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Spent coffee grounds as a sustainable coffee flavouring ingredient in muffins

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Abstract

Aim: United Nations calls for actions to meet future challenges, and industries and governments need to look for new solutions. Coffee is one of the largest industries in the world, and spent coffee grounds (SCG) represents 50% of its waste. Sustainable ways to manage this waste are of interest. Research has shown that SCG is rich in dietary fibres and antioxidants, and we liked to examine if SCG could be used in flavouring muffins. The objectives were to investigate the viability of processing SCG through a comparison of different drying methods, to evaluate how SCG influences properties of baked goods and to investigate consumer acceptance of muffins with SCG.

Methods: Three methods for drying SCG were used: oven drying, freeze drying, and vacuum drying. Muffins were baked with 10% milled and sieved SCG related to flour weight, and a control with 2.5% espresso powder. C-cell-, texture- and moisture analyses were conducted along with a sensory analysis.

Results: The laboratory measurements showed that SCG powders were comparable to the control regarding textural parameters, except for the slice area parameter. The sensory analysis showed no clear difference in bitterness but a difference in graininess and coffee flavour. The least grainy was the control which also had the strongest coffee flavour. The vacuum dried was the grainiest and the freeze dried had the least coffee flavour. Ranking data showed the control in top and the vacuum dried bottom.

Conclusions: SCG has the potential as flavouring coffee muffins but a finetuning in the processing and recipe development is needed to retrieve more coffee flavour without increasing bitterness or graininess.

Keywords

Circularity, coffee, baking, flavour, sustainability, waste

Introduction

Coffee is one of the most consumed beverages worldwide with an annual consumption of 43.6 liters per person [1]. However, coffee produces a large amount of waste due to its by-product spent coffee grounds (SCG). This waste has a substantial environmental impact, and there is a need to find usages for the by-product to progress towards sustainability and circularity [2–4]. Processing coffee includes drying, dehulling, roasting, grinding, and brewing [5, 6], and by-products are coffee husk, coffee pulp, silver skin, and SCG [7]. Worldwide, 6 million tons of SCG is produced annually [8, 9]. Currently, most of it ends up as waste on landfills where it releases methane and contributes to global warming. The United Nations (UN) calls for sustainable development and consumers are increasingly aware of environmental issues related to food production and consumption. Alternative uses of SCG can be soil amendment [10, 11], animal feed [6], or biofuel [2, 12, 13], but in practice such applications are limited [14]. This paper explores the use of SCG as an ingredient in baking. The rationale is that SCG contains beneficial micronutrients and fibre, which might be of interest for the food industry in addition to reducing waste deposals [15]. SCG contains 60% dietary fibres of which 84% are insoluble [16]. The antioxidants in SCG are mainly chlorogenic caffeic and coumaric acids. It also contains caffeine, which is a stimulant [17], but where daily intakes should not exceed 400 mg [18]. On the other hand, the caffeine content in SCG is significantly lower than in the extracts from coffee beans [14].

There literature on the use of SCG in baking is limited. Ballesteros et al. [15] showed that SCG has good water and oil holding capacities. Martinez-Saez et al. [19] explored the application of SCG in biscuits looking into physicochemical parameters, thermal stability, and food safety. The SCG was prepared through drying, and the results showed that SCG has a value-adding possibility as an ingredient and drying at 40°C or 70°C produced a better quality than drying at 100°C. Similar results were found by Khashpakyants et al. [20]. They used vacuum-dried SCG and found no clear negative impact the rheological properties of the dough. A study by Trà et al. [16] investigated different amounts of SCG in cookies and showed a risk for reduced acceptability of the product, but with 10–20 g SCG per 100 g flour the products were acceptable. Severini et al. [21] used 15–30 g SCG per 100 g flour in muffins and found that the phenolic content increased 2–4 times and the dietary fibre to a level where the products could be claimed as “high in fibre” according to EU regulations. The volume of the muffins did not change, and the sensory properties were overall good. Both in taste, softness, general appearance and colour the 15 g SCG samples scored higher than the 30 g SCG samples, but also higher than the reference samples with no SCG. Aguilar-Raymundo et al. [22] used 0, 10, 17.5 and 25 g SCG per 100 g ingredients in cookies and found that the texture properties were not negatively affected by the SCG while the content of dietary fibre increased from not detectable values with no SCG to 4.8% by the highest amounts of SCG. The highest amount was acceptable, but 25% meant it gave a coffee taste that was too strong. The intermedium levels (10 g/100 g and 17.5 g/100 g) were the most preferred amounts.

