Comparison of oil, shortening, and a structured shortening on wheat dough rheology and starch pasting properties

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Abstract

Monoacylglycerol-stabilized oil in water emulsion (MAG gel) is an alternate shortening that is free of *trans* fatty acids, and low in saturated fatty acids. However, the behaviour of MAG gels in comparison to other lipids has not been studied. This study investigated effects of structured MAG gel, a mixture of MAG gels' unstructured components (mixture), canola oil (oil) or interesterified soy shortening (IE Soy) at different levels (6-24%) on hard or soft wheat dough properties. Doughs were prepared with different lipid types at equivalent lipid contents. Dough mixing and water absorption parameters were evaluated using a Farinograph; gluten behavior was measured using a Gluten Peak Tester (GPT); and pasting characteristics were measured using a Micro-ViscoAmyloGraph (MVAG). Water absorption values decreased with increasing lipid content. Dough development times were similar between the MAG gel and IE Soy, but Farinogram curve characteristics during mixing were similar between MAG gel, mixture and oil. The trend for peak max time in GPT was similar between MAG gel and IE Soy exhibiting delayed gluten aggregation; whereas mixture and oil exhibited earlier gluten aggregation. In MVAG, starch interaction with monoglyceride component of MAG gel and mixture appeared to be the dominating factor resulting in an increased pasting temperature and a second viscosity peak during cooling at higher levels of lipid addition.

Key Words: shortening, lipid, dough, rheology, farinograph, gluten peak tester, micro-viscoamylograph

Introduction

Lipids are utilized in a majority of baked products; in bread formulations at a level of 2-5%, in cakes at a level of 5-25%, in sweet goods at a level of 20-30%, in puff pastry at a level of 30-40% and in pie crust at a level of 20-35% on a flour weight basis (fwb). Lipids in baked goods serve multiple purposes including ‘shortening’, lubrication, aeration, help with heat transfer, extension of shelf life, as well as provide structure and desirable textural properties such as tenderness, richness and improved mouthfeel. Lipids used in baked products such as liquid oils or high melting plastic fats have a range of properties depending on the specific applications. In recent years the baking industry has been seeking alternatives to solid hydrogenated shortening that provide unique functionality to baked products but are low in *trans* fatty acids. Interesterified fats are one alternative but they still contain high levels saturated fatty acids (Table 1) that are also linked to negative health effects (World Health Organization 2004).

The applications of lipids and emulsifiers in baked products have been extensively studied for their effects on different characteristics, particularly dispersion, lubrication and softening in bread (Azizi, Rajabzadeh, and Riahi 2003; Azizi and Rao 2004b; Baldwin, Baldry, and Johansen 1972; Ghotra, Dyal, and Narine 2002; Goesaert et al 2005) and biscuits/cookies (Baldwin, Baldry, and Johansen 1972; Chevallier 2000; Ghotra, Dyal, and Narine 2002; Jissy Jacob and Leelavathi K 2007; Maache-Rezzoug et al 1998; Manohar and Rao 1999; Pareyt 2008; Sudha et al 2007; Zoulias, Oreopoulou, and Kounalaki 2002). Lipids and emulsifiers have also been investigated for their interactions with starch (Azizi and Rao 2005; Ghotra, Dyal, and Narine 2002; Mira, Eliasson, and Persson 2005; Stauffer 1999; Watanabe, Larsson, and Ann-

Charlotte 2002) Starch-lipid complexes can have a large effect on starch gelatinization and retrogradation characteristics (Goesaert et al 2005).

The structured shortening alternative (MAG gel) used in this study is a cellular-solid that is an oil-in-water emulsion with water-swollen monoacylglycerol multilamellae surrounding 1-5 micrometer oil globules (Figure 1). The globules are interconnected with each other via hydrogen bonding and stearic acid aids in both emulsion formation, water-binding and surface charge modulation (Marangoni et al 2007). The physicochemical and structural attributes of MAG gels have been well characterized; and it has also been demonstrated that the consumption of MAG gels lowers triglyceride levels and free fatty acids after ingestion, as well as decreasing insulin sensitivity compared to oil consumption (Marangoni et al 2007). MAG gel is composed of canola oil (55.25%), water (40%), monoglyceride (4.5%) and stearic acid (0.25%). Mono- and diglycerides are the most widely used food grade emulsifiers and are generally added to bakery products at a level of 0.75-1% to improve dough softness and for shelf life extension (Stauffer 1999). Structured MAG gel is a solid at room temperature, similar to other commercial shortening, but is composed of structured liquid oil, water and monoglyceride.

While the effects of individual components that make up MAG gel on dough and baked product attributes have been investigated extensively, questions remain about the functionality of structured MAG gels in baked products. This study compares the functionality of the MAG gel to a mixture of its unstructured components, interesterified soy shortening (IE Soy) or canola oil with hard or soft wheat flour with lipid contents ranging from 6 up to 24% which is the standard lipid content (fwb) in an AACC cookie procedure.

Materials and Methods

Hard wheat flour (HWF; 12% moisture, 12% protein) and soft wheat flour (SWF; 12% moisture, 8% protein) were provided by Griffith Laboratories (Toronto, ON, Canada). Wheat starch (Midsol™ 50) was provided by MGP Ingredients Inc. (Atchison, KS, USA). Interestserified soy shortening (IE Soy) was provided by Archer Daniels Midland Company (Decatur, Illinois, USA). Canola oil was provided by Sunspun (Toronto, ON, Canada). MAG gel is composed of 55.25% canola oil (Sunspun, Toronto, ON, Canada), 40% deionized water, 4.5% distilled monoglyceride (Caravan Ingredients, Lenexa, KS, USA), and 0.25% stearic acid (Caravan Ingredients, Lenexa, KS, USA). MAG gel was produced by vigorously mixing a hot (75˚C) oil-monoglyceride solution with alkaline deionized water by using an immersion hand blender and a static mixer described by Marangoni et al. 2007. The mixture was produced by combining the same proportions of deionized water (40%), canola oil (55.25%), and monoglyceride (4.5%) present in the MAG gel at room temperature prior to experimentation.

Microscopy

Monoacylglycerol crystals are birefringent and their microstructure encapsulating the liquid oil droplets in the MAG gel can be conveniently observed using polarized light microscopy (PLM). For the PLM study, a small droplet (~10μL) of MAG gel was placed on the glass slide, and then a glass cover was placed over the sample and slightly compressed to form a uniform film with approximate thickness of 10-15um. The microstructure of the MAG gel was observed by using an Olympus BH microscope

(Tokyo, Japan). Images were acquired with a Sony XC-75 CCD video camera (Sony Corporation, Japan), and an LG-3 PCI frame grabber using Scion Image (Scion Corporation, Frederick, MD) using a 40x long range objective lens with a numerical aperture of 0.9.

