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Carrot fibre enrichment of fat reduced cake

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RESEARCH ARTICLE

Abstract

Cake is a broadly consumed product and its dietary profile can be improved by using dietary fibre to replace part of flour or fat. The replacement of flour (10-30%) by carrot fibre in full fat and reduced fat cakes was examined. Flour replacement in full fat cakes increased batter viscosity and decreased air incorporation, providing harder cakes with dense structure. Inulin was used to replace 65% of fat in the reduced fat cakes, which presented lower batter viscosity but not significantly different volume development compared to the full fat cake. The incorporation of 10% carrot fibre in the reduced fat formulation appeared to counteract the effect of inulin in terms of batter viscosity and bubble size distribution, but impaired the volume development and the textural properties. The quality characteristics of the enriched cake were improved by the use of emulsifiers (monoglycerides, sodium stearoyl lactylate, diacetyl tartaric acid esters of mono- and diglycerides), which also had a stabilising effect on the bubble formation in the batter. Sodium stearoyl lactylate in particular provided the best results in terms of hardness, porosity and sensorial characteristics.

Keywords: inulin, flour replacement, emulsifiers, texture

1. Introduction

Increased intake of dietary fibres has been associated with the decreased incidence of coronary heart disease, diabetes, and colon cancer (Kendall *et al.*, 2010). Dietary fibres can be found in foods such as vegetables, fruits, grains, cereal brans, or can be added to food in order to enhance its nutritional content and/or its physical or sensorial properties. The latter involves the fibre contribution to the rheological behaviour, the textural and sensorial attributes. More specifically, depending on their hydration properties, solubility, thickening effect, etc., dietary fibres can serve as bulking agent, gelling agent, fat substitute, or stabiliser (Guillon and Champ, 2000; Shoaib *et al.*, 2016).

Inulin is a non-digestible polysaccharide, which, apart from mimicking the functionality of fat, provides most of the health benefits of dietary fibres, e.g. is resistant to digestion in the small intestine and exerts intestinal physiological effects that contribute to the maintenance of health (Cherbut, 2002; Shoaib *et al.*, 2016). Additionally, inulin has attenuating effect on lipid, insulin and glucose concentration in blood (Jackson *et al.*, 1999). Carrot fibres are also beneficial to health since they improve the intestinal health (Chau and Chen, 2006), increase the HDL-cholesterol and decrease the LDL-cholesterol levels (Hsu *et al.*, 2006), increase satiety (Moorhead *et al.*, 2006) and therefore contribute to weight management.

Several attempts have focused on the improvement of the dietary profile of a broadly consumed product, cake, either by fat replacement or enrichment with dietary fibres. Cereal fibres (Gomez *et al.*, 2010; Lebesi and Tzia, 2011) and apple pomace (Sudha *et al.*, 2007) as flour replacers, as well as dietary fibres such as β-glucan concentrates (Kalinga and Mishra, 2009) and inulin (Rodriguez-Garcia *et al.*, 2012, 2014; Zahn *et al.*, 2010) as fat replacers in cake have been investigated. However, no data are reported on the combined incorporation of fibres as flour and fat substitutes in cakes. In a previous research we studied several fat replacers (both carbohydrate- and protein-based) and inulin presented the most promising results when replacing fat up to 65% (Psimouli and Oreopoulou, 2013). Therefore, in the present work we tried to further improve the dietary profile of the cake by combining inulin to replace 65% of fat and carrot fibres to replace part of flour. Carrot fibres were selected because of their aforementioned health beneficial effects; however, their compatibility to cakes has not been investigated yet. Moreover, carrot fibres are a by-product of the carrot processing companies and their commercial exploitation would be beneficial to the industry and the environment (Chantaro *et al.*, 2008; Nawirska and Kwasniewska, 2005). Furthermore, three emulsifiers were selected with varying hydrophilic-lipophilic balance values, to improve the quality of the cake. The emulsifiers contribute to the cake structure by providing gas bubble stability. Hence they prevent coalescence and promote a uniform bubble size distribution in the batter (Sahi and Alava, 2003).

2. Materials and methods

Materials

Flour (13.2% moisture, 0.52% ash, 10.35% protein) was kindly donated by P. Dakou Mills (Inofita, Greece). The shortening was margarine for cake, containing 20% (w/w) water, produced by Minerva S.A. (Inofıta, Greece). The other ingredients used in cake formulations were purchased from the local market. Carrot fibres were kindly donated by Gewürzmüller Nesse (Frutarom Savory Solutions GmbH, Korntal-Münchingen, Germany) and granulated inulin by Orafti Active Food Ingredients (Tienen, Belgium). Distilled monoglycerides (MG; Dimodan HP KOSHER; Danisco Inc., Copenhagen, Denmark), diacetyl tartaric acid esters of mono- and diglycerides (DATEM; Panodan AB 100 VEG-FS KOSHER; Danisco Inc.) and sodium stearoyl lactylate (SSL; Grindsted SSL P 45 VEG; Danisco Inc.) were used as emulsifiers.

