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Valorization of spent coffee grounds for scented candle production

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Abstract

Approximately 6 million t of spent coffee grounds (SCG) are produced annually but only 25% are reused and the rest ends up in landfills. One of the potentials of SCG is its use as a scented candle. This is due to low moisture and ash content, and high oil fraction of SCG. This research aimed to investigate the physicochemical properties of different types of SCG and the suitability of the SCG to be used in scented candle making. SCG from different brewing methods such as moka pot and espresso were used in this study. The physicochemical properties of these SCGs were analysed. In candle making, different concentrations of SCG were applied, ranging from 20 to 50%. From the results, it could be seen that the physicochemical properties of the moka pot and espresso-brewed SCG were different, which could affect the performance of the scented candle produced using the SCG. The burning performance such as wax consumption rate, pool size, and flame height, were measured. In conclusion, the suitable concentration of SCG in scented candle making was found to be 30% and 40% for the Moka pot with the addition of soy wax, 20% for espresso concentration, and 30% for the Moka pot with the addition of paraffin wax.

1. Introduction

After petroleum and its derivatives, coffee is the world's second most valuable commodity (Tucker, 2011). Coffee beans are harvested from coffee fruit and used to make a popular beverage. In 2015, over 9.1 billion kg of coffee was consumed worldwide (International Coffee Organization, 2016). The production of coffee is reported to be more than 105 million annually (Konkin, 2023). Approximately 6 million tonnes of wasted coffee grounds (SCG) are produced annually by the manufacturing of instant coffee and coffee brewing worldwide (Getachew and Chun, 2016).

The trend of general coffee consumption has been continuously increasing, for instance, in 2018-19, the annual global production of coffee in the fiscal year 1990 -1991, 2000-2001, and 2010-2011 raised by 83.35%, 50%, and 20%, respectively (Atabani *et al.,* 2022). Globally, spent coffee grounds (SCGs) are a significant waste product, with estimates suggesting that more than 90% of SCGs end up in landfills without proper composting or valorization (Laubert *et al*., 2023). This contributes to the environmental challenges resulting in growing studies in valorization of SCG. Spent coffee grounds have a diverse chemical composition, including organic compounds like fatty acids, lignin, cellulose, and hemicellulose. It also contains lipids, carbohydrates, potassium, phosphorus, magnesium, and calcium, making them a source of valuable nutrients The active substances in SCGs include caffeine and chlorogenic acid (Pujol *et al.*, 2013; Franca and Oliveira, 2022)

Currently, the usage of SCG is still low as only 25% is reused and the rest ends up going to landfills (Kanniah, 2020). Efforts are being made to reduce the environmental impact of SCG disposal and explore innovative ways to upcycle this waste, contributing to a more sustainable coffee industry. Spent coffee grounds have a diverse chemical composition, including organic compounds like fatty acids, lignin, cellulose, and hemicellulose. It also contains lipids, carbohydrates, potassium, phosphorus, magnesium, and calcium, making them a source of valuable nutrients The active substances in SCGs include caffeine and chlorogenic acid (Pujol *et al*., 2013; Franca and Oliveira, 2022). Coffee grounds are also a flexible and long-lasting bulk raw material. In plastics, printing inks, cosmetics, textiles, and other products, coffee grounds can be utilized to replace virgin or synthetic, generally

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petroleum-based materials. In order to promote plant development, SCGs are often used in society today as soil fertilizers by adding minerals to the soil. The characterization of SCGs and their reuse in various applications, such as cosmetics and pharmaceuticals, is an ongoing area of research (Liu and Price, 2011; Cruz *et al*., 2014; Ribeiro *et al*., 2017; Atabani *et al*., 2022; Bomfim *et al*., 2023; Laubert *et al*., 2023; Forcina *et al*, 2023; Singh *et al*., 2023). Spent coffee grounds have gained significant attention as a precursor material for various value-added applications in the food industry. SCG is rich in diverse compounds like polysaccharides, proteins, phenolics, lipids, and alkaloids, making it suitable for food-related uses. Research has focused on extracting bioactive compounds such as chlorogenic acids, derivatives, and caffeine from SCG to be used in food formulations, ingredients, and composite materials for food packaging (Franca *et al*., 2022).