As demonstrated in this brief review, there are a few reports available but beyond these studies are limited, meaning that there is a gap in the existing research. Within the food industry, sustainability has become crucial. Food by-products have received interest as novel ingredients due to their functional components, such as dietary fibre and polyphenols. However, consumers cannot perceive or directly experience such benefits of novel ingredients, only their taste and sensorial characteristics. Cattaneo et al. [23] showed that consumers who received information on the foods and their benefits are more likely to purchase them as it increases their confidence. This indicates that the food industry should invest in communicating with their consumers. Sousa et al. [24] showed that consumers were significantly lacking in information and knowledge on the concept of by-products from the food industry.

Different drying methods can be used in processing SCG. Firstly, oven drying removes moisture by warm air, which has been proven effective to many foods. Oven drying is commonly done with fan assistance (convection drying) that helps in circulating the air. Vacuum drying removes moisture using vacuum at low temperature and oxygen contents. It is used for materials that are sensitive to heat and oxygen. The evaporation rate increases at a set temperature. Vacuum-dried products require less drying compared to conventional hot-air-drying and tend to lead to a higher quality result. Furthermore, they are also generally said to have higher prosperity which means they are more capable of rehydration and reconstitution as well as less shrinkage. The method requires a relatively high energy consumption. Freeze-drying (also termed lyophilisation) is used for many applications in the preservation of varied materials. First, the material is frozen to ultra-low temperatures using liquid nitrogen before being dehydrated using a vacuum which removes the ice through sublimation. It is the standard process of drying products such as fruits because it preserves the nutritional value and extends the shelf life. However, it is an expensive technology which will cost the manufacturers both as an initial investment and during use.

This paper aims to explore how SCG can be used to create a sustainable coffee flavouring of muffins and to investigate whether such a product would be accepted by consumers or not. The objectives were: 1) to investigate the viability of processing SCG into a coffee flavouring by comparing different drying methods; 2) to evaluate the way SCG influences structural, textural, and sensorial properties of baked goods using sensory analysis and laboratory tests; and 3) to investigate whether a product containing SCG would be accepted by consumers using sensory analysis and analysing consumer perceptions and attitudes.

Materials and methods

The SCG used for the study originated from a shop-bought "Waitrose Sumatra Mandheling 100% Arabica Dark Roast" (Waitrose & Partners, UK). After brewing the grounds were placed in a sealed container placed at –18°C until enough SCG had been obtained for starting the further processing.

Drying methods

Three methods of drying SCG were applied: 1) oven drying, 2) freeze drying, and 3) vacuum drying. In addition, a control with no SCG but espresso powder was added for the baking. Details on drying treatments and muffins recipes are provided in Table 1.

Table 1. Overview of the different treatments with drying details and recipe details

Treatment	Drying details	Recipe details
Oven dried muffins	SCG dried in a convection oven, 100°C, 2 h	200 g plain flour, 200 g butter, 200 g sugar, 200 g egg, 3.5 g baking powder, and 20 g SCG
Freeze dried muffins	SCG freeze-dried (Lyophiliser Machine), 48 h	200 g plain flour, 200 g butter, 200 g sugar, 200 g egg, 3.5 g baking powder, and 20 g SCG
Vacuum dried muffins	SCG dried in a vacuum oven, 22°C, 24 h	200 g plain flour, 200 g butter, 200 g sugar, 200 g egg, 3.5 g baking powder, and 20 g SCG
Control muffins	Not applicable	200 g plain flour, 200 g butter, 200 g sugar, 200 g egg, 3.5 g baking powder, and 5 g espresso powder

