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SHORT COMMUNICATION

Muffins made with monoglyceride oleogels: Impact of fat replacement on sensory properties and fatty acid profile

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Abstract

Most shortenings used in baked products are solid fats high in saturated fatty acids that may also contain *trans* fatty acids, which are nutritionally unhealthy. Successful solid fat replacement requires maintaining not only the physicochemical properties, but also the sensory quality of the products. In this study, the sensory properties and lipid profile of muffins formulated with a previously optimized monoglyceride oleogel were compared with those of muffins made with a commercial margarine (Control). Untrained consumers ($n = 130$) evaluated the effect of the fat replacement on several sensory attributes using a 5-point hedonic scale. In comparison with the Control, the oleogel-based muffin (M_o) scored similarly for flavor and sponginess, but rated significantly higher for appearance and color. Based on overall quality score, consumers liked M_o more than the Control. The reformulated muffins had a significantly improved lipid profile, with a 68% reduction in saturated fats and an almost 4-fold increase in monounsaturated fats. This study supports the use of monoglyceride oleogels as full-fat substitutes to develop healthier bakery products, maintaining or improving consumer acceptance. It is expected that the promising results presented here will help the food industry to accelerate the transition from conventional solid fats to oleogels.

KEYWORDS
consumer acceptance, fat replacer, lipid profile, muffin, oleogel, sensory properties

INTRODUCTION

High consumption of saturated and *trans* fats cause a deleterious impact on consumers' health by increasing the risk of cardiovascular diseases, chronic inflammation, obesity and diabetes, among others (Mozaffarian et al., 2009; Zhou et al., 2020). As a result of this evidence, key regulatory agencies have established recommendations to regulate their consumption. The World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) recommend that saturated fatty acids (SFAs) and *trans* fatty acids (TFAs) not exceed 10% and 1% of total energy intake, respectively (FAO, 2010; WHO, 2020). The main sources of solid and *trans* fats are margarines and shortenings, which are key ingredients in bakery products due to their plasticity and low cost compared to butter (Garvey et al., 2020). Therefore, replacing these ingredients is a major challenge for the food industry.

Among bakery products, muffins are consumed globally as they are highly appreciated for their sensory attributes. Their main ingredients are sugar, wheat flour, water, eggs, a leavening agent, and solid fat, usually present in the form of shortening or margarine (Garvey et al., 2020). Thus, the nutritional profile of muffins can be greatly improved by replacing these fats with unsaturated fats. Oleogels have attracted great interest for this purpose. They are formed by the entrapment of a high amount of oil within a three-dimensional gel network created by structuring agents added in low concentrations. Most of studies on oleogels as fat replacers in bakery products are recent (Palla et al., 2022; Silva et al., 2022). For example, cakes and cookies made with oleogels from waxes and saturated monoglycerides (MGs) have shown similar appearance, texture, flavor, and overall acceptability to control products (Li et al., 2021; Pehlivanoğlu et al., 2018; Yilmaz & Öğütcü, 2015). Regarding muffins, some works have demonstrated that oleogels from hydroxypropyl methylcellulose-carnauba wax and MG-carnauba wax yield products with comparable physicochemical properties to those made with commercial shortenings (Jeong et al., 2021; Lim et al., 2017; Oh & Lee, 2018). In particular, we previously investigated the potential use of optimized MG oleogels as fat replacers in muffins (Giacomozzi et al., 2018). Oleogel-based muffins showed physicochemical properties very similar to those made with a commercial margarine (CM). Moreover, this oleogel was an effective oil-migration inhibitor for muffins.