Candle-making with the addition of SCGs is one approach that can be done to reduce the disposal of SCGs and also protect the environment. The current potential of making candles from SCG is significant, reflecting innovative and sustainable practices. SCGs can be utilized to create eco-friendly candles, offering various benefits as they serve as a sustainable and upcycled material for candle production, contributing to waste reduction and environmental conservation. It may retain the natural aroma of coffee, adding a pleasant fragrance to the candles without the need for artificial scents. It can be effectively vacuum-impregnated into natural wax, providing a sustainable and eco-friendly alternative to traditional candle-making materials. The chemical composition of SCG, as observed through FTIR analysis, contributes to its compatibility with natural wax for candle production (Yoo *et al*., 2019).

This study aimed to evaluate the physicochemical properties of arabica spent coffee grounds (SCG) brewed using espresso and Moka pot technique for suitability to be used as scented candles made from paraffin and soy wax and to compare the effect of spent coffee grounds concentrations on the burning performance including burning time, size of the burning pool, and flame height of scented candles.

2. Materials and methods

2.1 Selection of raw materials

This project utilizes two types of arabica spent coffee grounds (SCG): SCG from a local café, Appetit Village, labelled as ESS, and SCG from Moka Pot Brewing, labelled as MP. The collected SCGs are stored in the freezer for freshness (Bandurski, 2019). The main waxes used are paraffin wax and soy wax, both purchased online. Other project materials include cotton candle wicks and aluminium tealight holders.

2.2 Espresso brewing method

The espresso machine was preheated before use. Ground beans were measured, tamped flat and even to ensure proper extraction and avoid channeling. Pressurized air, reaching 15 bar, was introduced, followed by hot water, raising the pressure to 20 bar (Parenti *et al*., 2013). After a 10-second pre-infusion phase, the coffee flowed out. The spent coffee grounds were stored in an air-tight container and placed in the freezer.

2.3 Moka pot brewing method

Fine-ground arabica coffee was loosely placed in the filter funnel for the coffee to rise in the collector chamber. Cleaning the Moka pot's rim is crucial to prevent pressure loss. The pot was heated on a gas stove until it spurted, indicating removal from heat. Coffee spurting occurs at 98.6°C with a pressure of about 2.3 kPa (Gianino, 2006). The coffee was then poured once water rose from the bottom chamber.

2.4 Drying of coffee samples

Before the samples were analyzed, all samples were oven-dried at 105°C for 24 hrs (Panpraneecharoen and Rodkate, 2020). The dried SCGs were kept in air-tight containers at room temperature.

2.5 Proximate analysis

2.5.1 Moisture content

The moisture content was determined according to AOAC 925.10 (AOAC, 2000). Approximately 2 g of sample was placed in the electric oven. The temperature was set at 105°C for 2 hrs and it was cooled in desiccators for 15 mins before the sample was weighed. The sample was dried again for at least 1 hr cooled in a desiccator for 15 mins and weighed until gained a constant weight. (Carneiro *et al*., 2018).

2.5.2 Ash content

For the determination of ash content, 2 g of dried SCG was placed into crucible and ignited in the muffle furnace at high temperature of 550°C for 24 hrs. This method was based on AOAC 942.05 (AOAC, 2000). The crucibles then were placed into a desiccator to cool before being weighed (Ismail, 2017).

2.5.3 Protein content

The protein content of dried spent coffee grounds (SCG) was determined using the Kjeldahl method based on AOAC 990.03. In a digestion tube, 1 g of dried SCG

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and protein fraction solution underwent digestion with catalyst and sulphuric acid (H_2SO_4) at 420°C. After cooling, a blank tube without SCG was prepared. Post-cooling, 60 mL of distilled water was added. A conical flask with 25 mL of 4% boric acid was connected to the distillation apparatus, where 60 mL of 40% NaOH was dispensed into the digested SCG. The resulting solution was titrated with 0.1 N of sulfuric acid (Lim, 1992).

