LWT - Food Science and Technology 127 (2020) 109378

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Changing chemical leavening to improve the structural, textural and sensory properties of functional cakes with blackcurrant pomace

Elena Diez-Sánchez[a], Empar Llorca[a], Amparo Tárrega[b], Susana Fiszman[b], Isabel Hernando[a,*]

[a] Department of Food Technology, Universitat Politècnica de València, Camino de Vera s/n, Valencia, Spain
[b] Instituto de Agroquímica y Tecnología de Alimentos (IATA-CSIC), Paterna, Spain

ARTICLE INFO

Keywords:
Leavening agent
Structure
By-product
Flash profile
Bakery products

ABSTRACT

Blackcurrant pomace is a by-product with bioactive compounds and dietary fibre, which can be used as ingredient to elaborate bakery products. However, its high content of fibre results in techno-functional problems affecting texture and sensory properties. We hypothesised that the use of different chemical leavening agents can counteract the negative effects of pomace addition improving the quality of the final product. Citric acid, sodium acid pyrophosphate, and glucono-δ-lactone were used as leavening agents in combination with sodium bicarbonate (encapsulated and free). A micro-baking simulation showed the expansion of the bubbles in the batter. In the cakes, the structure, texture, colour and sensory profile were studied. Cakes prepared with pyrophosphate (regardless bicarbonate type) and glucono-δ-lactone (plus free bicarbonate) incorporated more air, which led to bigger gas cells and a softer instrumental texture. These cakes were perceived as brittle and spongy. All the formulations were acceptable according to an untrained sensory panel.

1. Introduction

By-products from the food industry can have a high nutritional value. This is the case of the by-products generated in the production of blackcurrant juice, composed of peel and seeds; rich in polyphenols and dietary fibre (DF) (Borges, Degeneve, Mullen, & Crozier, 2010; Paunović, Mašković, Nikolić, & Miletić, 2017). These components have beneficial effects on health; polyphenols have a positive impact on cardio-vascular health, reduce inflammation, and modify intestinal microbiota, among other effects; these effects are because of their inner antioxidant capacity (Del Rio et al., 2013; Shahidi & Ambigaipalan, 2015). DF is involved in disease prevention and health improvement, because of its contribution to physiological attenuations, such as cholesterol and fat binding, reduction of blood glucose levels, prevention of constipation, and facilitating good colonic health (Foschia, Peressini, Sensidoni, & Brennan, 2013). To appreciate these value-added ingredients, its incorporation in a food matrix could be interesting (Foschia et al., 2013; Zhao, 2007). Fruit pomace has been previously used in preparing bakery products like muffins and sponge cakes; Quiles et al. (2018) used blackcurrant and Aronia pomace to replace flour, fat, and sugar in cakes. Sudha, Baskaran, and Leelavathi (2007) and Masoodi, Sharma, and Chauhan (2002) incorporated apple pomace in cakes, and Diez-Sánchez et al., 2019 incorporated blackcurrant pomace in muffins. Finally, Walker, Tseng, Cavender, Ross, and Zhao (2014) studied the substitution of flour with wine grape pomace in muffins, breads, and brownies. One of the major drawbacks arising from these studies, on inclusion of ingredients high in fibre, come from detrimental effects on the creation of a well-aerated structure (Lebesi & Tzia, 2011; Quiles et al., 2018). This lack of aeration in cakes, which is determined by the amount of gas occluded, produced and retained by the batter, produces a firm texture and a reduction in cake volume. As expected, such deficiencies increase with higher levels of wheat flour substitution with fibre-rich ingredients.

In sponge cakes, the batter expansion during baking results from carbon dioxide release when an acid (or an acidic salt) reacts with sodium bicarbonate in the presence of moisture and heat to form a salt, water, and carbon dioxide (De Leyn, 2014; Narsimhan, 2014). This chemical reaction influences the expansion of the initial bubbles incorporated during the mixing process that function as nuclei for larger bubbles. Presence and good distribution of bubbles in cakes favour good final product characteristics like colour, texture, and volume (Book & Brill, 2015).

Sodium bicarbonate has been the most used leavening agent in general domestic baking, which reacts with the lactic acid of other ingredients like sour milk (Bennion, Bamford, & Bent, 1997). Now, there are chemical leavening agents with different characteristics that make them suitable for application in different conditions (De Leyn, 2014). When free bicarbonate (B) is used, the bubble formation in the first

* Corresponding author.
E-mail address: mihernan@tal.upv.es (I. Hernando).

https://doi.org/10.1016/j.lwt.2020.109378
Received 26 September 2019; Received in revised form 20 February 2020; Accepted 5 April 2020
Available online 16 April 2020
0023-6438/

stages of baking results not only from the incorporated air due to the batter mixing but also from the CO_2 released by early leavening chemical reaction (Germain & Aguilera, 2008) and the CO_2 loss by diffusion through the batter (Godefroidt, Ooms, Pareyt, Brijs, & Delcour, 2019). However, as the bicarbonate dissociates in water almost immediately, the rate of carbon dioxide production is determined by the acid's rate of dissociation (Bellido, Scanlon, Sapirstein, & Page, 2008). The use of encapsulated bicarbonate (EB) avoids a rapid release of gas, retarding the chemical reaction until the capsule's external wall melts during baking (Gibbs, Kermasha, Alli, & Mulligan, 1999; Lakkis, 2016; Meiners, 2012). Hence, the type of acid and bicarbonate form (encapsulated or not) used in the formulation would have considerable influence in bubbles creation and growth. Dorko and Penfield (1993) studied that bicarbonate encapsulation resulted in lower initial CO_2 release in muffins, changing their final characteristics. Though different leavening agents have been used over the years, there are no recent studies comparing the effect of traditional leavening agents with newer ones.

Our hypothesis is that certain combinations of leavening agents including encapsulated sodium bicarbonate could improve aeration of high-fibre bakery products. Thus, the aim of the present study was to evaluate the effects of different leavening agents and their combinations, with encapsulated and free bicarbonate, on the improvement of the structural and sensory characteristics of sponge cakes, prepared with blackcurrant pomace.

