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Sweet corn cob as a functional ingredient in bakery products

T. Lau [a], T. Clayton [a], N. Harbourne [b], J. Rodriguez-Garcia [a], M.J. Oruna-Concha [a,*]

[a] Department of Food and Nutritional Sciences, University of Reading, Reading RG6 6DZ, UK
[b] UCD Institute of Food and Health, School of Agricultural and Food Science, University College Dublin, Belfield, Dublin, Ireland

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ABSTRACT

Gluten free (GF) products are often inferior in quality attributes, nutritional content and consumer acceptability. The use of GF by-products is a novel strategy to improve the structure and nutritional profile of these products. Sweet corn cob (SCC) is a by-product of sweet corn processing containing a considerable amount of fibre and ferulic acid. The effect of baking on ferulic acid content, colour, texture and physical characteristics on muffins incorporated with SCC flour (SCCF) as a value-added food ingredient was investigated using a GF model system. The freeze-dried SCCF, containing ferulic acid (6.02 mg g^{-1}) was used to replace the rice flour at varying levels of 10, 20, and 30%. In general, SCCF increased dietary fibre and free ferulic acid content of muffins. Inclusion of 20% SCCF showed an increase in terms of the height of the muffin and number of air cells in the crumb, along with a decrease in the hardness of muffins. Muffins with SCCF showed higher mean overall liking scores than rice flour muffin.

1. Introduction

Coeliac disease (CD) is a chronic inflammatory intestinal disorder that affects 0.5–1% of the world population and is induced by gluten ingestion in genetically susceptible individuals (Hall, Rubin, & Charnock, 2009). Strict adherence to a gluten free diet throughout one's lifetime is the only effective treatment for patients diagnosed with CD (Kim & Shin, 2014). As a result, demand for gluten-free (GF) products has increased from people suffering gluten intolerance and sensitivity, in addition to the increased consumer demands for wheat free products (Nachay, 2010). Generally, GF products are made from starches or flour with low dietary fibre content (Singh, Kaur, & Singh, 2016) and they are often of poor colour, having a crumbling crumb and low volume (Matos Segura & Rosell, 2011). In addition, several researchers have shown that coeliac patients' diets are of poorer nutritional quality as most GF products have nutritional defects; protein content is lower, fat content is higher and mainly saturated, carbohydrate content is higher, glycaemic index is higher and the supply of fibre, minerals, vitamins and calories into the diet is lower in comparison to wheat-based products (Gambuś et al., 2009; Naqash et al., 2017). Therefore, GF products should be formulated with ingredients naturally gluten free and high in additional nutrients (Gambuś et al., 2009), to respond to the growing demand for the production of a more nutritious and healthier GF food.

Incorporation of by products is one of the ways to increase the quality of GF products as they are an economical source of functional ingredients that may contain high levels of vitamins, antioxidants, protein and dietary fibre (Majzoobi, Poor, Jamalian, & Farahnaky, 2016). By-products of fruits and vegetables such as apple and tomato pomace have been applied in previous research in wheat-based bakery products such as flat breads or cakes (Majzoobi, Ghavi, Farahnaky, Jamalian, & Mesbahi, 2011; Sudha, Baskaran & Leelavathi, 2007), although their addition is still novel in the development of GF products, such as cakes and breads (Majzoobi et al., 2016; O'Shea, Rößle, Arendt, & Gallagher, 2015). Sweet corn cob (SCC), an under-utilised agricultural by-product of the corn processing industry, is rich in dietary fibre, minerals and phytochemicals, including ferulic acid (Lau, Harbourne, & Oruña-Concha, 2019). Dietary fibre consists of hemicellulose, cellulose, lignins, gum and pectins; it acts as a bulking agent in increasing the moisture content of stool and thus facilitates intestinal mobility (Sudha, Baskaran, & Leelavathi, 2007). On the other hand, ferulic acid (4-hydroxy-3-methoxycinnamic acid) is a phenolic compound present in many foods in the form of free, soluble conjugate or bound phenolics, offering beneficial effects against cardiovascular diseases, hypertension, inflammatory diseases, cancer, Alzheimer's and diabetes (Zhao & Moghadasian, 2008). These health benefits can be achieved by consumption of either free or bound phenolics. Consumption of bound

* Corresponding author.
E-mail addresses: til16@aber.ac.uk (T. Lau), niamh.harbourne@ucd.ie (N. Harbourne), j.rodriguezgarcia@reading.ac.uk (J. Rodriguez-Garcia), m.j.oruna-concha@reading.ac.uk (M.J. Oruna-Concha).

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phenolics will contribute towards the chemopreventive activity against colon cancer (Acosta-Estrada, Gutiérrez-Uribe, & Serna-Saldívar, 2014), while free and soluble conjugated phenolics are absorbed more rapidly in the small intestine and stomach as compared to bound phenolics (Wang, He, & Chen, 2014); thus they can be distributed throughout the body offering health benefits such as inhibition against oxidation of liposomes and low-density lipoprotein (LDL) cholesterol.