SCG: spent coffee grounds

The oven drying was done in a convection oven at 100°C for two hours after being spread out evenly onto a tray lined with parchment paper. On top of this, another sheet of parchment paper and an oven rack were placed to keep the paper from moving by the fan in the oven. After drying the grounds were cooled down for fifteen minutes and placed into an airtight container until further processing. The vacuum dried SCG was first prepared by dissolving 5 g of SCG in 10 mL of alcohol using a glass rod, thereafter, placed on a hot plate that had boiling water underneath for gentle heating and dried out for five minutes. Then the samples were placed into the vacuum oven (Vacuum Lyophiliser) and dried for 24 h at 22°C. The SCG were weighed into test tubes of 45 mL, 18 g in each tube, per freeze drying execution. The grounds were then frozen before being placed into the freeze drier where the temperature dropped further. The SCG was freeze dried for 48 h before being removed and transferred into an airtight container ready for milling. The moisture content was measured in the SCG before and after drying to achieve the desired percentage of under 14% before milling. The loss on drying (LOD) method was applied where a sample is continuously weighed during heating and drying, and the moisture content is determined when the sample stops losing weight based on the thermos-gravimetric principle. To assure an accurate reading, the SCG was tested five times for each dried sample.

Once dried, the SCG was collected and placed into an airtight container until ready to be milled. The SCG were milled using a KoMo millstone which is made from Corund ceramics [25]. For sieving, a test sieve was used with a mesh sieve of 1,500 micron. The grounds were sieved for two minutes, and the sieved powder was then stored in an airtight container until ready for muffin production.

Baking

A base recipe of 200 g plain flour, 200 g butter, 200 g sugar, 200 g egg, 3.5 g baking powder, and 10% SCG (20 g) of the weight basis of the flour (200 g) was selected. The same base recipe was used for all muffins. Espresso powder was chosen as the control as it is the coffee flavouring currently on the market that most closely resembles SCG powder. For a fair comparison, as espresso powder has a stronger and more concentrated flavour than SCG, a lower percentage, 2.5% (5 g), was used. The muffins were baked at 180°C in a deck oven for 22 min and then cooled for one hour on racks (Figure 1). After cooling, the muffins were examined for structural and textural properties. Muffins for sensory analysis were frozen and defrosted for four hours on the day of the analysis.

Figure 1. Appearance of the muffins after baking. Freeze dried (top left), vacuum dried (top right), oven dried (bottom left), and control (bottom right)

Structural and textural measurements

The top of the muffins was cut off at the rim and the base analysed by a C-cell instrument [26]. This is an image analysis system designed to evaluate the internal structure of baked goods, and which can determine a broad range of parameters. Parameters analysed were crumb of the cakes, slice area, clustering, area of cells, number of cells, and brightness. A texture analyser [27] was used to obtain the physical texture of the sample. The aperture includes a travelling arm that moves either an up or down direction to compress or stretch a sample. The distance and time data was collected as curves and analysed. Parameters included were two hardness scores (1—the first bite; and 2—the second bite), springiness, and cohesiveness. Springiness indicates how the product springs back up after compression and it may be used to determine the softness of a product like a cake [28]. Cohesiveness indicates the internal resistance in the product, and it is used to see how well the product holds together [29]. Nine replicate muffins samples were measured per treatment.

Sensory analysis

Sensory analysis or organoleptic evaluation is a method which provides data on consumers' experience of a certain product. A 40 persons panet was selected based on convenience. The persons were asked to rate the muffins on a 5-point scale (from low to high) based grittiness, coffee flavour and bitterness, respectively. They were also asked to rate overall appearance, flavour, and texture on a 4-point scale (from poor to excellent). Lastly, they were asked which of the samples they preferred the most. For attribute scorings, one person did not fill in all the required answers and was removed from the further data analyses. For overall appearance, flavour and texture four persons did not fill in all the required answers and was removed from the analyses, which leaves a total of 36 persons that provided their feedback to this part of the study.

