Original article

# Use of berry pomace to replace flour, fat or sugar in cakes

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**Summary** Pomace from fruit juice production is a by-product with a high fibre and bioactive compound content. It is commonly used as animal feed, so using it in food brings added value. The present study assessed the effect of using black currant and aronia pomace to replace either part of the flour, fat or sugar in sponge cakes. Batters in which sugar was replaced showed the highest viscosity. On the other hand, flour replacement led to batters with the lowest viscosity and gave place to softer cakes with fewer but larger-sized air cells. Sugar replacement conferred greater hardness and a larger number of small air cells. In general, fat replacement gave rise to intermediate crumb texture and structure properties in comparison with flour and sugar replacements. *In vitro* starch digestion showed that the flour-replaced sponge cakes possessed the lowest hydrolysis index and glycaemic index values. The sponge cakes with the different replacements were well accepted by consumers, who expressed a high level of buying intention for all of them.

**Keywords** Aronia, black currant, fibre, pomace, sponge cake.

## Introduction

In recent years, owing to the rise in obesity, consumers have tended to reduce the consumption of refined carbohydrates in their daily diet. While the rapid digestibility and absorption of carbohydrates have benefits for some aspects of the nutrition of sportspeople, their ingestion is generally not considered desirable, as it results in high blood sugar and triglyceride levels (Hu & Malik, 2010; Romero-Lopez *et al*., 2011), particularly for those affected by diabetes or metabolic syndrome. However, consumption of slow-release carbohydrates is associated with beneficial health effects (Jenkins *et al*., 2002).

Wheat flour in sponge cakes has been replaced by fibre from different sources, including carrots, apples and chickpeas (Sudha *et al*., 2007; Gómez *et al*., 2008; Vasantha Rupasinghe *et al*., 2008; Salehi *et al*., 2016). However, replacing the flour in sponge cakes with fibre causes structural modifications such as a reduction in final volume, due to lower retention of $CO_2$, which in turn increases the hardness of the product. Furthermore, substituting flour by fibre can increase the moisture in the final product, and make it darker (Walker *et al*., 2014).

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Sugar stabilises moisture in the final product, acts as a bulking agent and limits the swelling of starch, resulting in a finer-textured final product (Beesley, 1995). It can also help increasing temperature of starch gelatinisation and protein denaturation, as well as controlling viscosity of the batter by limiting the quantity of free water (Pateras & Rosenthal, 1992). In addition, sugar improves air incorporation during beating and air bubble stabilisation during baking (Beesley, 1995). However, it is very difficult to find a substitute; some studies have shown that replacing sugar with dietary fibre gives rise to more viscous batters and a final product of smaller volume owing to the water retention capacity of the fibres (Struck *et al*., 2016a).

Fat influences the volume of the product, as it helps to trap air during mixing, and also the development of a spongy texture, as it provides a shortening effect by lubricating the matrix components, which limits gluten network development and gives rise to a final product with a softer, smoother texture (Bennion *et al*., 1997). It also gives rise to more compact but spongy products with a crumb that does not crumble. In addition, it influences the sensory characteristics of baked products (taste, colour, odour, crispiness, creaminess, melting texture) (Rios *et al*., 2014).

However, excessive fat consumption can bring health risks by causing lipid metabolism disorders, excess weight or obesity (Wu *et al.*, 2013) which, in turn, is related to numerous diseases. Replacing fat in foods leads to a reduction in the stability of the air bubbles, causing a reduction in the volume of the sponge cakes and a harder texture (Barker & Cauvain, 1994; Rodríguez-García *et al.*, 2012).

Industrial by-products from fruit processing, especially pomace, can be an interesting source of bioactive compounds, mostly phenolic compounds and anthocyanins at low cost. Previous studies have suggested to use pomace from raspberry, blueberry, grape and black currant, in the formulation of bakery products (Górecka *et al.*, 2010; Pasqualone *et al.*, 2014; Rohm *et al.* (2015); Šarić *et al.*, 2014; Schmidt *et al.*, 2018), but no study has been found to use them in cakes. Berry pomaces are fibre-rich ingredients with a high phenolic compound content (Määttä *et al.*, 2001; Jurgoński *et al.*, 2016; Struck *et al.*, 2016b). Dietary fibre presents numerous nutritional benefits, helps to reduce and control blood pressure, reduces the risk of colorectal cancer and cardiovascular diseases and helps to control type II diabetes mellitus, because it not only increases the feeling of satiety but can also regulate glucose and lipid metabolism. Polyphenols are powerful antioxidants and are considered to possess many health benefits (Dufour *et al.*, 2018), such as reducing the risk of cardiovascular diseases, cancer, neurodegenerative diseases, diabetes and osteoporosis.