Muffins are very popular among the consumer as a snack food due to their good taste and soft and spongy texture (Matos, Sanz, & Rosell, 2014). Traditionally, wheat flour, fat, sugar, milk and egg have been used for muffin production. However, those suffering from CD are unable to consume this type of product as it contains wheat flour. Rice is one of the most suitable cereals for the preparation of GF products due to its hypoallergenicity, low fat, low sodium, high digestibility and bland taste (Marcoa & Rosell, 2008). However, the use of rice flour in the preparation of muffins causes issues such as lower volume, poor texture, colour and crumb structure (Matos et al., 2014). The lack of gluten protein in rice leads to failure in the entrapment of carbon dioxide, reducing the quality of finished products (Sakač, Torbica, Sedej, & Hadnađev, 2011). Therefore, previous authors have tried to improve the quality of GF muffins by incorporating protein isolates (Shevkani, Kaur, Kumar, & Singh, 2015) or xanthan gum and fibre (Singh et al., 2016). In addition, rice flour contains low levels of fibre and ferulic acid (0.62 g/100 g and 84 mg/kg, respectively), as reported by Wanyo, Chomnawang, and Siriamornpun (2009) and Zhou, Robards, Helliwell, and Blanchard (2004). In contrast, our previous study showed that SCC contained 59.5 g/100 g of insoluble dietary fibres and 306 mg/100 g of ferulic acid (Lau et al., 2019), and thus, the incorporation of SCC flour into the formulations can be used to improve the ferulic acid content, dietary fibre and functional properties of GF rice flour muffins.

There have been limited studies reporting the use of SCC flour in bakery products. Therefore, the present study was undertaken to produce GF rice muffin supplemented with varying levels of SCC flour to evaluate the changes in physicochemical properties, texture and consumer acceptability as compared to regular GF rice muffins.

2. Materials and method

2.1. Materials

The sweet corn used in the experiments was harvested in Senegal (March 2019) and was provided by Barfoots of Botley Company Ltd (UK). The corn kernels were removed manually from the cobs and discarded. The sweet corn cobs were then chopped into 5 cm pieces in length, and frozen in the blast freezer (-18 °C) for an hour and then freeze dried (Christ Gamma 2–16, Germany) until constant weight was achieved. The dried samples were finely ground in a mill (Apex Comminuting Mill, United Kingdom), sieved through a 150 mesh screen (particle size < 0.1 mm), thoroughly mixed and stored in the freezer (-18 °C) until further analysis.

2.2. Extraction and quantification of ferulic acid content in rice and SCC flour

The extraction and quantification of free, soluble conjugate and insoluble-bound phenolic compounds in rice and SCC flour was carried out according to Lau, 2018. Briefly, the free ferulic acid was extracted using 50% ethanol before centrifugation to separate the supernatant and pellet. The soluble conjugate and bound ferulic acid were obtained by the addition of 4 M NaOH to the supernatant and pellet, respectively.

2.3. Water holding capacity (WHC) and oil holding capacity (OHC) of rice and SCC flour

The WHC and OHC of rice flour and SCC flour were determined using the method as described by Mateos-Aparicio, Redondo-Cuenca, and Villanueva-Suárez (2010). Briefly, 0.5 g of sample was mixed in 30 mL of water (for WHC) or oil (for OHC) at room temperature for 18 h. The samples were then centrifuged (3000 × g for 20 min) and the supernatants were decanted. The weight of the residue was recorded and the WHC and OHC were calculated as the amount of water or oil retained by the pellet (g of water or oil/ g of sample dry weight).

2.4. Batter and muffin preparation

The muffins were prepared according to the recipe by Shevkani et al. (2015) with slight modifications. A control muffin was prepared with 100 % rice flour (100RF) and three more formulations were prepared by replacing 10, 20, and 30% of rice flour by SCC flour (10SCCF, 20SCCF and 30SCCF, respectively). 150 g of flour or flour mix, 90 g of white granulated sugar, 5 g of baking powder, 75 g of pasteurised egg, 75 g of whole milk and 75 g of sunflower oil were mixed for 5 min (speed-3 for 3 min followed by speed-5 for 1 min) in an electric mixer (Model A901, Kenwood Chef, United Kingdom). 65 g of batter were then dispensed into muffin paper cups (65 mm diameter). The muffins were arranged in a muffin baking tray and baked for 23 min at 180 °C in a rotary electric oven that was preheated for 10 min. After baking, the muffins were left to cool down to room temperature for an hour before packing them into polyethylene bags and storing them at 20 °C for 1 day, after which time the analyses were conducted. Each formulation was prepared in three replicates on three separate days.

2.5. Ferulic acid content in batter and muffin

The batter and muffin were frozen at −18 °C and then freeze dried (Christ Gamma 2–16, Germany) until constant weight was achieved. The freeze-dried samples were ground by a pestle and mortar at room temperature for 10 min and stored in the freezer (-18 °C) until analysis. The samples were defatted with hexane and subjected to alkali hydrolysis in order to determine the amount of ferulic acid, as described by Lau et al. (2019).