Data analysis

The measurements produced continuous numeric data. One-way ANOVA and Tukey post hoc tests were conducted. P values between 0.05 and 0.10 was regarded as a tendency, while P values below 0.05 was regarded as significant. The sensory analysis produced data on consumers' appreciation given on scales that included 5 points (from low to high) for the attribute ratings and 4 points (from poor to excellent) for the preference scorings. Non-parametric Friedman tests were conducted to analyse the data with mean ranks and chi square (χ^2) values as main outputs. As described above Tukey post hoc tests were run if significant differences were obtained. The statistical analyses were done in SPSS software (IBM, New York, USA) while Excel [Microsoft (Seattle, USA)] was used to make the figures. To determine the effectiveness of the various drying methods, the milling and sieving losses were calculated. This was done through first weighing a pre-decided weight of SCG set to 10 g. Then it was milled prior to being re-weighed. Using these two numbers, the milling loss was determined. Furthermore, the sieving loss was determined using the same calculation, only using the previous weight after milling and comparing that to the weight after sieving.

Results

Moisture content and milling and sieving losses of the SCG

Three different drying methods were compared. The ANOVA showed that the method significantly affected the moisture content in the SCG after drying ($P < 0.001$). The Tukey test showed that vacuum dried samples had a much higher moisture content than oven dried and freeze dried samples (Table 2). The two latter methods resulted in an acceptable moisture content while the vacuum drying did not. After drying the SCG samples were milled and sieved. A significant effect of drying method was found for powder loss during the milling ($P < 0.001$). The Tukey test showed that freeze dried samples had a higher milling loss than oven dried and vacuum dried samples. No effect of drying method was found for powder loss in the sieving of the dried and milled SCG.

Structural and textural properties of the muffins

Muffins were baked with milled and sieved SCG powder from oven dried, vacuum dried and freeze dried samples, respectively. In addition, a control with espresso powder was added. The results were obtained by C-cell and texture analyser measurements. For slice area the samples showed significant differences ($P = 0.04$). The Tukey post hoc test revealed that muffins with the freeze dried SCG had a higher slice area score than the other samples (Table 3). For brightness a tendency of difference was found ($P = 0.09$), where the oven dried muffins tended to higher brightness score than the others. No significant differences were found

Table 2. Overview of moisture content analysis and analysis of powder loss during milling and sieving with mean values of the samples and with *P* values from one way ANOVA test of significance[1]

Sample	Moisture content (%)	Powder loss milling (%)	Powder loss sieving (%)
Oven dried	9.5	0.25	7.1
Vacuum dried	43.7	0.15	7.0
Freeze dried	7.4	1.13	6.9
P values	$P < 0.001$	$P < 0.001$	$P = 0.69$

[1] In the first step of preparing the SCG for the muffins, three drying methods were compared. There was no espresso powder control here as it is in the results of the structural and sensory results of the baked muffins that has espresso powder as the control

for the other C-cell parameters ($P = 0.39$ for coarse/fine clustering, $P = 0.19$ for area of cells, $P = 0.6$ for number of cells). Furthermore, no significant differences between the muffin samples were found for any of the texture parameters ($P = 0.17$ for hardness 1, $P = 0.38$ for hardness 2, $P = 0.24$ for springiness, and $P = 0.24$ for cohesiveness) (Table 4).

Table 3. Overview of C-cell analysis with mean values of the samples and with *P* values from the one-way ANOVA test of significance

Sample	Clustering (0–1 scale)	Cell volume (mm^3)	Area of cells (%)	Number of cells (*n*)	Brightness (0–100 scale)	Slice area (mm^2)
Control	0.29	56.7	58.8	1,963	30.8	3,298
Oven dried	0.27	46.7	56.2	2,179	39.7	3,430
Vacuum dried	0.24	57.0	58.9	2,045	28.0	3,242
Freeze dried	0.35	89.0	62.1	1,963	33.4	4,080
P values	$P = 0.76$	$P = 0.16$	$P = 0.19$	$P = 0.60$	$P = 0.09$	$P < 0.05$

Clustering is measured on a 0–1 scale, cell volume in mm^3, clustering in area of cells in % of the slice area, number of cells (*n*) as counted within the slice area, brightness on a 0–100 scale where darkest black = 0 and brightest white = 100, and slice area is measured in in mm^2

Table 4. Overview of texture analysis with mean values of the samples and with *P* values from the one-way ANOVA tests of significance

Sample	Hardness 1 (N)	Hardness 2 (N)	Springiness (mm)	Cohesiveness (ratio)
Control	10.7	9.5	9.3	0.54
Oven dried	11.7	10.0	9.6	0.55
Vacuum dried	12.0	10.3	9.7	0.56
Freeze dried	12.8	10.3	10.3	0.58
P values	$P = 0.17$	$P = 0.38$	$P = 0.24$	$P = 0.24$

Sensory results

The muffins flavoured with oven dried, freeze dried and vacuum dried SCG powder as well as the control with espresso powder were provided for a test panel of 40 persons. They were asked for attribute scoring, preference scorings, and their most preferred sample.