Considering that a new functional ingredient must be accepted by consumers, sensory acceptability is a crucial step in its evaluation as a potential ingredient for the food industry (Silva et al., 2022; Yilmaz, 2022). Sensory analysis provides useful information about how humans perceive variations in products caused by changes in ingredients, processing, packaging, or shelf-life beyond their physical properties (Lawless & Heymann, 2010). This reduces the risk of new or reformulated products failing when they are introduced to the market. As previously mentioned, some works have studied how oleogels affect sensory properties of baked products, but little is known about their impact on muffins. Indeed, it is still unclear how MG oleogels influence the sensory attributes of muffins. Based on these considerations, the aim of the present work was to evaluate sensory properties—appearance, color, flavor, texture, and overall acceptability—and lipid profile improvement of muffins formulated with an optimized MG oleogel. Since this work represents the final stage of an extensive study on the development of a suitable oleogel as a solid fat substitute, we evaluated only the oleogel that exhibited optimal characteristics. In addition, muffins prepared with a CM were also evaluated for comparison purposes. Finally, the relationship between sensory attributes and physicochemical properties previously measured was also determined.

MATERIALS AND METHODS

Materials

MGs (Myverol 18-04 K SG) were kindly donated by Kerry (Ireland). Refined high oleic sunflower oil (HOSO) (Ecoop, Argentina), the CM (Molinos Río de la Plata S.A, Argentina), and all the ingredients used for muffin formulation (refined wheat flour, sugar, baking powder, eggs, and vanilla essence) were bought at a local supermarket. The fatty acid (FA) weight composition of MGs, HOSO, and CM determined by gas–liquid chromatography (GLC) (see Section 2.2) was the following. MG mixture was mainly composed of 16:0 (53.6 ± 0.1%) and 18:0 (43.9 ± 0.1%). HOSO was mainly composed of 16:0 (4.0 ± 0.0%), 18:0 (2.2 ± 0.0%), 18:1 (83.9 ± 0.1%), and 18:2 (8.0 ± 0.0%). The fat content of the CM was 40.5 ± 0.6%, being composed mainly of 12:0 (12.5 ± 0.1%), 16:0 (13.5 ± 0.1%), 18:0 (16.4 ± 0.3%), 18:1 (15.5 ± 0.5%), and 18:2 (28.5 ± 0.4%). Trans FAs were also found in the composition of CM in an amount of 2.2 ± 0.6%. According to the manufacturer, the other ingredients of the CM were water and additives (salt, vitamin A and D, flavoring agent, preservative, antioxidant and colorant).

Determination of fatty acid (FA) composition

The fat extraction from CM was performed following the reference method Standard ISO 17189/IDF 194 (ISO/IDF, 2003) using petroleum ether as solvent.

The FA composition in the acylglycerols of HOSO, MG, and the fat extracted from the CM was determined by GLC. Samples were subjected to cold transesterification treatment to obtain FA methyl esters, which were analyzed using a 7820A series gas chromatograph (Agilent). These procedures were carried out by following the AOCS Official Methods Ce2-66, Ce1h-05 and Ce1-62 (AOCS, 2009).

Oleogel preparation

Oleogels were produced by structuring HOSO with MG (6.6% w/w) according to the optimized methodology described by Giacomozzi et al. (2018). Briefly, HOSO and MG were mixed at 80°C and stirred at 200 rpm for 30 min. After that, molten samples were cooled to 17.5°C, and the gelified material was stored at 5°C for 24 h to allow the stabilization of the crystalline network. Oleogels were used to prepare muffin batters immediately after being removed from the refrigerator.

Muffin preparation

A base muffin recipe was used to evaluate the ability of the MG oleogel to replace the CM. The reformulation was made by replacing the lipid phase of CM with oleogel and adding the necessary amount of water to maintain the aqueous phase/lipid phase ratio of the CM. The muffin batters were produced in 600 g batches following the procedure described by Giacomozzi et al. (2018). The batter formulas were composed of flour 156.5 g, sugar 156.5 g, eggs 113 g, water 93.1 g, MG oleogel 63.4 g –or CM 156.5 g without adding water–, baking powder 8.7 g, and vanilla essence 8.7 g. Portions of 30 g of batter were placed on silicone molds (diameter 43 mm, height 35 mm). Twelve individual molds were filled with each batch of preparation,