Cake preparation

The main ingredients of the control cake and of the cakes prepared with carrot fibres or inulin are presented in Table 1. Carrot fibres were used to replace flour by 10, 20 and 30%, and inulin to replace fat by 65%. Inulin was dissolved in water at a concentration of 20% (w/w) and the solution was stored at 4 °C overnight, so as to obtain a gel (Psimouli and Oreopoulou, 2013). Fat was replaced by an equal weight of inulin gel, and the amount of milk was adjusted according to the water present in the inulin gel and the shortening, so that the total water content remained the same as in the control cake formulation. For the cake formulations enriched with carrot fibre, water was added at amounts selected according to preliminary tests. Additionally, in all formulations sodium bicarbonate (1.11 g), sodium acid pyrophosphate (1.35 g), monocalcium phosphate (0.20 g), and salt (1.90 g) on 100 g flour basis were added.

Emulsifiers were used at the formulation containing fat replacer (65% inulin) and flour replacer (10% carrot fibre). MG was added at concentrations of 1 and 2% on flour basis, while DATEM and SSL at concentrations of 0.25 and 0.5%. DATEM was in a semi-liquid form and was added to the shortening during the creaming process. MG and SSL were dispersed in water, at emulsifier to water ratio: 1:4, and heated to 60 and 55 °C, respectively. The obtained dispersion was cooled to ambient temperature, forming a gel. The MG and SSL gels were added to the mixture of shortening, fat replacer and sucrose at the initial creaming process.

The sugar batter process (Bennion and Bamford, 1997) was used for the preparation of the samples. Initially the shortening (and the fat replacer) and sucrose were creamed for 10 min at high speed (180 rpm) in a Kenwood mixer (model KM 800; Kenwood Limited, Havant, UK). Eggs were then added and mixed for 7 min. Following, milk, flour enriched with sodium bicarbonate, sodium acid pyrophosphate and monocalcium phosphate, and the fibre were added and mixed for 5 min at low speed (90 rpm).

Duplicate samples of 400 g each were placed in aluminium pans 21.0×7.2×5.0 cm and the cakes were baked for 50

Table 1. Cake formulations with fat and/or flour replacement.

Ingredients (g)	Control	Inulin 65% (in65)	Carrot fibre			Carrot fibre 10% + inulin 65% (cf10in65)
			10% (cf10)	20% (cf20)	30% (cf30)	
Wheat flour	100	100	90	80	70	90
Carrot fibre	–	–	10	20	30	10
Sucrose	90	90	90	90	90	90
Fresh whole eggs	67	67	67	67	67	67
Shortening	53.5	18.7	53.5	53.5	53.5	18.7
Inulin gel	–	34.8	–	–	–	34.8
Fresh milk	66.6	45.7	66.6	66.6	66.6	45.7
Water	–	–	20	40	60	20

min, at 180 °C, in a laboratory oven with air circulation (Thermawatt TG103; Thermawatt, Athens, Greece). After baking the cakes were cooled at room temperature for 2.5 h, packed with air in polyethylene packages, and stored at ambient temperature. The cakes were subjected to textural, physical and sensory measurements 20 h later. Each cake formulation was prepared twice, on different days.

Hydration properties determination

The water holding capacity (WHC) of carrot fibre and wheat flour was determined, following the procedure recommended by Robertson *et al.* (2000). WHC was determined by mixing 5 g of the fibre or the flour with 100 ml distilled water. After equilibration (for 18 h) the excess water was removed, the hydrated solid was weighed, and values were expressed as g water/g solid.

Batter rheology and specific gravity measurements

The rheology measurements were conducted in a rotational viscometer (RC1 Rheometer; Rheotec Messtechnic GmbH, Raderburg, Germany) coupled with a circulating cooling bath (Lauda RE312, GmbH, Germany). Quantities of 18 g of the cake batter were subjected to shear rate increasing from 0.05/s to 200/s in 5 min at constant temperature of 25 °C, according to the procedure described by Psimouli and Oreopoulou (2013). Shear stress and shear rate data were fitted to the Ostwald model following the power law equation:

$$\tau = K \times \gamma^n$$

where τ is the shear stress (Pa), K is the consistency index (Pa s^n), γ is the shear rate (s^{-1}) and n is the flow index.

The specific gravity of batter was determined as the ratio of the weight of a standard container filled with the batter to the weight of the same container filled with distilled water.

