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Effect of sodium stearoyl-2-lactylate, carboxymethyl cellulose and guar–xanthan gums on muffins enriched with soybean milk powder and amaranth flour

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ABSTRACT
Soybean milk powder (SMP) and amaranth flour (AF) can improve the nutritional profile of bakery products. Nonetheless, these ingredients can impart undesirable effects on batter rheology and product texture. In this study, the effect of three additives (carboxymethyl cellulose(CMC), sodium stearoyl-2-lactylate (SSL), guar–xanthan gum mix (GX)) was evaluated on batter rheology and the physical, chemical and textural parameters of muffins baked with SMP and AF. Protein content was increased in all muffins made with SMP–AF. SMP–AF also increased muffins’ hardness and chewiness, but additives distinctly counteracted this effect on texture, crumb total color difference and specific volume. Of all additives, SSL ameliorated the effect of SMP–AF on the batter’s rheology. Overall results indicate that muffins’ nutritional value can be improved by using ingredients such as SMP and AF. Moreover, SSL can be added to muffins’ formulations to compensate the effect of SMP and AF on textural and rheological characteristics.

KEYWORDS
sodium stearoyl-2-lactylate, carboxymethyl cellulose, guar–xanthan gum, soybean milk powder, amaranth flour

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RESUMEN
La leche de soya en polvo (SMP) y la harina de amaranto (AF) pueden mejorar el perfil nutrimental de productos panaderos. Sin embargo, estos ingredientes imparten efectos no deseables en la reología de masa y textura de productos. En este estudio, el efecto de tres aditivos (carboximetilcelulosa(CMC), estearoil-2-lactilato de sodio-SSL), mezcla de gomas guar-xantana-(GX)) se evaluó en la reología de masa y parámetros físicos, químicos y textura en muffins con SMP-AF. Los muffins con SMP-AF tuvieron mayor proteína. La dureza y chicollosidad también se incrementaron, pero los aditivos contrarrestaron este efecto en la textura, diferencia total de color de la migas y volumen-específico. El SSL mejoró el efecto de SMP-AF en la reología de la masa. Esto indica que el valor nutrimental de muffins puede ser mejorado con SMP-AF. Además, SSL puede ser añadido a formulaciones de muffins para contrarrestar el efecto de SMP-AF en características texturiales y reológicas.

1. Introduction
Muffins are chemically leavened bakery products used for breakfast or as a snack. They are highly appreciated by consumers due to their good taste and soft texture. Muffin batter is a complex fat-in-water emulsion composed of an egg–sugar–water–fat mixture (continuous phase) and bubbles (discontinuous phase) in which flour particles are dispersed (Matos, Sanz, & Rosell, 2014). These bubbles are produced and entrapped during the mixing process. Batter is considered stable when the tiny air bubbles generate a final product with a porous structure and high volume (Baixauli, Sanz, Salvador, & Fiszman, 2008). Hence, the quality of ingredients and their interactions influence the quality of a final baked product.

Soybean milk powder (SMP) and amaranth flour (AF) are among the many ingredients that have been used in baked goods to improve their nutritional value. SMP contains no less than 38% protein, 13% fat and 90% of total solids. All soybean seed components (e.g. protein, isoflavones, soluble and insoluble dietary fiber) are present in its milk powder (Nilufer, Boyacioglu, & Vodovozt, 2008). The effect of soy flour and Okara (soy pulp) on the functional properties of baked goods has been extensively studied. However, little to no information is available on the effect of SMP on baked goods (Nilufer-Erdil, Serventi, Boyacioglu, & Vodovozt, 2012). In one study, soybean milk solids were found to contribute differently, and, in some cases, they had opposing effects on soy bread physicochemical properties (Nilufer et al., 2008). On the other hand, AF has been used as a complement of wheat flour to improve the nutrient profile of baked products (Capriles et al., 2008). Amaranth is an excellent source of high-quality protein, starch, lipids, minerals (e.g. calcium, potassium and phosphorus) and dietary fiber (De La Barca, Rojas-Martínez, Islas-Rubio, & Cabrera-Chávez, 2010). Its protein is rich in lysine, which is usually deficient or limited in cereal grains (Álvarez-Jubete, Auty, Arendt, & Gallagher, 2008).
2010). However, previous work on conventional pound cakes reported that replacement of wheat flour and corn starch at 30% by AF reduced their specific volume (Capriles et al., 2008).