The aim of this paper is to study the effect of replacing flour, sugar and fat in sponge cake characteristics, using black currant (*Ribes nigrum*) and aronia (*Aronia melanocarpa*) pomace as replacers.

## Materials and methods

### Ingredients

The ingredients used in the preparation of the cakes were the following: wheat flour (Harinas Segura S.L, Torrente, Spain; composition provided by the supplier: 9–11 g 100 $g^{-1}$ protein), sugar (AB Azucarera Iberica S.L.U., Madrid, Spain), liquid pasteurised egg white and yolk (Ovocity, Llombay, España), skim milk powder (Corporación Alimentaria Peñasanta, S.A., Siero, Spain), refined sunflower oil (Aceites del Sur-Coosur, S.A., Vilches, Spain), sodium bicarbonate and citric acid (Sodas y Gaseosas A. Martínez, S.L., Cheste, Spain), salt, sucralose (Emilio Peña, S.A, Torrent, Valencia, España) and water (Bezoya Pascual S.L., Aranda del Duero, Burgos, España). Black currant pomace was provided from Döhler GmbH (Darmstadt, Germany) and aronia pomace from Kelterei Walther GmbH (Arnsdorf, Germany). The pomaces were dried at 70 °C for 3 h and and milled in a ZM 100 ultracentrifugal mill (Retsch GmbH, Haan, Germany) at 14 000 rpm using a 0.5-mm sieve.

### Sponge cake preparation

Six cake samples were prepared based on three different formulations (30% replacement of flour, fat or sugar) using two different types of pomace (black currant or aronia) (Table 1). Sucralose was added in sugar-replaced cakes to compensate for reduced sweetness. The batters were prepared according to the all-in mixing procedure proposed by Rodríguez-García *et al.* (2014a), with some modifications. Liquid egg, milk and water were placed in a Kenwood Major Classic mixer (Havant, UK). The dry ingredients (wheat flour, sugar, pomace, sodium bicarbonate, citric acid and salt) were added, and oil was the last ingredient added. The mixing proceeded using a wire whisk at speed 1 for 30 s, followed by 1 min at speeds 2 and 3 min at speed 3.

For cake preparation, a conventional oven (Electrolux EOC3430DOX, Stockholm, Sweden) was preheated to 180 °C for 30 min, and the batter was placed in a Pyrex® baking pan (diameter = 20 cm) and baked at 180 °C for 43 min. The cakes were then kept at room temperature for at least 90 min before being analysed. All the cakes were prepared in triplicate, and all analyses were performed within 24 h after baking.

### Batter rheology

Flow behaviour of the batters was measured at 25 °C with a Physica MCR 300 rheometer (Anton Paar GmbH, Ostfildern, Germany) equipped with a concentric cylinder system. For viscosity analysis, the batters were prepared without bicarbonate and citric acid and kept 1 h at 25 °C after mixing for temperature adjustment and relaxation. After filling the sample into the cylinder and a 10-min holding period, shear rate was increased logarithmically from 1 to 100 $s^{-1}$.

**Table 1** Formulation of the different sponge cakes (g)

| | Replacement | | |
|---|---|---|---|
| **Ingredients** | **30% flour** | **30% fat** | **30% sugar** |
| Flour | 140 | 200 | 200 |
| Sugar | 200 | 200 | 140 |
| Egg Yolk | 54 | 54 | 54 |
| Egg White | 108 | 108 | 108 |
| Skim Milk | 100 | 100 | 100 |
| Sunflower Oil | 92 | 64.4 | 92 |
| Pomace (BC or AR) | 40 | 40 | 40 |
| Water | 10 | 40 | 40 |
| Sucralose | 0 | 0 | 0.1 |
| Bicarbonate | 8 | 8 | 8 |
| Citric Acid | 6 | 6 | 6 |
| Salt | 3 | 3 | 3 |

AR, aronia pomace; BC, black currant pomace.

