The effect of spent coffee grounds from different brewing cycles on the quality and antioxidant properties of butter cookies

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Abstract. One way to use spent coffee grounds in restaurants and cafes is to develop recipes for cookies, muffins, and biscuits that include them. These products have a grainy structure. This article presents the results of using spent coffee grounds after two brewing cycles to reduce the pronounced graininess of butter cookies and the effect on the quality and antioxidant properties. Spent coffee grounds were obtained after the first (SCG1) and second (SCG2) brewing cycles in a capsule coffee machine, using Robusta coffee, Vietnam, medium roast (7 g per 100 ml of water), after which the spent coffee grounds were dried to a layer thickness of 0.5–0.7 cm using the convective method at a temperature of +60 °C. Dry spent coffee grounds were further ground into powder using an electric coffee grinder and added in quantities of 5; 10; 15% to the recipe for butter cookies. After the second brewing, SCG2 increased its bulk density, water-holding capacity, and oil-holding capacity, while its biologically active compound content and antioxidant activity decreased slightly. Cookie quality parameters depended on the amount and type of SCG. Increasing the amount of SCG did not affect cookie thickness or diameter, but they became darker and crumblier, containing TPC and TFC of 74.5–157.4 and 33.0–79.8 mg/100 g, respectively, exceeding the control by 3.5 times or more. Compared to SCG1, cookies with SCG2 were lighter and crumblier, with a slightly noticeable graininess. Cookies with 15% SCG had the highest antioxidant activity, while sensory acceptance revealed that cookie formulations with 5 and 10% SCG1 and SCG2 were more accepted by the panellists.

1 Introduction

The popularity of coffee and its growing consumption are leading to increasing volumes of coffee waste – spent coffee grounds – and the challenges of disposing of them in the food service industry, which requires significant expense and centralized collection. Each cup of

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brewed coffee increases the volume of spent coffee grounds, whose moisture content reaches 60–70%, making them difficult to store due to microbiological instability [1, 2].

In recent years, numerous scientific studies have been published confirming that spent coffee grounds contain caffeine and other biologically valuable components such as polyphenols, tocopherols, and melanoidins [2], which contribute to their antioxidant and antiproliferative activity [3]. Biologically valuable components are extracted using various methods [4] and used primarily in the pharmaceutical and cosmetic industries, while the resulting waste, before or after extraction, is utilized as biofuels, biodiesel, and biocomposites [5]. At the same time, the dietary fibres, proteins, and lipids found in spent coffee grounds are utilized, which could be used in the development of functional foods [6].

In food production, it is proposed to use coffee ground extracts in beverages and yogurts to enrich them with antioxidants [7] or to prevent oxidative processes in meat products [8], and the powder is used to enrich bakery products, pasta [9], and flour confectionery products – muffins [10], biscuits [11], and cookies [12, 133] – with dietary fibres and antioxidants.

The quality of products depends not only on the amount of spent coffee grounds in the recipe but also on the drying method. Convective drying of spent coffee grounds preserves the coffee aroma with a pronounced bitterness, vacuum drying imparts the most pronounced graininess and bitterness with a weak aroma, and freeze-drying reduces the intensity of the coffee aroma and bitterness when used in the same amount of 20% in the muffin recipe. The volume and density of the muffins also varied depending on the drying method of the spent coffee grounds: convective < vacuum < freeze-drying [10]. Therefore, in flour confectionery products, the optimal amount of vacuum-dried spent coffee grounds is 2–2.5 times less than when dried by convection [12].

