

# Glass Transition Behavior and Rheological Properties of Surfactants and Gluten-Surfactant Mixtures

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ABSTRACT

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Diacetyltartaric acid esters of monoglycerides (DATEM) and sodium stearyl lactylate (SSL) displayed thermal events corresponding to glass transition temperature ( $T_g$ ) and melting of crystalline domains, while monoglycerides (MG) exhibited an endothermic peak corresponding to melting of crystalline structures when heated in a differential scanning calorimeter. The plasticizing effect of water on  $T_g$  of gluten exhibited little apparent change in the presence of DATEM, MG, or SSL (gluten-surfactant 10:1), in the moisture range of 6.5–21.3% as shown by mechanical spectrometry and differential scanning calorimetry. Gluten-surfactant mixtures showed higher  $G'$  and apart from gluten-SSL, which

displayed higher  $\tan \delta$  ( $G''/G'$ ) at  $\leq 2.51$  rad/sec, lower  $\tan \delta$  values than gluten in the frequency range of 0.1–100 rad/sec. DATEM and SSL softened the gluten network before cross-linking reactions, while MG shifted the onset of cross-linking reactions to higher temperatures at moisture contents of 30–40%. Complete vitrification of the gluten network occurred at higher temperatures, at the indicated moisture contents, in the presence of surfactants. Softening of the matrix and the delay in cross-linking of gluten, in the presence of surfactants, might allow for greater expansion of doughs during baking with concomitant increase in loaf volumes.

The behavior of wheat flour doughs during processing is largely determined by the rheological properties of gluten proteins. Furthermore, the structure and texture of baked products is shaped, to a large extent, by the heat-induced changes in gluten during baking (Davies 1986; Hoseney 1989). Gluten exists in an amorphous, metastable state that is sensitive to changes in moisture and temperature and undergoes a glass transition in a similar manner to amorphous synthetic polymers (Hoseney et al 1986; Cherian and Chinachoti 1996; Nikolaidis and Labuza 1996). Levine and Slade (1990) suggested that once heated through its glass transition, gluten acquires enough mobility due to thermal and water plasticization to form a thermoset network that is responsible, along with changes in the starch fraction, for the structure of baked products.

Monoglycerides (MG), diacetyltartaric acid esters of monoglycerides (DATEM), and sodium stearyl lactylate (SSL) are surface-active agents (surfactants) that are widely used in yeast-raised baked products as crumb softeners and dough strengtheners. Crumb softening refers to the ability of surfactants to reduce the rate of firming of baked products during storage, while dough strengthening is manifested in greater resistance of the dough to mechanical abuse, improved oven spring, and larger loaf volume of baked products (Stauffer 1999). Both crumb softening and dough strengthening effects are exhibited by the aforementioned surfactants to varying degrees. MG predominantly possesses crumb softening effects, while DATEM and SSL exhibit primarily dough strengthening effects in addition to possessing some ability to inhibit crumb firming (Tamstorf et al 1986; Knightly 1996). The crumb softening effects of surfactants are largely attributed to their interaction with the starch fraction of the dough. Surfactants adsorb onto the surface of starch granules, thereby leading to an increase in gelatinization temperature, reduced leaching of amylose from swollen starch granules, and inhibited starch retrogradation by forming complexes with amylose and the outer chains of amylopectin (Krog et al 1989; Rao et al 1992; Roach and Hoseney 1995). The dough strengthening effects of surfactants are believed to be modulated through their interactions with the gluten proteins. Hydrophobic interactions between the lipophilic moiety of surfactants and hydrophobic domains of gluten allow for the incor-

poration of the negative charges of anionic surfactants such as DATEM and SSL into the protein matrix. This leads to neutralization of surface charge of proteins and the formation of protein aggregates that impart strength to the dough (Schuster and Adams 1984; Orthofer 1997; Stauffer 1999).

The strong association between SSL and gluten (DeStefanis et al 1977) at the dough stage has been suggested to cause a delay in the denaturation and setting of gluten during baking, thereby leading to an increase in loaf volume (Stauffer 1999). Addition of DATEM to gluten results in increased resistance to extension (as measured in an extensigraph) that was highly correlated with the increase in bread loaf volume (Köhler and Grosch 1999). In common with surfactants, incorporating shortening into the bake mix results in an increase in bread loaf volume (Tamstorf et al 1986; Roach and Hoseney 1995; Knightly 1996; Stauffer 1999). Levine and Slade (1990) suggested that the increase in bread loaf volume brought about by shortening arises from lipid plasticization of gluten, thereby leading to an extension of its thermoplasticity early in the baking process, before thermosetting of the plasticized gluten network at the end of baking.

Substances that interact with gluten might affect its glass transition behavior and the kinetics of cross-linking reactions leading to network formation. Shortening increases the glass transition temperature ( $T_g$ ) of gluten (Levine and Slade 1987), while low molecular weight fatty acids have a plasticizing effect causing a decrease in  $T_g$  of gluten (Kalichevsky et al 1992). Dynamic oscillatory techniques have been particularly effective in mapping changes in viscoelastic behavior of gluten in response to processing and ingredient changes. Processes or ingredients that promote cross-linking or induce depolymerization of gluten result in changes in dynamic moduli of the material (Attenburrow et al 1990; Li et al 2000; Lambert and Kokini 2001).