2. Materials and methods

2.1. Cake ingredients

The ingredients used in the cake's batter preparation were: wheat flour (Harinas Segura S.L, Torrente, Valencia, Spain; composition provided by the supplier: 13.5–15.5 g/100 g moisture, 9–11 g/100 g protein), white sugar (AB Azucarera Ibérica S.L.U., Madrid, Spain), pasteurised egg yolk and white (Ovocity, Llombay, Spain), skimmed milk powder (Corporación Alimentaria Peñasanta, S.A., Siero, Asturias, Spain), refined sunflower oil (Aceites del Sur-Coosur, S. A., Vilches, Spain), sodium bicarbonate (E − 500ii, Sodas y Gaseosas A. Martínez, S. L., Cheste, Spain), micro-encapsulated bicarbonate (Grupo Indukern, S. L., Barcelona, Spain, melting point of the encapsulation provided by the supplier: 69–73 °C), citric acid (E − 300, Sodas y Gaseosas A. Martínez, S. L., Cheste, Spain), sodium acid pyrophosphate (E − 450i, Chemische Fabrik Budenheim KG, Budenheim, Germany), glucono-δ-lactone (E − 575, Emilio Peña, S. A., Torrente, Spain), mineral water (Pascual S. A. U., Aranda del Duero, Spain), and salt (Sal Bueno S.L., Xirivella, Spain). Blackcurrant pomace was kindly supplied by the Institute of Natural Materials Technology (Technische Universität Dresden, Germany). It was prepared by drying the fresh pomace at 70 °C for 2 h and milling it in a ZM 100 ultracentrifuge mill (Retsch GmbH, Haan, Germany) at 14000 rpm using a 1 mm sieve (Reißner et al., 2019).

2.2. Cake preparation

Six different formulations contained 100 g wheat flour, 100 g sugar, 50 g reconstituted skim milk, 27 g egg yolk, 54 g egg white, 5 g water, 20 g blackcurrant pomace powder, 46 g sunflower oil, and 1.5 g salt; different leavening agents were added to each formulation (Table 1). Encapsulated (EB) and free bicarbonate (B) were used in combination with three different acidic ingredients: citric acid (CA), sodium acid pyrophosphate (SAPP), and glucono-δ-lactone (GDL). These leavening agents were chosen for their different rates of carbon dioxide production, which is a function of the solubility of the acidic constituents. CA is a fast acting acid, SAPP is a slow acting acid and GDL is a continuous-releasing leavening agent by a two-step reaction mechanism. The ratios of acid and bicarbonate were selected according to Brose, Becker, and Bouchain (2001).

The batters were prepared using the "all in" mixing procedure (Rodríguez-García, Puig, Salvador, & Hernando, 2012), with some modifications. Egg white, egg yolk, milk, and water were placed in a planetary mixer Kenwood KM800 Major Classic mixer (Kenwood, Havant, UK), then the solid ingredients were added to the bowl, with the oil added last. All the ingredients were mixed for 30 s at 202 rpm, followed by 1 min at 260 rpm and 3 min at 320 rpm to achieve a homogeneous batter. An oven (Electrolux, model EOC3430DOX, Stockholm, Sweden) was preheated (20 min, 180 °C). The batter was placed in a 20 cm diameter Pyrex baking pan and baked in the preheated oven at 180 °C for 43 min. Cakes were kept covered at room temperature for 24 h and then analysed. All the batters and cakes were prepared in triplicate on three different days.

2.3. Light microscopy and image analysis of the cake batters at different baking temperatures

A microscopic examination during simulated micro-baking was carried out to record bubble changes of batter as previously described (Rodríguez-García, Salvador, & Hernando, 2014) using a temperature-controlled stage (Analysa-LTS350, Linkam, Surrey, UK), mounted under the lens of a light microscope (Nikon ECLIPSE 80i, Nikon Co., Ltd., Tokyo, Japan). Images were captured and stored every 10 s while three samples from each batter were examined. The images were analysed using the software ImageJ (National Institutes of Health, Bethesda, MD).

2.4. Crumb cellular structure

The baked product was cut into vertical slices of 1.5 cm thickness and scanned using a computer scanner (Epson Perfection 1250, Epson America Inc., Long Beach, CA). The images were acquired with a resolution of 300 dpi and were analysed using the software ImageJ (National Institutes of Health, Bethesda, Maryland, USA). The image was cropped to a 10 × 4 cm section, on which the analysis was performed. The image was split into colour channels and the contrast was enhanced; the image was then binarised after a grayscale threshold. The parameters calculated were air cell density (number of cells per field), air cell area (mm^2), and total air cell area within the crumb (%). Measurements were performed on three different slices of each sample.

2.5. Instrumental texture

Texture profile analysis (TPA) was conducted using a TA-TX plus Texture Analyser (Stable Micro Systems, Ltd., Godalming, UK) with the Texture Exponent Lite 32 software (version 6.1.4.0, Stable Micro Systems). TPA was performed on cubes (15 × 15 × 15 mm) taken from the central crumb of each cake. The test speed was 1 mm/s with a strain of 40% of the original cube height and a 5 s interval between the two compression cycles; the trigger force was 0.049 N. The double compression test was performed with a 35 mm diameter aluminium plate (P/35). The parameters obtained from the curves were hardness, chewiness, cohesiveness and springiness. Eight cubes of each cake were measured.

2.6. Colour measurements

The colour of the cake crumb was measured using a Chroma meter CR-400 (Minolta Co., Ltd., Osaka, Japan). The results were expressed per the CIE L*a*b* system, with reference to illuminant C and a visual angle of 2°. The parameters were $L*$ ($L* = 0$ [black]; $L* = 100$ [white]), $a*$ ($-a*$ = greenness; $+a*$ = redness), $b*$ ($-b*$ = blueness; $+b*$ = yellowness), $C*$ (chroma $C* = [(a*^2 + b*^2)^{1/2}]$), and $h_{ab}*$ (hue [$h_{ab}* = \arctan(b*/a*)$]). For each cake, three measurements were done.

Table 1
Amount of leavening agents in the six cake formulations.

Ingredient (in % flour basis)	Sample					
	CA-B	CA-EB	SAPP-B	SAPP-EB	GDL-B	GDL-EB
Free sodium bicarbonate (B)	4	–	4	–	4	–
Encapsulated sodium bicarbonate (EB)	–	4	–	4	–	4
Citric acid (CA)	3	3	–	–	–	–
Sodium acid pyrophosphate (SAPP)	–	–	5.6	5.6	–	–
Glucono-δ-lactone (GDL)	–	–	–	–	9	9

2.7. Sensory analysis

2.7.1. Sensory cake characterisation

Cake sensory characterisation using consumers was conducted through a Flash Profile test. This method, combines the free choice of the terms that characterise each of the samples, and the ratings of these terms by the panellist (Dairou & Sieffermann, 2002). Twenty-one untrained participants completed the test in two different sessions. In the first session, the six samples (CA-B, CA-EB, SAPP-B, SAPP-EB, GDL-B, and GDL-EB) were presented in triads and the participants created a list of attributes to describe the similarities and differences between them. The participants were told to focus on descriptive parameters such as flavour, texture, and appearance; and to avoid hedonic terms (Tárrega & Tarancón, 2014). In the second session each panellist ranked the cakes according to her/his own list of attributes created in the first session.