The use of spent coffee grounds in flour confectionery products allows them to be enriched primarily with dietary fibres and to enhance antioxidant properties, but changes the colour from brown to dark brown and imparts a noticeable graininess when chewed, which reduces their acceptability to consumers [9-11, 13]. It has been established that the use of hydrothermal brewing cycles causes a change in the texture of spent coffee grounds [2]. Subsequent brewing cycles of spent coffee grounds increase their porosity, which was studied using three brewing cycles using field emission scanning electron microscopy. With each subsequent cycle, the spent coffee grounds decrease in pigmentation, increase their water-holding capacity, and improve the extraction of compounds. The profile of mineral elements changes: the amount of potassium decreases with a simultaneous increase in calcium, which forms insoluble complexes with coffee polyphenols. The grainy texture of baked goods containing spent coffee grounds can also be avoided by using dry extracts obtained from spent coffee grounds using ultrasonic extraction [14]. The disadvantage is the almost complete absence of coffee aroma, but the main drawback is the need for specialized equipment, which is unacceptable for food service establishments.

The aim of this study was to study the effect of spent coffee grounds from different brewing cycles on the quality and antioxidant properties of sweet biscuits.

2 Materials and Methods

2.1 Materials

Spent coffee grounds were obtained after the first and second brewing cycles in a capsule coffee machine using Robusta coffee, Vietnam, medium roast (7 g per 100 ml of water), after which the spent coffee grounds were convective dried at a temperature of +60 °C. The thickness of the spent coffee grounds layer was 0.5–0.7 cm [15]. Dry spent coffee grounds were ground into powder in an electric coffee grinder – after the first brewing cycle SCG1, after the second cycle – SCG2.

To make cookies, SCG was mixed with premium wheat flour, successively replacing SCG1 or SCG2 wheat flour in quantities of 5.0, 10.0, and 15.0%. Then all the remaining prepared ingredients were added and the dough was kneaded, formed into circles and baked for 18 minutes at 170 °C. The studies were conducted after the cookies were cooled for 1 hour at room temperature. The cookie recipes for the control and experimental samples are presented in Table 1.

Table 1. The cookie recipes for the control and experimental samples.

Ingredients	**Raw material consumption, g Control Pilot samples**			
	Control samples	Experimental samples		
		Recipe 1	Recipe 2	Recipe 3
Premium wheat flour	560	532	504	476
Spent coffee grounds powder (PKG1 or PKG2)	-	28	56	84
Icing sugar	185	185	185	185
Butter	375	375	375	375
Melange	56	56	56	56
Vanilla powder	3	3	3	3
Total:	1179	1179	1179	1179
Yield	1000	1000	1000	1000

2.2 Methods

The spent coffee grounds were analysed for moisture, bulk density, water absorption capacity, fat retention capacity, and colorimetric characteristics. The cookies in the control and test samples were analysed for moisture, diameter and height, swelling, and strength. The antioxidant properties of the SCG and cookies were determined by caffeine content, total phenolic compounds (TPC), total flavonoids (TFC), and ferric reducing antioxidant power (FRAP).

The moisture content of the SCG and cookies was determined by drying to constant weight at 105°C.

Bulk densities were determined by measuring the volume of 10 g of SCG.

For the water-holding capacity (WHC) and oil-holding capacity (OHC), 0.1 g of dry SCG samples were taken and mixed with 10 mL of water or vegetable oil. The samples were incubated for 60 minutes, centrifuged at 3000 rpm for 10 minutes, the supernatant was decanted, and the SCG mass increase was measured as the ratio of the difference between the sample masses before and after absorption into water to the product mass, expressed as a percentage.

Colorimetric analysis was performed using the KONICA MINOLTA CM-5 spectrophotometer. Colour was assessed using the CIE Lab: L* (brightness) system, with colour coordinates a* (from green [-] to red [+]) and b* (from blue [-] to yellow [+]).

Cookie diameter and thickness were measured using callipers on 10 cookies. Structurometer ST-2 was used to determine cookie strength (g).