It is well known that hydrocolloids (gums) can alter the gelatinization and rheological characteristics of starches and improve texture and appearance of final baked products (Christianson, Hodge, Osborne, & Detroy, 1981; Mariotti, Lucisano, Pagani, & Ng, 2009). Traditionally, gums like guar, xanthan and carboxymethyl cellulose (CMC) are widely used in starch-containing foods to control rheological and textural properties of foods, as well as to improve moisture retention and stability (Chaisawang & Suphantharika, 2005). On the other hand, sodium stearoyl-2-lactylate (SSL) is an anionic oil-in-water emulsifier that improves the incorporation of ingredients and the stability of air bubbles. This results in a finer dispersion that improves cake quality. In batters, SSL decreases density by increasing the air incorporation (Jyotsna, Prabhasankar, Indrani, & Rao, 2004).

Even though SMP and AF may improve the nutritional value of baked goods, these ingredients may have undesirable effects on batter rheology and product texture. Therefore, the objective of this study was to evaluate the effect of three additives (CMC, SSL and a guar–xanthan gum mix (GX)) on the rheological properties of batters and on the physical, chemical and textural characteristics of muffins baked with a mix of SMP and AF.

2. Materials and methods

2.1. Batter and muffin preparation

Batters and muffins were prepared as recommended elsewhere (Serna-Saldívar, 2012). Ingredients were chlorinated cake flour (HEB, Monterrey, Mexico), soy milk solids (Latin Foods Int., Monterrey, México), whole AF (Serina®, Tehuacán, Mexico), brown sugar (Zulka®, Culiacan, Mexico), eggs (San Juan, Mexico), shortening (Lirio®, Monterrey, Mexico), nonfat dry milk (DairyAmerica®, Guadalajara, Mexico), molasses (Brer Rabbit®, BG Products, Roseland, NJ, USA), double-acting baking powder (Rexal®, PROMESA, Monterrey, Mexico), sodium bicarbonate (Arm&Harmer®, Church and Dwight, Mexico City, Mexico) and salt (Bahia®, Sales del Valle, Cd. Obregon, Mexico). Five formulations (Table 1) were prepared with the same ingredients, apart from different flour mixtures and the incorporation of different additives: (1) 100% chlorinated cake flour (BC), (2) 90% chlorinated cake flour and 10% soy milk solids:whole AF (8:2) without additive (BS), (3) BS with 0.02% of CMC (BCMC), (4) BS with 0.02% of SSL (BSSL) and (5) BS with 0.02% of guar–xanthan gum blend (1:1) (BGX).

First, shortening, nonfat dry milk, molasses, baking powder and salt were beat for 3 min at medium speed in a mixer (KitchenAid KSM150PSPK, Benton Harbor, MI, USA). Eggs (7.9 g) were added and mixed for 30 s at medium speed before the rest of the eggs (7.9 g) were added and mixed for another 30 s. Then, flour, additives (if mixes were BCMC, BSSL or BGX), brown sugar and sodium bicarbonate were added to the mix and beat at medium speed for 5 min. Batter was placed on paper muffin cups (45 g of batter/muffin cup). Muffins were baked for 18 min at 205°C in a preheated convection oven (Electrolux EOG 601 X, Stockholm, Sweden). Batches of muffins were baked on different days for each analysis.