2.5.4 Carbohydrate content

Carbohydrate content was assessed using the alkaline ferricyanide method, relying on the reduction of alkaline ferricyanide to ferrocyanide in the presence of reducing sugar. The difference in ferricyanide levels before and after reduction determines the quantity of reduced ferrocyanide, titrated directly using ceric sulphate and phenanthroline as indicators.

2.6 Oil content

Oil percentage inside SCG was analyzed to determine the burning properties of the SCG using Soxhlet based on AOAC 922.06 (AOAC, 2000). Oil extraction from 10 g of used coffee grounds involved recycling 180 mL of solvent over the sample for 6 hrs. A vacuum rotary evaporator separated the solvent and oil mixture at 40°C. The resulting oil was dried at 105°C for 3 hrs to remove residual solvent (Zayed *et al*., 2012).. The oil yield was calculated based on the dry weight of the sample .

2.7 Physical analysis

2.7.1 Colour analysis

The Hunter L*, a*, b* values of coffee samples were measured with a chromameter. The chroma (C*), hue angle (h˚) and total colour difference (ΔE*) values of coffee samples were calculated by using CIELAB scale parameters.

2.7.2 Solubility analysis

One gram of SCG sample was mixed with 100 mL distilled water in a magnetic stirrer for 5 mins at 700 rpm. The mixture was centrifuged at 3000×*g* centrifugal force for 5 mins. Approximately 25 mL of the supernatant was transferred to a petri dish and dried for 5 hrs at 103℃ in the oven. The solubility percentage (g of SCG sample per 100 g of water) was obtained by subtracting the weights after drying (Sarabandi *et al*., 2014).

2.7.3 Particle size analysis

Sieves were stacked in the order from smallest to largest, starting at the bottom, with the pan below the smallest sieve, before 5 g of sample was weighed and added to the top sieve. The sieve shaker was allowed to vibrate for 15 mins, and the mass retained on each sieve and in the pan was carefully weighed.

2.8 Candle preparation

The wax (250 g) was melted using a double-boiling technique. The melted wax was then mixed with SCG with different percentages. SCG percentages to be used in this project were 0% 20%, 30%, 40%, 50% and 100%. The mixture was dried at room temperature for 48 hrs prior to use.

2.9 Burning performing standard

The burning performance standard was measured according to ASTM F2417 (ASTM International, 2017) to make sure the candles produced are following the general safety standard. The standard required to observe several criteria during the initial burn and on every hr of the combustion process. Types of SCG candles samples used to find the burning rate, pool size and flame height were SCG brewed using an espresso machine and Moka pot that were mixed with soy wax and paraffin. The SCG candles samples were denoted as ESS+S for SCG brewed using an espresso machine with the addition of soy wax, ESS+P for SCG brewed using an espresso machine with the addition of paraffin wax, MP+S for SCG brewed using Moka pot with the addition of soy wax and MP+P for SCG brewed using Moka pot with addition of paraffin wax. As for control samples, the wax used was not added to anything else.

2.10 Burn rate measurement

To measure the candle burning rate under normal room conditions, each candle with a different SCG percentage was placed alternately on a table, 20 cm apart and allowed to burn for 30 mins. Overall burn rates were obtained by dividing the total weight loss during candle combustion by the total burn time (Rezaei *et al*., 2002).

2.11 Size of wax burning pool measurement

The size of the wax burning pool under normal room conditions was done by measuring the diameter of wax burning pool every 10 mins interval during the burning process. (Rezaei *et al*., 2002).

2.12 Flame height measurements

The flame height was determined by measuring the flame height for every 10-minute interval during the burning process. A ruler is used to measure the flame height for each candle sample (Rezaei *et al*., 2002).

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3. Results and discussion

3.1 Effects of different brewing methods on proximate analysis of spent coffee grounds

Figure 1 shows the percentage value between SCG brewed using an espresso machine, Moka pot, unbrewed coffee grounds used for espresso and unbrewed arabica coffee grounds used for Moka pot. For the espresso machine and Moka pot, SCG was dried using oven drying. There was no major difference in the ash content of espresso and Moka pot SCGs. Low ash content and moisture content not exceeding 15% in spent coffee grounds could produce positive behaviour of fuel during burning (Brunerova *et al*., 2019). Both the ash content of espresso and Moka pot SCGs were 1.2% and 1.7% respectively, thus both SCGs have the burning characteristic and are suitable to be used as candles.