Image analysis

The batter samples were observed by an optical microscope (Leica Microsystems DM750, Heerbrugg, Switzerland) at 10× magnification, equipped with a digital camera (Leica DFC295, Heerbrugg, Switzerland). The diameter of the bubbles was measured from the images with the diameter evaluation tool, provided by the microscope software. The bubble diameters were then grouped into 17 size classes of 5 μm wide over the range of 0 to 85 μm. In the case of the samples with fat replacer, bubbles with diameter above 85 μm were observed, and therefore the bubbles with diameter above 85 μm were grouped in two wider size classes (85 to 100 μm, and 100 to 200 μm). The number of observations in each bubble diameter class was expressed as percentage of the total and plotted at the midpoint of the class.

Measurement of cake specific volume

The specific volume of each cake was determined as the ratio of the volume (which was determined by the rapeseed displacement method) to its weight (Psimouli and Oreopoulou, 2013).

Colour measurement

The colour of crust and crumb was measured using a tristimulus chromatometer (Minolta Company, Osaka, Japan). Measurements at nine different regions were conducted, three times at every region, and the results are expressed as average of measurement in L, a and b values of the CIELAB system. The L value features the lightness and ranges from 0 (black) to 100 (white), a ranges from -100 (redness) to +100 (greenness) and b ranges from -100 (blueness) to +100 (yellowness).

The crust colour was featured through the browning index (BI), which was calculated by the equation (Maskan, 2001):

$$BI = \frac{[100(x - 0.31)]}{0.17}$$

where

$$x = \frac{(a + 1.75L)}{(5.645L + a - 3.012b)}$$

Textural characteristics

Crumb texture was determined by the texture analyser (TA-XTi2; Stable Microsystems, Surrey, UK). Samples of 20 mm thickness, after the crust had been removed, were subjected to a two cycle compression test (texture profile analysis; test speed 1 mm/s, penetration distance 8 mm, time between two cycles 15 s). The textural attributes were calculated from the Force-time diagram, namely hardness, which is defined as the maximum force during the first compression, cohesiveness, defined as the ratio of the compression work in the second compression cycle to the compression work in the first cycle, springiness and resilience, which are indicative of the sample's elastic recovery. More specifically springiness refers to the sample's recovery between two compressions and resilience reflects the symmetry of the first compression peak (Martinez-Cervera *et al.*, 2011).

Porosity

To determine the porosity three samples were cut from the crumb of each cake and dried overnight. The bulk volume (V_b, cm^3) was measured with a digital calliper. The volume of solids (V_s, cm^3) of the same samples was measured with a gas multipycnometer (Quantachrome MVP-1; Quantachrome Inc., Boynton Beach, FL, USA), while an analytical balance (Precisa XT220A; Precisa Gravimetrics

AG Dietikon, Switzerland) was used to determine the mass (m) of the samples.

The porosity was calculated by the equation:

$$\varepsilon = 1 - \rho_b/\rho_s$$

where $\rho_b = m/V_b$ is the bulk density and $\rho_s = m/V_s$ the true density.

Sensory analysis

The descriptive analysis of the cake samples was conducted by ten authorised panellists of the accredited (according to ISO 17025; ISO, 2005) sensory laboratory of the National Technical University of Athens. The panellists were trained in the sensory analysis (Lebesi and Tzia, 2011) and had experience in accessing bakery products. Cake samples were evaluated for taste and flavour on a nine-point scale ranging from 1 (extremely dislike) to 9 (extremely like). Additionally, samples were evaluated for crust and crumb colour lightness, crumb hardness and crumbliness (1: least intense to 9: most intense).

Statistical analysis

Triplicate measurements for each formulation were conducted, except for specific volume in which case duplicate measurements were conducted, and the presented results are mean values of duplicate experiments. The results were statistically analysed by analysis of variance (ANOVA) using Statistica 7.0 software (StatSoft Inc., Tulsa, OK, USA). Significant differences (P<0.05) were determined by Duncan's multiple range test. Correlation between parameters was evaluated by linear regression.

3. Results and discussion

Effect of carrot fibre and inulin on batter characteristics

The batter of the cake exhibited shear thinning behaviour, following the power law model (fit correlation coefficient ≥0.99), and the values of consistency coefficient and flow behaviour index are presented in Table 2. The replacement of fat by inulin caused a decrease in consistency and increase in the flow behaviour index, indicating a less complex structure, as discussed by Psimouli and Oreopoulou (2013). On the contrary, the addition of carrot fibre, to replace flour, led to increased consistency coefficient. The 30% flour substitution by carrot fibre led to highly viscous batter and the end product was of poor quality (data not shown); therefore it was not further examined. The increase of consistency by the addition of fibre was also reported by Gomez *et al.* (2010), Lebesi and Tzia (2011), and Şeker *et al.* (2016) and can be associated to the structure and the higher water absorption of the fibre. WHC of carrot fibre was found to be 7.10±0.66 g water/g solid, while the corresponding value of wheat flour was 1.38±0.15 g water/g solid. Although more water was added to the batter formulations with carrot fibre, it did not mask the significantly higher viscosity resulting from the substitution of flour. The incorporation of both carrot fibre (10%) and inulin compensated the reverse effects of either replacer and resulted in a batter with intermediate consistency, though significantly lower than the control.