The diverse functional roles of surfactants in food systems have been linked to different physical structures (mesophases) formed by these molecules when heated in the presence of water (Krog 1990; Bergenstahl 1997). However, little is known about the glass transition behavior of surfactants. In the present work, we report on the glass transition behavior of MG, DATEM, and SSL, and their mixtures with gluten, and on the dynamic oscillatory behavior of these mixtures.

## MATERIALS AND METHODS

Wheat gluten (80% protein on dry mass basis; lot # 127H0169) was obtained from Sigma Chemical Co. (St. Louis, MO). Distilled MG (Dimodan PVK; lot # 709SA58) and DATEM (Panodan

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PVK; lot # 709SB37) were obtained from Danisco Ingredients USA (New Century, KS); SSL (Emplex; lot # 268801602) was obtained from American Ingredients Co. (Grandview, MO).

### Preparation of Samples

Gluten was brought to 50% moisture content (mc) and mixed in a resistograph (Brabender Instruments, South Hackensack, NJ) at 63 rpm and 30°C for 10 min. The resulting gluten dough was fed into a single-screw extruder (Brabender Instruments, S. Hackensack, NJ) and extruded at 50 rpm and 50°C to shape into strips that were subsequently left at room temperature, until 10–12% mc was attained. A portion of the extrudate was freeze-dried (model 50-SRC, Virtis, Gardiner, NY) to 2–3% mc and milled (model ZMI, Glenmills Inc., Maywood, NJ) fitted with a 0.12-mm screen. The surfactants were added at a level of 10% (gluten basis) by dispersing in water at 50°C before mixing with gluten to facilitate even distribution of the surfactant. Gluten-surfactant mixtures were processed as described previously to produce strips and powders. Gluten and gluten-surfactant strips were sized, through rubbing with sand paper, to dimensions contingent with the rectangular torsion fixture of the mechanical spectrometer. The surfactants, gluten and gluten-surfactant strips and powders were equilibrated over P<sub>2</sub>O<sub>5</sub> or saturated solutions of LiCl, CH<sub>3</sub>COOK, K<sub>2</sub>CO<sub>3</sub>, NaBr, NaCl, or KCl, which produced equilibrium relative humidities of 0, 12, 23, 44, 52, 75 and 84% rh, respectively (DeGraaf et al 1993), to produce samples with different moisture contents.

Disks were cut from sheets obtained by pressing gluten or gluten-surfactant doughs between plexiglas plates to a thickness of 2 mm and storing at 5°C for 48 hr. The disks were equilibrated over saturated NaCl solutions to a final moisture content of 30 or 40% mc.

### Differential Scanning Calorimetry

DSC was conducted on a TA 4000 thermal analysis system with a DSC 30-S cell and a TC11TA processor (Mettler Instruments,

Hightstown, NJ). The system, fitted with a liquid nitrogen-controlled cooling accessory, was calibrated for temperature with *n*-hexane (mp -93.5°C), water (mp 0.0°C), and indium (mp 156.6°C), and for heat flow with indium (heat of fusion 28.45 J/g). Samples were placed in 40- $\mu$ L aluminum pans and scanned from -160 to 180°C at 5°C/min, using an empty aluminum pan as a reference. Thermograms were analyzed by Graphware TA72 software. The  $T_g$  was determined as the midpoint between onset and end temperatures of the endothermic shift in heat capacity.

### Mechanical Spectrometry

Mechanical spectrometry was conducted with a device fitted with liquid nitrogen-controlled cooling accessory (RMS-800, Rheometrics, Piscataway, NJ). Gluten and gluten-surfactant strips (length 43.7  $\pm$  2.34 mm, width 11.40  $\pm$  0.34 mm, thickness 1.49  $\pm$  0.03 mm) were placed in the rectangular torsion fixture of the RMS and scanned at 0.05% strain and 6.28 rad/sec (1 Hz), parameters found within the linear viscoelastic range of the materials, from -80 to 160°C at 5°C/min. The  $T_g$  was determined as the temperature at which the loss modulus ( $G''$ ) was maximum (Aklonis and MacKnight 1983).