2.7.2. Sample liking

A consumer liking test of the six samples was conducted with a total of 89 consumers aged 17–45 years. Each consumer received the six samples coded with three-digit random numbers monadically and randomly served at ambient temperature. The test was done using a 9-point hedonic scale (1 = "dislike extremely"; 9 = "like extremely") to score the liking of the 'appearance', 'texture', 'taste', and 'overall liking' of the cakes.

2.8. Data analysis

A categorical multifactorial experimental design with two factors: type of sodium bicarbonate (B or EB) and type of leavening acid (CA, SAPP, and GDL) was performed on the values for texture, cellular structure, and colour parameters. Analysis of variance (ANOVA) was performed on the data. The least significant differences (LSD) were calculated at the $P < 0.05$ significance level to compare the test means. A principal component analysis (PCA) was also performed to study the correlation between crumb structure parameters and texture parameters.

For the sensory analysis, a multi factorial analysis (MFA) was used for the Flash Profile data to identify the samples and terms most closely related to the characteristics of each cake formulation. A factorial map was generated to evaluate the general sensory positioning of the samples according to the participants' perception (Tarrega, Rizo, & Fiszman, 2017). To facilitate the interpretation of Flash Profile results, a hieratical cluster analysis (HCA) was subsequently performed. Beside this, the data obtained for consumer liking test were analysed using the analysis of variance (ANOVA), and the least significant differences (LSD) were calculated at the $P < 0.05$ significance level.

All the statistical analysis was performed with software XLSTAT version 2018.1 (Addinsoft España, Barcelona, Spain).

3. Results and discussion

3.1. Analysis of the crumb structure

3.1.1. Light microscope and image analysis of the cake batters at different baking temperatures

The images corresponding to the simulated micro-baking process are shown in Fig. 1A. They were taken at different temperatures to observe the evolution of the batter bubbles' expansion. The bubbles expand due to moisture evaporation and CO_2 produced by the reaction of the leavening agent (Narsimhan, 2014). The images obtained were analysed to quantify the size distribution of the bubbles for each formulation at different temperatures during micro-baking (Fig. 1B).

Batters formulated with encapsulated bicarbonate (EB) below temperatures of 70–80 °C showed a higher frequency of small bubble sizes (0–10,000 μm^2) in comparison with batters formulated with free bicarbonate (B). The melting temperature of the bicarbonate encapsulation is 69–73 °C; from that temperature on it can be observed that there is a sudden change in bubble size in formulations with EB, being the frequency of big bubbles (> 100,000 μm^2) lower than B batters. At that time, the encapsulated bicarbonate is released thus allowing it to react easily with the acid. In addition, at temperatures ranging from 80 to 95 °C the simultaneous occurrence of both starch gelatinisation and protein denaturation results in a large increase in batter viscosity leading to the matrix thermal setting (solid cake structure) (Germain & Aguilera, 2008; Godefroidt et al., 2019; Wilderjans, Luyts, Brijs, & Delcour, 2013). Therefore, at the end of the baking process, the bubble size distribution is mainly affected by the leavening agent rate of reaction and the matrix thermal setting. As a result, when reaching 90 °C formulations with EB have less time for the CO_2 release due to the encapsulation; this fact together with the viscosity increase lead to the formation of smaller bubbles than formulations with B.

Citric acid (CA) has a fast reaction with sodium bicarbonate, thus during batter preparation at ambient temperature most of the CO_2 is released (Brose et al., 2001). For batters made with this acid, the images show that the bubbles have a constant growth. In the initial stages, though the fast reaction with the sodium bicarbonate, the bubbles are small for the initial release of CO_2. In addition, bubbles at higher temperatures do not have a large size compared to the rest of the batters, even in batters with free bicarbonate. This behaviour can be seen in the histograms corresponding to the cakes prepared with CA (with both, free and encapsulated bicarbonate) (Fig. 1B, CA-B and CA-EB). The lower frequency of big bubbles (> 100,000 μm^2) at high temperatures could be due to its fast reaction from low temperatures, leading to a smaller amount of CA or bicarbonate available at the end of the baking process.

In contrast to CA, sodium acid pyrophosphate (SAPP) is a slow-acting acid readily soluble in hot water; therefore it reacts with the bicarbonate later than CA in the baking process (De Leyn, 2014). In batters with sodium acid pyrophosphate (SAPP) the bubbles grew when the temperature increased due to the need of heat for SAPP to react with bicarbonate (Fig. 1A). The histograms corresponding to the batters prepared with SAPP show a high frequency of big bubbles at high temperatures (Fig. 1B, SAPP-B and SAPP-EB). In SAPP-EB sample, the