Farinograph

Hard or soft wheat flour samples with 0, 6, 12, 18 or 24% of MAG gel, mixture, IE Soy or oil on an equal lipid basis were analyzed in a Farinograph-E (Brabender GmBh, Duisburg, Germany) using AACC Method 54-21 (AACC, 2000) in a 50 g mixing bowl at a constant temperature of 30˚C. The amount of water added was adjusted to obtain a consistency of 500 BU MAG gel, mixture, IE Soy and oil were added directly to the flour on an equal lipid basis (Table 2) and on a flour weight basis (fwb). The lipids were blended in the Farinograph to obtain a homogenous mixture for one minute before the addition of water. Water absorption values at 500 BU, and dough development times were obtained from the software. All analyses were conducted in duplicate. Statistical analysis was conducted on water absorption percentages and dough development times using SAS version 9.2 (SAS Institute Inc., Cary, NC, USA). ANOVA was preformed with averages compared using Tukey's test ($p<0.05$). Statistical comparison is referenced between flour types as well as levels within MAG gel, mixture, IE Soy or oil and within levels between MAG gel, mixture, IE soy or oil.

Gluten Peak Tester

HWF or SWF with the different levels of lipid addition were analyzed using a Brabender Gluten Peak Tester (GPT) (Brabender GmBh, Duisburg, Germany). HWF and SWF samples were evaluated at flour to water ratios of 0.85 and 1.19, respectively. The total weight of samples in the cup was 20g. Lipids in the range of 6 to 24% fwb were added. Tests were conducted at 30˚C and the samples were mixed at 3000 rpm for 10 min. The moisture content of the MAG gel and mixture were included in the water calculation to obtain the same flour to water ratio for all samples. The GPT records the torque generated by the sample and the peak maximum time (PMT) was determined using the software (Brabender GmBh, Duisburg, Germany). All analyses were conducted in duplicate. Statistical analysis was conducted on peak maximum times using SAS version 9.2 (SAS Institute Inc., Cary, NC, USA). ANOVA was preformed with averages compared using Tukey's test ($p<0.05$). Statistical comparison is referenced between flour types as well as levels within MAG gel, mixture, IE soy or oil and within levels between MAG gel, mixture, IE Soy or oil.

Micro-ViscoAmyloGraph

The pasting profiles of HWF, SWF and wheat starch with different levels of lipid addition were carried out in a Brabender Micro ViscoAmyloGraph (MVAG; Brabender GmBh, Duisburg, Germany). An 8% dry basis (db) slurry was used in the study. The moisture content of the MAG gel and mixture were included in the calculation of the water added to the slurry, so all samples had the same water content. The MAG gel, mixture, IE Soy or oil was added in addition to starch or flour at 6, 12, 18 or 24% levels on a starch or flour weight basis. The suspensions were premixed for 60 s and then subjected to stirring (250 min^{-1} and using a 235 cmg cartridge) with the following temperature profile: heating from 30˚C to 95˚C at 7.5˚C/min, holding at 95˚C for 5 min, cooling from 95˚C to 30˚C at 7.5˚C/min, holding at 30˚C for 5 min. Pasting temperature, peak viscosity and breakdown viscosity were determined using the software. All analyses were conducted in duplicate. Statistical analysis was conducted on pasting temperature, peak temperature, peak viscosity, second peak temperature, second peak viscosity and final viscosity using SAS version 9.2 (SAS Institute Inc., Cary, NC, USA). ANOVA was preformed with averages compared using Tukey's test ($p<0.05$). Statistical comparison is referenced between flour types and starch as well as levels within MAG gel, mixture, IE Soy or oil and within levels between MAG gel, mixture, IE soy or oil.

Results and Discussion

Effect of lipids on water absorption and dough development

A representative Farinogram curve at the 24% lipid addition level is shown in Figure 2a and 2b for HWF and SWF, respectively. The curves exhibited different characteristics for MAG gel, mixture, IE Soy or oil for SWF and HWF. In HWF, IE Soy dough displayed an initial hydration peak, then decreased in consistency and did not reach 500 BU in the 20 min test time. MAG gel, mixture and oil in HWF had low consistencies initially displaying no hydration peak and developed at 18, 17.7 and 18.6 min respectively. In SWF at 24% lipid addition level IE Soy dough developed at 1 min where MAG gel and oil dough displayed low consistencies initially with gradual development at 6.4 and 9.9 min respectively. The mixture displayed an initial hydration peak and then a gradual development at 14 minutes. The MAG gel, mixture and oil provided stability to the SWF at the 24% addition level and did not breakdown to the same extent compared to control.

Farinogram values for dough development time and water absorption of HWF and SWF at different levels of MAG gel, mixture, IE Soy or oil are shown in Figure 3. The amount of water required to reach 500 BU was lower at all lipid levels and types, compared to control for both flour types. The added water to reach 500 BU was higher when IE Soy shortening, mixture or oil was added compared MAG gel. Furthermore, differences between lipid types were more noticeable in HWF dough than SWF dough. The solid lines (Figure 3) represent total water, including the 40% water present in MAG gel. When the 40% water present in the MAG gel is compensated for in the water absorption percentage (dotted line Figure 3), there is a difference between the water absorption values for all lipid types in HWF, but not between oil, mixture or MAG gel in SWF. The dotted line for MAG gel is significantly ($p<0.05$) lower than IE Soy or oil in HWF at 18 and 24% addition, but was not significantly ($p<0.05$) different from oil at any addition level in SWF. The differences between lipid types were most noticeable at the higher lipid addition levels in both HWF and SWF dough.

Dough development time of HWF and SWF at different levels of lipid addition is displayed at the bottom of Figure 3. Dough development time for HWF at 6 or 12% of MAG gel or IE Soy addition were not significantly ($p<0.05$) different compared to control dough, while dough development was delayed at 18 or 24% level of MAG gel and IE Soy addition. The development time for 24% addition of IE Soy is not displayed because the lipid level was too high for the flour to reach 500 BU. The hydration peak was apparent, and the curve showed an upward slope similar to the 18% IE Soy addition, but did not develop within the twenty minute test time. Dough development times with oil and mixture at 6, 12 or 18% addition for HWF were significantly ($p<0.05$) lower than for control, and dough development time was significantly ($p<0.05$) delayed only at the 24% level of lipid addition. Development time at the 24% lipid level was not significantly ($p<0.05$) different between MAG gel, mixture or oil. SWF dough development times at 6 or 12% added lipids were not significantly ($p<0.05$) different from each other or from control dough. Dough development time with IE Soy was not significantly ($p<0.05$) different from control at any addition level, whereas dough development time was delayed with 18 and 24% MAG gel addition and with 24% oil and mixture addition compared to control SWF dough. The development time with oil and mixture at 24% addition level was significantly ($p<0.05$) higher than the development time for dough with MAG gel at the 24% addition level in SWF dough.