2.6. Height and cell crumb structure of the muffins

The height of the muffin was measured using a digital calliper from the highest point in the centre of the muffin to the bottom of the paper cup. For the evaluation of the cell crumb structure the muffins were cut horizontally at the height of the muffin paper cup and the crumb surface was scanned (HP Scanjet G2710, Hewlette-Packard, United States). The scanned images were analysed using Image J software (National Institutes of Health and the Laboratory for Optical and Computational Instrumentation, United States). The images were cropped to 5 cm × 5 cm sections and the image was split into colour channels, and blue was selected. Then the image was binarised and the number of cells per section and average cell size were calculated. Three muffins per batch were scanned and analysed.

2.7. Textural properties of muffins

The instrumental texture measurement of the muffins was carried out according to Matos et al. (2014). Texture profile analysis (TPA) was performed on crumb cubes (12.5 mm^3) using a texture analyzer (TAX-Plus, Stable Micro System) equipped with a 5 kg load cell. The double compression test was performed with a 75 mm diameter flat-ended cylindrical probe (P/75); samples were compressed to 50% of their initial height at a speed of 1 mm/s with 5 s waiting time between the two cycles. The results of firmness, springiness, cohesiveness, and chewiness were calculated by the software Exponent (Version 6.1.18.0, Stable Micro Systems, UK). Three muffins per batch were analysed.

2.8. Colour measurements

A colorimeter (Chroma meter CR400, Konica Minolta) was used to measure the crumb and crust colour of the muffin. The crust colour was measured at several points on the surface of the muffin. A serrated knife was used to remove the upper half of the muffin and the colour of the crumb was determined at several points. The results were expressed in accordance with the CIELAB system (Illuminant C and 10° viewing angle). The parameters measured were L^* [indicates lightness and ranges from 0 (for black) to 100 (for white)], a^* [ranges from -a^* (for greenness) to + a^* (for redness)], and b^* [ranges from -b^* (for blueness) to + b^* (for yellowness)]. Hue angle and chroma values were calculated according to Ahn and Lee (2008). Measurements were performed in three different muffins per batch. The total colour difference ΔE^* between the control muffin (100RF) and the rest of the muffin samples was calculated using the equation below (Francis & Clydesdale, 1975):

$$\Delta E^* = [(\Delta L*)2 + (\Delta a*)2 + (\Delta b*)2]1/2$$

According to Bodart, Penaranda, Deneyer, and Flamant (2008), ΔE^* values higher than 3 are totally perceptible to human eyes. As for a ΔE^* value between 1 and 3, the colour difference could be perceived and values lower than 1 are not perceptible to human eyes.

2.9. Consumer acceptability of muffins

It was estimated that a minimum of 100 consumers was necessary to detect a difference of 0.8 on a 9-point hedonic scale between two samples with $p < 0.05$ and 80% power (Hobbs, Ashouri, George, Lovegrove, & Methven, 2014). A total of 121 untrained, healthy consumers were recruited, 3 of which had CD (34 men, 87 women; between 18 and 65 years old), to evaluate the acceptability of the muffins (100RF, 10SCCF, 20SCCF, and 30SCCF). The study was conducted in accordance with the Declaration of Helsinki and all volunteers had the study fully explained, provided informed written consent, and were informed that all data would be anonymous, fully confidential, and of their right to withdraw. This consumer study was given a favourable ethical opinion to proceed by the School of Chemistry, Food and Pharmacy Research Ethics Committee at the University of Reading (Study Number – 07/19).

The four muffin formulations were prepared and baked a day before serving. The muffins were cooled to room temperature and stored overnight in a closed polyethylene bag. Consumers were given ¼ of each sample containing both crust and crumb sections. The muffins were assigned with 3-digit codes and presented to the consumers in a completely randomized design. Consumers were asked to individually taste each of the samples and rate their overall liking of the sample, followed by their aroma, texture, flavour and aftertaste liking, using a nine point categorical hedonic scale (1: dislike extremely; 2: dislike very much; 3: dislike moderately; 4: dislike slightly; 5: neither like or dislike; 6: like slightly; 7: like moderately; 8: like very much; 9: like extremely). The consumers were instructed to cleanse their palate between samples with water and plain crackers. The sensory sessions were carried out in separate booths (temperature-controlled room at 21 °C) equipped with a computerized system and Compusense sensory software 2019 (Compusense, Inc., Guelph, ON, Canada).

2.10. Statistical analysis

The quantitative data were analysed by one-way analysis of variance (ANOVA) using Minitab statistical software (State College, USA). To analyse the consumer sensory analysis, one-way analysis of variance was carried out in Senpaq (Qi Statistics Ltd., Reading, UK). Fisher test was used to assess the significant differences ($p < 0.05$) among samples.

3. Results and discussion

3.1. Ferulic acid content of rice and SCC flours

The ferulic acid content in rice and SCC flour is presented in Table 1. The total amount of ferulic acid was significantly higher ($p < 0.05$) in SCC flour than in rice flour. In addition, ferulic acid was present in rice flour as insoluble-bound form only. The high amount of ferulic acid in SCC might be attributed to the presence of high amounts of cellulose and hemicellulose (Lau et al., 2019), where most of the ferulic acid is attached. On the other hand, rice flour made from milled rice contains low level of ferulic acid due to the removal of the cellulose and hemicellulose rich bran layer during the milling process. It has been previously reported that the phytochemicals in rice are more abundant in the bran layer and only a small amount is present in the milled rice (Shen, Jin, Xiao, Lu, & Bao, 2009).

