies. This seems to be as a result of high liquid fat content due to high proportion of oleic acid in PO fraction, which is an unsaturated fatty acid (according to the results obtained from fatty acid analysis by gas chromatography). Increasing of the amount of unsaturated fatty acids causes higher Iodine Value as it has been observed in PO [11].

In addition, the PS treatments showed the highest values of the G* at all the measured frequencies. Also the same rheological behavior was observed (considerable reduction of G* value in 1 Hz frequency) from the BF treatments. It should be noted that PS contains a relatively high saturated fatty acids and lowest proportion of unsaturated fatty acids as compared to other shortening compositions used (data not given). This is due to the high amount of palmitic acid present that results in a low Iodine Value.

These results show that the four different compositions of shortenings used in the various dough treatments make them behave differently with regards to their rheological responses when measured over the frequency range of 0.1–100 Hz. Moreover, it seems that this could lead to the production of different qualities of dough and that they may behave differently when they are subjected to different processing methods. The general behavior was due to isolating of proteins and starch by fat and preventing of polymer interactions and so less cross-linking [12].

Variable results can be obtained due to slip of the material at high frequencies in spite of using serrated parallel plates, which can cause some errors in the results [6]. However, no such "slippage" was observed with the materials used in this study.

Baking test

All cookie doughs were baked and evaluated in terms of their surface appearance and internal texture. The effect of the added shortenings (including PO, PS and BF) on the baking quality of the cookie doughs was compared with the control cookies. As shown in Figure 6, the texture and appearance of treatments are quite different from those of the control. The control cookies have been observed to have an even surface structure with a uniform light colouring. Internally, they showed a dense structure with very small open areas. This represents a typical cookie with acceptable appearance and overall texture. Among the other three treatments, the cookies made with the blend of shortening showed properties very close to those of the control cookies. However, there were some small inclusions on the surfaces, and they showed a more "open" structure with slightly larger openings.

As Figure 6 shows, the cookies made using a dough containing PS are totally different in appearance from those made using the other three shortening compositions. They were found to have "laminar" or layered structure on the surface. This may have occurred because the shortening was not uniformly distributed by the mixing process, causing parts of the structure to separate from each other. Examination of the internal structure also confirmed this layered structure with uneven and poorly distributed openings. They, however, showed almost identical colouring of the surface to the control treatments.

The baked cookies containing PO shortening showed a very open structure with large holes and inclusions in the surface. They had a spongy texture with unevenly distributed openings, which were relatively large in size compared to the other three test treatments. Their colour was also darker than that of the control and other treatments. These cookies produced the most open structure (PO composition), while the baked BF cookies also produced some holes and inclusions; they were not as pronounced as those seen for the PO treatment. The holes in the PS cookies were smaller than either of the two other treatments (PO and BF).

According to Bloksma (1990) [13, 14], dough behavior during the baking process can be predicted through rheological measurement when the extent and rate of deformation are the same in both processing and rheological tests. But when frequency is increased (e.g. at high shear rate condition in real processing), the BF treatment is changed into a weaker system (more soft and sticky) more like the control. This shows that at the final frequency (100 Hz), the BF treatments demonstrate about the same consistency as the control.

The variable nature of these results suggests that the shortening distribution through the dough mixtures used in this study is very different depending on the composition used. This in turn leads to the production of final products with very different structure and colour. The most likely explanation of the origins of this variation in the final products is that the composition and, hence, the “hardness” of the shortenings do seriously alter their distribution throughout the dough during the mixing process.

Accordingly, it is concluded that the composition of shortening is an important factor, which affects dough behavior during both the processing and baking. Understanding how shortening composition (saturated-unsaturated ratio) and physical measurements are related to each other and how processing conditions can influence the quality of the final product is essential for formulation of suitable shortening [15].

CONCLUSION

The overall physical properties of four treatments of cookie dough made using different types of shortening were found to be dependent on the fatty acid composition. Although all of them showed a weak viscoelastic liquid behavior since G' and G'' were close to each other (with the tan δ of about 1) and G'' exceeded G' in most of the frequencies, each treatment set showed a specific rheological profile, which was different from the others to some extent.

PO treatments, containing high amount of palmitic acid, were the weakest dough system (softest and most sticky) with the lowest values of dynamic moduli in all of the measured frequencies and PS treatments, which had high quantity of stearic acid, were the strongest one with the highest values of G', G'' and G^* (highest interaction between the components). At low frequencies (0.1–1 Hz), the BF treatments’ rheological profile was similar to that of the PS treatment, which means that after dough mixing, they had the same consistency.

Baking test also produced four different types of dough cookies, which were all different in terms of both their appearance and texture.

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