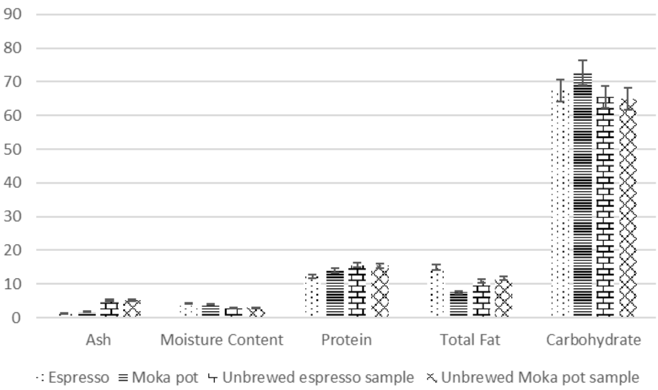

Figure 1. Proximate analysis of different types of SCG.

SCG had higher moisture content than unbrewed coffee grounds samples. This is due to the addition of water during brewing. To get a good efficiency of burning, firewood should have a content of less than 20% (Farkas, 2020). The value obtained for the moisture content might moisture affect the burning rate as high moisture content could reduce the ability of SCG to burn and indicates that the SCG needs to be dried prior to being used. The results of proteins and oil contents for both SCG brewed using the espresso machine and Moka pot were similar to Silva *et al*. (2018) in which they obtained the protein and oil contents of 10.03±0.30 and 14.70±0.6, respectively. However, the total fat for SCG brewed using Moka pot in our study was slightly different from the existing literature. The difference might be due to several factors such as cultivated area conditions, roasting conditions and extraction process (Kovalcik *et al*., 2018). The protein in SCG was slightly lower than in raw samples. Losses of protein might be due to the external factors mentioned earlier. Both types of SCGs contained high oil, indicating they could be used as fire burners.

3.2 Effects of different brewing methods on physical properties of spent coffee grounds

The distribution of particle sizes given as a per cent of the total dry weight is known as aggregate gradation (sieve analysis). Gradation is calculated by weighing the material retained on each sieve as it passes through a sequence of sieves stacked with increasingly smaller apertures from top to bottom. From Figure 2, the particle size of SCG brewed using the Moka pot had a larger size than the ones of SCG brewed using the espresso machine. The mass percentage retained for SCG brewed using the espresso machine was the highest when using 250 µm size sieve mesh (65.54%), while the mass percentage retained for SCG brewed using the Moka pot was the highest when using 500 µm size sieve mesh (89.18%). Both SCGs were ground at medium-to-fine size before brewing. The size for medium-to-fine is between 200-700 µm (Rovniakova, 2022). The average particle size of wax is about 0.1 µm to 6 µm (Leotsakos *et al*., 2014). This indicates that the particle size of wax is smaller than SCG. In candle production, wax particles will fit easily within the pores between large particles (Wiacek and Stasiak, 2018). Therefore, SCG that has a larger particle size can increase the ability of wax to fit perfectly between SCG particles to increase the burning performance. Based on the difference in SCG particles, it can be concluded that SCG brewed using the Moka pot is more likely to have better performance for candle burning compared to SCG brewed using the espresso method. Based on Table 1, the density of SCG brewed using the espresso machine and Moka pot was 1.2718 g/ cm^3 and 1.2907 g/cm^3, respectively. The volume of SGG brewed using the espresso machine and Moka pot were 0.7863 cm^3 and 0.7748 cm^3, respectively.