### Table 1

| Ingredients (%) | BC | BS | BCMC | BSSL | BGX |
|-----------------|----|----|------|------|-----|
| Chlorinated cake flour | 41.81 | 37.63 | 37.63 | 37.63 | 37.63 |
| Soybean milk powder | – | 3.35 | 3.35 | 3.35 | 3.35 |
| Amaranth flour | – | 0.84 | 0.84 | 0.84 | 0.84 |
| CMC | – | 0.02 | – | – | – |
| SSL | – | – | 0.02 | – | – |
| Guar–xanthan gum blend | – | – | – | 0.02 | – |
| Brown sugar | 15.89 | 15.89 | 15.89 | 15.89 | 15.89 |
| Eggs | 15.89 | 15.89 | 15.89 | 15.89 | 15.89 |
| Shortening | 15.89 | 15.89 | 15.89 | 15.89 | 15.89 |
| Nonfat dry milk | 5.02 | 5.02 | 5.02 | 5.02 | 5.02 |
| Molasses | 5.02 | 5.02 | 5.02 | 5.02 | 5.02 |
| Double acting baking powder | 0.27 | 0.27 | 0.27 | 0.27 | 0.27 |
| Sodium bicarbonate | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Salt | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Total | 100.00 | 100.00 | 100.02 | 100.02 | 100.02 |

2.2. Batter properties

Rheology of muffin batters was studied with a Rheometer (RHEOPLUS 32 V3.40, Germany) equipped with a thermostatic bath. A 50-mm diameter plate–plate (PP50-SN22586) with a 2-mm gap between plates was used. Sweep tests were performed at various amplitudes between 0.004 and 40.02 mrad at a constant frequency of 1.59 Hz. Three replicates from each batter type (2 g/sample) were run with good reproducibility. The viscoelastic parameters obtained were storage modulus (G’) and loss modulus (G”) in Pa.

Specific gravity of batters was calculated by the weight of a standard container filled with each batter divided by the same container’s weight filled with water (Matos et al., 2014).

2.3. Physical characteristics of muffins

Three baked muffins from each formulation were randomly selected to measure physical characteristics. Volume was measured by an adapted method of rapeseed displacement (AACC, 2000). Specific volume was determined by dividing each individual muffin’s volume by its weight (Matos et al., 2014). For color, a Minolta chromameter (model CR-300, Minolta Camera Co., Ltd., Chuo-Ku, Osaka, Japan) was used to measure values for L* (brightness or whiteness), a* (redness and greenness) and b* (yellowness and blueness). Each muffin’s crust color was measured directly on the cap from four different randomly selected spots. Crumb color was measured at the center of each freshly cut muffin. Another colorimetric informative model to measure color changes is the total color difference (TCD) (Martins & Silva, 2002; Maskan, 2006). TCD was calculated using the following equation:

\[
TCD = \left[ (L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2 \right]^{1/2}
\]

where \(L_0\), \(a_0\), \(b_0\) refer to reference values, that is, control parameters.
2.4. Chemical composition

Muffins were chemically characterized for moisture (n = 5 per treatment), crude protein (n = 5 per treatment) and crude fat (n = 5 per treatment) following official AACC (2000) methods 44–15.02, 46–13.01 and 30–20.01, respectively.

2.5. Textural analysis

Texture measurements were made using a TA.XT plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY/STable Micro Systems, Godalming, Surrey, United Kingdom) according to the American Institute of Baking (AIB, Manhattan, KS, USA). The Standard Procedure for Muffin Firmness and Elasticity (derivative of the Novo Nordisk modified version of the AACC method 74–09) was applied to six muffins per formulation. All muffins were cut horizontally. The upper halves were discarded, while the lower halves were used for analyses. A texture profile analysis (double compression test) was executed with a strain of 50% of the initial height with a flat-ended cylindrical probe (P/75) at a speed of 1 mm/s with a 5 s interval between the two compression cycles. Hardness, springiness, cohesiveness, and chewiness were measured from the curves.

2.6. Data analysis

Statistical software GraphPad Prism 7.00 was used for all data analyses. Values are presented as means ± SD. All parameters were analyzed by one-way analysis of variance (ANOVA) followed by Tukey’s post hoc test. Statistical significance was declared at p < 0.05.