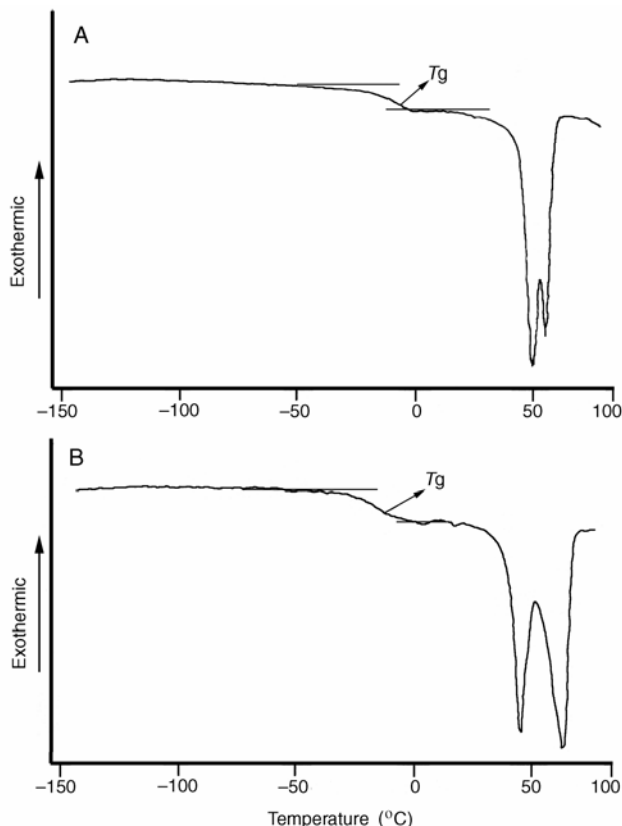
### Pressure Rheometry

The dynamic properties of gluten and gluten-surfactant mixtures were determined with a pressure rheometer (RPR, Rheometrics, Piscataway, NJ) operated at 200 psi to prevent moisture loss when samples were heated to >100°C. Disks (diameter 20 mm, thickness 2 mm) were placed between parallel plates, allowed to relax for 15 min, and then scanned, at 0.6% strain and 6.28 rad/sec (1 Hz) in the range of 40–190°C at 5°C/min. The coefficient of variation of replicate determinations of  $G'$  and  $G''$  had a range of 11.33–22.74% and 17.40–20.12%, respectively. Frequency sweeps in the range of 0.1–100 rad/sec were recorded at 25°C and atmospheric pressure. Moisture content of surfactants was determined by Karl-Fischer titration (AOCS 1990). Moisture content of gluten and gluten-surfactant samples was determined by vacuum drying at 100°C and 25 mmHg for 6 hr (AACC 1995). Reported values are means of triplicate determinations.

## RESULTS AND DISCUSSION

### Glass Transition Behavior of Surfactants and Gluten-Surfactant Mixtures

DSC thermograms of DATEM and SSL exhibited an inflection in heat capacity ( $C_p = dH/dT$ ), characteristic of  $T_g$ , followed by



**Fig. 1.** Differential scanning calorimetry heat flow curves (5°C/min) of DATEM (A) with 2.5% moisture and SSL (B) with 1.8% moisture.

**TABLE I**

**Glass Transition Temperature ( $T_g$ ) of Diacetyl Tartaric Acid Esters of Monoglycerides (DATEM) and Sodium Stearoyl Lactylate (SSL) at Different Moisture Contents Determined by Differential Scanning Calorimetry<sup>a</sup>**

	Moisture Content (%)	$T_g$ (°C)
DATEM	0.0 $\pm$ 0.00	7.6 $\pm$ 0.25
	0.8 $\pm$ 0.08	1.9 $\pm$ 0.30
	2.0 $\pm$ 0.07	-8.8 $\pm$ 0.82
	2.5 $\pm$ 0.08	-18.9 $\pm$ 0.71
	5.1 $\pm$ 0.14	-26.0 $\pm$ 1.12
	10.3 $\pm$ 0.17	-37.8 $\pm$ 0.72
SSL	1.5 $\pm$ 0.11	-3.6 $\pm$ 0.32
	1.8 $\pm$ 0.05	-17.7 $\pm$ 0.21
	4.2 $\pm$ 0.16	-27.6 $\pm$ 0.87
	5.9 $\pm$ 0.08	-57.1 $\pm$ 0.72; -35.9 $\pm$ 0.95
	10.5 $\pm$ 0.12	-77.4 $\pm$ 1.79; -5.18 $\pm$ 1.43
	16.1 $\pm$ 0.30	-86.1 $\pm$ 0.98; — <sup>b</sup>

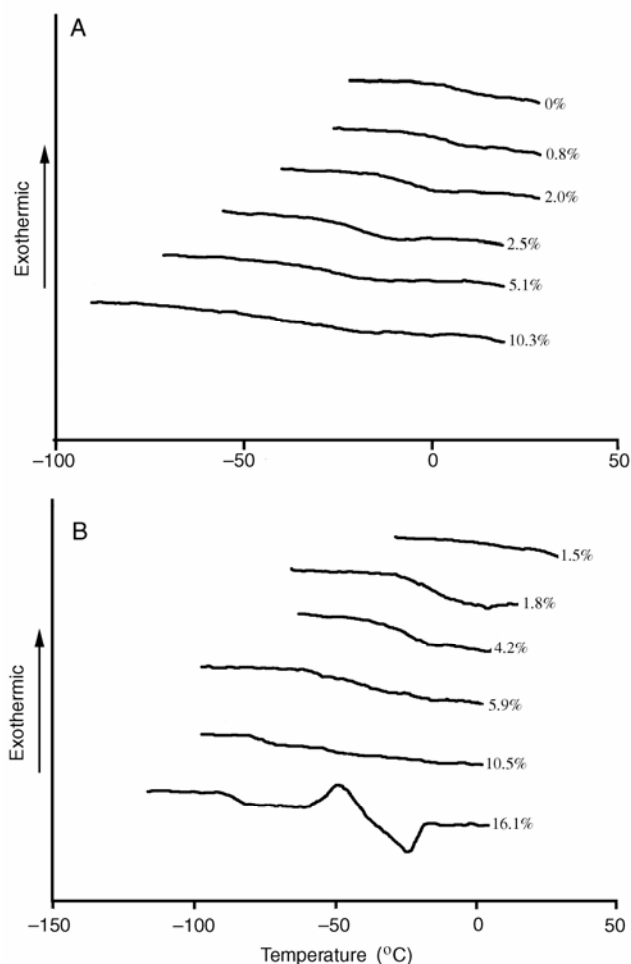
<sup>a</sup> Average of triplicate determinations  $\pm$  standard error of mean.