3.2. WHC and OHC of rice and SCC flour

The WHC of rice and SCC flour are presented in Table 1. The WHC of SCC flour was significantly higher ($p < 0.05$) than rice flour, which may be linked to the differences in fibre content. Our previous study showed that more than 60% of SCC was composed of insoluble dietary fibre (Lau et al., 2019). On the other hand, Fernando, Flint, Brennan, Ranaweera, and Bamunuarachchi (2012) reported that polished white rice flour contained 1.27% and 0.58% of insoluble and soluble dietary fibre, respectively. As reported by Hodge and Osman (1976), flours that contain more hydrophilic constituents such as polysaccharides have higher WHC. Therefore, the higher water absorption capacity of SCC flour could be attributed to the higher polysaccharide content of SCC as compared to rice flour.

Measurement of the OHC of flour is important for the retention of mouthfeel and flavour (Kinsella, 1976). Table 1 showed that SCC flour contained significantly higher OHC ($p < 0.05$) as compared to rice flour. These results can be related to the higher dietary fibre content in SCC in comparison to rice flour. Dietary fibre can affect some functional properties of food including an increase in OHC, and emulsification (Elleuch et al., 2011). In addition, Kinsella (1976) reported that the superior binding of hydrophobic protein towards lipids, indicates that non-polar protein side chains can bind to the paraffin chain of fats. Based on this suggestion, it could be inferred that SCC flour, which showed higher OHC, contains more available non-polar side chains on its protein, as compared to rice flour.

The WHC and OHC of rice flour reported in this study was slightly lower than the value reported by Joshi, Liu, and Sathe (2015) (1.54 g water g^{-1} of sample and 1.10 g oil g^{-1} of defatted rice flour). This might be due to the slight difference in the measurement protocol as well as the difference in the source of rice flour. Meanwhile, the WHC and OHC of SCC was higher as compared to other GF flours such as chickpea (2.54 g water/g flour; 1.19 g oil/g flour), soybean (3.53 g of water g^{-1} flour; 1.61 g oil g^{-1} flour), and almond flour (2.20 g water g^{-1} sample; 2.32 g oil g^{-1} flour) (Joshi et al., 2015), possibly due to the high insoluble

Table 1
Ferulic acid content, water holding capacity (WHC) and oil holding capacity (OHC) of rice (RF) and sweet corn cob flours (SCCF).

Sample	Ferulic acid fraction (mg g^{-1} DW)			WHC	OHC
	Free	Esterified	Insoluble-bound	(g of water g^{-1} DW)	(g of oil g^{-1} DW)
RF	ND	ND	0.02 ± 0.01^b	1.19 ± 0.07^b	0.81 ± 0.02^b
SCCF	0.01 ± 0.00^a	0.20 ± 0.01^a	5.82 ± 0.41^a	7.73 ± 0.19^a	4.51 ± 0.04^a

Results are expressed as means ± standard deviation (n = 3) with different letters within a column indicate significant differences at p < 0.05. ND = Not detectable dietary fibre in SCC flour (306 mg g^{-1}, Lau et al., 2019) as compared to the rest of the flours. The high WHC and OHC of SCC flour suggests that incorporating SCC into food products can help to avoid syneresis in the formulated product and can be used to stabilise foods with a high percentage of fat (Elleuch et al., 2011).

3.3. Physical characteristic of muffins

3.3.1. Height and cell crumb structure of the muffins

Table 2 shows the height, cell number and average cell size values of the different muffins. Muffin height was significantly ($p < 0.05$) affected by the level of SCC flour incorporated. RF showed the lowest height ($p < 0.05$), followed by 10SCCF, 20SCCF and 30SCCF, which showed the largest height ($p < 0.05$). In contrast, the cell crumb structure results showed that 10SCCF muffins showed the highest ($p < 0.05$) number of cells, followed by muffin 20SCCF, 30SCCF and 100RF. 30SCCF showed the lowest ($p < 0.05$) cell size as compared to the rest of the muffins.

The total fibre content of the muffins was calculated using the ingredients' nutritional composition from the supplied specifications. As expected, the fibre content of the muffins rose as the rice flour was replaced by SCC flour; the fibre content of the muffins was 0.13, 1.83, 3.52 and 5.22 g/100 g for RF, 10SCCF, 20SCCF and 30SCCF, respectively. The presence of fibre (cellulose and hemicellulose) could have strengthened the muffin GF network made of carbohydrates (gelatinised starch) and proteins during baking, preventing them from collapse. This is especially important to GF products as they are lacking in gluten, a network strengthening component, as compared to products containing wheat. Similarly, Gularte, Hera, Gómez, and Rosell (2012) reported that during thermal treatment, oat fibres were able to give some strength to the network to counteract the collapse of GF layer cake. Another factor that helps explaining the higher height of muffins with CCF is that some of the components of SCC flour (e.g. fibre and proteins) may increase the gelatinisation temperature of starch by reduction of the water available for starch gelatinization (Majzoobi et al., 2016) and therefore allow more time for expansion during baking as the thermal setting of the muffin will be delayed. Therefore, it can be concluded that the replacement of SCC flour in muffins resulted in a more aerated and taller muffin compared to 100% RF.