Attribute scorings were made for bitterness, graininess, and coffee flavour and 39 persons tasted and provided their feedback to this part (one person did not answer these questions and was therefore removed from the analyses). For bitterness the χ^2 test showed a strong tendency to differences among the samples ($P = 0.05$) where a low bitterness score was more frequently given for freeze dried and control samples compared to the oven dried and vacuum dried samples (Table 5). There was a significant difference in graininess among the samples ($P < 0.001$). The control sample showed a lower graininess score than the other samples where most of the respondents replied that this sample was not grainy. The vacuum dried sample showed some very high scores, which put this sample on the high end of the score in graininess. There was also a significant difference in coffee flavour among the samples ($P < 0.01$). The strongest coffee flavour was obtained in the control sample, followed by the freeze dried and with the oven dried and vacuum dried samples in the lower end of for coffee flavour scoring.

Table 5. Overview of attribute testing with mean scores based on 39 of the 40 persons in the test panel that replied on these parameters, and with values ranging from 1 to 5 where 1 is low in bitterness, graininess or coffee flavour

Sample	Bitterness	Graininess	Coffee flavour
Control	2.4	1.9	3.0
Oven dried	2.8	2.5	2.7
Vacuum dried	2.7	3.3	2.4
Freeze dried	2.2	2.4	2.0
P values	$P = 0.05$	$P < 0.001$	$P < 0.01$

The *P* values are from a chi square test of significance comparing the numbers for muffins baked with oven dried, freeze dried and vacuum dried SCG powder, and the control with espresso powder. SCG: spent coffee grounds

Overall preference scorings were made for appearance, flavour, and texture, and 36 persons provided their feedback to this part of the study (four persons did not reply on this part of the study and were therefore removed from the analyses). The overall result of the preference testing is summarized in Table 6. There was a significant difference among the samples regarding the persons' preferences in appearance ($P < 0.001$), flavour ($P < 0.01$), and texture ($P < 0.05$). Overall, the control was preferred the most, followed by freeze dried and oven dried samples, while the vacuum dried sample was in the bottom.

Table 6. Overview of attribute preference testing with mean values of the samples based on 36 of the 40 persons in the test panel that responded to these parameters, and with χ^2 and *P* values from chi square test of significance

Sample	Appearance	Overall flavour	Overall texture
Control	3.2	3.1	2.9
Oven dried	2.5	2.6	2.3
Vacuum dried	1.9	2.1	2.2
Freeze dried	2.4	2.2	2.6
P values	$P < 0.001$	$P < 0.01$	$P < 0.05$

Discussion

Viability of the drying method

To be viable a drying method should reduce the moisture content to a desired level (below 14%) and do this in an effective way without too much energy. Our results indicated that both oven drying and freeze drying reduced the moisture content sufficiently, but vacuum drying did not. For the latter, either the temperature (22°C) was too low or the period (24 h) was too short. Regarding time, oven drying was the most efficient as it took only 2 h in comparison to 24 h (vacuum drying) and 48 h (freeze drying). Energy consumption was not measured, but previous research has shown that convective oven dryers are often preferred but infrared radiation ovens are more efficient in the energy use [30]. Among the methods compared in this study, oven drying is generally regarded as more energy efficient than vacuum drying and freeze drying [31–33]. Freeze drying requires much energy and is also seen as the most expensive method of dehydrating products [34]. An additional aspect of the amount of energy used is the sources of energy and their sustainability [33, 35].