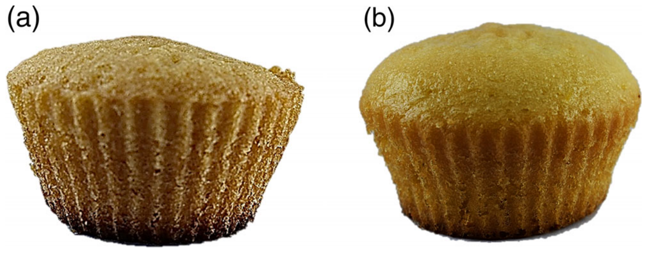

FIGURE 1 Images of muffins formulated with commercial margarine (control) (a) and monoglyceride oleogel (M_o) (b)

arranged on a baking tray, and baked in an electric oven (20 min at 200°C, 10 min pre-heating). The muffins produced with oleogels (M_o) or CM (Control) were allowed to cool to room temperature for 1 h, and then stored in plastic containers at 20°C for 24 h before sensory analysis.

Sensory analysis

A sensory analysis was carried out to determine the degree of consumer acceptance of each muffin formulation and to compare their sensory attributes. The study was approved by the Safety, Health, and Environment Committee at the institute Planta Piloto de Ingeniería Química (PLAPIQUI), and informed consent was obtained from each subject prior to participation in the study. This was conducted in accordance with the ethical principles of the Declaration of Helsinki (World Medical Association (WMA), 2018). A total of 130 participants (untrained panelists) were politely recruited among staff and students of the CCT CONICET Bahía Blanca (Argentina). They were selected based on interest, consumption frequency (at least occasionally), and time availability. The evaluation was performed in a room under white light. Each consumer received two muffins (Control and M_o) (Figure 1) and a glass of water for mouth rinsing among samples. The muffins were coded with 3-digit blind codes and served at room temperature in random order.

Sensory analysis of reformulated bakery products has been extensively assessed using hedonic scales, as they are easy to understand and do not require in-depth training for panelists (Garvey et al., 2020). For this reason, participants used a 5-point hedonic scale (5 = like very much, 4 = like moderately, 3 = neither like nor dislike, 2 = dislike moderately, and 1 = dislike very much) to score the most relevant sensory attributes of the muffins—appearance, color, flavor, and sponginess—as well as their overall quality. Participants were also asked to indicate aspects related to fat flavor detection, crumbling, and willingness to buy each muffin, with the aim of allowing free expression of consumers' ideas.

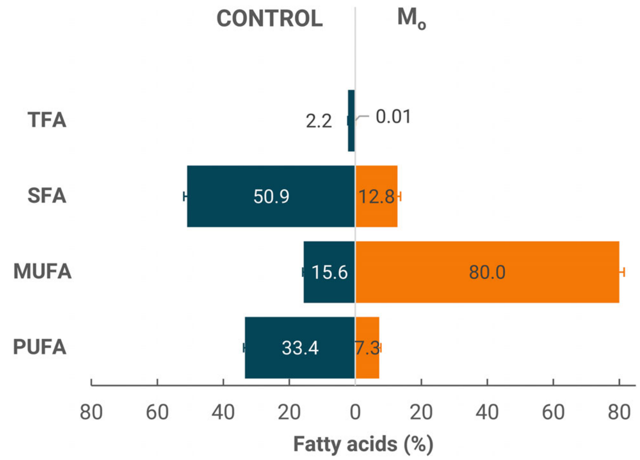

FIGURE 2 Lipid profile of muffins elaborated with margarine (control) or oleogel (M_o) as fat ingredient. TFA, *Trans* fatty acids; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids. Error bars represent the standard deviation of mean values

Statistical analysis

The statistical analysis was performed using the Infostat software (Di Rienzo et al., 2011). The results were expressed as mean ± SD. Additionally, the 95% confidence interval was included when necessary. Comparisons of means were conducted using Student's *t*-test ($p < 0.05$).