3.3.2. Muffin texture

The effect of incorporating SCC flour on the texture of muffins is shown in Table 3. Overall, muffins supplemented with SCC flour (10SCCF and 20SCCF) showed significantly lower hardness as compared to muffins baked with rice flour (100RF). These results could be related with the higher height and aerated cell crumb structure of these muffins. The hardness values increased as the fibre content rose with 30SCCF muffin being significantly harder than 100RF muffin. The change in muffin texture when flour is replaced by SCC flour might be related to the lower number and smaller cells in 30SCCF muffin crumb, which resulted in a denser crumb structure and an increase in the force needed for compression and hence lead to an increase in hardness and chewiness of the muffins. The increase in hardness as the amount of SCC flour increased might also be due to the large amount of insoluble dietary fibre in the muffins contributed by SCC flour which increased the force needed for compression. Similarly, Martínez-Cervera, Salvador, Muguerza, Moulay, and Fiszman (2011) reported a decrease in hardness (N) in wheat flour muffin when increasing cocoa fibre content to 34.5 g/100 g flour.

Table 2
Physical characteristics of rice flour (RF) muffin prepared with different level of sweet corn cob flour (SCCF).

Muffin	Height (mm)	Cell number	Average cell size (cm^2)
100RF	37.11 ± 0.74[c]	464 ± 34[d]	0.007[a]
10SCCF	43.07 ± 1.12[b]	738 ± 55[a]	0.006[a]
20SCCF	43.44 ± 0.79[b]	656 ± 45[b]	0.006[a]
30SCCF	45.66 ± 0.86[a]	513 ± 35[c]	0.003[b]

Results are expressed as means ± standard deviation (n = 3). Different letters within a column indicate significant differences at p < 0.05.

Table 3
Texture parameters of rice flour (RF) muffin incorporated with different level of sweet corn cob flour (SCCF).

Muffin	Hardness (g)	Springiness	Cohesiveness	Chewiness (g)
100RF	376.00 ± 64.11[b]	0.73 ± 0.05[a]	0.30 ± 0.03[a]	82.47 ± 22.76[ab]
10SCCF	237.04 ± 48.95[d]	0.76 ± 0.05[a]	0.37 ± 0.03[a]	66.54 ± 12.37[b]
20SCCF	325.00 ± 36.37[c]	0.68 ± 0.03[b]	0.34 ± 0.04[a]	75.57 ± 13.51[ab]
30SCCF	424.05 ± 53.06[a]	0.63 ± 0.06[c]	0.34 ± 0.06[a]	93.93 ± 28.73[a]

Results are expressed as means ± standard deviation (n = 3). Different letters within a column indicate significant differences at p < 0.05.

Springiness is how well a product physically springs back after it has been deformed during the first compression. It is related to the elasticity and freshness of a product. Springiness decreased as SCC flour increased from 10% to 30%. A decrease in springiness has been associated with a denser matrix (Martínez-Cervera, Sanz, Salvador, & Fiszman, 2012). These results are in agreement with the cell crumb structure of 30SCCF muffins that showed a lower cell number and cells of smaller sizes than other muffins. Chewiness, a secondary texture parameter associated with difficulty in chewing the sample and formation of bolus before swallowing (Martínez-Cervera et al., 2011), showed a slight increase when comparing 10SCCF and 30SCCF muffins. These results meant that higher forces are needed to chew samples that are harder and denser, such as 30SCCF.

Diverse results have been reported previously when different fibre sources were added to GF baked products. The firmness, cohesiveness and chewiness of GF cakes improved with the addition of up to 40% of sweet potato flour. On the other hand, Gularte et al. (2012) observed an increase in hardness and cohesiveness on the textural properties of GF cakes incorporated with insoluble oat fibres. Therefore, the concentration and type of fibres, as well as the hydrocolloid used to produce the GF baked products is crucial to improve the texture of GF baked products. The results indicated that softer GF muffins could be prepared by incorporating SCC flour at level of ≤ 20%.

3.3.3. Muffin colour

Incorporation of SCC flour in the muffin also had an impact on the colour of the crust and crumb of the baked muffins. Fig. 2 shows the images of muffin incorporated with different levels of SCC flour. The colour value (L^*, a^*, b^*), hue, chroma (C_{ab}) and ΔE^* of the crust and crumb colour of muffins was recorded in Table 4.