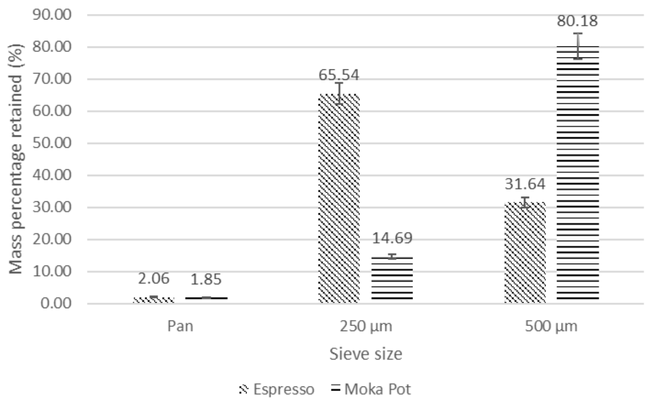

Figure 2. Sieve analysis of spent coffee grounds using espresso and Moka pot brewing methods.

Processing and storage conditions, powder composition, pH, density, and particle size are all factors that impact solubility (Rahman and Perera, 2007). Table 2 shows the solubility of SCG from different brewing methods. The average solubility for SCG brewed using the Moka pot was higher than SCG brewed using the

Table 1. Density and volume of spent coffee grounds with different brewing methods.

Cycle	Moka Pot		Espresso	
	Volume (cm^3)	Density (g/cm^3)	Volume (cm^3)	Density (g/cm^3)
1	0.7722	1.295	0.7832	1.2768
2	0.7758	1.2889	0.7841	1.2753
3	0.7747	1.2908	0.7869	1.2708
4	0.7767	1.2875	0.7882	1.2688
5	0.7744	1.2913	0.7891	1.2672
Average	0.7748	1.2907	0.7863	1.2718

espresso machine which was 1.19% and 0.93%, respectively. This was because the SCG brewed using the Moka pot had a higher particle size than the SCG brewed using an espresso machine. A larger size indicates a larger surface area which allows greater interactions with the solvent molecules, which resulted in increased solubility (Hussain *et al*., 2019). The high solubility of SCG was associated with the fact that the SCG is water-soluble. Water-soluble components are suitable to be used as a source of burning. Bracero *et al*. (2019) mentioned that biomass with a water-soluble characteristic increases the burning period, thus providing strong evidence that biomass with high solubility is a source for burning. For that, SCG brewed using the Moka pot method is suitable to be used as a candle. The CIELAB colour system has a lightness channel (L^*) and colour channels (a^* and b^*). The chromatic a^* axis in the three-dimensional model runs from green ($-a^*$) to red ($+a^*$), whereas the chromatic b^* axis runs from blue ($-b^*$) to yellow ($+b^*$). L^* represents the lightness dimension, which spans from 0 (complete black) to 100 (complete white) L^* value shows the lightness of the SCG. The ΔE^* is a single number that accounts for the discrepancies between the sample and standard's L^*, a^*, and b^*. The ΔC^* represents the chroma difference between the sample and the standard in a polar coordinate system. For this work, four different types of samples were examined which were SCG from the Moka pot, SCG from espresso, unbrewed coffee grounds used for the espresso method and unbrewed coffee grounds used for the Moka pot method. Based on Figure 3 and Figure 4, the SCG brewed using the Moka pot had higher L^*, b^* together with ΔC^* compared to SCG brewed using the espresso machine. This indicates that Moka pot SCG had a lighter colour compared to espresso SCG. The value of ΔE^* for Moka pot SCG was smaller than the ones of the espresso machine indicating less colour changes happened between brewed and unbrewed coffee. In general, the colour of SCG brewed using the Moka pot is lighter than the SCG brewed using the espresso machine. This corresponds to the larger particle size of the SCG from the Moka pot method. This can also be seen in Figure 5 and Figure 6 which show the actual SCG brewed using espresso and moka pot method the unbrewed samples. According to the findings of Mendonça *et al*. (2009), the overall colour difference between coffee samples increases as the roasting degree of the coffee increases, and this difference is statistically significant.