3. Results and discussion

The effect of additives such as gums and SSL was evaluated on muffins enriched with high-quality protein sources in order to ameliorate possible undesirable characteristics perceived by consumers. The main findings were changes in batter viscosity and muffins’ crumb color and texture, which were mainly improved by SSL, and the increase in protein content caused by SMP and AF flours.

3.1. Strain sweeps and specific gravity of batters

The viscoelastic functions of muffin batters, storage modulus (G’) and loss modulus (G”) were affected by diluting the refined wheat flour content. The rheograms for all muffin batters at 25°C showed that all batters were more elastic than viscous, since G’ was slightly higher than G” (Figure 1). As expected, the batters’ consistency was affected by substituting 10% of wheat flour with SMP and AF. The BS batter was the least elastic and viscous compared to the BC batter (control) and to all formulations with additives. This may be the result of lower water absorption due to the lack of a binding agent (Sivaramakrishnan, Senge, & Chattopadhyay, 2004) and to the diluted effect of wheat gluten (Sanz, Salvador, Vélez, Munoz, & Fiszman, 2005), since some of the wheat flour was replaced with soy and amaranth. Concomitant with this study, others have also shown a decrease in viscoelastic functions in batters when wheat flour was partially replaced with either wheat starch or modified corn starch (Sanz et al., 2005) and resistant starch (Baixauli et al., 2008). Although higher moduli are positively associated with higher protein levels (Navickis, Anderson, Bagley, & Jasberg, 1982), the BS batter was the least elastic and viscous. This observation may be explained by the starch in the AF. The low amylose and high amylopectin quantities in amaranth, as well as its starch morphology, result in higher water absorption compared to wheat (Tömösközi et al., 2011). This and the higher amount of soluble proteins from amaranth cause the delayed formation of the gluten network in batters with amaranth (Tömösközi et al., 2011).

Gums and SSL improved the viscoelasticity of muffin batters with SMP and AF (Figure 1). First, the addition of gums and SSL increased the viscosity of the batters due to the interaction of gums with the solubilized starch and swollen starch granules (Chaisawang & Suphantharika, 2005). Nunes, Moore, Ryan, and Arendt (2009) demonstrated that the consistency of gluten-free batters improves with the addition of emulsifiers, that is, lecitin, distilled monoglycerides and SSL (Nunes et al., 2009). Conversely, different gums interact differently with starch. In this study, the batter supplemented with the guar-xanthan gum blend had the highest consistency. This was most likely attributed to the interaction of starch with both guar gum (a neutral gum) and xanthan gum (a negatively charged gum) (Chaisawang & Suphantharika, 2005). A blend of these gums was used, since xanthan gum by itself may have resulted in a more rigid structure (Chaisawang & Suphantharika, 2005). Most importantly, the viscoelastic functions of the SSL batter compares with that of control. The reason for this is that SSL is an anionic emulsifier that enhances structure by increasing dough strength through its interaction with gluten proteins (Gómez et al., 2004).

SSL and gums improved the specific gravity of batters enriched with SMP and AF (Table 2). The BS batter had a significantly higher specific gravity compared to control. A low specific gravity in batters is a required characteristic for...
baked products’ structure and indicates more air being incorporated in the batter (Turabi, Sumnu, & Sahin, 2008b). In this study, additives improved gas retention, since BCMC, BSSL and BGX batteries were not significantly different from control.

3.2. Physical and chemical characteristics of muffins

The addition of different gums and SSL to muffins made with SMP–AF affected specific volume and color. Muffins’ volume is an important quality parameter related to the amount of air entrapped and retained in the final product. It is well known that a final cake’s volume is affected by the batter’s viscosity. An optimal viscosity has to be achieved in order to yield cakes with high volume. When viscosity is too low, the batter cannot hold air bubbles, causing the cake to collapse, and when the viscosity is too high, the batter can hold air bubbles but the expansion is limited because of the batter’s high viscosity (Sahi & Alava, 2003). Accordingly, the BS batter’s viscosity produced muffins with the lowest specific volume values. Lower viscosity is related to less formation of air bubbles and a failure to entrap air cells in the mix (Lakshminarayan, Rathinam, & KrishnaRau, 2006), thereby affecting the product’s final volume.