To simulate structural changes during baking, small strain oscillatory measurements were performed with a 50-mm parallel plate geometry (Schmidt *et al.*, 2018). Tests were conducted in the linear viscoelastic region at a strain of 0.005. The batter was placed on the lower plate with a spoon, and the gap was adjusted to 0.525 mm as trimming position to carefully remove excess batter. Final gap was 0.5 mm. The gap was then covered with vaseline oil, and a solvent trap was placed around the measuring zone to limit moisture loss. After 10-min relaxation time at 25 °C, temperature was increased linearly with a heating rate of 5 K $min^{-1}$ to 100 °C at constant frequency of 1 Hz. Because of the increase in batter stiffness above 85 °C, the gap was controlled by applying a normal force of 5 N. The temperature sweep was followed by a holding phase at 100 °C and 1 Hz for 10 min. All experiments were performed in duplicate from two batches.

## Mass loss during baking

The loss of mass m during baking was calculated using the following equation:

$$m_{loss}(\%) = \left[\frac{(m_{batter} - m_{cake})}{m_{batter}}\right] \times 100 \qquad (1)$$

## Cake height

The cakes were cut vertically with a stainless steel knife and scanned (Epson Perfection 1250; Epson America, Inc., Long Beach, USA). The maximum cake height was measured using ImageJ software (National Institutes of Health, Bethesda, Maryland, USA). The measurements were performed in triplicate.

## Image analysis of the cellular structure of the crumb

The cakes were cut vertically with a stainless steel knife into four slices of 15 mm thickness. Scanned images were analysed using ImageJ. Each image was cropped to a 50 × 50 mm section, on which the analysis was performed. The cell density (number of cells per field), cell area ($mm^2$) and circularity were calculated. The data were obtained by measuring the cells in twelve different images for each formulation.

## Instrumental texture measurements

Texture measurements were carried out using a TA-XTplus Texture Analyzer (Stable Microsystem, Godalming, UK) with Texture Exponent Lite 32 software (version 4.0.8.0, Stable Microsystems).

The test was performed on four cube-shaped (1.5 cm) samples taken from the central crumb of two cakes prepared on different days ($n = 8$). A double compression test was performed with a 35 mm diameter aluminium plate (P/35). The test speed was 1 mm $s^{-1}$, maximum deformation was 40% of the original cube height, and the interval between two successive compression cycles was 5 s. A trigger force of 5 g was selected. The parameters obtained from the curves were hardness, springiness, chewiness and resilience.

## *In vitro* digestibility of the starch cakes

An *in vitro* gastrointestinal model consisting of oral, gastric and intestinal phases was used to simulate the biological fate of ingested samples. The method for the oral and gastric phases has been described in detail previously (Borreani *et al.*, 2017), so only a brief description of the method and modifications is given here.

Oral phase: 3.5 mL of fresh artificial saliva was mixed with 10 g of the sponge cake for 15 s, then 70 mL of deionised water at 37 °C was added and mixed with a hand (Ufesa, model BP4566, Barcelona, Spain) blender for 1 min to simulate chewing.

Gastric phase: The sample obtained after the oral phase was mixed with 5 g of pre-incubated (37 °C; 5 min) simulated gastric fluid. The pH was adjusted to 2.0 with HCl, and 0.8 mg pepsin (P7125, pepsin from porcine gastric mucosa, ≥400 units $mg^{-1}$ protein, Sigma-Aldrich) and 5 g simulated gastric fluid were added. The mix was maintained at 37 °C with continuous stirring for 60 min.

Intestinal phase: The protocol of Gao *et al.* (2016) was used with some modifications. 4 mL of 2.25% pancreatin from porcine pancreas (P3292, Sigma-Aldrich) in phosphate buffer and 0.4 mL of amyloglucosidase were added, and the mix was maintained at 37 °C with continuous stirring for 180 min. Samples aliquots (0.1 mL) were taken at 0, 20, 60, 90, 120 and 180 min and mixed with 1.4 mL of ethanol. This solution was centrifuged (2515 ***g***, 3 min), and the hydrolysed glucose content in the supernatant was measured using the GOPOD enzymatic assay (Megazyme u.c., Wicklow, Ireland) at 510 nm. The glucose was converted into starch using a conversion factor of 0.9.