RESULTS AND DISCUSSION

Fatty acid composition

Figure 2 shows the FA composition of muffins elaborated with margarine (Control) or oleogel (M_o) as fat ingredient. Using oleogel resulted in muffins with a significantly reduced content of SFAs (68% of reduction) and an almost 4-fold higher content of monounsaturated FA. Since TFAs were found in the CM composition, reformulation with oleogel also eliminated these undesirable FAs. The degree to which saturated and *trans* fats are reduced by using an oleogel to replace a commercial fat in a food formulation depends on the FA composition of both lipid materials and the substitution level (Palla et al., 2022). In this work, the oleogel was used for full-fat replacement in a relatively low-fat (10.43 wt%) muffin formulation. Thus, the overall nutritional quality of the product is expected to be further improved if substitutions are made in formulations with higher fat content. For example, the full replacement of palm shortening or butter with MG-ethylcellulose/MG oleogels in a high-fat (40 wt%) tart pastry formulation resulted in a reduction from 16.6–18.3 to 7.2–9.3 g SFA/g product (Sim et al., 2021).

TABLE 1 Mean scores ± standard deviation (95% confidence interval) of sensory attributes evaluated by panelists ($n = 130$) using a 5-point hedonic scale

Attributes	Control	M_o	*p*value
Appearance	3.75 ± 0.88 (0.15)^b	4.15 ± 0.76 (0.13)^a	0.0001
Color	3.78 ± 0.93 (0.16)^b	4.31 ± 0.69 (0.12)^a	<0.0001
Flavor	3.93 ± 0.90 (0.16)^a	4.01 ± 0.80 (0.14)^a	0.4674
Sponginess	3.99 ± 0.93 (0.16)^a	4.09 ± 0.77 (0.13)^a	0.3107
Overall quality	3.72 ± 0.83 (0.14)^b	4.12 ± 0.69 (0.12)^a	<0.0001

Note: Control: Muffins formulated with a commercial margarine. M_o: Muffins formulated with the optimized monoglyceride oleogel as the fat ingredient. Values followed by the same letter on the same row do not differ significantly ($p > 0.05$) according to Student's *t*-test.

SENSORY ANALYSIS

Panelists

The demographic characteristics of the panelists are summarized below. Most of them (50.8%) were within the age range of 26–35 years. This age range is preferred because the individuals usually have well-defined consuming habits and good health (Lago-Vanzela et al., 2011). The other panelists were categorized as <26 (13.8%), 36–50 (23.8%), and >50 years (11.5%). From the total panelists, the percentage of females and males were 63.1% and 36.9%, respectively. Regarding the consumption frequency, all panelists were defined as muffin consumers (as requested for the study), with 93% being occasional consumers (between one and two-times per month) and 7% being regular consumers (between one and two-times per week). This is consistent with the fact that this food is not usually chosen for daily consumption (Garvey et al., 2020).

Sensory attributes

Table 1 shows the average scores of each sensory attribute and the overall quality score for both muffin formulations. As it can be seen, all the attributes had scores higher than 3.72, which means that they can be considered acceptable according to the panelists' appreciation (Yilmaz & Öğütcü, 2015). While there were no significant differences between the Control and M_o samples in terms of flavor and sponginess, M_o had a higher score for both appearance and color. Probably, the use of oleogels from HOSO, which is an oil with a very neutral taste and no marked pigmentation, helped to obtain positive results for flavor and color. Furthermore, most of the panelists noted a color difference between Control and M_o samples (Figure 3). They reported a lighter brownish color in the muffin elaborated with oleogel, as can also be observed in Figure 1. This consumer's perception is consistent with our previously reported results of the analytical measurement of crumb color, where it was found that oleogel-based muffins had lower a^* (<0: greenness; >0: redness) and b^* (<0: blueness; >0: yellowness) values, indicating a less brownish tone compared to the Control (Giacomozzi et al., 2018). Furthermore, we had found that according to the result of the total color difference (ΔE^*) between Control and M_o, the color differences would not be detected by consumers (2.58 < 3 (reference value)), but they were perceived, highlighting the importance of sensory evaluation.

Similar to our results, the sensorial analysis of cookies made with 40 wt% of MG-corn oil oleogel showed no significant differences in flavor score compared to shortening-based cookies (Li et al., 2021). However, in this case, reformulated cookies were also comparable to the control in appearance and color. Since there is very limited research on sensory analysis of bakery products prepared with MG oleogels, it is useful to compare our results with those obtained in products made with oleogels formulated with another crystalline gelator such as wax. When cookies were produced using oleogel from hazelnut oil and sunflower wax or beeswax instead of shortening (24.07 wt% of fat in cookie formulation), they also scored higher than control cookies for appearance (Yilmaz & Öğütcü, 2015).