<sup>b</sup> Glass transition superimposed on melting and crystallization of polymorphic forms of surfactant (Fig. 2).

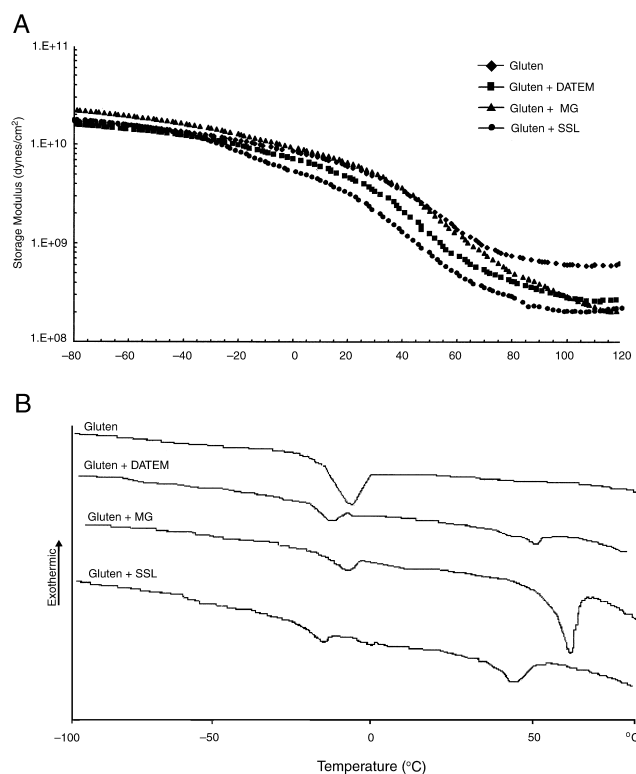
large endothermic peaks between 40 and 70°C due to melting of crystalline structures (Fig. 1). The small endothermic shift moved to lower temperatures, with increasing moisture contents, consistent with it being due to a glass transition (Table I, Fig. 2). DATEM sorbed less moisture at a given relative humidity than SSL possibly due to its lower hydrophilic/lipophilic balance (Schuster and Adams 1984). At moisture contents  $\geq 5.9\%$ , SSL displayed two  $T_g$ , with one being superimposed on melting and crystallization of polymorphic forms at moisture content of 16.1%, possibly due to partitioning of the different forms and isomers at these moisture levels. This finding coupled with the display of multiple melting peaks in the DSC thermograms is consistent with the presence of multiple isomers in commercial preparations of DATEM and SSL (Zielinski 1997; Stauffer 1999; Köhler 2001). The presence of an endothermic shift, characteristic of  $T_g$ , and endothermic peaks corresponding to the melting of crystalline regions in the heat flow curves delineate DATEM and SSL as partially crystalline materials (Slade et al 1988). MG displayed an endothermic peak corresponding to melting of crystalline structures at 65–70°C and did not show a  $T_g$  under the conditions of measurement, possibly due to its predominantly crystalline nature (data not shown).

The magnitude of drop in  $G'$  at  $T_g$  increased in the presence of MG, DATEM, and SSL, mainly due to a decrease in the rubbery storage modulus (Fig. 3). This broadening of glass transition zone, which is indicative of an increase in relaxation times of polymeric constituents (Ferry 1980) by surfactants, has been reported for wheat gluten (Kalichevsky et al 1992) and corn gluten meal (Di Gioia and Guilbert 1999). No drop in  $G'$  corresponding to  $T_g$  of DATEM or SSL was observed in mechanical spectrometry thermo-