With high levels of added lipids to dough, there is a high level of lubrication and little water is required to achieve desired dough consistency. D'Applonia et al (1984) reported a decrease in water absorption and stability on Farinograph characteristics with the addition of shortening in the range 0 to 6%. If the same amount of water were added to dough containing lipids, then the dough with MAG gel would exhibit the least resistance. The dotted line in Figure 3 shows decreased water absorption for MAG gel in hard wheat flour dough and suggests a softer dough than with IE Soy, oil or mixture; a desirable property for lipids utilized in baked goods to 'shorten' or soften dough. A surfactant gel made with 0.5% monoglyceride with varying shortening contents in the range of 0 to 2% were shown to improve Farinograph characteristics, but the improvements decreased as the amount of shortening within the gel increased from 0-2% (Azizi and Rao 2004a). Furthermore, a canola oil/caprylic acid structured lipid lowered the elastic and viscous attributes of soft wheat flour, which was attributed to a dilution effect of increasing oil content (Agyare et al 2004). Dispersion of lipid plays a large role in reaching desired Farinogram consistency (Maache-Rezzoug et al 1998). Liquid oils get dispersed in the form of globules which are not effective in coating flour proteins and therefore less effective at ‘shortening’ which leads to an increase in dough consistency. Depending on the firmness of solid lipids, they may get dispersed as large lumps or smeared over flour particles (Baltsavias, Jurgens, and vanVliet 1997). In this research IE Soy is harder and has a higher solid fat index at room temperature than MAG gel and is likely to be dispersed in clumps whereas the MAG gel is likely to be smeared over the flour particles, while liquid oil and the mixture would be dispersed as globules. Therefore, if water absorption is influenced by the lubrication properties and consistency of the added lipid, then liquid oil and the mixture should have the lowest water absorption levels. However, in this case the MAG gel had the lowest water absorption values. This could be due the presence of monoglycerides in the structured MAG gel; and monoglycerides are known to aid in uniform distribution of lipids in dough (O'Brien et al 2003). MAG gel could be more evenly distributed, coating the flour particles resulting in lower amounts of water required to reach 500 BU than oil which is unevenly distributed in globules and IE Soy, which would take more time to be distributed evenly and coat flour particles. In hard wheat flour dough it is of particular interest that less water is required to reach the same consistency dough with the MAG gel as compared to both IE Soy shortening, oil, and mixture even when taking into consideration the added water (dotted line) from the MAG. Therefore, the MAG gel structure appears to confer some additional functionality to the dough that is more evident in HWF dough when compared to SWF dough. These observations on dough development attributes highlight differences in the functionality of the monoglyceride in the structured MAG gel versus the unstructured mixture. The flour proteins in SWF appear to interact with the structured MAG gel resulting in a rapid development time;

suggesting either all the water in the structured gel becomes available for absorption or that the oil is released from the structure resulting in reduced consistency. However, the same effect is not apparent in HWF, where the behaviour of MAG gel and mixture was similar. These differences in dough development time could be a function of several interacting factors including; a) the availability of water during mixing when the water is present in the structure MAG gel or whether it is free added water; b) the presence of increasing amounts of monoglyceride; and/or c) the availability and activity of monoglyceride when it is in the structure versus when it is added in the mixture.

The development curves at 24% lipid addition level are similar to results described by Jacob et al (2007) with 30% lipid level cookie dough consistencies. The dough containing solid shortening initially displayed the highest consistency similar to IE Soy described here and then after mixing decreased in consistency suggesting a softening and 'shortening' effect. Cookie dough containing 30% fwb liquid oil displayed the lowest consistency initially then after mixing increasing in resistance and displaying a higher consistency suggesting less softening and shortening ability after mixing similar to the Farinogram curves for liquid oil, mixture and MAG gel described here.

Effect of lipids on gluten aggregation

Gluten Peak Tester (GPT) profiles of peak maximum time (PMT) are shown in Figure 4. The peak time of HWF and SWF cannot be directly compared since the flour to water ratios was different in the test: however the changes in trends are informative. The PMT of HWF dough with MAG gel significantly ($p<0.05$) increased at levels greater than 12% lipid; and with IE Soy, PMT increased at all lipid addition levels when compared to control dough. However, the trend was opposite for dough with oil or mixture. The increasing trend with MAG gel and IE Soy and the decreasing trend for oil and mixture clearly observed in HWF were somewhat similar in SWF doughs, but the differences between them were smaller. PMT is reflective of the time required for gluten to aggregate and exhibit maximum torque on the spindle. We have established that native starch by itself does not generate torque in the GPT even in presence of lipids and/or monoglyceride (data not shown); therefore, the effects are primarily due to the gluten proteins. In principle, PMT values of dough are similar to dough development time in a Farinograph; SWF dough develops earlier in the Farinograph compared to HWF dough. However, the interaction of MAG gel, mixture, IE Soy or oil with gluten in particular, and the differences between hard and soft wheat gluten proteins, is better elicited in this test. This data also confirms the observations for water absorption obtained from the Farinogram (Fig 4; dotted line). When the water in the MAG gel is accounted for it behaves similarly to IE Soy with PMT and water absorption values in HWF; and is similar to IE Soy, mixture and oil for SWF.

The delay in gluten aggregation in HWF with MAG gel or IE Soy when compared to mixture or oil is likely due to the ability of MAG gel or IE Soy to coat flour proteins 'shorten' and prevent gluten aggregation. Oil and mixture are dispersed in globules and therefore is likely to have promoted gluten aggregation. The delay in gluten aggregation with MAG gel could also be influenced by the availability of its structured water. If the water is strongly bound, it could take more time and energy to become available for gluten aggregation. The water present in the MAG gel was compensated for during the addition of water to the GPT sample cup, therefore it is possible that the bound water in the gel was unavailable for the flour proteins to absorb and utilize for gluten formation that would cause a delay in the time for gluten to aggregate. It is also possible that MAG gel is dispersed quickly and evenly and is efficient at coating and lubricating flour particles to 'shorten' them and prevent aggregation. The ability of the MAG gel to prevent gluten aggregation is apparent in this test compared to the mixture containing the same components unstructured which does not prevent gluten aggregation. This is beneficial since MAG gel mimics a similar delay in gluten aggregation as IE Soy shortening which is industrially available as an effective shortening for numerous baked goods.