The caffeine content, total phenolic compound content, total flavonoids, and FRAP were determined using a UNICO-2800 spectrophotometer (USA). Extraction was performed with distilled water of the crushed product at a ratio of 1:10, followed by centrifugation at 8000 g for 10 min. To determine caffeine, the obtained extracts were alkalized to pH 12.5 and extracted with chloroform. The organic layer was used for measurements at a wavelength of 276 nm and calculated taking into account the background (310 nm) in terms of pure caffeine. The total content of phenolic compounds calculated as gallic acid was determined as a result of the oxidation reaction of the test objects with the Folin-Ciocalteu reagent and subsequent measurement of the optical density at a wavelength of 765 nm. The total content of flavonoids calculated as rutin was determined by spectrophotometric method with aluminum chloride at the wavelength of 420 nm. Antioxidant activity expressed as ascorbic acid was determined using the FRAP (ferric reducing antioxidant power) method with o-phenanthroline at a wavelength of 505 nm.

The studies were conducted in triplicate, with subsequent statistical processing of the experimental data in Microsoft Excel 2010.

3 Results and Discussion

Samples SCG1 and SCG2 had almost the same moisture content after drying, but differed in bulk density, water absorption and fat-retaining capacity, the values of which increased after the 2nd brewing cycle (Table 2).

Table 2. Composition and properties of spent coffee grounds from different brewing cycles

Indicators	SCG1	SCG2
Moisture, %	6,40 ± 0,12	6,34 ± 0,10
Bulk densities, g/cm^3	0,34 ± 0,01	0,37 ± 0,01
Water holding capacity, %	2,65 ± 0,05	2,88 ± 0,06
Oil holding capacity, %	1,50 ± 0,03	1,59 ± 0,03
Colorimetric characteristics		
L*	25,18 ± 0,06	25,10 ±0,06
a*	1,92 ± 0,02	1,98 ± 0,03
b*	2,88 ± 0,03	2,54 ± 0,04
Biologically active compounds		
TPC, мg / 100 g	985,0 ± 18,6	951,8 ± 20,0
TFC, мg / 100 g	505,2 ± 10,4	477,2 ± 11,0
Caffeine, мg / 100 g	411,1 ± 8,0	383,5 ± 6,2

FRAP, мg / 100 g	377,7 ± 8,0	341,0 ± 8,2

With the brewing cycles, the bulk density of SCG increased and in SCG2 it was 8.8% higher than in SCG1, which indicates a looser grain structure. Compared to coffee, according to [2], the bulk density of SCG1 after brewing coffee and its subsequent drying increased by 6.2%. The authors confirm this fact by an increase in the porosity of SCG with subsequent brewing cycles by, %, 3.9; 6.0; 1.4 after the 1st, 2nd and 3rd brewing cycles [2]. Results on the effect of drying modes on the particle size of SCG have been published [15]. This can explain the increase in the water absorption and fat retention capacity of the studied SCG2 samples by 8.7% and 2.7%, respectively, compared to SCG1. Moreover, SCG, regardless of the brewing cycle, had a higher water absorption capacity than the ability to retain fats, which is important when choosing flour confectionery recipes.

SCG were characterized by a dark colour, as evidenced by low L* lightness values, occupying an intermediate position according to published data: L* = 20.73 [19] and L* = 32.77 [2]. Fluctuations in L* values may be related to the heat treatment conditions during coffee roasting and SCG drying. No significant influence of the botanical coffee species on L* lightness was found. The difference in L* values between SCG from Arabica and Robusta beans under the same heat treatment conditions did not exceed 0.4% [2]. Re-brewing of SCG did not significantly affect the change in L* lightness; statistically significant changes were not observed. At the same time, a shift in colour coordinates occurred: the a* coordinates toward red hues, and the b* coordinates toward blue hues.

The second brewing cycle resulted in a decrease in the content of biologically active compounds in SCG2, but their amounts remained significant (Table 2). For example, in SCG2, the total phenolic content decreased by 3.4%, total flavonoids by 5.5%, and caffeine by 6.7%. This was reflected in the antioxidant activity (FRAP test), which decreased by 9.7% during the second brewing of SCG.