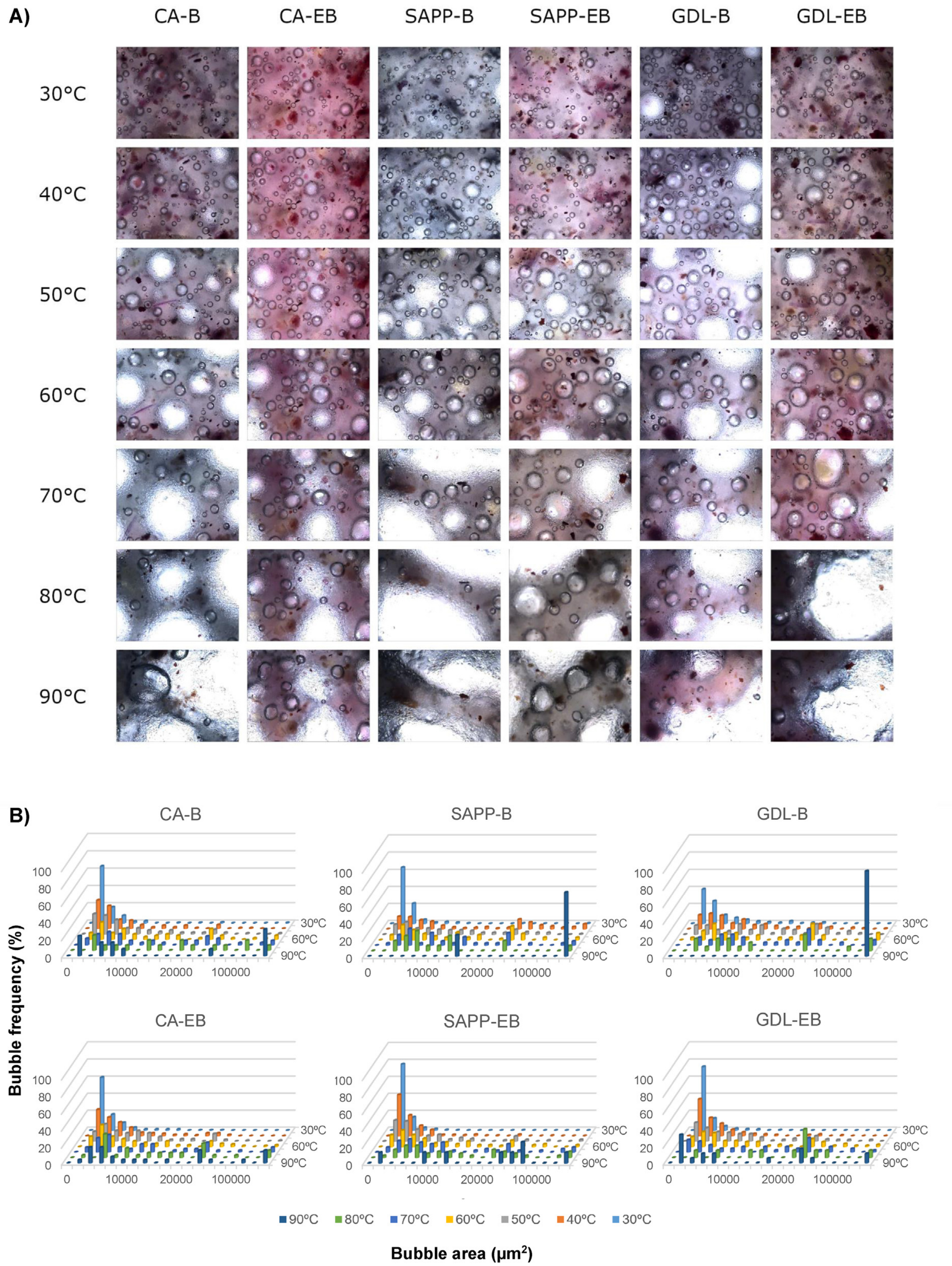

Fig. 1. **(A)** LM images (4x) of bubble expansion in the six batters at different temperatures during micro-baking. **(B)** Bubble size distribution histograms on the six batters at the different temperatures during micro-baking. CA: citric acid; SAPP: sodium acid pyrophosphate; GDL: glucono-δ-lactone; B: free bicarbonate; EB: encapsulated bicarbonate.

bubble size distribution is broader and shows a homogeneous distribution of bubble sizes which are smaller than is SAPP-B. This is because the encapsulation of bicarbonate melts near 70 °C, which together with the need for solubilisation of the acid that occurs at temperatures close to the batter thermal setting and the end of the baking process, led to the reaction taking place at a higher temperature; therefore, the release of CO_2 is lower compared to SAPP-B.

Glucono-δ-lactone (GDL) is an acidic agent that needs to

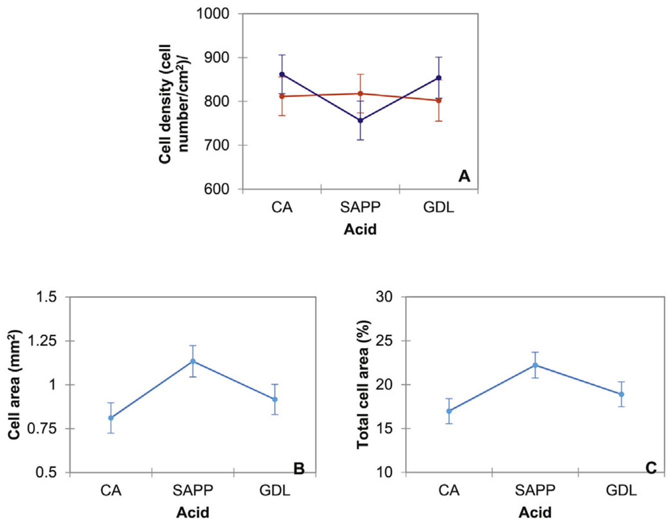

Fig. 2. Mean values for cell structure with LSD intervals. **(A)** Interaction between the acid agent and bicarbonate (free bicarbonate in red and encapsulated bicarbonate in blue) for cell density. **(B)** Mean values for cell area; effect of acid agent. **(C)** Mean values for total cell area; effect of acid agent acid used. CA: citric acid; SAPP: sodium acid pyrophosphate; GDL: glucono-δ-lactone; B: free bicarbonate; EB: encapsulated bicarbonate. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

hydrolysate into gluconic acid to react with sodium bicarbonate to form CO_2. In both reactions carbon dioxide is released continuously being the reaction with bicarbonate much faster than the hydrolysation (Bellido et al., 2008; Brose et al., 2001). Bubbles in the GDL-B sample at low temperatures show a broader size distribution, *i.e.* compared with the other formulations (Fig. 1B, GDL-B and GDL-EB), the frequency of small bubbles (< 10,000 μm^2) is lower but there is a higher frequency of bigger bubbles (10,000–20,000 μm^2). This phenomenon is because at the first stages there is a slow release of CO_2 from the hydrolysation of GDL into gluconic acid, which has a faster reaction with the bicarbonate in the baking stage with the subsequent CO_2 release (Bellido et al., 2008). Moreover, the sample GDL-EB has smaller bubbles in the first baking stages because the encapsulation of the base has not melted.

3.1.2. Cellular structure of the cake crumb

The images were analysed to quantify and compare the macrostructure of the crumb between samples. Two factors were considered: type of acid (CA, SAPP, and GDL) and type of bicarbonate (encapsulated or free). Fig. 2 shows the numerical data corresponding to the image analysis of the crumb. The results are presented only when there is a significant effect or an interaction between factors ($P > 0.05$).

Significant interactions ($P < 0.05$) between factors were only found for cell density, thus both the acid and the base had an influence on the number of cells In Fig. 2A, results corresponding to B-samples did not show significant differences among them regardless the type of acid used. In EB-samples, cakes with SAPP had a significantly lower cell density ($P < 0.05$) compared to CA and GDL samples. This was due to the slow-acting effect of SAPP explained earlier. In addition, there were no significant differences among samples with B or EB with the same acid. Hence, despite the interaction between both factors, there were only slightly differences between samples that could be negligible.

The type of acid used significantly affected ($P < 0.05$) the values for cell area and total cell area (Fig. 2B and C), but the effect of bicarbonate type (free or encapsulated) was not significant. In cakes with SAPP, the values for cell area and total cell area were significantly higher ($P < 0.05$) in comparison with CA and GDL. These results are consistent with those obtained for bubble size distribution during micro-baking, where a high frequency of big bubbles was observed at high temperatures. The late gas release from SAPP, when the batter viscosity has increased (temperatures near to the thermal setting point), lead to bigger bubbles due to a better retention of the CO_2 into de matrix. On the contrary, the rapid gas release of CA could lead to an excessive loss of leavening gas thus forming smaller bubbles at the end of the baking process (Penfield & Campbell, 1990).