Effect of lipids on pasting characteristics

The pasting properties of the flours and starch with MAG gel, IE Soy and oil are shown in Table 3. The pasting properties with MAG gel and mixture are shown in Table 4. Overall, MAG gel exhibited significant differences based on amount of lipid added and between HWF, SWF and WS. IE Soy and oil exhibited similar pasting characteristics with little differences between levels of addition, but differences were observed between HWF, SWF and WS. Pasting temperature of HWF did not change with increasing levels of either MAG gel or mixture. Pasting temperature significantly ($p<0.05$) increased with increasing levels of MAG gel addition in SWF and WS; and did not change with the addition of mixture to SWF or WS. Different levels of IE Soy or oil showed no reportable significant ($p<0.05$) differences within HWF, SWF or WS. Peak temperature significantly ($p<0.05$) increased in HWF and SWF with the addition of either 6% MAG gel or mixture but did not increase with increasing lipid levels thereafter. No significant ($p<0.05$) differences in peak temperature were observed in HWF, SWF or WS with IE Soy or oil. There was a significant ($p<0.05$) increase in peak viscosity only in SWF with MAG gel addition at 18 and 24%. Final viscosity had a significantly ($p<0.05$) decreasing trend with increasing lipid addition of MAG gel and mixture in HWF and WS, and there was a greater decrease in final viscosity for WS. However, the trend was reversed for SWF wherein the final viscosity increased with lipid addition compared to control. MAG gel had a significantly ($p<0.05$) lower final viscosity compared to IE Soy and oil in HWF and WS. At 18 and 24% levels of MAG gel or mixture addition, a second peak was observed for both the flours and the starch samples during the cooling cycle shown in Table 4. A second peak was not observed with any level of addition of IE Soy or oil and is not shown in Table 3. The temperature and viscosity of the second peaks were higher at 24% MAG gel and mixture addition for both flours but was not significantly ($p<0.05$) different for the starch. Furthermore, the temperature was not significantly ($p<0.05$) different between flour with mixture or MAG gel, but was significantly ($p<0.05$) different between starch with mixture or MAG gel. The viscosity for the second peak was lowest for SWF and highest for starch with added lipids. Zhang et al (2003) reported a second peak in the presence of starch, lipid and protein together, but that the second peak does not appear when only two of the three components are present. Oil or IE Soy with HWF, SWF or WS did not display a second peak at any level of addition; but monoglyceride by itself did exhibit a second peak (data not shown). The monoglyceride portion of the structured MAG gel and unstructured mixture seem to dominate their interaction with starch. Differences in the availability of the water and monoglyceride in the MAG gel versus the mixture are likely accountable for their significant differences noted in Table 4; particularly the pasting temperature increase with MAG gel in SWF and WS and not with mixture. This increase could result from a delayed availability of monoglyceride and water from the structure until the MAG gel reaches its dropping point and oil is released from the structure. The components of the MAG gel become available to interact with starch resulting in the increased temperature which is more apparent in SWF and WS than HWF. Researchers have shown that starch helices interact with the hydrophobic domains of amphiphilic molecules such as fatty acids, monoglycerides, and surfactants (Stauffer 1999). Starch pastes made with emulsifiers, including monoglyceride, display increases in pasting temperature, hot viscosity, temperature to peak and set-back viscosity (Condepetit and Escher 1992; Eliasson 1986). Lipids added to bakery applications such as shortening also interact with starch, breaking the continuity of the protein and starch structure, reducing starch swelling and gelatinization, resulting in a soft texture (Ghotra, Dyal, and Narine 2002). Monoglyceride starch interactions are beneficial for bakery applications such as cakes because the complexes they form with amylose give cakes a softer texture and longer shelf life (Krog 1977). Azizi and Rao (2004) showed increasing shortening content from 0-2% with 0.5% monoglyceride added to wheat starch resulted in an increase in gelatinization temperature, and an increase in final viscosities. MAG gel exhibited an increase in gelatinization temperature with wheat starch at increasing addition levels, but a decrease in final viscosities, whereas IE Soy showed no significant ($p<0.05$) difference in gelatinization temperatures at increasing addition levels but exhibited an increase in final viscosity with increasing addition levels. The increase in final viscosity with IE Soy during cooling is expected since IE Soy solidifies at ambient temperatures, contributing to increased viscosity. Depending on the destruction of structured MAG gel during agitation in MVAG, the cooled monoglyceride would increase the final viscosity but the liquid oil portion would decrease the final viscosity. As monoglyceride levels increase, larger effects on pasting properties are expected because with the presence of more surfactant, there is more granule surface coverage or granule penetration and thus complex formation (Mira, Eliasson, and Persson 2005). Again differences were observed in pasting properties between flour type and lipid type. These observations suggest that the MAG gel interacts differently with flour components compared to mixture, IE Soy or oil; and also that gluten protein quality and gluten-starch interaction in flour play a role in the nature of interaction.

Conclusion

This research compared conventional lipid sources to MAG gel and a mixture of its unstructured components at equivalent lipid contents. The water, oil and monoglyceride components structured in the MAG gel seem to give it a) attributes which are not similar to the same components when added individually in an unstructured form; b) attributes that are different from other lipid sources such as water absorption parameters and pasting profiles; c) attributes that are similar to shortening such as development time and prevention of gluten aggregation. There are significantly ($p<0.05$) different interactions between MAG gel and HWF or SWF, likely because of the interaction of their protein and starch components with the structured monoglyceride component of the gel. Each of these parameters will play a part in the effectiveness of the MAG gel to replace other lipid sources in baked goods. For example in HWF dough with MAG gel will require less water to reach optimal development and development time and mode of development will vary with the level of MAG gel replacement. The MAG gel's ability to 'shorten' and prevent gluten aggregation will be beneficial for baked products that do not rely on gluten network formation for structure. Differences in the pasting properties with the inclusion of MAG gel will have an effect during heating of baked products, gelatinization of starch as well as retrogradation and staling characteristics compared to other lipid sources.