The specific gravity increased significantly with the addition of either replacer, indicating a significant decrease of air incorporation (Table 2). The increased specific gravity of the batter with the addition of insoluble fibres was also reported by Gomez *et al.* (2010). More specific data about the bubble size distribution of the incorporated air in the batter was provided through image analysis. The incorporation of

Table 2. Rheological properties and specific gravity of batter, specific volume, porosity, crust and crumb colour of cakes with fat and/or flour replacement.[1]

Sample		Batter properties			Cake properties			
		Consistency coefficient (K) (Pa s^n)	Flow behaviour index (n)	Specific gravity (g/cm^3)	Specific volume (cm^3/g)	Porosity	Browning index crust	L crumb
Control		31.8±1.2^b	0.48±0.02^c	0.97±0.01^d	2.43±0.01^a	0.76±0.01^a	132.7±4.2^a	74.5±1.8^{ab}
Inulin	65%	10.1±0.1^d	0.64±0.00^a	1.21±0.01^a	2.35±0.09^{ab}	0.77±0.02^a	121.3±7.2^b	70.4±0.4^c
Carrot fibre	10%	34.8±0.4^a	0.46±0.00^c	1.08±0.01^c	2.27±0.20^b	0.71±0.01^b	136.2±0.9^a	74.9±1.3^a
	20%	36.8±1.7^a	0.47±0.00^c	1.14±0.01^b	1.94±0.00^c	0.67±0.02^c	109.8±3.4^c	73.3±0.8^b
cf10in65[2]		23.2±1.7^c	0.61±0.00^b	1.20±0.02^a	2.07±0.03^c	0.71±0.01^b	121.1±2.8^b	70.0±0.7^c

[1] Results are given as the mean values ± standard deviation. Values followed by different letters in the same column are statistically different (P<0.05).
[2] Carrot fibre 10% + inulin 65%.

carrot fibre at 10 and 20% levels of flour substitution lead to batters with narrow bubble size distribution, i.e. 80 and 84% of the bubbles, respectively, were distributed within diameter range 0-10 μm. The results of image analysis of the cake with 10% carrot fibre are presented in Figure 1 together with the control and inulin containing cakes. The replacement of fat by inulin resulted in broader bubble size distribution, i.e. 43% of bubbles had diameter higher than 30 μm compared to control with only 10% of the bubble population distributed within the respective range. This result can be explained by the lower content of the fat that functions as bubble stabiliser (Psimouli and Oreopoulou, 2013; Rodriguez-Garcia *et al.*, 2012, 2014). The lower viscosity of the batter with inulin is another important factor that may affect the coalescence of the bubbles. The combination of inulin and carrot fibre (10%) is also presented in Figure 1, and, as can be seen, carrot fibre compensated the effect of inulin towards a narrower bubble size distribution even than the control, with 84% of the bubble population below diameter of 20 μm.

Effect of carrot fibre and inulin on cake physical properties

The expansion of the cakes can be evaluated through the specific volume and porosity values, which are also presented in Table 2. The batter characteristics, and more specifically the amount of incorporated air and the air holding capacity during baking, affect the volume development of the cake. Hence the cakes with fibres showed significantly lower specific volume and porosity values compared to the control, following the trend of specific gravity. However, the fact that the volume development is not only affected by the initial amount of air entrapped is demonstrated by the moderate correlation between the specific gravity of batter and the specific volume of cake and even weaker correlation with porosity (r=-0.49 and r=-0.10, respectively). Another factor might be the viscosity; the significantly higher viscosity of the batters with carrot fibre limited the evolution of the already smaller air bubbles, resulting in significantly lower specific volume and porosity compared to control. On the contrary the fat replacement by inulin decreased notably the viscosity of the batter and consequently limited its ability to entrap and retain air. Nevertheless, fat replacement by inulin did not affect the specific volume and porosity of the cake, which could be attributed to the increase of starch gelatinisation temperature induced by inulin of low degree of polymerisation, as observed by Psimouli and Oreopoulou (2013). The combination of fat replacement by inulin and flour replacement by carrot fibre presented low entrapment of air (as indicated by specific gravity) and lower ability to retain the air bubbles (due to low batter consistency), leading to further decrease of the specific volume compared to the cake with 10% carrot fibre.