The different macroscopic structures seen in the crumb may be explained by the uneven expansion of the bubbles during baking, as observed in the micro-baking experiment (Fig. 1). Therefore, the formulations that achieved a lower bubble size at high temperatures (CA and GDL), presented a greater number of smaller cells, giving a lower percentage of total cell area, which implies less air in the crumb. Sodium acid pyrophosphate, regardless of the bicarbonate used, produced cakes with a higher amount of air incorporated in the crumb, since they presented a total cell area significantly higher ($P < 0.05$) than CA and GDL formulations.

3.2. Instrumental cake texture

The instrumental texture results for hardness, chewiness, cohesiveness, and springiness are shown in Fig. 3A–E. The results are only presented when a significant effect or an interaction between acid and base factors ($P > 0.05$) were found.

A significant interaction ($P < 0.05$) between acid and base for hardness values was detected (Fig. 3A). Hardness values of B-cakes (prepared with free bicarbonate) were significantly higher ($P < 0.05$) for cakes with CA, followed by GDL and SAPP (Fig. 3A). The same order was observed for the hardness values in EB-cakes (prepared with encapsulated bicarbonate) but significant difference ($P > 0.05$) was not

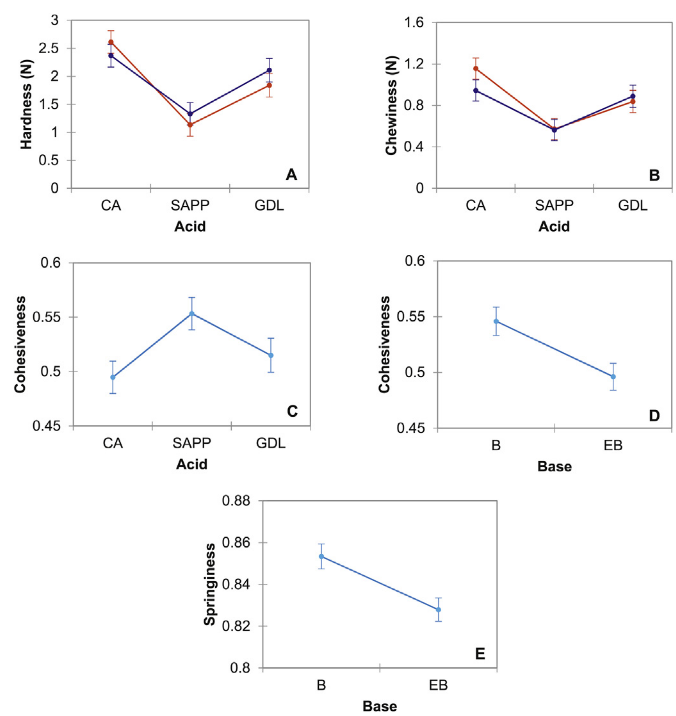

Fig. 3. Mean value of instrumental texture parameters of the six cakes with LSD intervals. **(A, B)** Interaction effect between the acid and bicarbonate form for hardness and chewiness, respectively (free bicarbonate in red and encapsulated bicarbonate in blue). **(C, D)** Mean values for cohesiveness; effect of the acid agent and bicarbonate form, respectively. **(E)** Mean values for springiness; effect of the bicarbonate form. CA: citric acid; SAPP: sodium acid pyrophosphate; GDL: glucono-δ-lactone; B: free bicarbonate; EB: encapsulated bicarbonate. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

found between CA and GDL samples. As expected, these results are in line with the macroscopic crumb structure features already analysed. SAPP samples had the highest total cell area values, which implies a more aerated structure that offers less resistance to compression. This relationship has been previously observed in sponge cakes prepared with oil substituted by inulin (Rodríguez-García, Puig, Salvador, & Hernando, 2013). Chewiness presented a similar trend as hardness values (Fig. 3B).

No significant interaction ($P > 0.05$) between acid and base factors were found for cohesiveness and springiness parameters. Fig. 3C and D shows the means plots with the least significant difference (LSD) intervals for cohesiveness. Both the acids and bases had a significant influence on the results. The use of CA and GDL produced significantly ($P < 0.05$) less cohesive cakes compared to those prepared with SAPP. In addition, the use of EB decreased cohesiveness values significantly ($P < 0.05$) in comparison with B. Rodríguez-García el al. (2013) described that higher cohesivity in cakes was related to large air cells and compact crumb structures. Therefore, when the cells are bigger (Fig. 2B), a more cohesive final structure is created, i.e. big bubbles give place a more compact structure.

Springiness values showed no significant interaction ($P > 0.05$) between the type of acid and base used (Fig. 3E). The type of bicarbonate was the factor with higher influence on the results, with EB-cakes having significantly lower springiness values ($P < 0.05$). Here, the generation of CO_2 is retarded until the encapsulation melted, which could lead to a more compact structure. Other authors (Rodríguez-García et al., 2014) related the lower springiness values to a decrease in the number of crumb cells and the existence of a denser matrix. Interestingly, while no differences were detected in the crumb structure when different bicarbonates were used, springiness values showed that the leavening agent reaction rate had an impact on the height recovery of the crumb after the first compression.

As Dewaest et al. (2018) described in their work, a principal component analysis (PCA) was carried out to understand the correlation between crumb structure and texture parameters. The main conclusions obtained were that hardness and chewiness parameters were strongly inversely correlated with bubble size. Thus, higher values of hardness and chewiness are related to smaller bubble size. The springiness parameter was not correlated with crumb cell structure and on the contrary, cohesiveness was negatively correlated with the number of cells and positively correlated with the cell size, being the latter factor the one with higher correlation.

3.3. Colour measurements

Table 2 shows the colour parameters (L^*, C^*, and h_{ab}^*) for the crumb of the different cakes. For crumb colour parameters, no interactions were detected between factors. L^* values did not present significant differences ($P > 0.05$) between samples, and the values indicated that all samples were dark.

Table 2
Mean values of sponge cake colour parameters (L^*, C^* and h_{ab}^*), by formulation. CA: citric acid; SAPP: sodium acid pyrophosphate; GDL: glucono-δ-lactone; B: free bicarbonate; EB: encapsulated bicarbonate.