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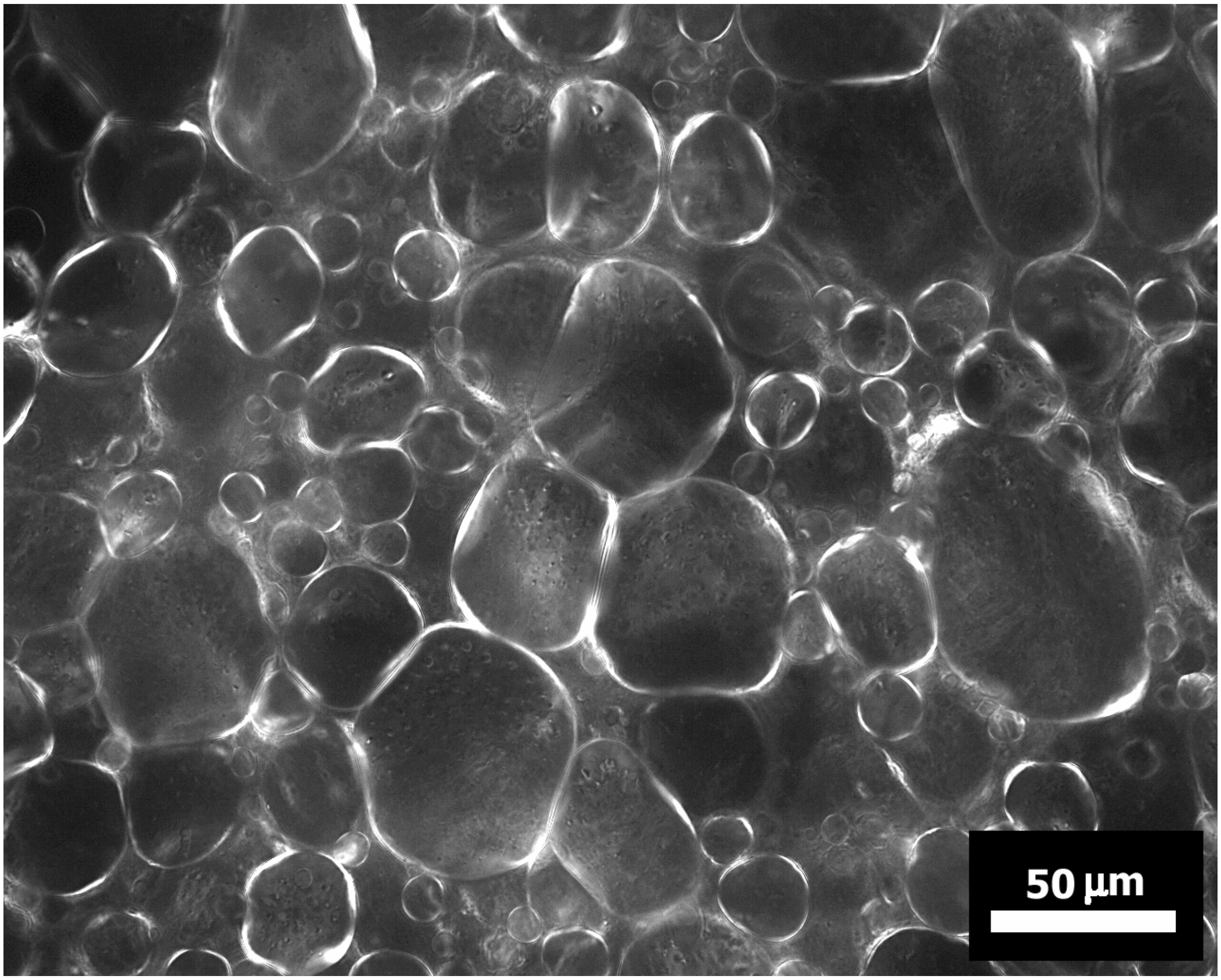

Figure 1: Polarized light micrograph of the MAG gel

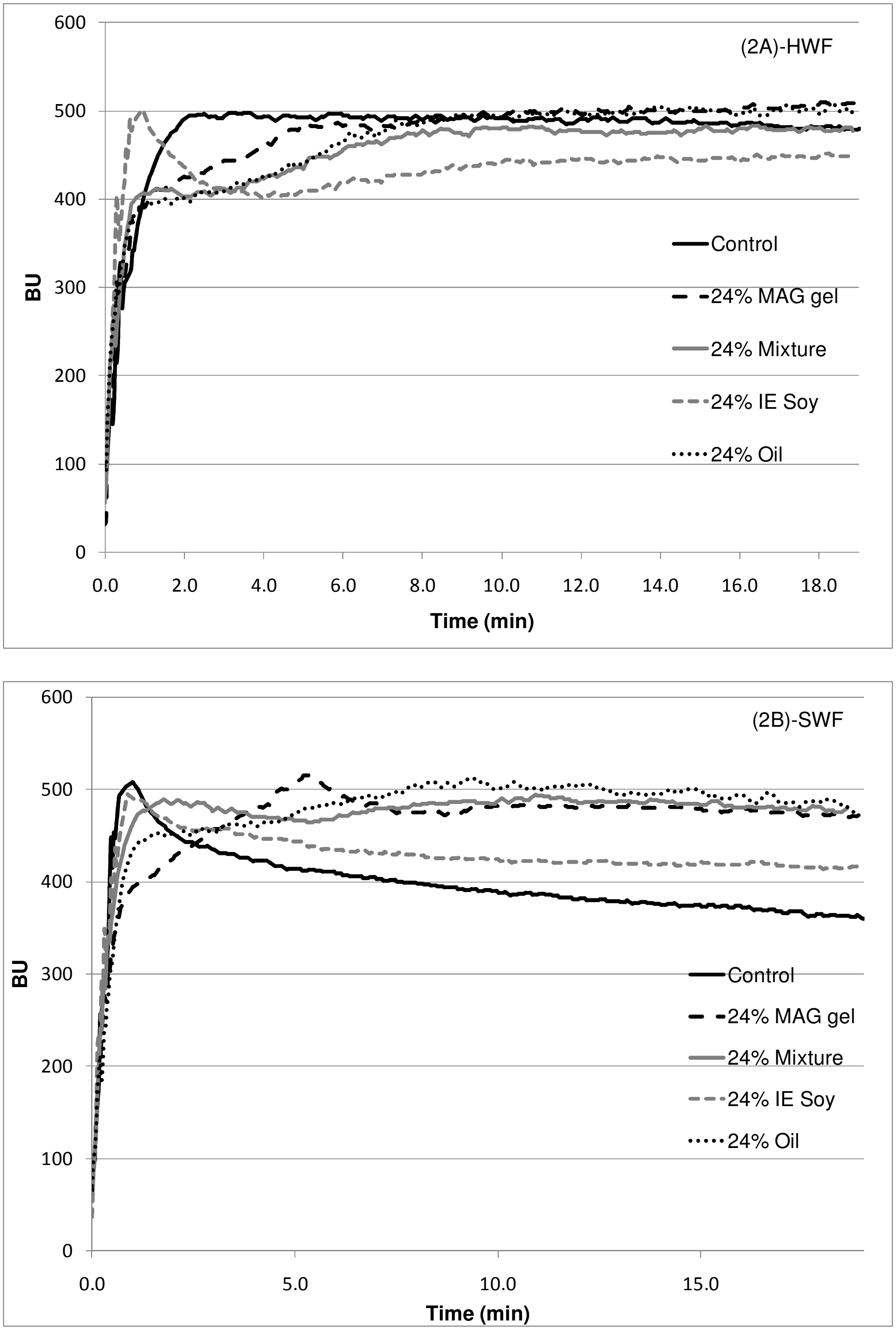

Figure 2A & B: Farinogram development curves for hard wheat flour (2A) and soft wheat flour (2B) following the addition of 24% MAG gel, mixture, IE Soy or oil.