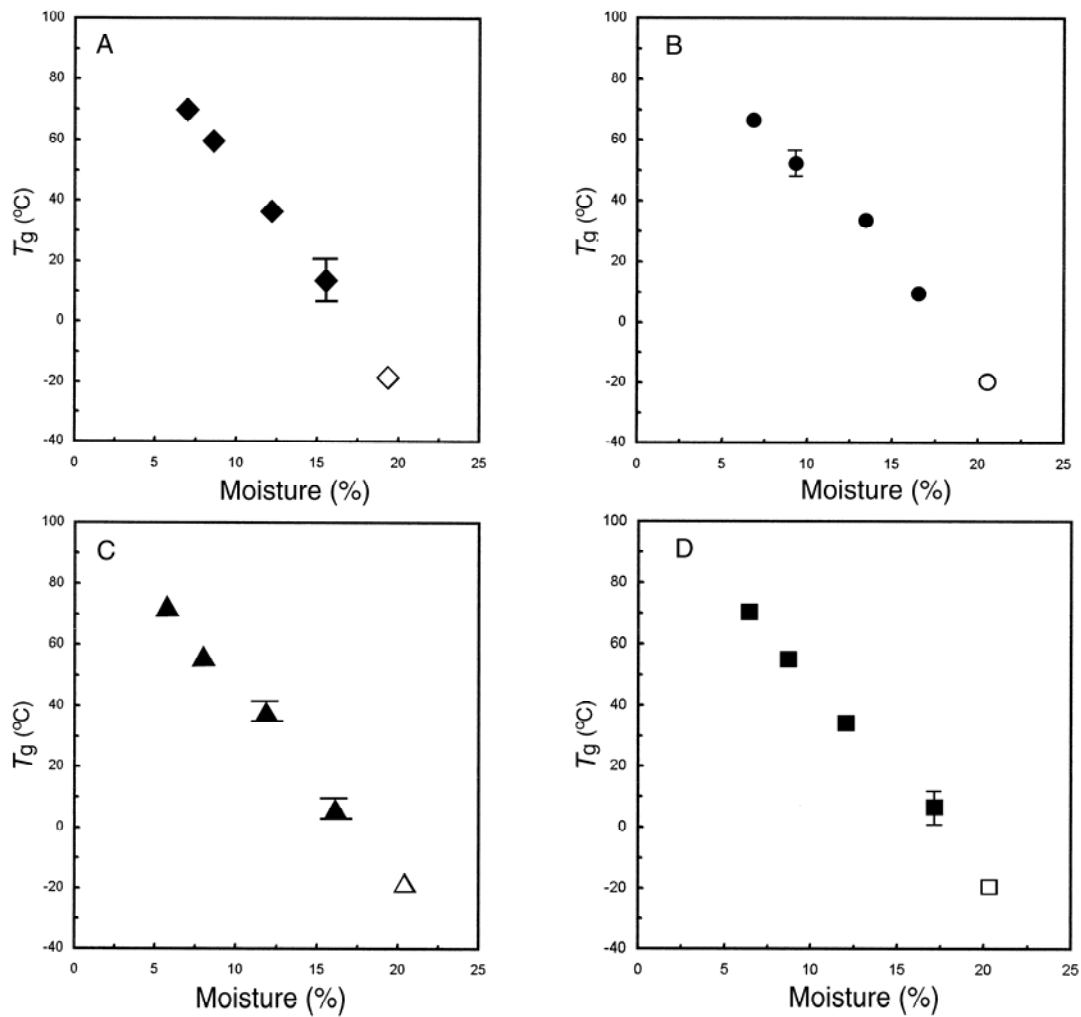
grams of gluten-surfactant mixtures, possibly due to the low concentration of surfactant in the mixture or a change in the molecular order of surfactants in the presence of gluten (Fig. 3). Thermal events associated with glass transition were not detected for surfactants in the mechanical spectra of blends of corn gluten meal and surfactant (Di Gioia and Guilbert 1999). At  $<15\%$  mc, DSC thermograms of gluten-surfactant mixtures displayed broad peaks reflecting thermal events associated with glass transition of gluten and melting of the surfactant, and no unambiguous determination of  $T_g$  could be made. However, at moisture contents allowing resolution of peaks corresponding to the aforementioned thermal events, DSC thermograms showed essentially no change in  $T_g$  of gluten, irrespective of the surfactant added (Fig. 3). The plasticizing effect of water on  $T_g$  of gluten showed little apparent change in the presence of surfactants in the investigated moisture range (6.5–21.3% mc) (Fig. 4). The rate of decrease in  $T_g$  of gluten as a function of water was 6.1°C/1% water, a value close to those reported by others: 5°C/1% water by Gontard and Ring (1996), 8°C/1% water by Nicholls et al (1995); those for gluten-surfactant complexes had a range of 6.2–6.3°C/1% water. These findings indicate that the overall hydrophilicity, and therefore compatibility of gluten with water, is essentially unaltered by the investigated surfactants. The plasticizing effect of water on  $T_g$  of gluten was not affected in the presence of MG (Kalichevsky et al 1992). Gluten is effectively plasticized by water, consistent with its hydrophilic nature, with the increase in  $\beta$ -sheet conformation observed on hydration from the dry state being attributed to the ordering resulting from transition from the glassy to the rubbery region (Belton 1999). Polar lipids of flour, which exhibit similar functionality to surfactants (Knightly 1996), do not affect the proportion of  $\beta$ -sheet regions in gluten as evidenced by the similar hydration behavior of gluten and its polar-lipid-free counterpart (Grant et al 1999). These observations suggest that surfactants do not interact with the hydrophilic domains of gluten that are