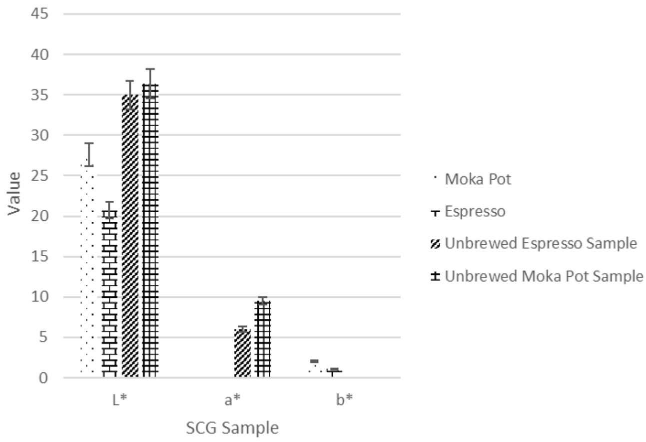

Figure 3. L^*, a^* and b^* values of spent coffee grounds with different brewing methods.

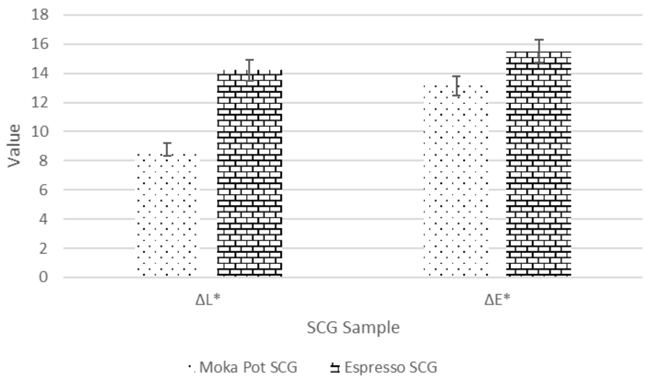

Figure 4. ΔL^* and ΔE^* values of spent coffee grounds with different brewing methods.

Table 2. Solubility of spent coffee grounds with different brewing methods.

Sample	Weight of SCG used (g)	Weight after dry (g)	Weight before dry (g)	Solubility (%)	Average solubility (%)	Standard deviation
Espresso	1.0056	47.965	47.967	0.80	0.93	0.1863
	1.0071	47.500	47.503	1.19		
	1.0065	47.780	47.782	0.79		
Moka Pot	1.0066	45.045	45.048	1.19	1.19	0.0030
	1.0054	53.370	53.373	1.19		
	1.0057	53.646	53.649	1.19		

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Figure 5. Spent coffee grounds sample brewed using the espresso method (A) and the Moka pot method (B).

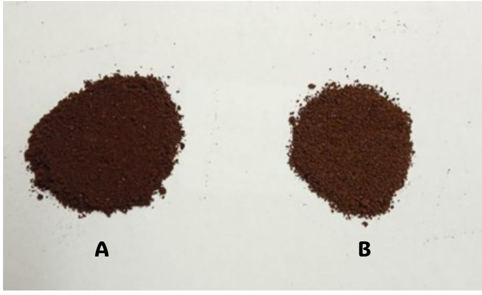

Figure 6. Unbrewed coffee grounds sample using the espresso method (A) and the Moka pot method (B).

3.3 Effects of different concentrations of spent coffee grounds on burning test analysis

The burning time was kept constant at 30 mins for each candle. Based on Table 3, ESS stands for espresso, MP for Moka pot, S for soy wax and P for paraffin wax. The rate of wax consumption between different types of SCG produced from different brewing methods shows that the highest wax consumption was observed in candles made from the espresso brewing method with the addition of paraffin wax of 12.1220 g/h (40% of the SCG total content). A 20% SCG concentration for each candle sample and 40% SCG concentration for the Moka pot with additional soy wax candles had similar rates of wax consumption which were below 3 g/h. The lowest rate of wax consumption was observed in the sample with a 30% SCG concentration candle produced from Moka pot brewing with the addition of soy wax of 1.7702 g/h.