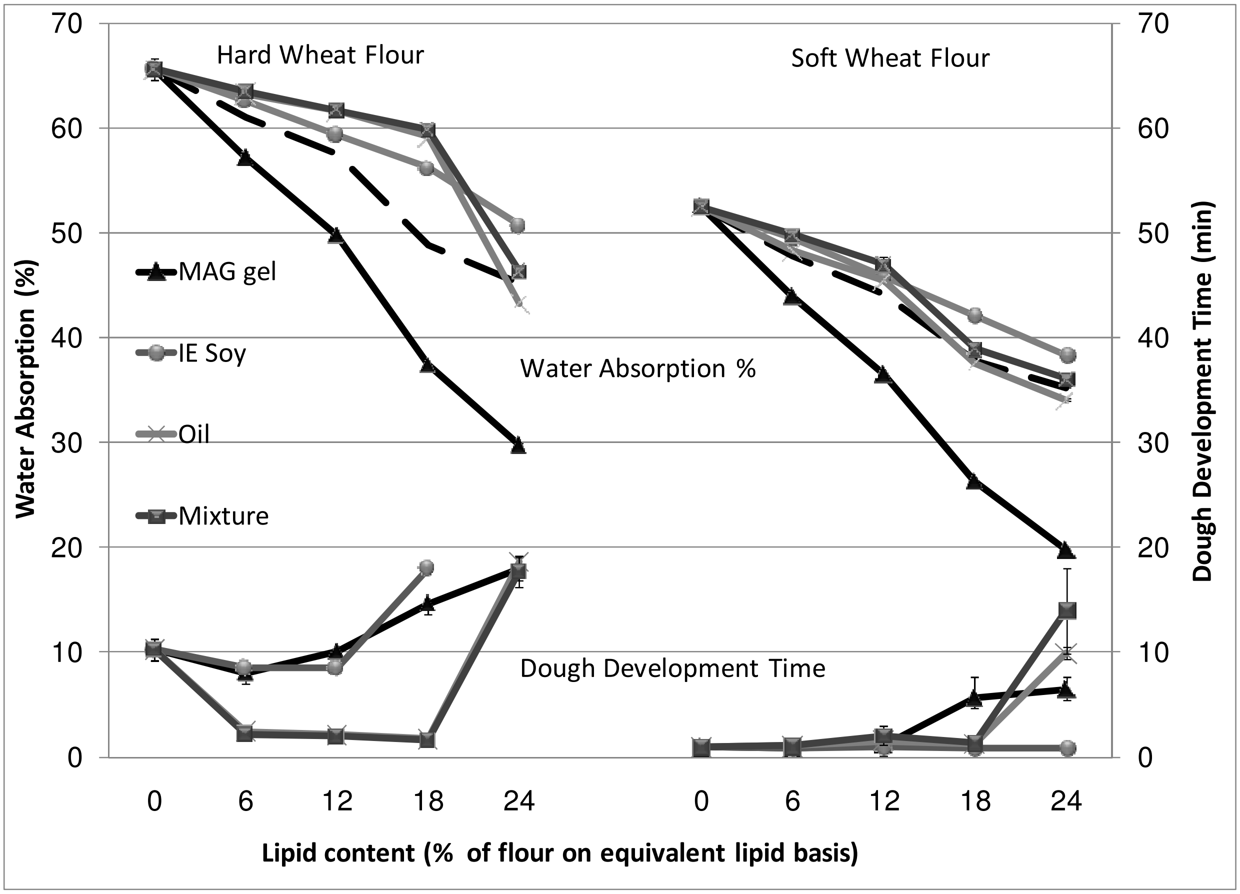

Figure 3: Water absorption (top graph) required to reach 500 BU and the development time (bottom graph) for hard and soft wheat flour following the addition of different levels of MAG gel, mixture, IE Soy or oil. The dotted lines for MAG gel water absorption values represent the added water. The solid lines are the total water in the dough, i.e., water present in MAG gel plus added water to reach 500 BU. Significance reported at $p<0.05$, $n=2$.