Sample	L*	C*	h*ab
CRUMB			
CA-B	$25.37^{a} \pm 2.43$	$8.46^{a} \pm 0.64$	$60.19^{d} \pm 2.29$
CA-EB	$26.48^{a} \pm 0.97$	$8.81^{ab} \pm 0.18$	$55.86^{c} \pm 2.02$
SAPP-B	$25.23^{a} \pm 3.88$	$11.79^{c} \pm 2.44$	$57.51^{c} \pm 0.82$
SAPP-EB	$25.47^{a} \pm 1.24$	$11.74^{c} \pm 0.95$	$56.85^{c} \pm 1.78$
GDL-B	$27.87^{a} \pm 0.50$	$10.25^{b} \pm 0.69$	$50.48^{b} \pm 1.60$
GDL-EB	$26.99^{a} \pm 1.87$	$9.95^{b} \pm 0.52$	$46.01^{a} \pm 2.23$

Values for colour parameters are mean ± standard deviation of (n = 9) determinations. Means in the same row without a common letter are significantly different ($P < 0.05$) according to the LSD multiple range test.

Table 3
List of the terms generated in the first session of the Flash Profile.

Texture	Global appearance	Taste	Odour
Spongy (n = 15)[a]	Dark (n = 9)	Sweet (n = 11)	Intense odour (n = 2)
Compact (n = 11)	Greyish (n = 8)	Acid (n = 7)	
Brittle (n = 7)	Brownish (n = 7)	Berry taste (n = 4)	
Grainy (n = 7)	Reddish (n = 7)	Oily (n = 3)	
Dry (n = 5)	Alveoli size	Bitter (n = 2)	
Juicy (n = 5)	Intense colour	Fruity (n = 2)	
Hard (n = 4)		Salty (n = 2)	
Gummy (n = 3)		Cake	
Soft (n = 3)		Carrot	
Sticky (n = 3)		Intense taste	
Chewable		Mint	
Pasty		Neutral	
Rough		No identified	
		Rancid	
		Strange	
		Spicy	
		Sweetened	
		Tasty	
TOTAL:66	**TOTAL:33**	**TOTAL:42**	**TOTAL:2**

[a] In brackets appears the frequency of mention of the terms named in more than one occasion.

C^* values presented significant differences ($P < 0.05$) between formulations depending on the acid used in the formulation, being significantly higher ($P < 0.05$) for SAPP, followed by GDL and CA. Higher values of C^* indicate that the red colour is less saturated and more vivid. The bicarbonate form used did not present differences in C^* values.

GDL samples had a hue angle value (h_{ab}^*) significantly closer to reddish tones ($P < 0.05$) than the crumb from cakes CA and SAPP. Considering the bicarbonate type, the formulations for each acid made with EB had greater reddish hue compared to cakes with B.

3.4. Sensory analysis

3.4.1. Flash profile

All the terms generated by the participants are shown in Table 3. A total of 38 different terms were collected (13 of texture, 6 of appearance, 18 of flavour, and 1 of odour). The participants gave high importance to the attributes of texture, since texture-related terms had 66 mentions, followed by flavour (n = 42), appearance (n = 33), and odour (n = 2).

Fig. 4A shows a two-dimensional Multi Factorial Analysis (MFA) plot of the sample configuration. The two first factors of the plot explain 62.76% of the experimental data's variability. The first factor explains 37.94% of the variability; it separates the samples with CA and SAPP-B (positive values of the X-axis) from the rest although the latter one is placed towards the zero value of this axis. The second factor (27.82% of the variability) separates principally the sample GDL-EB (very positive values of Y-axis) from sample SAPP-B (very negative values of Y-axis); also, in negative values of Y-axis are placed the samples SAPP-EB and GDL-B.

The sensory terms used to describe the samples are shown in Fig. 4B. Many of the attributes were spread all over the map, especially those corresponding to aspect and flavour such as berry flavour, and dark, indicating that they are not distinctive for any cake. Conversely, texture attributes do make the difference. Thus, as described by Lassoued, Delarue, Launay, and Michon (2008), a Hieratical Cluster Analysis (HCA) was carried out in order to more easily identify the attributes that describe each sample. The HCA revealed three cluster groups of sensory attributes (Fig. 4B). The attributes that are most

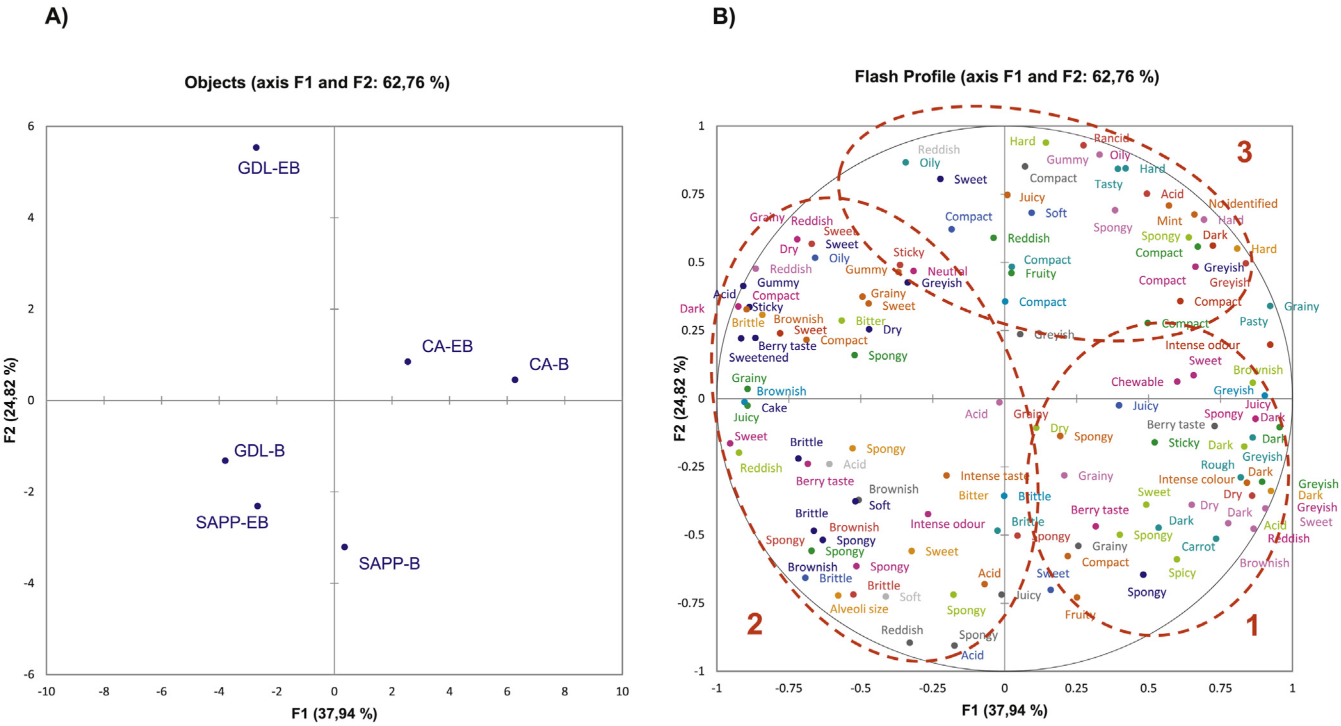

Fig. 4. (A) Representation of the six cakes formulations along the first two dimension of the Multi Factorial Analysis (MFA). **(B)** Representation of the terms from the flash profiling data with the Clusters defined by HCA represented with doted lines. CA: citric acid; SAPP: sodium acid pyrophosphate; GDL: glucono-δ-lactone; B: free bicarbonate; EB: encapsulated bicarbonate.