3.3.3.1. Crust colour. In general, muffin crust colour was darker (lower L^* value) than crumb colour due to the occurrence of Maillard reaction during baking. Similar effects were observed by Martínez-Cervera et al. (2012) when baking muffins made of wheat flour. During baking, reactions between proteins and reducing sugars as a result of the Maillard reaction are important for the development of the brown colour as well as flavour and texture (Michalska, Amigo-Benavent, Zielinski, & del Castillo, 2008). The increase in temperature during baking causes the water content of the crust layer to reduce rapidly, causing the degradation of sugar and thus favouring the occurrence of Maillard reaction. However, water losses in the interior of the muffin (crumb) are lower causing slower progress of Maillard reaction, therefore, crumb is only slightly coloured (González-Mateo, González-SanJosé, & Muñiz, 2009).

Lightness and yellowness (L^* and $+{}^*b$ values) of the crust colour increased with the increase of SCC flour in the formulation. While incorporation of 20% and 30% SCC flour showed significantly lower redness ($+a^*$) on the crust colour as compared to rice flour and 10% SCC flour muffin. These results may be attributed to the natural yellowish colour of SCC flour due to its carotenoid content. Previous research by

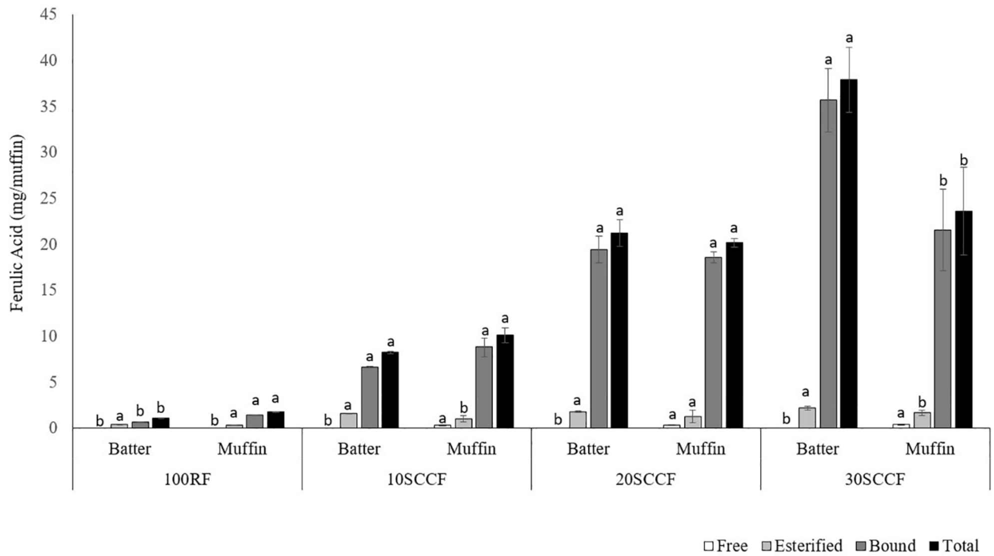

Fig. 1. Changes in ferulic acid content (free, esterified, bound and total) in batter and muffin incorporated with different levels of sweet corn cob flour (10SCCF, 20SCCF, and 30SCCF). Results are expressed as mg/muffin (n = 3). Different letters within the same fraction of batter and muffin indicate significant difference at $p < 0.05$.

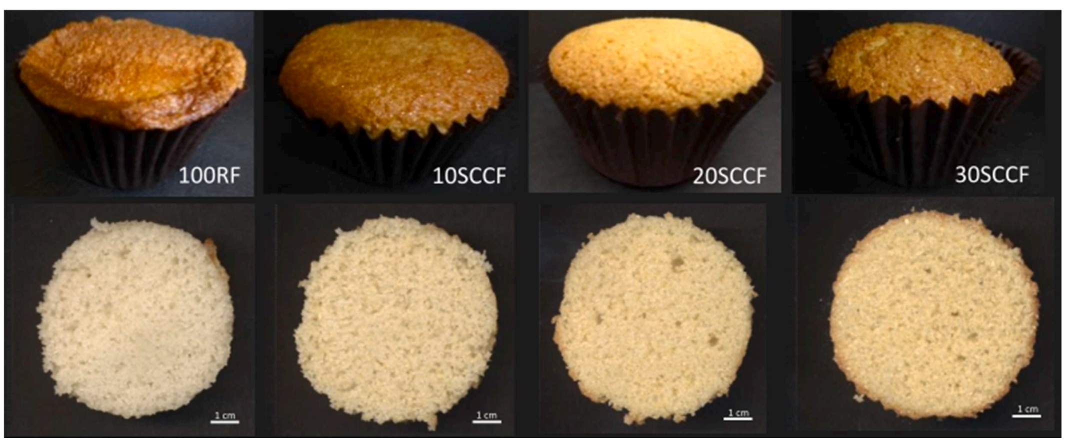

Fig. 2. Pictures of the muffins and scanned images of cross sections of the crumb of rice flour muffin (100RF) and muffins prepared with different level of rice flour replacement by sweet corn cob flour (10, 20 or 30% SCCF).

Lau et al. (2019) showed that SCC flour contains β-carotene (177.29 μg/g), lutein (3.81 μg/g) and zeaxanthin (8.47 μg/g). The differences in crust colour between each of the three SCCF samples and the RF samples were perceptible by the human eye (ΔE*greater than3).