Gums but not SSL increased muffins’ specific volume values to control values (Table 3). Other research showed that on rice cakes, the addition of both xanthan gum and an emulsifier blend increased specific volume values (Turabi, Sumnu, & Sahin, 2008a). Furthermore, the relation between viscosity and specific volume was observed with gums but not with SSL (Figure 1 and Table 3). These two parameters are usually positively associated (Sahi & Alava, 2003; Sanz-Penella, Wronkowska, Soral-Smietana, & Haros, 2013). Additionally, the difference in specific volume between BC and BS muffins may be attributed to the lipid content of the amaranth (higher than wheat flour) acting as a surface-active agent, thereby contributing to gas cell stabilization prior to starch gelatinization (Alvarez-Jubete et al., 2010).

SMP–AF affected the color of baked muffins (Table 3). This effect may be attributed to: (1) the intrinsic color of individual components and (2) the color developed from the components’ interaction in the mix, which is partly determined by the degree of Maillard, caramelization and other enzymatic and chemical reactions (Purush & Salvadori, 2007; Shittu, Aminu, & Abulude, 2009). Consistent with other studies, SMP–AF reduced lightness (L* value) and increased redness (a* value) on the crust, while the crust’s lightness and yellowness (b* value) were higher compared to control muffins (Banks, Wang, & Brewer, 1997; Capriles et al., 2008; Majzoobi, Ghiasi, Habibi, Hedayati, & Farahnaky, 2014; Nune et al., 2009). Nonetheless, except for muffins with CMC, which crust was less yellow compared to all treatments, there was no distinct effect on crust color when gums or SSL were added to the BS batter. Furthermore,

Table 2. Specific gravity of batters.

|          | BC            | BS            | BCMC          | BSSL          | BGX          |
|----------|---------------|---------------|---------------|---------------|--------------|
| Specific gravity (g/mL) | 1.17 ± 0.02<sup>a</sup> | 1.21 ± 0.02<sup>b</sup> | 1.19 ± 0.02<sup>ab</sup> | 1.20 ± 0.01<sup>ab</sup> | 1.19 ± 0.01<sup>ab</sup> |

Values are means ± SD. Different superscripts in the same line indicate p < 0.05 by Tukey’s post hoc ANOVA.

Table 3. Physical characteristics of muffins.

|          | BC            | BS            | BCMC          | BSSL          | BGX          |
|----------|---------------|---------------|---------------|---------------|--------------|
| Specific gravity (g/mL) | 1.90 ± 0.11<sup>a</sup> | 1.50 ± 0.08<sup>b</sup> | 1.89 ± 0.11<sup>a</sup> | 1.58 ± 0.09<sup>a</sup> | 1.67 ± 0.17<sup>ab</sup> |

Values are means ± SD. Different superscripts in the same line indicate p < 0.05 by Tukey’s post hoc ANOVA.
only gums and SSL decreased greenness (a* value) compared to control and BS muffins. However, additives restore lightness to control values. In terms of the magnitude of overall color differences between all muffins, TCD calculations showed that the use of additives ameliorated the change in color caused by the use of SMP and AF only on the crust. This may be explained by the kinetics of color changes that are also influenced by water activity due to hydrocolloids–water interaction (Shittu et al., 2009).

Protein content in muffins made with SMP–AF ranged between 15% and 19%, despite no difference in moisture or crude fat content (Table 4). BS muffins exhibited protein content of 18.97%, while BCMC, BGX and BSSL had 16.15%, 15.56% and 14.97%, respectively. The addition of soy and AF increased protein content as shown elsewhere (Dhingra & Jood, 2010; Olaoye, Onilude, & Idowu, 2006; Sanful & Darko, 2010; Sanz-Penella et al., 2013). However, the incorporation of additives attenuated the increase in protein content observed in muffins prepared with no additives. This difference may be the result of the interaction between structural elements from the flours with the different gums and SSL.