The textural properties of the cakes are presented in Figure 2. The incorporation of carrot fibre at 10% provided cakes of no significant differences compared to control in terms of crumb hardness, while cakes with 20% flour replacement by carrot fibre exhibited considerably increased hardness. The combination of inulin and carrot fibre (10%) resulted in a cake harder than the control and the cakes prepared with each replacer because of the loss of the tendering effect of fat and the lower volume of the cake. The incorporation of carrot fibre led to significantly decreased cohesiveness and elasticity (as expressed by resilience and springiness), which can be associated to the significantly decreased porosity compared to control. On the other hand the samples enriched with inulin and carrot fibres did not differentiate significantly from control in terms of cohesiveness and presented higher resilience and springiness, which could be attributed to the adverse effect of inulin to increase cohesiveness and elasticity through strengthening of the crumb network (Zahn *et al.*, 2010). In general cakes of more dense structure exhibited higher hardness as demonstrated

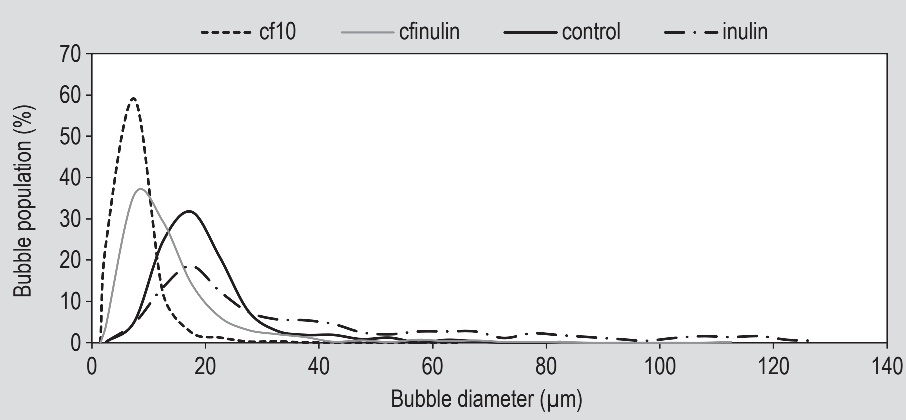

Figure 1. Bubble distribution of control formulation, and formulations with 10% flour replacement by carrot fibre (cf10), 65% fat replacement by inlulin (inulin), or both (cfinulin).

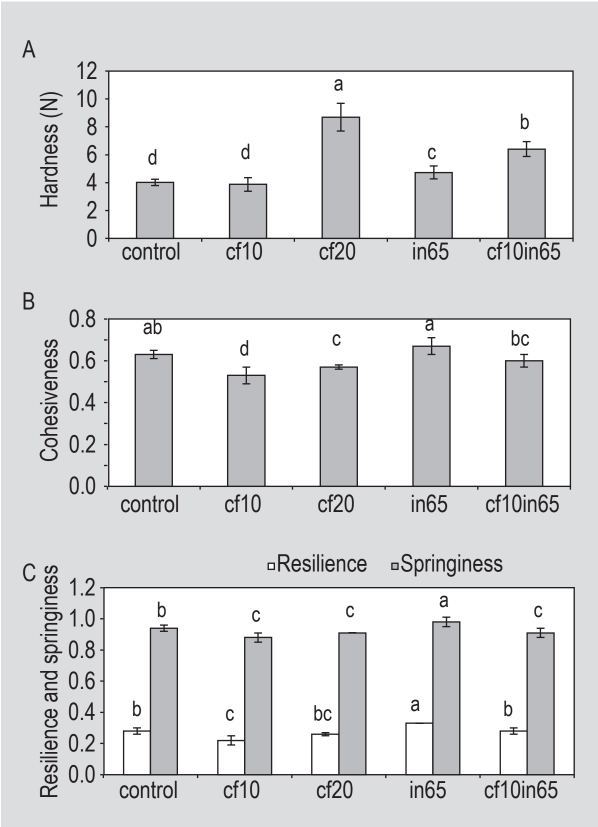

Figure 2. Textural properties of cakes with fibres: (A) hardness, (B) cohesiveness, and (C) resilience and springiness (cf10 = formulation with 10% flour replacement by carrot fibre; cf20 = formulation with 20% flour replacement by carrot fibre; in65 = formulation with 65% fat replacement by inulin; cf10in65 = formulation with 10% flour replacement by carrot fibre and 65% fat replacement by inulin). Error bars represent standard deviation. Bars with different letters are statistically different (*P*<0.05).

by the negative correlation between specific volume and porosity with hardness (r=-0,93, r=-0,74, respectively). Furthermore, the more porous structure yields greater cohesiveness and elasticity as demonstrated through the correlation of porosity with cohesiveness and springiness (r=0.74 and 0.78, respectively).