differentiating between groups are for Cluster 1: dry, greyish and sweet (samples CA-B and CA-EB); for Cluster 2: brittle, spongy, brownish/reddish and sweet (samples SAPP-B, SAPP-EB and GDL-B); and for Cluster 3: hard, compact, gummy, greyish, oily and rancid (sample GDL-B). These characteristics of texture perceived by the panellists could be related to the values obtained from the instrumental texture analysis (TPA) and cellular structure analysis of the crumb. SAPP-B and SAPP-EB from Cluster 2 described above as spongy and brittle cakes, were characterized as softer cakes with higher cohesiveness values and bigger cell area compared with cakes in Cluster 1 (CA-B and CA-EB) which were characterized as dry cakes. On one hand the attributes that principally defined the second cluster confirm the differences in texture and related air cell distribution of the cakes perceived by the panellists, and on the other highlight the importance of the different colours as a discriminant factor between samples. Thus, the flash profile could be considered as a complementary analysis for texture and colour characterisation.

3.4.2. Consumer liking testing

The scores for liking of 'appearance', 'texture', 'taste', and 'overall liking' of the different formulations are shown in Table 4.

Table 4
Consumer acceptance test results. CA: citric acid; SAPP: sodium acid pyrophosphate; GDL: glucono-δ-lactone; B: free bicarbonate; EB: encapsulated bicarbonate.

Sample	Appearance	Texture	Taste	Overall acceptability
CA-B	5.6^{ab}	5.8^{a}	6.0^{bc}	6.3^{cd}
CA-EB	5.9^{ab}	6.0^{a}	5.6^{b}	5.7^{bc}
SAPP-B	6.2^{b}	6.3^{a}	6.3^{c}	6.3^{cd}
SAPP-EB	6.0^{b}	6.0^{a}	6.3^{c}	6.4^{d}
GDL-B	5.4^{a}	5.7^{a}	5.6^{b}	5.6^{ab}
GDL-EB	6.0^{ab}	5.9^{a}	4.9^{a}	5.1^{a}

Means in the same row without a common letter are significantly different ($P < 0.05$) according to the LSD multiple range test.

The statistical analysis showed that the mean values for liking of cake appearance only had significant difference ($P < 0.05$) between formulations SAPP-EB and GDL-B. Regarding the texture liking, the consumers did not score significant different mean values ($P > 0.05$) between any of the tasted samples. The cakes made with SAPP were the rated the significantly more liked ($P < 0.05$) in terms of taste while the cake GDL-EB obtained the lowest score. Taste liking results are related with the flash profile results, as GDL-EB cakes were characterised as oily and rancid, that could be considered as negative attributes. Finally, the cakes CA-B, SAPP-B, and SAPP-EB had an overall liking mean values significantly ($P < 0.05$) higher than the rest of formulations, which could be attributed to a softer, spongy texture.

4. Conclusion

The strategy of changing and combining leavening agents with different rates of CO_2 release produced modifications in the size distribution of the bubbles into the batter, giving place to differences in cake crumb structures that were correlated to texture parameters. These differences were perceived by consumers, which were able to identify attributes describing each sample. Cakes prepared with pyrophosphate (regardless bicarbonate type) were described as brittle, spongy and sweet, and obtained high scores in global acceptability. Therefore, pyrophosphate could be considered as a good option in bakery to facilitate the use of functional high-fibre ingredients, such as by-products of the fruit and vegetable industry. We believe these practices surely would contribute to greater sustainability in the food industry.

CRediT authorship contribution statement

Elena Diez-Sánchez: Investigation, Validation, Formal analysis, Writing - original draft. **Empar Llorca:** Methodology, Investigation. **Amparo Tárrega:** Methodology, Formal analysis. **Susana Fiszman:** Conceptualization, Writing - review & editing. **Isabel Hernando:** Conceptualization, Supervision, Resources, Funding acquisition, Writing - review & editing.

Declaration of competing interest

Declarations of interest:none.

Acknowledgments

The authors are grateful to Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA-Spain) for financial support through the BERRYPOM – Adding value to fruit processing waste: innovative ways to incorporate fibres from berry pomace in baked and extruded cereal-based foods project included in the ERA-NET – SUSFOOD programme. They would also like to thank Phillip John Bentley for his assistance in correcting the manuscript's English. They would also like to thank Phillip John Bentley for his assistance in correcting the manuscript's English.