3.3.3.2. Crumb colour. Similar lightness was observed among muffins' crumb, except for 10SCCF which showed a significant decrease in L* in comparison to 100RF muffin crumb. As the percentage of SCC flour increased, greenness (-*a*) decreased, and yellowness (*b*) increased ($p < 0.05$). Similar to crust colour, this could be due to the fact that SCC flour, which contains naturally occurring yellow pigments due to its carotenoid content, impart yellowness to the product when mixed with rice flour. Similarly, the increase in chroma (C_{ab}) was observed with the increase of SCC flour in the formulation due to the increase in the intensity of yellow colour (*b* value), contributed by the pigmented carotenoid compounds in SCC flour. The crumb colour difference of muffins with SCC flour was also perceivable by the human eye (ΔE*greater than3).

3.4. Effect of baking on ferulic acid content in the muffins

The effect of baking on free, esterified and bound ferulic acid in muffin with different levels of SCC flour is presented in Fig. 1. Baking significantly increased ($p < 0.05$) the level of free ferulic acid in all muffin recipes except in 100RF formulation. After baking, an increase of 29%, 32% and 40% free ferulic acid was detected in muffins incorporated with 10, 20 and 30% of SCC flour, respectively. The increase of ferulic acid after baking was similar to that observed by Abdel-Aal and Rabalski (2013), where the free ferulic acid increased (70.5%) in wholegrain muffin baked with a mixture of einkorn and corn flour. The significant increase in free ferulic acid could be due to the release of esterified and bound ferulic acid. This is further confirmed by a decrease of esterified ferulic acid was found in muffins 10SCCF (-37%), 20SCCF (-29%), and 30SCCF (-25%). Previously, Cheng et al. (2006) had reported that the degradation of conjugated polyphenolic compounds due to heat stress caused an increase in free phenolic acids in wheat.

Bound ferulic acid showed a different pattern depending on the proportions of flours used in the muffin formulation. Significant increase in bound ferulic acid was found in muffin 100RF. On the other hand, muffin incorporated with 30% SCC flour showed a significant decrease

Table 4
Crust and crumb colour parameters of muffin incorporated with sweet corn cob flour (SCCF).

Muffin	*L**	*a**	*b**	C_{ab}	*ΔE**
Crust colour					
100RF	53.44 ± 4.82[b]	12.60 ± 2.10[a]	36.96 ± 3.53[b]	39.10 ± 3.43[cb]	–
10SCCF	53.35 ± 1.75[b]	12.36 ± 1.86[a]	39.42 ± 3.93[ab]	41.37 ± 3.69[ab]	3.59
20SCCF	63.04 ± 1.93[a]	6.73 ± 1.56[c]	40.68 ± 1.69[ab]	41.26 ± 1.79[ab]	11.23
30SCCF	61.77 ± 2.58[a]	9.22 ± 1.95[b]	42.73 ± 1.56[a]	43.74 ± 1.74[a]	10.60
Crumb colour					
100RF	73.52 ± 3.55[a]	−2.92 ± 0.71[b]	18.35 ± 1.85[c]	18.58 ± 1.90[c]	–
10SCCF	69.77 ± 2.94[b]	−2.35 ± 0.37[b]	28.09 ± 0.79[b]	28.19 ± 0.81[b]	13.35
20SCCF	72.43 ± 1.45[ab]	−1.88 ± 0.42[ab]	31.16 ± 1.91[b]	31.21 ± 1.92[b]	12.81
30SCCF	72.65 ± 1.67[ab]	−1.10 ± 0.77[a]	36.01 ± 1.93[a]	36.03 ± 1.94[a]	17.76

Results are expressed as means ± standard deviation (n = 3). Different letters within a column indicate significant differences at $p < 0.05$. Also, L* value is a measure of the lightness (0 = black; 100 = white). A* measures redness (positive value) or greenness (negative value) while b* measures yellowness (positive value) or blueness (negative value). C_{ab} value is a measure of the chroma. ΔE* showed the total colour difference between control muffin and the muffin with SCC flour.

in soluble conjugate (from 2.20 to 1.64 mg/muffin) and bound (from 35.68 to 21.53 mg/muffin) ferulic acid after baking. Holtekjølen, Bævre, Rødbotten, Berg, and Knutsen (2008) reported an increased in bound phenolic acids in bread containing barley flour after baking. This might be due to the release of bound phenolics from the matrix during baking or thermal processing (Duodu, 2011). On the other hand, phenolics have been reported to be very reactive and unstable (Cheynier, 2005), and degradation of phenolics will occur due to oxidation during heat treatment throughout the baking process. During baking, various mechanisms such as thermal degradation, polymerization and oxidation of phenolics, depolymerisation of high molecular weight phenolics such as condensed tannins, products of Maillard reaction and release of bound phenolics from food matrix can influence the change in the phenolic acid profile (Duodu, 2011) of a given food. In this study, the bound ferulic acid in SCC flour might be more sensitive to heat treatment as compared to the ferulic acid in rice flour leading to a decrease in bound phenolics after baking.