Structural and textural properties

The texture analysis indicated that all three SCG treatments are comparable to espresso powder in respect to the parameters analysed of the baked muffins (slice area, coarse/fine clustering, area of cells, number of cells, brightness). This is an indication that SCG can be used as a substitute for espresso powder without any major influence on texture. Similar results were also found in the structural properties seen in the C-cell analysis where the results indicated that almost all the powders were comparable to the control on all parameters tested. However, a significant difference in slice area was found between the freeze dried and vacuum dried samples. Although these two samples were significantly different from each other, all samples had a slice area that was in the range of the control. The overall picture is that SCG does not affect structural or textural properties. This is in line with what has been confirmed in other studies. Severini et al. [21] found that volume of the muffins did not change by adding 15–30 g SCG per 100 g wheat flour, but the softness decreased somewhat with the highest SCG amount. Aguilar-Raymundo et al. [22] used up to 25 g SCG per 100 g ingredients and found no negative effect on texture.

Sensorial properties and likelihood of consumer acceptance

The sensory analysis showed that for bitterness no significant difference between the samples was found, which means they are all comparable to the control. However, past research has shown that applying SCG can lead to greater bitterness when added in larger quantities [7]. For this project, 10% of SCG powder was added which is the level deemed as acceptable to consumers [16]. As also demonstrated by Aguilar-Raymundo et al. [22] 25% SCG could have negative effects on sensorial properties, e.g., by giving too much coffee taste but also a bitterness of the products.

Regarding graininess and coffee flavour, there was a significant difference between the samples. When comparing with the control, all SCG muffins had a higher score for graininess and lower score for coffee flavour. Freeze dried was the closest to the control regarding graininess while oven dried had the most coffee flavour. As all samples were milled and sieved to the same size, the graininess is likely caused by the method of drying. Oven drying gives a stronger coffee flavour but a grainier texture while freeze dried gives a weaker coffee flavour and less of a grainy texture (Figure 2).

The most preferred sample (the control) scored high in coffee flavour and overall appearance and flavour at the same time as it scored low in bitterness and graininess. The least preferred sample (the vacuum dried) scored low in flavour and overall appearance at the same time as it scored high in graininess and low in texture. When analysing this data, it is evident that there was a significant difference between the various samples. Firstly, the ranking data shows that control has the highest scores while vacuum dried has the lowest. This indicates that overall, espresso powder gave the best result in a muffin in comparison to the SCG powders. Very few of the muffins received excellent on appearance, texture and flavour except for the control which further proves this point. Out of the SCG powders, on the other hand, the overall best ranked was oven dried in flavour and appearance but in texture it was freeze dried. This coincides with the results seen in the attribute testing as those statistics showed a lower ranking of graininess. Graininess is commonly an attribute with negative implications for texture so therefore, if a product is lower in graininess, it is likely it will rank higher in texture.

Furthermore, the same correlation in results can be seen with coffee dried being preferred with flavour as it was ranked the highest in coffee flavour out of the SCG powders. For a coffee muffin, a distinct coffee flavour is expected. On an average among appearance, flavour, and texture, control was ranked closer to 3 (good) while the SCG powders ranked closer to 2 (average). This indicates that none could directly compare to the control. However, as the results were quite close to the control, specifically oven dried within flavour and appearance and freeze dried in texture, there may be potential for consumer acceptance. Furthermore, the results on the preferred sample showed that although most participants preferred the control sample (15 respondents), the freeze dried and oven dried muffins scored well too (8 and 6 respondents, respectively). With these results in mind, it is evident consumers are open to the alternative coffee flavouring, with some also preferring it to the espresso powder.

Weaknesses of the study

There were weaknesses to this study which can be found in the production of the samples and how they were tested. Firstly, the powder was collected over the course of a month and various batches were used for the drying of the powders. Although frozen some SCG powder was produced using older batches. This may have affected the final products. Furthermore, due to the machines used not being able to process larger batches, specifically the freeze dryer and vacuum dryer, the production of these powders was drawn