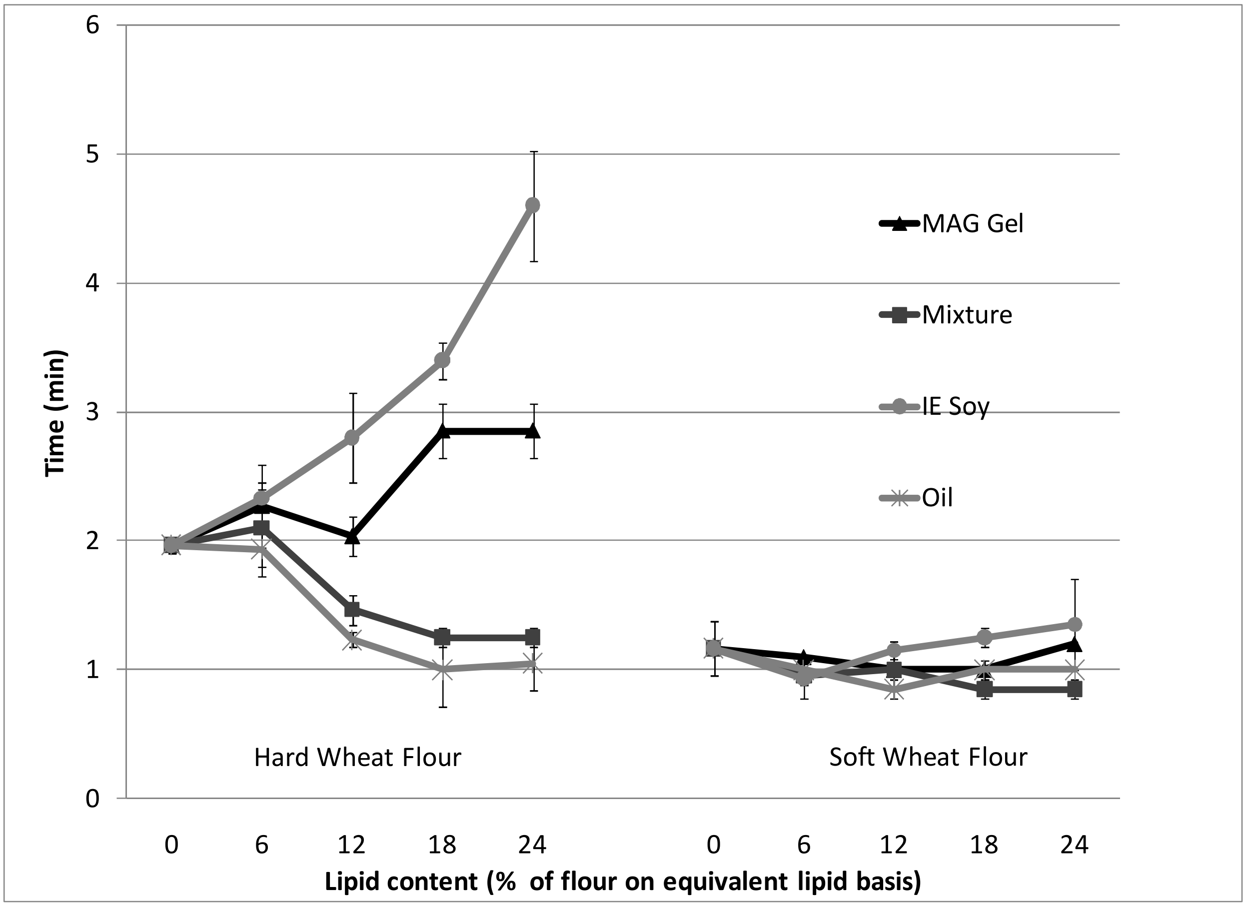

Figure 4: Peak maximum time values, as measured by using a Gluten Peak Tester, of hard and soft wheat dough with increasing levels of lipids added as MAG gel, mixture, IE Soy or oil. Significance reported at $p<0.05$, n=2.

	Interesterified soy shortening	**MAG gel**	**Mixture**	**Canola Oil**
% Total Lipids	100	60	60	100
% Saturated fatty acids	38	7	7	6
% *Trans* fatty acids	0	0	0	0
% Water	0	40	40	0

Table 1: Percent total lipids, saturated fatty acids, *trans* fatty acids and water for lipid sources used in this study.

	% added lipid on flour weight basis			
Lipid source	**6**	**12**	**18**	**24**
MAG gel	10	20	30	40
Mixture (Oil/Monoglyceride)	5.5/0.5	11.1/0.9	16.6/1.4	22.1/1.9
Interesterified soy shortening	6	12	18	24
Oil	6	12	18	24

Table 2: Percent of added lipid source based on flour weight needed to obtain standardized lipid contents within dough

	Lipid %	Pasting Temperature (˚C)			Peak Temperature (˚C) Peak Viscosity (mPas)			Final Viscosity (mPas)		
		MAG	Oil	IE Soy	MAG	Oil	IE Soy	MAG	Oil	IE Soy
HWF	0	68.9 ^{a}	68.9 ^{a}	68.9 ^{a}	93.9 ^{a} 210.0 ^{a}	93.9 ^{a} 210.5 ^{a}	93.9 ^{a} 210.5 ^{a}	475.5 ^{a}	475.5 ^{a}	475.5 ^{a}
	6	67.9 ^{ab}	68.0 ^{b}	68.2 ^{a}	96.6 ^{bx} 211.5 ^{a}	94.0 ^{ay} 215.5 ^{a}	93.7 ^{ay} 213.0 ^{a}	443.5 ^{ay}	500.0 ^{abcx}	489.0 ^{axy}
	12	68.9 ^{a}	67.4 ^{bc}	68.9 ^{a}	96.6 ^{bx} 214.0 ^{a}	94.1 ^{ay} 214.5 ^{a}	93.6 ^{ay} 215.5 ^{a}	373.5 ^{by}	510.5 ^{bcx}	467.5 ^{ax}
	18	67.9 ^{ab}	68.1 ^{ab}	68.0 ^{a}	96.9 ^{bx} 214.5 ^{a}	94.1 ^{ay} 215.5 ^{a}	93.2 ^{ay} 216.0 ^{a}	325.5 ^{cy}	490.0 ^{abx}	501.0 ^{ax}
	24	67.5 ^{b}	66.9 ^{c}	67.8 ^{a}	96.6 ^{bx} 212.0 ^{a}	94.2 ^{ay} 211.5 ^{a}	93.6 ^{ay} 219.0 ^{a}	318.0 ^{cy}	523.0 ^{cx}	514.0 ^{ax}
SWF	0	75.7 ^{a}	75.7 ^{a}	75.7 ^{a}	91.7 ^{a} 157.0 ^{a}	91.7 ^{a} 157.0 ^{a}	91.7 ^{a} 157.0 ^{a}	313.5 ^{a}	314.0 ^{a}	314.0 ^{a}
	6	77.3 ^{abx}	75.2 ^{ay}	76.1 ^{axy}	95.2 ^{bx} 156.5 ^{a}	91.1 ^{ay} 158.5 ^{a}	91.1 ^{aby} 159.5 ^{a}	347.0 ^{bc}	312.5 ^{a}	335.5 ^{a}
	12	79.7 ^{bcx}	74.7 ^{ay}	75.9 ^{az}	95.7 ^{bx} 158.5 ^{a}	90.9 ^{ay} 156.0 ^{a}	90.6 ^{by} 155.0 ^{a}	358.0 ^{cy}	323.5 ^{ax}	322.5 ^{ax}
	18	80.8 ^{cx}	73.3 ^{ay}	75.9 ^{az}	95.4 ^{bx} 187.5 ^{bx}	90.7 ^{ay} 153.0 ^{ay}	90.8 ^{aby} 158.5 ^{ay}	328.5 ^{ab}	328.0 ^{a}	324.5 ^{a}
	24	81.7 ^{cx}	73.3 ^{ay}	75.7 ^{az}	95.8 ^{bx} 203.0 ^{bx}	91.1 ^{ay} 153.5 ^{ay}	90.9 ^{aby} 152.5 ^{ay}	351.0 ^{bcy}	328.0 ^{ax}	322.5 ^{ax}
WS	0	75.1 ^{a}	75.1 ^{a}	75.1 ^{a}	95.9 ^{a} 363.5 ^{a}	95.9 ^{a} 363.5 ^{a}	95.9 ^{a} 363.5 ^{ab}	877.0 ^{a}	877.0 ^{a}	877.0 ^{a}
	6	83.4 ^{bx}	75.1 ^{ay}	75.3 ^{ay}	95.9 ^{axy} 385.5 ^{a}	96.4 ^{ax} 377.0 ^{a}	95.7 ^{ay} 355.0 ^{b}	828.5 ^{ay}	1003.5 ^{bx}	932.5 ^{axy}
	12	86.0 ^{cx}	76.3 ^{ay}	75 ^{ay}	96.3 ^{a} 370.0 ^{a}	96.1 ^{a} 366.5 ^{a}	96.4 ^{a} 374.0 ^{a}	739.0 ^{ab}	874.0 ^{a}	945.0 ^{a}
	18	87.1 ^{cx}	77.1 ^{ay}	76.3 ^{ay}	95.3 ^{a} 356.5 ^{a}	95.7 ^{a} 372.0 ^{a}	96.3 ^{a} 370.5 ^{ab}	602.0 ^{bcy}	972.4 ^{abx}	982.5 ^{ax}
	24	87.5 ^{cx}	76.9 ^{ay}	75.4 ^{ay}	96.2 ^{a} 359.5 ^{a}	95.7 ^{a} 373.5 ^{a}	96.0 ^{a} 358.5 ^{ab}	508.0 cy	957.0 ^{abx}	1005.0 ^{ax}