Starch hydrolysis curves were adjusted following the model of Goñi *et al.* (1997)

$$C_t = C_\infty(1 - e^{-kt}) \qquad (2)$$

where $C_t$ is the concentration at time $t$, $C_\infty$ is the equilibrium concentration, $k$ is the kinetic constant and $t$ is the chosen time.

The areas under hydrolysis curves (AUC, 0–180 min) were calculated as the integral of the kinetic equation and were used to obtain the starch hydrolysis index (HI). The HI was calculated as the relation between the AUC for a sample and the AUC for a reference food, white bread, expressed as a percentage (Goñi *et al.*, 1997). The predicted glycaemic index pGI was calculated according to Goñi *et al.* (1997):

$$pGI = 39.71 + 0.549HI \qquad (3)$$

For each formulation, this procedure was performed in triplicate.

### Sensory analysis

A consumer test was carried out with cakes prepared with black currant pomace. Eighty consumers (aged 18–65) were recruited among employees and students of the Universitat Politècnica de València. The samples were assessed in a standardised tasting room equipped with individual booths. Each consumer received three pieces of cake (representing flour-replaced, fat-replaced and sugar-replaced cakes). Three-digit random numbers were used for encoding. The cakes were served at room temperature in random order. Water was supplied to clean the consumers' mouths between each sample. Consumer acceptance testing was performed with successive category scales to score the 'texture', 'taste' and 'overall acceptance' of the product. The scale was a 9-point hedonic scale (1 = dislike extremely to 9 = like extremely). The consumers also rated their probability of purchasing each sample on a five-point scale ranging from 1 = 'I would definitely not buy it' to 5 = 'I would definitely buy it'.

### Statistical analysis

Analysis of variance (ANOVA) was performed on the data using the Statgraphics Plus 5.1 software package (Statistical Graph Co., Rockville, USA). Least significant difference (LSD) Fisher's test was used to evaluate the mean values differences ($P < 0.05$).

## Results and discussion

### Rheology of the batters

The replacement of flour, fat and sugar affected batter viscosity in different ways (Fig. 1). Irrespective of pomace type, the sugar-replaced batter had an apparent viscosity that was more than twice as high as that of the reduced-flour batter at low shear rate. In general, batters with aronia pomace had higher viscosities than batters containing black currant. This can be attributed to the water binding capacity that was higher for aronia pomace (3.85 g $g^{-1}$ dry matter) than for black currant pomace (3.20 g $g^{-1}$ dry matter, determined according to Zahn *et al.*, 2013). Differences in water binding capacity can, in turn, most likely be ascribed to the differences in soluble fibre content of both pomaces (39.7 g $kg^{-1}$ and 70.4 g $kg^{-1}$ for black currant and aronia pomace, analysed using the total dietary fibre kit (Megazyme u.c., Bray, Ireland) based on AOAC 991.43 according to Lee *et al.*, 1992). Differences in apparent viscosity between the samples became less pronounced with increasing shear rate.

During simulated baking, batter stiffness, expressed as complex modulus G*, slightly decreased to a minimum because of temperature-induced viscosity reduction and fat melting (see Fig. 2 for batters containing aronia pomace). Temperature at minimum G* was lower for batters with pomace from black currant (52–57 °C) than for batters with aronia pomace (60–64 °C). This can also be attributed to the higher water binding capacity of aronia, which may have caused a delay in starch granule swelling as less water was available (Bean and Yamazaki, 1978). Subsequently, G* increased as a result of structure formation through starch gelatinisation and protein coagulation. At approx. 96 °C, the sugar-replaced batters reached maximum stiffness that slightly decreased afterwards. This maximum can be ascribed to the low sugar