The different amounts of wax consumption rates between different brewing methods of SCG could be due to several factors such as type of wax, melting point, and density. Soy wax and paraffin have different burning characteristics due to their different chemical compositions. The melted wax in a burning candle is simply known as the "melt pool." When the melted wax completely covers the candle's top layer, it forms a full melt pool. From Table 4, the overall pool size is bigger for candles with the addition of soy wax compared to candles with the addition of paraffin wax and the controlled candles made with 100% wax. As for candle samples made with 100% SCG, the rate of wax consumption cannot be determined since the candles failed to burn. Therefore, no pool was formed. This indicates that SCG candles made from 100% SCG were not suitable to be converted into candles. The diameter of the pool size measured is shown in Figure 7. The maximum pool size that can be achieved for each tealight container was 3.5 cm. Candles made with soy wax most probably reached the maximum pool size faster than candles made with paraffin wax, which most probably at 10 mins of burning. Soy wax candles reached the maximum pool size faster compared to paraffin wax candles reaching the maximum pool size in 20 mins of burning.

Over the course of a 30-minute burn, the diameter of the pools in each type of candle produced was measured. Compared to paraffin wax candles, soy wax candles produced broader liquid pools, as seen in Figure 7. These results were consistent with Rezaei *et al*. (2002). The wax's melting and solidification profiles are one of several factors that might affect the molten pool's size. Soy wax had lower melting start and peak temperatures than paraffin, which made the wax produce more liquid during candle burning. The size of the pool increases as the amount of liquid generated by burning increases.

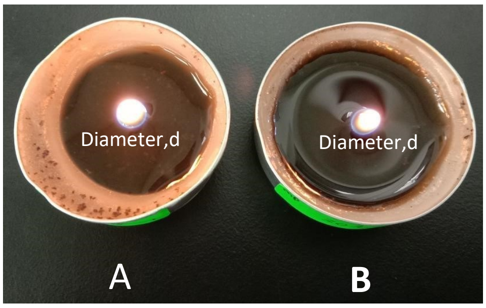

Figure 7. Candle made from SCG with the addition of paraffin wax (A) and soy wax (B).

A candle flame provides an example of the fundamental characteristics of a diffusion flame. In contrast to uncontrolled fire, it quickly establishes a steady state and includes the evaporation of liquid fuel from a porous surface. Very tall candle flames were typically a sign that the flame was excessively hot and could cause accidents. Small candle flames are typically caused by inadequate combustion, which results in a lower flame height. According to ASTM F2417 standard, the acceptable flame height is less than 3 cm. Based on Table 5, the flame height for the first 10 mins of the burning of candles shows that the flame height of different percentages of SCG concentrations was inconsistent due to amount of wax used in each type of candle. It can be concluded that, for every different percentage of SCG to wax ratio, candles made from soy wax were shorter in flame height compared to candles made from paraffin wax. After 20 mins of burning, for both 50% SCG concentration for espresso and Moka pot candles with the addition of paraffin wax, the candles become fire logs in which all the candle mixture was excessively burned and had a flame height of more than 3 cm as shown in Figure 8(A) while normal candle has

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Table 3. Rate of wax consumption between the different concentrations of spent coffee grounds.

Candle sample	Weight before (g)					Different weight of candle after 30 mins of burning time (g)					Rate of wax consumption (g/h)				
	100% of Wax					100% of Wax					100 % of Wax				
Paraffin	10.2705					2.9457					5.8914				
Soy Only	10.2233					1.6804					3.3608				
	Percentage of SCG (%)					Percentage of SCG (%)					Percentage of SCG (%)				
	20	30	40	50	100	20	30	40	50	100	20	30	40	50	100
ESS+S	10.3015	10.3015	10.3015	10.3015	-	1.1352	1.4056	4.9914	4.8962	-	2.2705	2.8112	9.9828	9.7923	-
ESS+P	10.4315	10.3732	10.4024	10.4024	-	1.3330	2.6117	6.0610	3.8042	-	2.6660	5.2234	12.1220	7.6083	-
MP+S	10.3447	10.5564	10.2639	10.5732	-	1.0446	0.8851	1.0134	4.5039	-	2.0893	1.7702	2.0267	9.0078	-
MP+P	10.5145	10.6754	10.6946	10.8991	-	1.0874	1.1203	2.9664	5.0402	-	2.1747	2.2406	5.9327	10.0803	-

Table 4. Pool diameter size of different brewing methods and percentage of spent coffee grounds.