Figure 2. Spider diagrams showing the attribute and overall preference scorings

out over a longer period. This meant that although the same processing method was used, the batches of the same powder would have ended up being slightly different. This would be due to difference in SCG batch, the finished powder being affected by moisture absorption and due to human error. The effect of these errors was tried to be minimised using airtight containers for storing and following carefully put into place procedures for production. Moreover, the oven dried, vacuum dried, and control muffins were all baked on the same day while the freeze dried were baked a week later. This was due to insufficient amount of freeze dried powder. This error meant that although the same quantities of ingredients were used, there would be unavoidable differences in batch of ingredients. The above-mentioned issues may have caused some bias. This is especially of concerns regarding the moisture content analysis as this was sometimes conducted after being stored for a few days. For a more accurate results for this test, the dried SCG should have been tested on the same day the drying process was complete. Furthermore, a direct comparison was not used regarding the amount of espresso powder and SCG used. This meant that it may not be seen as a fair comparison or a comparison difficult to measure. However, research was conducted prior to the decided percentage of SCG powder to use. Muffins were made using 10, 20, and 30 percent SCG powder to see how much could reasonably be added. According to past research 10–20% was the amount seen to be accepted by consumers and not have a great effect on the product. Using this research, 10% was decided upon. However, this method of deciding recipe may be seen as improper, causing error in the base recipe used. Furthermore, not using the same amount of espresso powder and SCG powder may have been the reason for the attribute differences. The greater addition of SCG may have led to its graininess and caused the participants to dislike its sensorial properties. On the other hand, this research showed that despite the greater addition, the coffee flavour of the SCG muffins was still weaker than the control. This indicates that

SCG is not likely to work as a coffee flavouring which, linking back to the title of this project, is what this research is about. Lastly, another weakness can be found in the sensory analysis as the participants were untrained. This can particularly be seen as an issue regarding the attribute ranking as they may not have been aware of what to look for. However, the effect of this was attempted to be minimised by explaining clearly what each number meant and giving a short description of each attribute at the start of the study. Furthermore, some participants were also removed from part of the study causing a lower accuracy rate due to such missing values.

In the current study only sensory evaluation by a test panel was included as supporting evidence demonstrating the effect of SCG on the flavour of muffin. Supplementary measures, such as using electronic nose, electronic tongue, or GC-MS, could have strengthened the evidence. This was, however, not possible to do within the frame of the current study.

Concluding remarks

The study showed no clear differences between the samples in the texture analysis. This shows that the various SCG powders can be compared to the control muffins made with espresso powder regarding the hardness, springiness, and cohesiveness. Moreover, the C-cell measurements only established a significant difference for the slice area parameter. The sensory analysis showed no clear difference between the samples in bitterness but there was a clear difference in graininess and coffee flavour in favour of the control. The findings show that there is potential for SCG to be used as a novel coffee flavouring, however, more research is needed before it is ready for the market. Firstly, the time, energy usage and cost of production requires further development to make it economically and practically viable. Secondly, regarding the coffee flavour, retrieving more flavour may cause difficulties without adding a larger amount of SCG. Past research has proven, though, that a greater amount of SCG increases the bitterness and lowers the overall consumer acceptance. Therefore, innovation is needed to make SCG usable as a coffee flavouring. However, due to being highly nutritious, another way to use SCG within the baking industry would be as a fibre enrichment for coffee flavoured baked goods. The UN sustainability goals include aspects of health, responsibility, and innovation, and there is a willingness among consumers to choose environmentally friendly products. The coffee industry which produces a large amount of waste and a way to manage this is needed. To enable a sustainable future, major and minor changes are needed. In such a context the use of SCG in baking, either as a flavouring or enrichment, is an opportunity where the coffee industry and baking industry can collaborate. With further research done on the topic there is a possibility for both viability and consumer acceptance of such a product.

Abbreviations

SCG: spent coffee grounds

Declarations

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Author contributions

SBS: Conceptualization, Investigation, Writing—original draft, Writing—review & editing. SØS: Writing—review & editing, Validation. Both authors have read and approved the submitted version.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical approval

Ethical approval was obtained from Devon Petrie, Ethics Lead for National Bakery School, London South Bank University, Reference number HSEC2223010/26/01/2023.

Consent to participate

Consent to participate was obtained for the involved persons taking part in the sensory analysis of the baked muffins.

Consent to publication

Not applicable.

Availability of data and materials

The datasets generated for this study can be found in the Zenodo, https://doi.org/10.5281/zenodo.14258175.

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