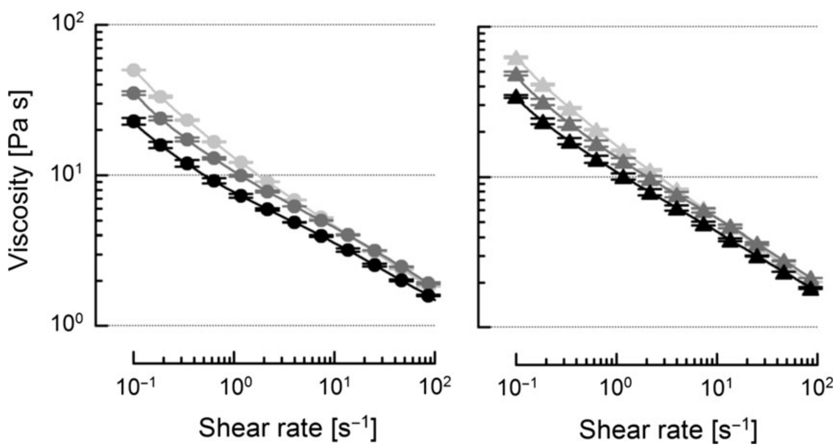


**Figure 1** Viscosity of sponge cake batters at 25 °C with black currant pomace (left, circles) and aronia pomace (right, triangles) replacing 30% flour (black), 30% fat (dark grey) or 30% sugar (light grey) (n = 2).

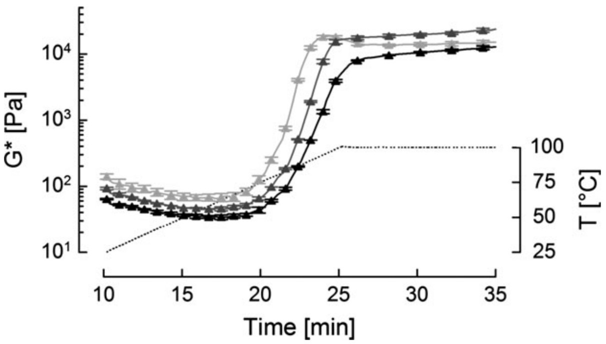


**Figure 2** Stiffness development of sponge cake batters with aronia pomace replacing 30% flour, fat or sugar during simulated baking (n = 2). Dotted line: temperature profile during heating. Black triangles, flour-replaced batter; dark grey, fat-replaced batter; light grey, sugar-replaced batter.

content that lowers starch gelatinisation and protein denaturation temperature (Manisha *et al.*, 2012; Struck *et al.*, 2016a). Stiffness of the other batters increased with increasing temperature until G* was nearly constant.

At the beginning of temperature sweeps, G* showed relatively large differences. These can be attributed to the type of replacement and are related to the differences in batter viscosity at low shear rate. With increasing temperature, the differences became smaller. Whereas pomace type had a significant influence on G* during simulated baking for all samples, only the baked sponge cakes in which flour had been replaced showed significant differences in G* at 100 °C (data not shown).

### Mass loss and cake height

Mass loss during baking is summarised in Table 2. Cakes prepared with black currant pomace presented no significant differences ($P > 0.05$) when this ingredient was used to replace flour and sugar, but a significantly lower mass loss ($P > 0.05$) was observed when it was used to replace fat. Sponge cakes made with aronia pomace followed the same trend as those prepared with black currant pomace. When comparing all the formulations, it is evident that the type of pomace (black currant or aronia) did not lead to significant differences ($P > 0.05$) in moisture loss between the flour-replaced sponge cakes. Similarly, no differences were observed between the sponge cakes in which fat or sugar had been replaced by either of the pomaces. In all cases, fat reduction led to a lower mass loss than the other types of replacement. The water retention capacity of the sugar and of the starch granules in the flour would explain the greater mass loss when either of these two ingredients was replaced.

In addition, significant differences ($P < 0.05$) in cake height were observed between the flour-replaced cakes and all the other cases of replacement (Table 2): irrespective of whether the pomace used was black current or aronia, the sponge cakes were less high when flour was replaced than when fat or sugar was replaced. This can be attributed to a lower retention of the gas produced by the leavening agents when 30% of the flour was eliminated, as flour is the ingredient responsible for forming the gluten network that retains these gases (Kohajdová *et al.*, 2012).