Candle sample	Pool diameter Size (cm)														
	10 mins					20 mins					30 mins				
	Percentage of SCG (%)					Percentage of SCG (%)					Percentage of SCG (%)				
	20%	30%	40%	50%	100%	20%	30%	40%	50%	100%	20%	30%	40%	50%	100%
ESS+S	3	2.9	3.5	3.5	-	3.2	3.2	3.5	3.5	-	3.4	3.4	3.5	3.5	-
ESS+P	2.9	2.7	3.5	3.5	-	3	3.2	3.5	3.5	-	3.2	3.5	3.5	3.5	-
MP+S	3.1	2.7	2.8	3.5	-	3.4	3	3.1	3.5	-	3.5	3.2	3.4	3.5	-
MP+P	2.6	2.6	2.9	3.5	-	3.1	2.8	3.2	3.5	-	3.4	2.9	3.5	3.5	-
Paraffin Only	-	-	-	-	3	-	-	-	-	3.5	-	-	-	-	3.5
Soy wax Only	-	-	-	-	3.4	-	-	-	-	3.5	-	-	-	-	3.5

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Table 5. Flame height (cm) of different brewing methods and percentage of spent coffee grounds.

Candle sample	Flame height (cm)														
	10 mins					20 mins					30 mins				
	100% of wax					100% of wax					100% of wax				
Paraffin Only	2.8					3.4					3.7				
Soy Wax Only	1.3					1.5					1.7				
	Percentage of SCG (%)					Percentage of SCG (%)					Percentage of SCG (%)				
	20%	30%	40%	50%	100%	20%	30%	40%	50%	100%	20%	30%	40%	50%	100%
ESS+S	0.6	2.1	3.2	3.7	-	0.9	1.4	3.7	4.2	-	0.9	1.3	3.6	Turn into fire log	-
ESS+P	1.4	0.5	3.2	4.5	-	1.2	2.5	3.2	Turn into fire log	-	1.3	3.1	3.4	Turn into fire log	-
MP+S	0.4	0.5	0.5	4.3	-	0.3	0.6	0.8	4.5	-	0.4	0.5	0.9	2.8	-
MP+P	1.1	1	1.5	4.6	-	0.9	0.8	1.8	Turn into fire log	-	1.1	0.9	2.3	Turn into fire log	-
ESS Only	-	-	-	-	Not burn	-	-	-	-	Not burn	-	-	-	-	Not burn
MP Only	-	-	-	-	Not burn	-	-	-	-	Not burn	-	-	-	-	Not burn

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lower flame height with stable flame size as shown in Figure 7B. Candles with larger flame heights were not suitable for indoor use. After 30 mins of candles burning, the number of candles that turned into fire logs increased. SCG candles that turned into fire logs were not suitable to be used. Furthermore, candles that turned into fire logs were observed to happen on the 50% SCG to wax ratio only. This indicates that the maximum and suitable amount of SCG to the wax ratio that can be used to produce candles was 40%. A 50% ratio of SCG to wax is currently not suitable as the wax amount is not enough to properly bind the SCG together. As for candles made from 100% SCG for both SCG obtained from brewing using the espresso machine and the Moka pot, there was no flame produced at all as shown in Table 5.

4. Conclusion

In this study, scented candles were successfully produced using SCG from the espresso machine and Moka pot brewing methods. The physical and physicochemical properties influence the results of the burning test including the rate of wax consumption, pool size, and flame height. Candles with the addition of soy wax had a lower rate of wax consumption than the ones added with paraffin wax. As for the pool size, after 30 mins of combustion, candles with 30% Moka pot SCG concentration with the addition of paraffin wax had the smallest pool diameter size of 2.9 cm. This shows that SCG has good potential in candle production where it also aligns with upcycling practices, contributing to waste reduction and sustainable candles. It also exhibits unique textures and colours, providing a natural and aesthetically pleasing appearance. SCGs may retain the natural aroma of coffee, offering the potential to create coffee-scented candles without the need for artificial fragrance.

Conflict of interest

The authors declare no conflict of interest.

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