The addition of SCG to cookies, regardless of the brewing cycle, had no significant effect on their diameter and thickness, which were almost indistinguishable from the control sample. The changes were within the error limits. However, the moisture content of cookies with SCG decreased, especially with the addition of 15% SCG (Table 3). The use of SCG2 changed the moisture content of cookies similarly to SCG1, although there was a tendency for lower moisture content in cookies with 15% SCG compared to SCG1. Koay et al. [13] attribute the decrease in moisture content in cookies with SCG to the high water-holding capacity of fibre, which is the main component of SCG. The addition of SCG to cookies had a greater effect on swelling, hardness force, and colour characteristics (Table 3). With increasing SCG content, the cookies became crumblier. Swelling increased by more than 8% compared to the control, and hardness force decreased to 12.4%, showing a more pronounced trend with the addition of SCG2. Similar results were obtained by other authors, who showed a decrease in hardness values with the addition of SCG in quantities of up to 17.5% [12, 13], but 25% SCG increases hardness [12]. According to [14], cookies with SCG extracts even in small quantities contribute to an increase in hardness.

Table 3. Quality indicators of cookies

Indicators	**Control samples**	**Cookies with SCG1 additive in quantity**			**Cookies with SCG1 additive in quantity**		
		5%	10%	15%	5%	10%	15%
Moisture, %	53.2 ± 0.8	53.2 ± 1.0	53.1 ± 0.6	53.0± 1.0	53.1 ± 1.1	53.1 ± 0.8	53.0 ± 0.9
Thickness, mm	6.9 ± 0.1	6,8 ± 0.1	6.7 ± 0.1	6.7 ± 0.1	6.9 ± 0.1	6.9 ± 0.1	6.7 ± 0.1

Moisture, %	5.9 ±0.1	5.8 ± 0.1	5.7 ± 0.1	5.4 ± 0.1	5.8 ± 0.1	5.6 ± 0.1	5.2 ± 0.1
Swelling, %	159.1 ± 3.5	163.0 ± 2.8	167.4 ± 2.0	172.2 ± 1.7	164.0 ± 2.5	170.6 ± 3.0	175.4 ± 1.9
Hardness force, g	958 ± 12	926 ± 18	890 ± 16	852 ± 21	939 ± 10	859 ± 17	833 ± 11
L*	76.2±0.15	58.14±0.34	46.74±0.88	39.32±0.59	60.22±1.10	52.35±0.98	42.20±0.60
a*	2.83±0.05	3.04±0.07	3.12±0.07	4,19±0.09	3.01±0.05	3.10±0.06	3.76±0.08
b*	24.54±0.56	17.53±0.38	12.36±0.30	12.12±0.30	17.98±0.40	14.00±0.32	12.22±0.28

SCG has a characteristic brown colour that varies slightly across brewing cycles, becoming slightly lighter after the second cycle (Table 3). The addition of SCG to the cookies imparts a brown colour that intensifies with increasing SCG content. This is evidenced by the L* lightness values, which decreased by 31.1% in cookies with 5% SCG1 compared to the control. Increasing the SCG content to 10 or 15% darkened the cookies. Compared to cookies with 5% SCG1, the L* lightness values changed by 14.6% in cookies with 10% SCG1 and sharply decreased by almost 2 times (47.9%) in cookies with 15%. Moreover, the a* colour coordinates shifted slightly toward redness, and the b* coordinate moved away from yellow hues. Similar colour dynamics were observed in butter cookies with 2 to 10% SCG [13] and sponge cakes with 2 to 6% SCG [11].

Increasing the amount of SCG in cookies enhanced their antioxidant properties. Compared to the control, cookies with 5% SCG1 had a 3.3- and 4.0-fold increase in TPC and TFC content, respectively (Table 4), leading to a 4.9-fold increase in their antioxidant activity. The more significant increase in antioxidant activity could be due to the formation of melanoidins [12]. A further increase in the amount of SCG1 in cookies increased the TPC and TFC content and antioxidant activity. No significant differences in antioxidant properties were found between cookies with SCG1 and SCG2.