Carrot fibres did not affect the crumb colour (Table 2), showing an advantage compared to other pomace waste that can be used in cakes (Şeker *et al.*, 2016). Also, the BI of the crust of samples with 10% carrot fibre did not differentiate from the one of control. At 20% level of flour replacement a lighter browning of the crust was observed that can be attributed to the lower proportion of flour used, which affects the Maillard reactions and consequently the browning of the surface. Fat replacement by inulin yielded significantly lower BI of the crust and darker crumb compared to the control. Consequently, the values of the samples containing carrot fibre and inulin are closer to the values of the cake containing inulin.

Addition of emulsifiers on the properties of batter and cake containing inulin and carrot fibre

The addition of emulsifiers at low levels did not induce any significant difference to the rheological properties and specific gravity of the batter. At higher levels, however, they increased the consistency and decreased the specific gravity of the batter as indicated in Table 3. This can be attributed to the greater air incorporation to the batter. Kim and Walker (1992) reported the ability of air bubbles to increase viscosity, due to stearic hindrance, while Rodrigues Garcia *et al.* (2014) commented that, in addition to the incorporated air, the ability of the emulsifiers to bind water

Table 3. Effect of emulsifiers on batter characteristics and on the specific volume, porosity, crust and crumb colour of cakes containing inulin (65% fat replacement) and carrot fibre (10% flour replacement).[1]

Emulsifier[2]	Batter properties			Cake properties			
	Consistency coefficient (K) (Pa s^n)	Flow behaviour index (n)	Specific gravity (g/cm^3)	Specific volume (cm^3/g)	Porosity	Browning index crust	L crumb
None	23.2±1.7^c	0.61±0.00^a	1.20±0.02^a	2.07±0.03^c	0.71±0.01^c	121.1±2.8^a	70.0±0.7^a
MG 1%	23.9±0.6^{bc}	0.61±0.00^a	1.19±0.01^a	2.08±0.02^{bc}	0.73±0.01^{abc}	122.9±0.5^a	70.8±0.4^a
MG 2%	28.7±0.6^a	0.61±0.02^{ab}	1.15±0.01^c	2.14±0.03^a	0.74±0.01^{ab}	120.7±2.9^a	70.3±0.7 ^{a}
SSL 0.25%	23.8±1.9^{bc}	0.55±0.01^c	1.19±0.01^a	2.09±0.01^{bc}	0.72±0.01^{bc}	122.4±3.1^a	70.4±0.4 ^{a}
SSL 0.5%	28.3±0.6^a	0.59±0.02^{ab}	1.14±0.02^c	2.16±0.05^a	0.74±0.02^a	121.4±0.7^a	70.5±0.3 ^{a}
DATEM 0.25%	23.5±1.9^c	0.58±0.00^b	1.19±0.00^a	2.08±0.02^{bc}	0.73±0.01^{abc}	120.3±2.3^a	70.6±0.2 ^{a}
DATEM 0.5%	27.1±1.1^{ab}	0.58±0.00^b	1.17±0.01^b	2.12±0.05^{ab}	0.73±0.02^{abc}	124.1±1.7^a	70.7±0.3 ^{a}

[1] Results are given as the mean values ± standard deviation. Values followed by different letters in the same column are statistically different (*P*<0.05).
[2] DATEM = diacetyl tartaric acid esters of mono- and diglycerides; MG = distilled monoglycerides; SSL = sodium stearoyl lactylate.

and their interactions with other recipe constituents result in increased consistency of the batter.

The cake batter can be considered as a fat in water emulsion with four phases, which are the aqueous, fat, gas and solid starch granules. Hence the emulsifiers by acting as surface active agents in the fat-water interface stabilise the formation of the bubbles. In the case of decreased fat formulation, as in the present study, the aeration could be facilitated by the emulsifiers' ability to lower the tension between the liquid and gas phases and form an interfacial film around the bubbles, as suggested by Sahi and Alava (2003). Furthermore, the air incorporation is aided by the ability of the α-tending emulsifiers to form lamellar structure, which, when cooled, forms an α-gel phase with better stabilising effect, important for the aeration of the product. More specifically the a-gels are believed to form layered structure at the bubble surfaces (Richardson *et al.*, 2002, 2004).

As regards bubble size distribution, the emulsifiers caused a slight shifting of the curve peak to smaller sizes (data not shown). This observation verifies the bubble stabilising ability of the emulsifiers.

Table 3 presents also the specific volume and porosity of the cakes. Similarly to the batter characteristics, no significant difference was observed with the addition of emulsifiers at low levels, while at higher levels an increase in specific volume and porosity was observed. The increase of the specific volume and porosity of the cake may be linked to the increased air incorporation in the batter and the emulsifiers' stabilising effect on small air bubbles but, also, to the dough strengthening effect caused by the emulsifiers through interacting with the water phase and forming lipid-water structures (Krog, 1981). Nunes *et al.* (2009) reported a similar trend concerning SSL and DATEM on the specific volume of gluten free breads, and commented that the specific volume is highly related to the strength of the dough, which increased its elasticity and allows expansion during proofing and baking. The increased volume development of the cake as a result of the air incorporation in the batter is demonstrated through the inverse relationship of batter specific gravity with cake specific volume (r=-0.99).