### 3.3. Textural analysis

Differences in texture were dependent on protein source and additives (Table 3). The partial substitution of wheat flour with SMP and AF significantly increased muffins’ hardness and chewiness. In contrast, when soy protein isolate was used to enrich rice-based, gluten-free muffins, these two attributes were not affected (Matos et al., 2014). BS muffins’ significantly higher hardness and chewiness compared to control muffins may be explained by amaranth’s greater protein content. Protein content is positively associated with chewiness (Shao, Lin, & Chen, 2015) and with a stronger network, which helps retain more air in cake leavening (Tan, Chin, Yusof, Taip, & Abdullah, 2015) Furthermore, the hard texture of pound cakes with 20% or 30% amaranth was explained by the faster rate of AF’s starch retrogradation (De La Barca et al., 2010).

Moreover, the use of additives had different effects on all muffins’ texture properties. BCMC’s muffins’ chewiness was comparable to that of control muffins, albeit only improving its hardness. On the other hand, GX gums improved hardness to control levels but increased chewiness values. Concomitantly, chewiness was also increased by the addition of xanthan gum in eggless cakes (Shao et al., 2015). Others have also shown that the interaction between hydrocolloids and starch affects the rate of starch retrogradation (De La Barca et al., 2010), which directly affects hardness. On the other hand, high springiness is related to a higher batter viscosity, which favors air bubble stability during baking (Sanz, Salvador, Baixauli, & Fiszman, 2009). This is in agreement with the positive association between the BGX batter’s viscosity (Figure 1) and the BGX muffins’ springiness. Although GX and CMC gums were able to increase cohesiveness in eggless cakes (Shao et al., 2015), this quality attribute was not improved in BCMC muffins. This demonstrates that each gum interacted differently with SMP and AF components. Out of all additives, only SSL significantly ameliorated the effect of SMP and AF on hardness, springiness, cohesiveness and chewiness values. SSL is known to significantly lower starch retrogradation, consequently affecting crumb strength measured by peak force (Cortés-Ceballos, Pérez-Carrillo, & Serna-Saldívar, 2015). Accordingly, other emulsifiers, that is, distilled glycerol mono stearate, lecithin and sorbitan mono stearate, decreased firmness values on eggless cakes containing soy milk (Rahmati & Mazaheri Tehrani, 2014). Furthermore, texture similarity between BC and BSSL muffins may be related to the batter’s viscosity, since the two batters displayed comparable behavior (Figure 1).

### 4. Conclusion

In conclusion, SMP and AF increased protein content in muffins. The addition of SSL, but not CMC or GX, ameliorated the effect of SMP and AF on rheological and textural characteristics of enriched muffins. This indicates that baked products’ nutritional value can be improved by using ingredients such as SMP and AF without detrimentally affecting textural and rheological characteristics.

### Disclosure statement

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**Table 4. Chemical composition of muffins.**

|          | BC     | BS     | BCMC   | BSSL   | BGX   |
|----------|--------|--------|--------|--------|-------|
| Moisture (%) | 15.6 ± 3.29 | 14.44 ± 5.84 | 14.97 ± 0.02 | 16.15 ± 0.01 | 16.44 ± 3.28 |
| Crude protein (%) | 38.0 ± 1.0 | 37.2 ± 1.3 | 37.6 ± 0.8 | 36.2 ± 4.4 | 35.1 ± 2.2 |
| Crude fat (%) | 13.4 ± 0.01 | 13.34 ± 0.01 | 15.24 ± 3.79 | 15.56 ± 0.02 | 14.97 ± 0.02 |
| N | a | a | ab | a | ab |
| a | b | c | d | e | f |

Values are means ± SD. Different superscripts in the same line indicate p < 0.05 by Tukey’s post hoc after ANOVA.

**Abreviaciones:** BC: 100% harina pastelera clorinada; BS: 90% harina pastelera clorinada y 10% leche de soya en polvo:harina de amaranto (8:2) sin aditivo; BCMC: BS con 0.02% de CMC; BSSL: BS con 0.02% de SSL; BGX: BS con 0.02% de mezcla de gomas guar-xantana (1:1).