### Macroscopic structure of the crumb

Figure S1 shows scanned, contrasted and binarised images of the different sponge cakes. The images were analysed to quantify certain parameters of the crumb structure (Table 3). When comparing the cakes by pomace and type of replacement (flour, fat or sugar), those prepared with aronia pomace can be seen to contain a larger number of cells ($P < 0.05$) than those prepared with black currant pomace. When comparing the different types of replacement with each other, irrespective of the type of pomace employed, sugar replacement gave rise to the sponge cake with the greatest number of cells ($P < 0.05$).

**Table 2** Mass loss, height and texture profile analysis values of sponge cakes

| Fibre | Black currant | | | Aronia | | |
|---|---|---|---|---|---|---|
| Replacement | Flour | Fat | Sugar | Flour | Fat | Sugar |
| Mass loss (%) | 8.49 ± 0,03a | 7.73 ± 0,23b | 9.11 ± 0,66a | 8.46 ± 0.28a | 7.79 ± 0.22b | 8.61 ± 0.16a |
| Height (cm) | 5.83 ± 0.04a | 7.01 ± 0.22b | 6.92 ± 0.14b | 5.61 ± 0.17a | 7.00 ± 0.06b | 6.79 ± 0.03b |
| Texture | | | | | | |
| Hardness (N) | 1.20 ± 0.07a | 1.98 ± 0.19b | 2.55 ± 0.18d | 1.88 ± 0.17b | 2.17 ± 0.13c | 3.13 ± 0.31e |
| Springiness (-) | 0.89 ± 0.01a | 0.91 ± 0.01b | 0.92 ± 0.01b | 0.89 ± 0.01a | 0.91 ± 0.01b | 0.92 ± 0.01b |
| Chewiness (N) | 0.71 ± 0.04a | 1.06 ± 0.12b | 1.50 ± 0.11d | 1.06 ± 0.11b | 1.20 ± 0.06c | 1.82 ± 0.26d |
| Resilience (-) | 0.31 ± 0.02ab | 0.31 ± 0.02ab | 0.32 ± 0.01b | 0.29 ± 0.04a | 0.30 ± 0.02ab | 0.32 ± 0.03b |

Mean ± standard deviation values. Means in the same row without a common letter differ significantly ($P < 0.05$) according to the LSD multiple range test.

**Table 3** Mean values and standard deviations of crumb cell structure characteristics

| Fibre Replacement | Black currant Flour | Black currant Fat | Black currant Sugar | Aronia Flour | Aronia Fat | Aronia Sugar |
|---|---|---|---|---|---|---|
| Cell density | 689 ± 45a | 788 ± 30b | 919 ± 46c | 839 ± 121b | 927 ± 98c | 1060 ± 79d |
| Cell area ($mm^2$) | 2.34 ± 0.39a | 1.62 ± 0.16b | 1.43 ± 0.19b | 2.03 ± 0.38a | 1.6 ± 0.06b | 1.47 ± 0.2b |
| Circularity | 0.46 ± 0.01a | 0.49 ± 0.03c | 0.49 ± 0.02c | 0.43 ± 0.01b | 0.43 ± 0.01b | 0.42 ± 0.02b |

Means in the same row without a common letter differ significantly ($P < 0.05$) according to the LSD multiple range test. BC: black currant pomace, AR: aronia pomace.

With regard to mean cell size, the sponge cakes with the largest cells ($P < 0.05$) were those in which flour had been replaced, irrespective of the type of pomace. For this parameter, no significant differences ($P > 0.05$) were found among the rest of the sponge cakes studied. Replacement of flour by either of the two pomaces (black currant or aronia) generally led to sponge cakes with a smaller number of cells, but of larger size, compared with the other types of replacement. This could be related to the flour-replaced batters having less capacity to retain the gas generated during fermentation (Kohajdová *et al*., 2012). Cell size can also be associated with batter viscosity. A low viscosity, especially at low shear rate, promotes the rise of air bubbles and hence the formation of larger cells (Campbell & Mougeot, 1999). Consequently, cake batters in which flour had been replaced showed the lowest viscosity and the largest cells, and sugar-replaced batters had the highest viscosity and the smallest cell areas. Since structural setting of sugar-replaced cakes appears at an earlier baking stage according to simulated baking, this also contributes to smaller pores in the crumb (data not shown). In general, cell area seems to be related to the number of cells: smaller cell sizes correspond to higher number of cells.