The number and size of air cells in muffin crumble structures can be related to sponginess. Using image analysis, we found in our previous work that the Control had a significantly higher number of big air cells (Giacomozzi et al., 2018). This result, which can be interpreted as an increase in sponginess, was not detected by consumers during the sensory evaluation. On the other hand, using texture analysis, we found that M_o and Control samples did not differ significantly in terms of hardness (Giacomozzi et al., 2018). Since the attribute of sponginess showed the same response as hardness, it suggests that the behavior of both parameters could be correlated.

The results of the overall quality score of muffins indicate that M_o was preferred by consumers over the Control. This is a remarkable result since the replacement of a traditional ingredient may affect the acceptability of the product, but in this case, the use of MG oleogels resulted in muffins with better acceptability. Similarly, Yilmaz and Öğütcü (2015) found that wax

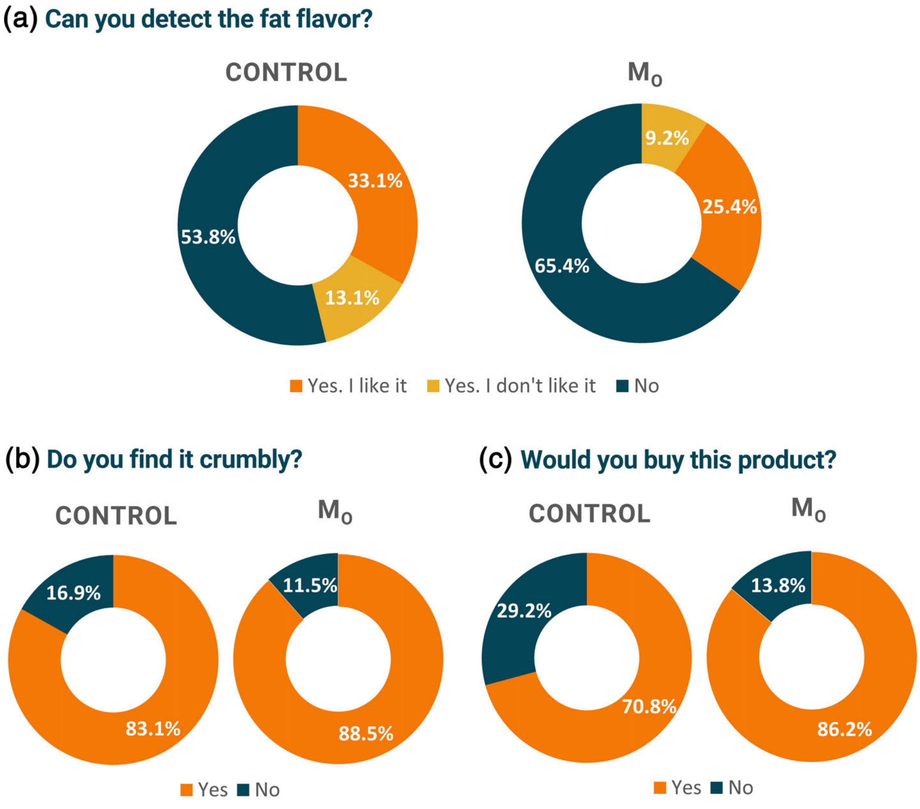

FIGURE 3 Questions asked to the panelists during the sensory analysis and their answers. Samples: Muffins prepared using margarine (control) or monoglyceride oleogel (M_o)

oleogel-based cookies had an equivalent or even better sensory score than the shortening-based cookies. Also, Pehlivanoglu et al. (2018) found that the highest acceptability score was given to the cake prepared with oleogels from carnauba wax and a mixture of sunflower and cottonseed oils. All these results are very promising in relation to the total substitution of shortenings in bakery products.