The highest amount of total ferulic acid was observed in muffin incorporated with 30% and 20% of SCC flour (20.15 mg/muffin), followed by muffin with 10% SCC flour (10.08 mg/muffin) and 100RF (1.76 mg/muffin). A significant decrease in total ferulic acid was found in formulations with 30% SCC flour before and after baking. The decrease in total ferulic acid content is due to the significant decrease in bound phenolics after baking. Although muffin incorporated with 20% and 30% of SCC flour showed a decrease in the total ferulic acid content after baking, the level of ferulic acid still remained high (20.15 and 23.58 mg FA/muffin, respectively) as compared to control muffin made with 100% RF (1.76 mg FA/muffin).

3.5. Consumer sensory evaluation of muffins

The level of SCCF incorporation on muffins had an effect on consumer overall liking and on liking on each modality (aroma, flavour, texture and aftertaste). Sensory attributes of the muffins are shown in Fig. 3. Overall, muffins with SCC flour had significantly ($p < 0.05$) better sensory scores than control muffin. Control muffin showed the lowest score in aroma, texture, flavour, aftertaste and overall liking, as compared to the muffins with SCC flour. 10SCCF muffin showed the highest scores in all the attributes, including overall acceptability. Scores then decreased significantly ($p < 0.05$) with the increase of SCC flour content. There was a decrease in texture liking score as SCC flour increase. These results could be due to the increase in muffin hardness as SCC flour increase, due to the fibre content and a more dense crumb structure. This is also in agreement with Sudha et al. (2007), where the inclusion of up to 20% of apple pomace in cakes showed highest sensory score, and cake with 30% substitution of apple pomaces showed significantly reduced sensory score.

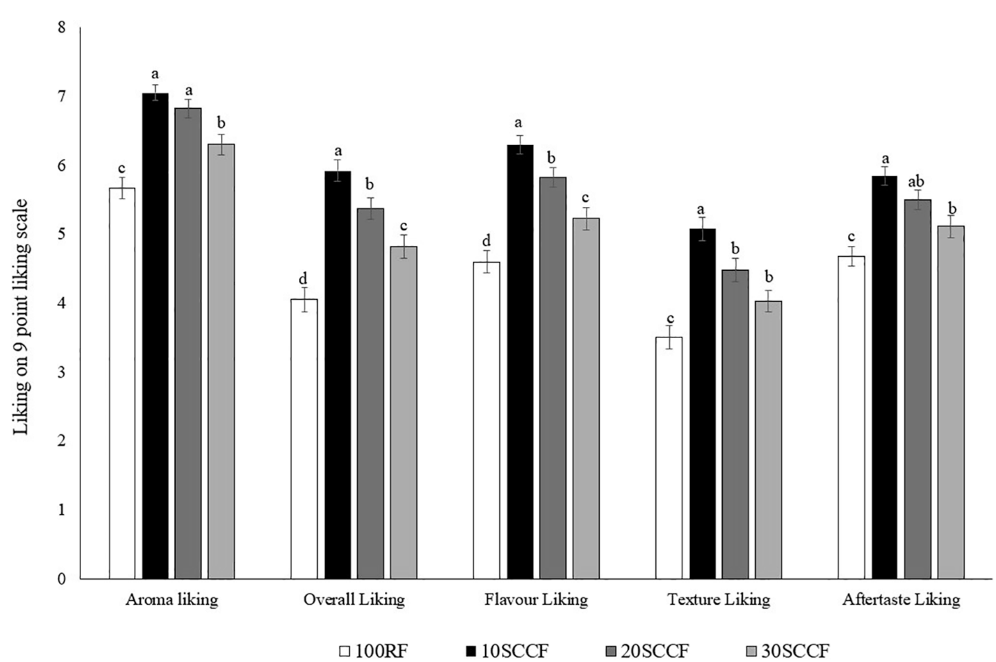

Fig. 3. Scores on aroma, flavour, texture, aftertaste and overall liking in muffin incorporated with different levels of sweet corn cob flour (10SCCF, 20SCCF and 30SCCF). Preference data represents mean scores ± standard error, from a 9-point hedonic scale for all 121 volunteers. Different letters indicate significant difference at $p < 0.05$.

4. Conclusion

The nutritional value of the GF rice muffins was improved by the enrichment with SCC flour, which resulted in a progressively higher fibre and ferulic acid content. This study showed that GF rice muffins with SCC flour up to 20% can improve height, colour and texture as well as increasing the amount of total ferulic acid in the muffin. In accordance to Europe legislation, muffin 20SCCF and 30SCCF can be classified as 'source of fibre' because these products contain more than 3 g of dietary fibre per 100 of product. To improve the acceptability of GF rice muffins with higher content of by-product flour, further work on improving the quality and properties of the flours should be conducted. Due to the highly fibrous characteristics of this by-product, the milling process, specifically, is very challenging and further research should be conducted in this area. The use of SCC, a by-product from the corn processing industry can offer alternative solutions towards environmental concerns regarding disposal. The results indicate that SCC could be considered as an alternative GF flour or value-added food ingredient for bakery products, functional foods and nutraceuticals.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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