With regard to circularity, the sponge cakes prepared with black currant pomace showed more circular cells than those prepared with aronia pomace. Probably, the higher viscosity of the aronia batters, as observed in the rheology results, could disturb movement, distribution and displacement of the cells. This fact could be decreasing circularity values. Replacing fat or sugar with black currant pomace increased the circularity of the cells, whereas replacing flour, fat or sugar with aronia pomace did not influence this parameter.

## Sponge cake texture

Table 2 also shows hardness, springiness, chewiness and resilience of the sponge cakes prepared with the different replacements. In general, for the same ingredient replaced, the sponge cakes made with aronia pomace were harder than those with black currant pomace. However, irrespective of the type of pomace employed, sugar replacement produced harder ($P < 0.05$) cakes, followed by fat replacement and then flour replacement. The increased hardness of the sugar-replaced cakes could be due to premature gelatinisation of the starch, as described by Gao *et al.* (2016) and to an early thermosetting mechanism as observed previously in sugar-replaced cakes (Ronda *et al*., 2005; Rodríguez-García *et al*., 2014b). Starch gelatinisation is encouraged by reducing the amount of sugar in the sponge cake formulation, hence reducing the competition for water. Of all the formulations studied, the sponge cake with sugar replaced by aronia pomace was the hardest ($P < 0.05$), and the least hard ($P < 0.05$) was the cake in which flour had been replaced by black currant pomace. There seems to be a direct relationship between the batter viscosity and the cake hardness.

For springiness, significant differences ($P < 0.05$) were found between the sponge cakes in which flour had been replaced (whether by black currant or by aronia pomace) and the remaining formulations. The flour-replaced cakes were the least springy. The reason could be that removing a certain percentage of the flour eliminated part of the glutenins, which are responsible for the elasticity and strength of the batter. For chewiness (Table 2), significant differences ($P < 0.05$) were found between all the formulations, whether prepared with black currant pomace or with aronia pomace. In general, chewiness showed the same tendency as hardness.

With regard to resilience, no significant differences ($P > 0.05$) were found between the sponge cakes prepared with black currant pomace. In contrast, the sponge cakes prepared with aronia pomace presented significant differences ($P < 0.05$) between the flour-replaced and sugar-replaced cakes, with the latter presenting the highest values for this parameter.

During simulated baking, when sugar-replaced batter reached its maximum at approx. 96 °C, batter stiffness was related to product hardness. Sugar-replaced sponge cakes were the hardest and stiffest, and flour-replaced cakes showed lowest hardness and lowest stiffness. The decrease in G* in sugar-reduced batters

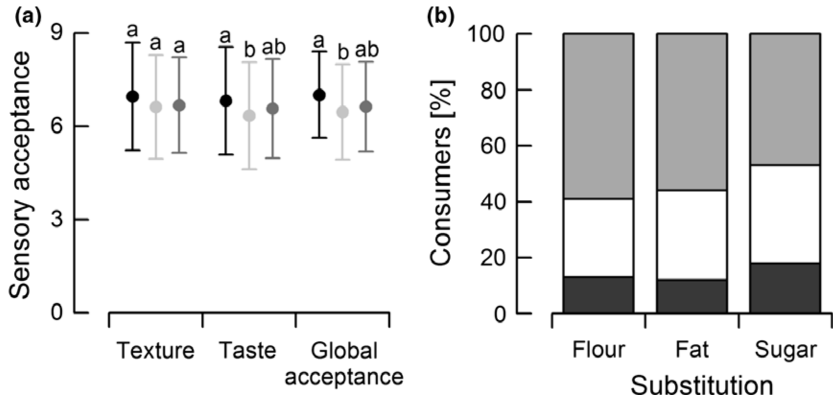


**Figure 3** Mean consumer acceptance scores for the sponge cakes prepared with black currant pomace as a flour, fat or sugar replacer (a), and intention to purchase for the sponge cakes prepared with black currant pomace as a flour, fat or sugar replacer (b). Light grey: 'yes'; white: 'maybe'; dark grey: 'no'. The same letter indicates no significant differences between means for the same attribute.

after reaching this maximum could most likely be explained by structural changes that took place despite the low deformation that was applied, but which was also observed by Struck *et al.* (2016a).