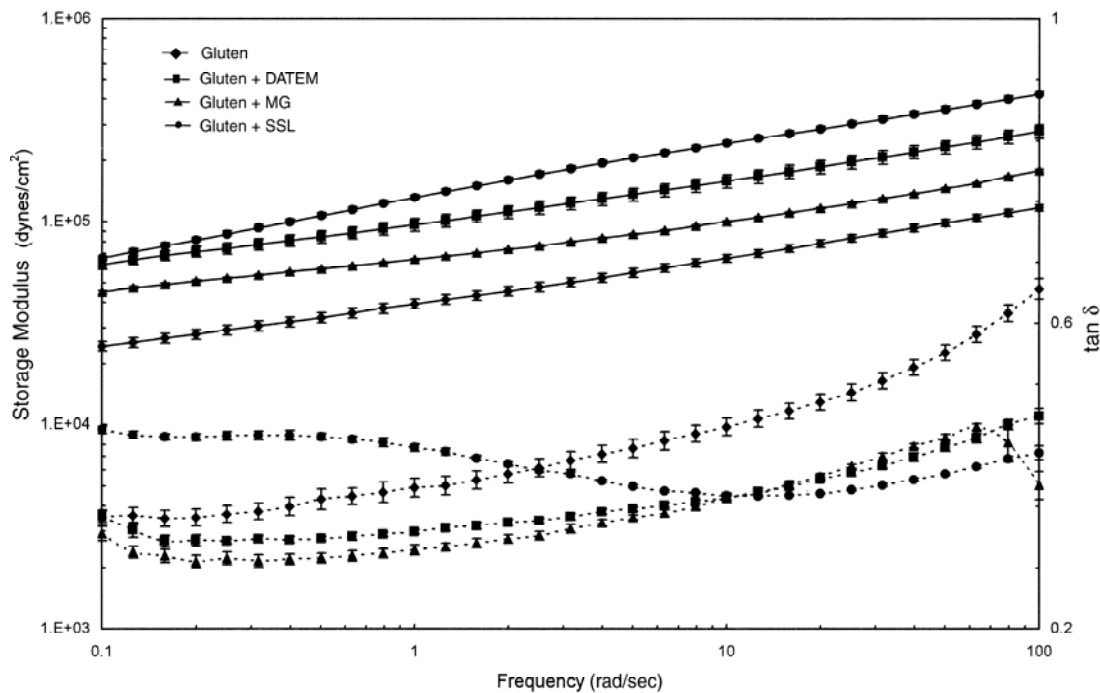
**Fig. 2.** Differential scanning calorimetry heat flow curves (5°C/min) at different moisture contents of DATEM (A) and SSL (B).



**Fig. 3.** Storage moduli of gluten and gluten-surfactant mixtures (strain 0.05%,  $\nu$  6.28 rad/sec) at moisture contents of 12.0–13.6% (A) and differential scanning calorimetry heat flow curves (5°C/min) of gluten and gluten-surfactant mixtures at moisture contents of 20.5–21.3% (B).



**Fig. 4.** Glass transition temperatures of gluten (A), gluten+SSL (B), gluten+MG (C), gluten+DATEM (D) at different moisture contents from mechanical spectrometry (solid symbols) and differential scanning calorimetry (open symbols).



**Fig. 5.** Frequency dependence of the dynamic oscillatory behaviors of 50% moisture gluten and gluten-surfactant mixtures at 0.6% strain and at 25°C.  $G'$  (—),  $\tan \delta$  (---).

responsible for glass transition and are largely present in the hydrophobic areas buried inside the network. The similar  $T_g$  of native and hydrophobized gluten prepared by treatment with caproic acid anhydride has been reported to be due to similar hydration behaviors (Micard and Guilbert 2000).

### Dynamic Oscillatory Behavior of Gluten-Surfactant Mixtures

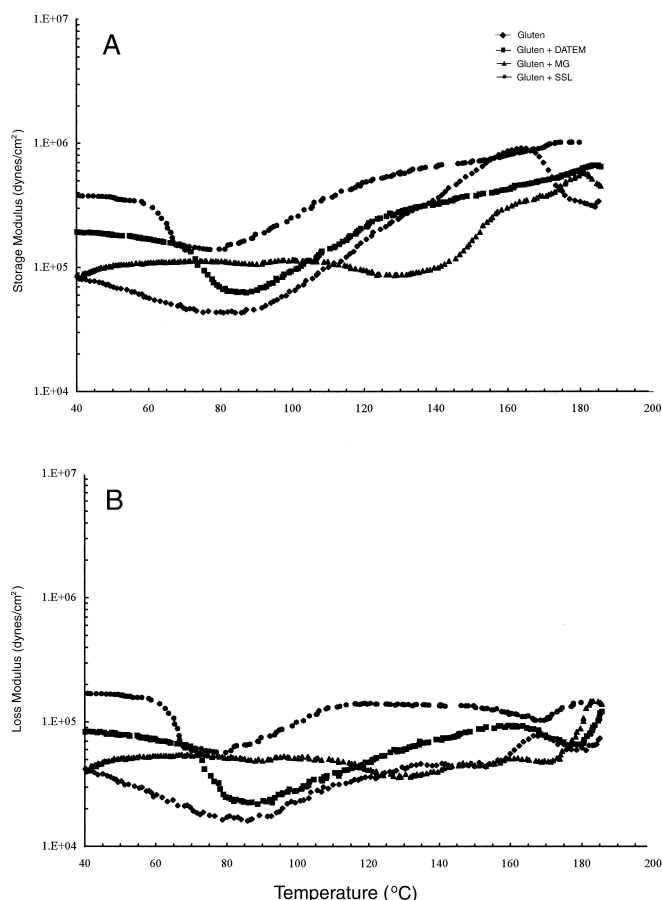
Gluten-surfactant mixtures containing 50% moisture exhibited higher  $G'$  as compared with gluten throughout the frequency range investigated. Furthermore, apart from gluten-SSL that showed higher  $\tan \delta$  ( $G''/G'$ ) at  $\leq 2.51$  rad/sec, the mixtures had lower  $\tan \delta$  values at all the frequencies examined (Fig. 5). A similar pattern was observed at the 40% mc (data not shown). The observed increase in the elastic character of gluten in the presence of surfactants is indicative of a higher order of association between gluten polymers. An increase in size distribution of gluten (Cornec et al 1994) and degree of association and cross-linking of gluten polymers (Khatkar et al 1995; Miller and Hoseney 1999; Larré et al 2000) are known to result in an increase in the elastic character of gluten networks. These findings lend support to the surfactant-mediated aggregation of gluten proteins believed to be responsible for dough-strengthening effects of surfactants (Stauffer 1999) and the hyperaggregation of high molecular weight glutenin subunits in the gluten network brought about by increased hydrophobic interactions in the presence of surfactants (Hamer and van Vliet 2000).