Regarding the question asked about the detection of the fat flavor, most of the participants were unable to detect this flavor in either type of muffin, even so, it was less perceptible in M_o samples (Figure 3a). A smaller percentage of participants were able to detect the fat flavor in both products, and most of them indicated that it was pleasant. Only an even smaller percentage of panelists found it unpleasant, and this percentage was higher for the Control. In addition, most panelists considered that neither Control nor M_o were products that crumbled easily, indicating that both samples had a good level of compaction (Figure 3b). This parameter is related to the cohesiveness of the sample. In our previous work, we found that oleogel-based muffins showed a less cohesive (~15%) and more easily deformable structure (Giacomozzi et al., 2018). Therefore, the difference in cohesiveness between muffins previously recorded by texture analysis was not detected by the consumers, which highlights the importance of sensory analysis as a decision tool for the evaluation of replacements in food formulations. Finally, most panelists stated that they would be willing to buy both types of muffins due to their acceptable appearance and attractive texture. Moreover, the oleogel-based muffin had a higher percentage of positive responses (Figure 3c).

Although no significant differences were found between M_o and Control in terms of flavor score, some participants commented that the muffin formulated with the oleogel had a more pleasant flavor. They indicated that M_o showed a lower degree of roughness in the mouth after swallowing, resulting in a greater humidity and softness palatability perception compared to the Control. In addition, some of the consumers indicated that a higher degree of sweetness was perceived with M_o. Calligaris et al. (2010) reported that MG self-assembled structures modified the affinity of flavor compounds to the oil, and they could act as flavor release modulators by increasing flavor retention due to their role as emulsifiers. This suggests that the MGs from oleogels would have influenced the perception of flavor and the mouthfeel of muffins.

The present results reinforce the findings of our previous work (Giacomozzi et al., 2018), which demonstrated that the use of the optimized oleogel as a commercial fat substitute does not affect the main physicochemical properties of muffins. In this study, the sensory properties of muffins formulated with MG oleogel were satisfactorily scored by the panelists. It is worth mentioning that the oleogel used in this work did not contain any additives (colorants, flavor enhancers, etc.), only oil and gelator. Therefore, the incorporation of such components opens the possibility of further improving the sensory properties of oleogel-based muffins.

Some studies indicate that there is a correlation between consumer acceptance and perception of a product and knowledge of its nutritional characteristics (Tarancón et al., 2014; Wardy et al., 2018). In the present work, some panelists (9.2%) indicated that in spite of liking both formulations, they would be willing to pay a higher price for the healthier option or they would prefer to buy the muffin with the improved nutrition profile. A previous study showed the change in consumers' hedonic expectations for biscuits made with vegetable oils instead of saturated fats (Tarancón et al., 2014). When consumers were informed about the improved nutritional properties of reformulated biscuits, their preference for these samples increased significantly. In the present study, the lipid profile of the muffins was not disclosed to the participants. Accordingly, claiming M_o as a free-*trans* fat and reduced saturated fat product could result in even greater consumer acceptance.

CONCLUSIONS

This work aimed to investigate whether and to what extent muffins made with an oleogel with optimized physical properties differ from those made with a commercial light margarine in terms of sensory properties and consumer acceptance. Furthermore, both products were compared based on their lipid profiles.

The participants of the sensory analysis found both muffin formulations acceptable. The oleogel-based muffin was rated better than the Control muffin in terms of appearance, color and overall quality, with no significant differences between them for flavor and sponginess.

According to these results, oleogel-based muffins would be a good option to launch a new product with a healthy fatty acid profile in which consumers are really interested. Thus, the effectiveness of using the proposed MG oleogel as a full fat replacer in muffins was demonstrated, resulting in a nutritionally superior product with similar or preferred sensory attributes. It is expected that these promising results will help the food industry to accelerate the transition from conventional solid fats to oleogels.

AUTHOR CONTRIBUTIONS

Anabella S. Giacomozzi: investigation, methodology, data analysis, writing—first draft. **María E. Carrín**: conceptualization, investigation, methodology, supervision, writing—review & editing. **Camila A. Palla**: conceptualization, investigation, methodology, supervision, writing—review & editing, funding acquisition. All authors contributed to and approved the final draft of the manuscript.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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