References

Bellido, G. G., Scanlon, M. G., Sapirstein, H. D., & Page, J. H. (2008). Use of a pressuremeter to measure the kinetics of carbon dioxide evolution in chemically leavened wheat flour dough. *Journal of Agricultural and Food Chemistry, 56*(21), 9855–9861.
Bennion, E. B., Bamford, G. S. T., & Bent, A. J. (1997). Chemical aeration. *The Technology of cake making* (pp. 100–106). Springer US.
Book, S., & Brill, R. (2015). Effects of chemical leavening on yellow cake properties. *Cereal Foods World, 60*(2), 71–75.
Borges, G., Degeneve, A., Mullen, W., & Crozier, A. (2010). Identification of flavonoid and phenolic antioxidants in black currants, blueberries, raspberries, red currants, and cranberries. *Journal of Agricultural and Food Chemistry, 58*(7), 3901–3909.
Brose, E., Becker, G., & Bouchain, W. (2001). *Chemical leavening agents (second)*. Chemische Fabrik Budenheim KG.
Dairou, V., & Sieffermann, J. M. (2002). A comparison of 14 jams characterized by conventional profile and a quick original method, the Flash Profile. *Journal of Food Science, 67*(2), 826–834.
De Leyn, I. (2014). Other leavening agents. In W. Zhou,, Y. H. Hui,, I. De Leyn,, M. A. Pagani,, C. M. Rosell,, & J. D. Selman, (Eds.). *Bakery products science and Technology* (pp. 176–181). (Second). John Wiley & Sons, Ltd.
Del Rio, D., Rodriguez-Mateos, A., Spencer, J. P. E., Tognolini, M., Borges, G., Crozier, A., Godefroidt, T., Ooms, N., Pareyt, B., Brijs, K., & Delcour, J. A. (2013). Ingredient functionality during foam-type cake making: A review. Dietary (poly)phenolics in human health *Comprehensive Reviews in Food Science and Food Safety, 18*(5), 1550–1562 2019, htt. Antioxidants & Redox Signaling, 18(14), 1818–1892.
Dewaest, M., Villemejane, C., Berland, S., Neron, S., Clement, J., Verel, A., et al. (2018). Effect of crumb cellular structure characterized by image analysis on cake softness. *Journal of Texture Studies, 49*(3), 328–338.
Diez-Sánchez, E., Quiles, A., Llorca, E., Reiβner, A.-M., Struck, S., Rohm, H., et al. (2019). Extruded flour as techno-functional ingredient in muffins with berry pomace. *Lebensmittel-Wissenschaft und -Technologie, 113*, 108300.
Dorko, C. L., & Penfield, M. P. (1993). Melt point of encapsulated sodium bicarbonates: Effect on refrigerated batter and muffins baked in conventional and microwave ovens. *Journal of Food Science, 58*(3), 574–578.
Foschia, M., Peressini, D., Sensidoni, A., & Brennan, C. S. (2013). The effects of dietary fibre addition on the quality of common cereal products. *Journal of Cereal Science, 58*(2), 216–227.
Germain, J. C., & Aguilera, J. M. (2008). Structural image analysis of food foams and aerated food products. In G. M. Campbell, M. G. Scanlon, & D. L. Pyle (Eds.). *Bubbles in food 2* (pp. 109–116). AACC International, Inc.
Gibbs, B. F., Kermasha, S., Alli, I., & Mulligan, C. N. (1999). Encapsulation in the food industry: A review. *International Journal of Food Sciences and Nutrition, 50*(3), 213–224.
Godefroidt, T., Ooms, N., Pareyt, B., Brijs, K., & Delcour, J. A. (2019). Ingredient functionality during foam-type cake making: A review. *Comprehensive Reviews in Food Science and Food Safety, 18*(5), 1550–1562.
Lakkis, J. M. (2016). Encapsulation and controlled release in bakery applications. In J. M. Lakkis (Ed.). *Encapsulation and controlled release technologies in food systems (Second* (pp. 204–235). John Wiley & Sons, Ltd.
Lassoued, N., Delarue, J., Launay, B., & Michon, C. (2008). Baked product texture: Correlations between instrumental and sensory characterization using flash profile. *Journal of Cereal Science, 48*(1), 133–143.
Lebesi, D. M., & Tzia, C. (2011). Effect of the addition of different dietary fiber and edible cereal bran sources on the baking and sensory characteristics of cupcakes. *Food and Bioprocess Technology, 4*(5), 710–722.
Masoodi, F. A., Sharma, B., & Chauhan, G. S. (2002). Use of apple pomace as a source of dietary fiber in cakes. *Plant Foods for Human Nutrition, 57*(2), 121–128.
Meiners, J. A. (2012). Fluid bed microencapsulation and other coating methods for food ingredient and nutraceutical bioactive compounds. *Encapsulation Technologies and Delivery Systems for Food Ingredients and Nutraceuticals,* 151–176.
Narsimhan, G. (2014). A mechanistic model for baking of leavened aerated food. *Journal of Food Engineering, 143*, 80–89.
Paunović, S. M., Mašković, P., Nikolić, M., & Miletić, R. (2017). Bioactive compounds and antimicrobial activity of black currant (*Ribes nigrum L.*) berries and leaves extract obtained by different soil management system. *Scientia Horticulturae, 222*, 69–75.
Penfield, M. P., & Campbell, A. M. (1990). *Experimental food science* (3rd ed.). Academic Press, Inc.
Quiles, A., Llorca, E., Schmidt, C., Reißner, A. M., Struck, S., Rohm, H., et al. (2018). Use of berry pomace to replace flour, fat or sugar in cakes. *International Journal of Food Science and Technology, 53*(6), 1579–1587.
Reißner, A. M., Al-Hamimi, S., Quiles, A., Schmidt, C., Struck, S., Hernando, I., et al. (2019). Composition and physicochemical properties of dried berry pomace. *Journal of the Science of Food and Agriculture, 99*(3), 1284–1293.
Rodríguez-García, J., Puig, A., Salvador, A., & Hernando, I. (2012). Optimization of a sponge cake formulation with inulin as fat replacer: Structure, physicochemical, and sensory properties. *Journal of Food Science, 77*(2).
Rodríguez-García, J., Puig, A., Salvador, A., & Hernando, I. (2013). Functionality of several cake ingredients: A comprehensive approach. *Czech Journal of Food Sciences, 31*(4), 355–360.
Rodríguez-García, J., Salvador, A., & Hernando, I. (2014). Replacing fat and sugar with inulin in cakes: Bubble size distribution, physical and sensory properties. *Food and Bioprocess Technology, 7*(4), 964–974.
Shahidi, F., & Ambigaipalan, P. (2015). Phenolics and polyphenolics in foods, beverages and spices: Antioxidant activity and health effects - a review. *Journal of Functional Foods, 18*, 820–897.
Sudha, M. L., Baskaran, V., & Leelavathi, K. (2007). Apple pomace as a source of dietary fiber and polyphenols and its effect on the rheological characteristics and cake making. *Food Chemistry, 104*(2), 686–692.
Tarrega, A., Rizo, A., & Fiszman, S. (2017). Sensory space of battered surimi rings: Key features determined by Flash Profiling. *Journal of Sensory Studies, 32*(4), e12274.
Tárrega, A., & Tarancón, P. (2014). Free-choice profile combined with repertory grid method. In P. Varela, & G. Ares (Eds.). *Novel techniques in sensory characterization and consumer profiling* (pp. 157–174). Taylor & Francis Group.
Walker, R., Tseng, A., Cavender, G., Ross, A., & Zhao, Y. (2014). Physicochemical, nutritional, and sensory qualities of wine grape pomace fortified baked goods. *Journal of Food Science, 79*(9), S1811–S1822.
Wilderjans, E., Luyts, A., Brijs, K., & Delcour, J. A. (2013). Ingredient functionality in batter type cake making. *Trends in Food Science & Technology, 30*(1), 6–15.
Zhao, Y. (2007). Processing technologies for developing value-added berry fruit products. In Y. Zhao (Ed.). *Berry fruit: Value-added products for health promotion* (pp. 448). (1st ed.). Taylor & Francis Group.