### *In vitro* digestibility of the starch in the sponge cakes

*In vitro* digestibility tests were performed to study the starch digestibility and glycaemic response for the sponge cakes with the different replacements. The results are shown in Supporting information (Fig. S2 and Table S1). Figure S2 shows the starch hydrolysis curves of sponge cakes prepared with black currant or aronia pomace adjusted following the model of Goñi *et al.* (1997). Pomace and replacement type appear not to affect the speed of starch hydrolysis.

Table S1 shows the kinetics of *in vitro* starch digestibility. The equilibrium concentration ($C\infty$) and area under the curve (AUC) were generally higher ($P < 0.05$) in the fat-replaced cakes and lower in the flour-replaced ones, whichever pomace was used; the sugar-replaced sponge cakes presented intermediate values. The hydrolysis index (HI) and the glycaemic index (pGI) followed similar tendencies to the AUC: in general, the sponge cakes in which flour had been replaced presented the lowest values and those in which fat had been replaced presented the highest values.

### Sensory analysis

To discover the degree of acceptability of the different types of replacement, a consumer acceptance and preference test was conducted. The sponge cakes used for this purpose were those prepared with black currant pomace. Figure 3 shows the texture, flavour and overall acceptability values obtained from the consumer scores.

No significant differences ($P > 0.05$) between the three samples were found in the texture assessment; all the cakes obtained a high level of acceptance for this attribute, scoring 6–7 on a nine-point scale. The differences detected in the instrumental tests, in which the sugar-replaced cake presented significantly ($P < 0.05$) higher hardness values, were not noticed by the consumers. With regard to flavour, the acceptance of flour-replaced and fat-replaced cakes was significantly ($P < 0.05$) higher, although the scores for this attribute were generally high for all three samples. Lastly, overall acceptance followed the same tendency as flavour; in other words, it was significantly ($P < 0.05$) greater for the sponge cakes in which flour and fat had been replaced than for the sugar-replaced cakes.

The purchase intention (Figure 3) was, in general, good as around 50% of the tasters would buy the sponge cakes with any of the replacements and around 30% might buy them, although the sugar-replaced cake obtained a slightly lower purchase intention. Additionally, few tasters indicated that they would not buy these products (the percentage was under 18%).

## Conclusions

Comparison between the sponge cakes prepared by replacing part of the flour, fat or sugar showed that irrespective of whether the substitute was black currant or aronia pomace, most of the parameters studied generally presented similar tendencies. The sponge cakes in which flour was replaced by either of the two types of pomace showed lower height and hardness, as well as a smaller number of pores, although larger in size. The sponge cakes in which fat was replaced showed less mass loss during baking and, consequently, greater height than those in which flour had been replaced. The sponge cakes which sugar was replaced generally presented the highest values for the textural parameters and a greater number of air cells, which were small in size. In general, the *in vitro* starch digestibility tests found that the flour-replaced cakes presented the lowest glycaemic index values and the fat-replaced ones the highest, while the sugar-replaced cakes obtained intermediate values.

All the sponge cakes with their different replacements were acceptable to consumers, who expressed a high purchase intention, but the most acceptable samples were those where flour or fat had been replaced. Pomace produced by the dried fruit industry is a promising ingredient for flour, fat and sugar replacement in bakery products. Using this ingredient as a substitute, sponge cakes with a better nutritional profile that are acceptable to consumers can be obtained.

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## Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Figure S1.** Cellular structure of the crumb. Binarised images of scanned crumbs.

**Figure S2.** *In vitro* starch digestibility of sponge cakes prepared with black currant pomace (left, circles) or aronia pomace (right, triangles) replacing 30% flour (black), fat (dark grey) or sugar (light grey).

**Table S1.** Kinetics of *in vitro* starch digestibility. k = kinetic constant, $C\infty$ = equilibrium concentration, AUC = area under hydrolysis curve, HI = starch hydrolysis index, pGI: predicted glycemic index.