Table 3: Micro ViscoAmylograph data for pasting temperature, peak temperature, peak viscosity and final viscosity for HWF, SWF and WS with varying addition levels of MAG gel, IE Soy or oil. Means within a treatment type (HWF, SWF, WS) for each pasting attribute within a row with the same letter (a, b, c) are not significantly different ($p<0.05$), n=2. Mean within each lipid type (0,6,12,18,24%) for each treatment (HWF, SWF, WS) within a column with the same letter (x, y, z) are not significantly different (p,0.05), n=2.

	Lipid %	Pasting Temperature (˚C)		Peak Temperature (˚C) Peak Viscosity (mPas)		Second Peak temperature (˚C) Second Peak Viscosity (mPas)		Final Viscosity (mPas)	
		MAG gel	Mixture	MAG gel	Mixture	MAG gel	Mixture	MAG gel	Mixture
HWF	0	68.9 ^{a}	68.9 ^{a}	93.9 ^{a} 210.0 ^{a}	93.9 ^{a} 210.5 ^{a}	N/A	N/A	475.5 ^{a}	475.5 ^{a}
	6	67.9 ^{ab}	68.3 ^{a}	96.6 ^{b} 211.5 ^{a}	96.5 ^{b} 209.0 ^{a}	N/A	N/A	443.5 ^{a}	423.0 ^{b}
	12	68.9 ^{a}	68.1 ^{a}	96.6 ^{b} 214.0 ^{a}	96.8 ^{b} 208.5 ^{a}	N/A	N/A	373.5 ^{b}	359.5 ^{c}
	18	67.9 ^{ab}	67.6 ^{a}	96.9 ^{b} 214.5 ^{a}	96.8 ^{b} 214.0 ^{a}	58.8 ^{a} 403.5 ^{a}	59.4 ^{a} 412.5 ^{a}	325.5 ^{c}	327.0 ^{d}
	24	67.5 ^{b}	67.7 ^{a}	96.6 ^{b} 212.0 ^{a}	96.5 ^{b} 226.0 ^{a}	65.7 ^{b} 412.5 ^{a}	66.6 ^{a} 412.0 ^{a}	318.0 ^{c}	328.5 ^{d}
SWF	0	75.7 ^{a}	75.7 ^{a}	91.7 ^{a} 157.0 ^{a}	91.7 ^{a} 157.0 ^{a}	N/A	N/A	313.5 ^{a}	314.0 ^{a}
	6	77.3 ^{ab}	76.8 ^{a}	95.2 ^{b} 156.5 ^{a}	94.0 ^{ab} 160.0 ^{a}	N/A	N/A	347.0 ^{bc}	330.0 ^{ab}
	12	79.7 ^{bcx}	75.8 ^{ay}	95.7 ^{b} 158.5 ^{a}	94.7 ^{b} 172.5 ^{a}	N/A	N/A	358.0 ^{c}	353.5 ^{b}
	18	80.8 ^{cx}	76.0 ^{ay}	95.4 ^{b} 187.5 ^{b}	95.9 ^{b} 190.5 ^{a}	50.1 ^{a} 348.0 ^{a}	49.9 ^{a} 357.5 ^{a}	328.5 ^{ab}	333.0 ^{ab}
	24	81.7 ^{cx}	75.1 ^{ay}	95.8 ^{b} 203.0 ^{b}	96.0 ^{b} 188.0 ^{a}	63.6 ^{b} 388.0 ^{b}	63.4 ^{a} 370.0 ^{a}	351.0 ^{bcx}	337.0 ^{aby}
WS	0	75.1 ^{a}	75.7 ^{a}	95.9 ^{a} 363.5 ^{a}	95.9 ^{a} 363.5 ^{a}	N/A	N/A	877.0 ^{a}	877.0 ^{a}
	6	83.4 ^{bx}	76.2 ^{ay}	95.9 ^{a}	96.4 ^{a}	N/A	N/A	828.5 ^{a}	786.0 ^{ab}

				385.5 [a]	347.5 [a]				
	12	86.0 [cx]	77.7 [ay]	96.3 [a] 370.0[a]	95.9 [a] 352.5 [a]	N/A	N/A	739.0 [ab]	723.0 [bc]
	18	87.1 [cx]	75.1 [ay]	95.3 [a] 356.5 [a]	95.9 [a] 352.5 [a]	69.9 [ax] 830.5 [a]	66.3 [ay] 835.0 [a]	602.0 [bc]	616.5 [cd]
	24	87.5 [cx]	75.7 [ay]	96.2 [a] 359.5 [a]	96.0 [a] 340.5 [a]	72.0 [ax] 818.0 [a]	66.6 [ay] 805.0 [a]	508.0 [c]	572.0 [d]

Table 4: Micro ViscoAmyloGraph data for pasting temperature, peak temperature, peak viscosity, second peak temperature, second peak viscosity and final viscosity for HWF, SWF and WS with varying addition levels of MAG gel or mixture. Means within a treatment type (HWF, SWF, WS) for each pasting attribute within a row with the same letter (a, b, c) are not significantly different ($p<0.05$), n=2. Means within each lipid type (0,6,12,18,24%) for each treatment (HWF, SWF, WS) within a column with the same letter (x, y, z) are not significantly different ($p<0.05$), n=2.

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