SSL and MG, when added at higher levels, appeared to be the most effective, also in terms of improvement of the texture of the final product, since they led to significant decrease of crumb hardness (Figure 3). Roman *et al.* (2015)

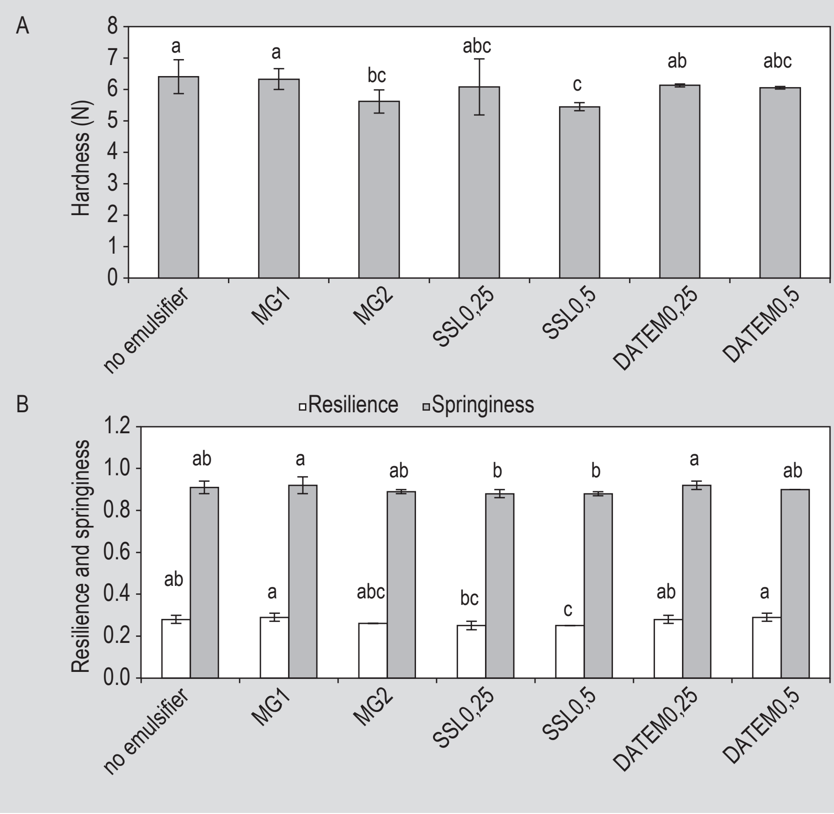

Figure 3. Textural properties of cakes with fibres and emulsifiers: (A) hardness, and (B) resilience and springiness (DATEM = diacetyl tartaric acid esters of mono- and diglycerides; MG = distilled monoglycerides; SSL = sodium stearoyl lactylate.). Error bars represent standard deviation. Bars with different letters are statistically different (*P*<0.05).

also observed that emulsifier incorporation in reduced fat cakes minimises the negative effects of fat reduction and leads to good quality cakes, maintaining the volume and reducing the hardness. The decrease of hardness is mainly attributed to the less dense structure as demonstrated by the significant negative correlation of porosity with hardness (r=-0.80). The lower crumb hardness obtained by SSL could be also attributed to its strong binding ability with starch (Pisesookbunterng and D'Appolonia, 1983), hence retarding the starch retrogradation. Figure 3 also indicates that the emulsifiers did not affect the elasticity of the samples, while neither cohesiveness was affected (data not presented).

On the other hand the addition of emulsifiers to the cake did not lead to significant differences regarding the crust and crumb colour. The latter is expected since the emulsifiers do not affect the presence of sugars and amino acids and hence the Maillard reactions.

Effect of carrot fibre, inulin and emulsifiers on cake sensorial properties

The results of sensory analysis are presented in Table 4. The significant differences detected by the sensory panel regarding the brown colour of the crust and the lightness of the crumb generally agree with the instrumental measurements.

The replacement of flour with 10% carrot fibres increased hardness but did not differentiate significantly crumbliness, which expresses the breaking of a slice of the cake with fingers. Moreover, the samples with 10% carrot fibre ranked high in terms of taste and flavour. A further replacement of 20% flour resulted in low scores. The combination of 10% carrot fibres with inulin resulted in cakes with acceptable sensorial properties, although taste, flavour, and especially hardness received significantly worse scores than the control.