Table 4. The effect of spent coffee grounds from different brewing cycles on the antioxidant properties of cookies

Indicators	**Control samples**	**Cookies with SCG1 additive in quantity**			**Cookies with SCG1 additive in quantity**		
		5%	10%	15%	5%	10%	15%
TPC, mg/100 g	22.7±0.5	76.0±1.0	118.5±1.6	157.4±2.5	74.5±1.6	115.2±2.0	155.5±2.1
TFC, mg/100 g	8.8±0.2	35.1±0.7	57.4±1.0	79.8±1.3	33.0±0.8	54.7±1.4	75.8±1.4
Antioxidant activity FRAP, mg AC /100 g	3.89±0.02	19.38±0.26	39.15±0.30	57.12±0.44	18.90±0.28	37.12±0.20	54.48±0.42

Cookies with varying amounts of SCG1 and SCG2 were rated on organoleptic characteristics, with values ranging from 1 to 5 for a test panel of 20 individuals, where 0 represents the absence of the characteristic and 5 represents the most pronounced characteristic. The evaluations were based on appearance, bitterness, graininess, crispness, and coffee flavour (Table 5). Finally, they were asked to rate the overall acceptability.

All tasters noted an increased coffee aroma and darker colour in the cookies with increasing amounts of SCG1 and SCG2. Cookie appearance was acceptable with SCG levels of 5% and 10%. Cookies with 15% SCG were too dark, with cracks appearing on the surface, which the tasters did not appreciate when evaluating the appearance. Moreover, the majority of tasters in this cookie, regardless of SCG1 and SCG2, noted the severity of the bitter taste and rated this feature at 5.0 and 4.95 points, respectively.

Table 5. Evaluation of organoleptic characteristics of cookies with SCG, average score

Indicators	Cookies with SCG1 additive in quantity			Cookies with SCG1 additive in quantity		
	5%	10%	15%	5%	10%	15%
Appearance	4,95	4,85	3,40	5,00	4,95	3,45
Bitterness	0,55	1,65	5,00	0,55	0,60	4,95
Graininess	4,85	4,85	5,00	1,60	1,65	2,10
Fracturability/ crumbliness	4,70	4,70	3,95	4,95	5,00	4,80
Coffee flavour	4,85	4,95	5,00	4,85	4,95	5,00
Overall acceptability	4,85	4,70	3,10	5,00	5,00	3,50

Almost all tasters detected a graininess in the SCG1 cookies, especially in the cookies with 15% SCG1. Most tasters considered the cookies with 5 and 10% SCG2 to be acceptable and barely noticeable. Increasing the SCG2 content to 15%, the graininess became more noticeable. All SCG cookie samples had a crumbly texture, which was rated as low only in the cookies with 15% SCG1.

At the end of the tasting, tasters selected cookie samples that they would purchase in a store. The best-received cookies, according to tasters, were the 5 and 10% SCG2 cookies, which all tasters would purchase. However, most tasters would buy the 5 and 10% SCG1 cookies, which received average overall acceptability scores of 4.85 and 4.7, respectively. These tasters liked the pronounced graininess, reminiscent of poppy seed inclusions in cookies. Those who prefer a bitter taste in cookies would have also bought cookies with 15% SCG, but such tasters were few in number.

4 Conclusions

Spent coffee grounds obtained after the first and second brews contain biologically valuable components—total phenolic compounds, total flavonoids, and caffeine—which determine their antioxidant activity. With increasing brewing cycles, the proportion of biologically valuable components decreases slightly, but bulk densities, water holding capacity, and oil holding capacity increase.

Spent coffee grounds obtained after two brewing cycles can be used in cookie recipes; increasing the amount increases their antioxidant properties. Cookies with 5 and 10% SCG demonstrate the best overall acceptability for consumers, regardless of brewing cycle, despite the grainy texture of cookies with SCG 1. The cookies have a beautiful appearance with a distinct coffee flavour and a crisp texture. Increasing the SCG to 15% is not advisable due to deterioration in appearance and bitterness in the taste.

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