The magnitudes of  $G'$  and  $G''$  for 40% moisture gluten decreased between 40 and 75°C and showed little changes with further heating to 93°C. The storage modulus increased sharply, as the material was heated above 93°C, and reached a maximum at 162°C, while  $G''$  increased slowly from 93 to 120°C, remained

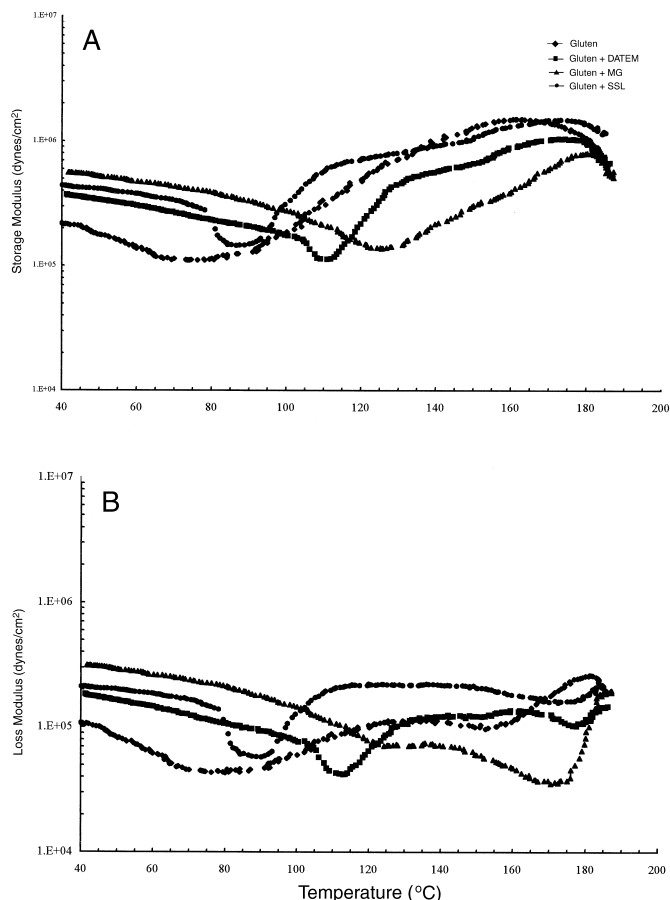
almost constant between 120 and 140°C, and exhibited a minimum at 160°C. The pattern of change in  $G'$  and  $G''$  indicates the formation of cross-links, presumably through disulfide bonds (Lefebvre et al 2000; Apichartsrangkoon 2002), tyrosine cross-links (Tilley et al 2001), and hydrophobic interactions (Roy et al 1999), and the development of a network structure with maximum cross-link density (Kokini et al 1995) at 160–162°C. Heating gluten to  $>130^\circ\text{C}$  reportedly affects cross-linking of gliadins to glutenins (Singh and MacRitchie 2001) and to result in a 97.7% decrease in solubility in SDS solutions (Micard et al 2000). The storage modulus decreased while  $G''$  increased to a maximum at 170°C on further heating, thereby indicating softening and devitrification (Kokini et al 1995) of the vitrified network (Fig. 6).

The dynamic moduli of gluten-SSL decreased slowly in the temperature range of 40–58°C and exhibited a marked drop in magnitude to a minimum at 70°C with further heating. The moduli showed little change as the temperature increased to 82°C and increased sharply on heating to 120°C. The storage modulus increased more slowly with further heating, while  $G''$  showed little change up to 150°C and then exhibited a small dip to a minimum at 170°C and slowly increased thereafter. In contrast to gluten, complete vitrification and subsequent devitrification and softening were not observed for gluten-SSL in the investigated temperature range (Fig. 6).

Gluten-DATEM exhibited a similar behavior to gluten-SSL with the drop in the magnitude of  $G'$  and  $G''$  taking place between 68 and 80°C and the biphasic increase in  $G'$  at 93 and 120°C. In common with SSL, DATEM slowed down the rate of cross-linking reactions in the gluten network and complete vitrification was not observed in the investigated temperature range (Fig. 6). The dynamic moduli of gluten-MG remained almost constant in the



**Fig. 6.** Temperature sweep of 40% moisture gluten and gluten-surfactant mixtures (strain 0.6%;  $\nu$  6.28 rad/sec; pressure 200 psi). Storage modulus ( $G'$ ) (A). Loss modulus ( $G''$ ) (B).