The data of sensory evaluation of the samples containing emulsifiers are also presented in Table 4. The incorporation of MG and SSL in cakes with carrot fibre and inulin were not evaluated as significantly different from the cakes without emulsifiers in terms of all sensorial attributes, except for hardness. Both emulsifiers at high levels decreased the hardness of the fibre-enriched cake. Additionally, the taste and flavour of the samples with SSL 0.5% were the closest to the control. On the other hand the samples with DATEM did not present significant difference from the cake with no emulsifiers in hardness, and ranked low in terms of taste and flavour.

4. Conclusions

The incorporation of carrot fibre as well as the addition of inulin affected the rheological properties of the batter and the characteristics of the cake. The wheat flour substitution by carrot fibres led to increased viscosity and lower air incorporation, leading to cakes of dense structure and increased hardness. Fat replacement resulted in batters of low viscosity and cakes of increased hardness and elasticity.

The enrichment with carrot fibre to cake formulations containing inulin as fat substitute appeared to counteract the effect of the inulin in terms of batter viscosity and bubble size distribution, as well as elasticity of the cakes towards resemblance to the control samples. Nevertheless the incorporation of both fibres led to further increase of

Table 4. Sensory analysis of cakes with fibres and emulsifiers.[1]

Sample		Crust colour	Crumb lightness	Crumbliness	Hardness	Taste	Flavour
Control		5.2 ± 1.5^{b}	7.5 ± 0.8^{a}	5.4 ± 0.8^{a}	3.7 ± 0.5^{d}	7.7 ± 1.1^{a}	7.4 ± 0.8^{a}
cf10[2]		5.9 ± 1.5^{ab}	6.4 ± 0.6^{ab}	5.7 ± 1.1^{a}	5.0 ± 0.6^{bc}	7.0 ± 0.7^{ab}	7.0 ± 0.9^{ab}
cf20		6.5 ± 1.2^{a}	6.2 ± 1.6^{ab}	3.8 ± 1.2^{b}	6.8 ± 0.8^{a}	6.0 ± 0.7^{cd}	6.0 ± 1.0^{cd}
in65		5.2 ± 0.9^{b}	5.3 ± 0.8^{bc}	3.2 ± 1.0^{b}	5.2 ± 1.0^{bc}	6.2 ± 0.6^{bcd}	6.3 ± 0.9^{bcd}
cf10in65		6.0 ± 0.9^{ab}	4.9 ± 1.2^{c}	5.5 ± 1.0^{a}	6.0 ± 0.8^{ab}	6.3 ± 0.9^{bc}	6.4 ± 0.8^{bcd}
cf10in65	MG[3] 1%	5.5 ± 0.7^{ab}	4.7 ± 1.6^{c}	5.7 ± 1.2^{a}	5.5 ± 0.9^{bc}	6.3 ± 1.0^{bc}	6.2 ± 1.1^{bcd}
	MG 2%	5.7 ± 1.2^{ab}	4.6 ± 1.9^{c}	5.9 ± 1.9^{a}	4.9 ± 0.6^{c}	6.2 ± 1.1^{bcd}	6.0 ± 0.7^{cd}
	SSL 0.25%	6.1 ± 1.1^{ab}	4.6 ± 1.1^{c}	5.9 ± 1.2^{a}	5.2 ± 1.6^{bc}	6.4 ± 0.7^{bc}	6.5 ± 0.7^{bc}
	SSL 0.5%	5.7 ± 0.9^{ab}	5.0 ± 1.3^{c}	6.0 ± 1.2^{a}	4.6 ± 0.9^{c}	6.6 ± 1.0^{bc}	6.8 ± 1.1^{abc}
	DATEM 0.25%	6.1 ± 1.1^{ab}	5.2 ± 1.7^{bc}	5.5 ± 1.0^{a}	5.2 ± 0.8^{bc}	5.3 ± 1.4^{de}	5.6 ± 0.9^{de}
	DATEM 0.5%	5.9 ± 1.1^{ab}	4.9 ± 1.4^{c}	5.0 ± 1.3^{a}	5.1 ± 1.4^{bc}	5.0 ± 1.2^{e}	5.0 ± 0.8^{e}

[1] Results are given as the mean values ± standard deviation. Values followed by different letters in the same column are statistically different ($P<0.05$).
[2] cf10 = 10% flour replacement by carrot fibre; cf20 = 20% flour replacement by carrot fibre; in65 = 65% fat replacement by inulin; cf10in65 = 10% flour replacement by carrot fibre and 65% fat replacement by inulin.
[3] DATEM = diacetyl tartaric acid esters of mono- and diglycerides; MG = distilled monoglycerides; SSL = sodium stearoyl lactylate.

crumb hardness and decrease of volume development. The quality characteristics, and more specifically the hardness, specific volume and porosity, of the enriched cake were improved with emulsifiers, with SSL exhibiting the best results in terms of sensorial attributes.

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