**Fig. 7.** Temperature sweep of 30% moisture gluten and gluten-surfactant mixtures (strain 0.6%;  $\nu$  6.28 rad/sec; pressure 200 psi). Storage modulus ( $G'$ ) (A). Loss modulus ( $G''$ ) (B).

temperature range of 40–115°C and decreased slowly on heating to 130°C. The storage modulus increased sharply as the material was heated to >130°C, while  $G''$  remained almost constant between 130 and 160°C and showed a minimum at 175°C thereby indicating maximum structure buildup. In contrast to the complexes between gluten and DATEM or SSL, gluten-MG exhibited devitrification in the investigated temperature domain at 182°C.

Softening of the matrix in the early stages of the heating cycle and the onset of cross-linking reactions shifted to higher temperatures for gluten-DATEM and gluten-SSL mixtures at 30% mc (Fig. 7). Gluten-MG complexes exhibited higher moduli than gluten-DATEM and gluten-SSL complexes at this moisture level, possibly due to the formation of mesophases with higher interactive capacity with gluten. However, the onset of cross-linking reactions in the gluten-MG complex showed no variation with changes in moisture levels and took place at 130°C at 30 and 40% mc. Furthermore, at 30% mc complete vitrification and devitrification of gluten-surfactant mixtures were realized in the investigated temperature domain, although at a higher temperature than observed for gluten. The higher order of cross-linking in the gluten network attained at 30% mc could be attributed to the closer proximity of the polymer chains and, therefore, enhanced ability to associate by S-S and tyrosine cross-links and hydrophobic interactions.

These findings indicate that binding of surfactants to gluten, possibly through hydrophobic interactions and electrostatic bonds in the case of DATEM and SSL, causes conformational changes in the polymer chains that affect the dynamics of cross-linking reactions during heating. MG shifted the onset of cross-linking reactions in gluten from 93 to 130°C, while DATEM and SSL induced softening of the gluten network, as evidenced by the drop in  $G'$  and  $G''$ , prior to cross-linking reactions at moisture contents of 30–40%. Furthermore, complete vitrification of the gluten network was delayed in the presence of surfactants and occurred at higher temperatures at the aforementioned moisture levels. The ability of surfactants to impart a fine grain structure to yeast-leavened baked products has been related to their ability to inhibit coalescence of small gas cells at the dough stage through increasing the surface dilatational modulus at the dough-gas interface (Kokelaar et al 1995). Such an increase in dilatational modulus, a measure of strength and stiffness of gas-dough interface, is not expected to be responsible for the increase in loaf volume of breads baked from surfactant-containing doughs, especially as the rate of carbon dioxide release on baking did not affect the loaf-volume potential of doughs (Junge and Hosney 1981). Shortening and surfactants exhibit similar functionality, fine grain structure and higher loaf volume, in yeast-leavened baked products. The increase in loaf volume brought about by shortening has been related to the ability of the shortening-containing dough to remain extensible for a longer time during baking and that such a delay in dough setting is not due to shifting of starch gelatinization to higher temperatures (Junge and Hosney 1981). The delay in cross-linking coupled with softening of the gluten network during the early stages of the heating cycle in the presence of surfactants observed in the present work might allow for a greater expansion of surfactant-containing wheat flour doughs during baking, thereby yielding products with larger volume. The increase in bread loaf volume on incorporation of shortening into wheat flour doughs has been hypothesized to arise from enhanced thermoplasticity of gluten (Levine and Slade 1990; Fu et al 1997).

## CONCLUSIONS

Diacetyl tartaric acid esters of monoglycerides (DATEM) and sodium stearyl lactylate (SSL) exhibited changes associated with glass transition and melting of crystalline domains on heating in differential scanning calorimetry. Monoglycerides (MG) displayed thermal events corresponding to melting of crystalline structures

under the same conditions. Monoglycerides, DATEM, or SSL did not induce apparent changes in the plasticizing effect of water on  $T_g$  of gluten. Apart from gluten-SSL complexes that exhibited higher viscous component in viscoelastic response at  $\leq 2.5$  rad/sec, frequency sweeps (0.1–100 rad/sec) showed an increase in the elastic character of gluten networks, reflected by an increase in the storage modulus, in the presence of surfactants. The observed lack of effect on glass transition behavior and the marked changes in gluten viscoelasticity observed at moisture contents and temperatures where gluten is known to exist in a rubbery state indicate that surfactants influence gluten rheology in the rubbery domain. A similar behavior has been reported for  $KBrO_3$ , another functional additive used in dough systems, which exhibited marginal effects on glass transition of gluten (Cherian and Chinachoti 1997) and induced marked changes in the viscoelastic response of gluten in the rubbery state (Attenburrow et al 1990). Surfactants softened the network, slowed down the rate, and delayed the onset of cross-linking reactions in gluten on heating. The changes in gluten rheology induced by surfactants during heating might allow for a greater expansion of wheat flour doughs on baking and production of larger loaf volumes.

## ACKNOWLEDGMENTS

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#### Erratum

Corrections were made to this article on January 12, 2005. The affiliations and addresses were corrected. The second sentence in the abstract and the second sentence under the heading "Mechanical Spectrometry" were changed. The top line of the second column on page 584 was also changed. Figure 7 was replaced.