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Valorisation of Sarawak *Liberica coffee cascara* and spent grounds: GC-MS profiling and prototype development of tea and soap

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Abstract

Coffee processing generates substantial by-products such as cascara and spent coffee grounds, which remain underutilised despite their potential for value-added applications. This study aimed to evaluate the utilisation of Sarawak Liberica coffee by-products through the development of cascara tea and soap prototypes. Bioactive compounds in the ethanolic extract of cascara powder were identified using gas chromatography–mass spectrometry (GC-MS). Cascara powder was formulated into original and flavoured tea variants and evaluated using a 9-point hedonic scale. Soap prototypes incorporating cascara and spent coffee grounds were produced via the cold process method and assessed for total phenolic content (TPC), total flavonoid content (TFC), and antioxidant activity using standard colorimetric assays. The flavoured cascara tea demonstrated higher sensory acceptance across multiple attributes compared to the original formulation. GC-MS analysis identified 30 bioactive compounds, indicating functional potential. Both cascara-based soaps and spent coffee ground-based soaps exhibited TPC and TFC value with strong antioxidant activity, with optimal performance observed at higher incorporation levels. Collectively, these findings highlight the feasibility of transforming Sarawak Liberica coffee by-products into value-added functional food and cosmetic products, providing a sustainable approach to waste utilisation while expanding their industrial application potential.

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Antioxidant Activities, Coffee Cascara, Gas Chromatography-mass Spectroscopy (GC-MS), Total Flavonoid Content, Total Phenolic Content.

1. Introduction

Coffee is one of the most widely consumed beverages globally, second only to water, and represents a key agricultural commodity with substantial economic, social, and cultural importance (1). The coffee trade is dominated by *Coffea arabica L.* and *Coffea canephora Pierre* (Robusta), which collectively account for almost 99% of global production, while *Coffea liberica* contributes less than 1% (2). In Malaysia, however, the cultivation pattern diverges

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from global trends. Here, *C. liberica* is the dominant species, comprising nearly three-quarters of national production, largely due to its resilience and adaptability to Malaysia's lowland tropical climate (3,4). Sarawak has a long history of coffee cultivation dating back to the late 1800s, when Liberica coffee was introduced to replace Arabica because of its superior yield and tolerance to local environmental stressors (5). Today, Liberica remains central to the identity of Sarawak's coffee industry, yet it is relatively underexplored compared to Arabica and Robusta in both research and commercialization (6).

The coffee fruit is composed of multiple layers: outer skin, pulp, mucilage, parchment, and silverskin, surrounding the central bean (7). During processing, only the bean is typically retained for roasting, while the remaining material collectively termed coffee by-products or "cascara" is discarded. These by-products can represent up to 50–60% of the coffee cherry's mass (8). Large-scale disposal of cascara has been linked to environmental issues such as soil acidification, methane emissions, and water pollution due to its high organic and phenolic content (9,10). At the same time, cascara is increasingly recognized as a promising raw material, rich in bioactive compounds including polyphenols, flavonoids, anthocyanins, and chlorogenic acids, with reported antioxidant, antimicrobial, and metabolic regulatory activities (11–13).

The valorization of coffee by-products aligns with global sustainability goals and the circular bioeconomy approach, aiming to reduce agro-industrial waste while creating value-added products (14). Research has highlighted Cascara's potential in several industries. For instance, cascara tea, prepared from dried husks of coffee cherries, has emerged in specialty markets as a functional beverage with fruity, raisin-like flavour notes and high antioxidant activity (15,16). Other applications include cascara flour in baked goods, natural dyes, animal feed, and cosmetic prototypes such as exfoliating soaps and skincare formulations (17–19). However, most published studies focus on Arabica or Robusta cascara, with minimal attention given to Liberica, despite its dominance in Malaysia and unique biochemical profile.

Preliminary studies suggest that Sarawak Liberica cascara exhibits a distinctive composition, with high antioxidant capacity, significant total phenolic and flavonoid content, and lower caffeine levels compared to Arabica cascara (20,21). These properties may support the development of functional beverages, nutraceuticals, and personal care products tailored to consumer demand for natural, sustainable alternatives. Nevertheless, little is known about consumer acceptability of Liberica cascara products or their feasibility in sustainable product design.

Therefore, the present study investigates the potential of Sarawak Liberica cascara for product innovation and sustainability. Specifically, we developed cascara-based prototypes, including tea and soap while conducting phytochemical analyses and sensory evaluations to assess bioactivity and consumer acceptance. The findings provide new insights into the valorization of Liberica cascara, supporting both environmental sustainability and the economic resilience of Sarawak's coffee industry.

2. Materials and Methods

2.1 Materials

The Sarawak Liberica coffee cherries were collected from a local plantation area in Kampung Long Selapun, Ulu Tinjar, Baram, Sarawak, Malaysia. Spent coffee grounds were collected from a local coffee shop that uses Liberica coffee. All chemicals used were of analytical grade.

2.2 Methods

2.2.1. Sample Preparation

The structure and shape of Sarawak Liberica coffee cascara can be remained by proceeding to drying process after the depulp process. Sarawak Liberica coffee cascara was dried with moderate temperature in oven for 50 °C (122 °F) for 120 hours until completely dried to preserve the compound in Sarawak Liberica coffee pulp. Sarawak Liberica coffee cascara was grinded into solid powder compound.

2.2.2. Gas Chromatography-Mass Spectrometry (GC-MS) Analysis

Maceration was employed as the extraction method for Sarawak Liberica coffee cascara (22,23). The dried cascara was ground into powder form and extracted using 50% ethanol (solvent-to-sample ratio of 10:1, v/w) (10). The mixture was allowed to stand for 48 hours at room temperature with occasional stirring. After extraction, the solution was filtered, and the filtrate was diluted with 50% ethanol to obtain a concentration of 10 µL/mL for analysis. The analysis was performed using a Shimadzu GC–MS QP2010 Plus system (Shimadzu, Japan) equipped with a BPX-5 fused-silica capillary column (30 m × 0.25 mm i.d., 0.25 µm film thickness; Trajan Scientific and Medical, Australia). The injector and detector temperatures were maintained at 250 °C. Helium was used as the carrier gas at a constant flow rate of 1.0 mL/min. A 1 µL aliquot of the extract was injected in split mode (20:1).

The oven temperature program was set as follows: initial temperature of 40 °C (held for 1 min), increased to 220 °C at a rate of 5 °C/min, and maintained until the total run time of 37 minutes was completed. The interface temperature was set at 250 °C. The mass spectrometer operated in electron impact (EI) mode at 70 eV, scanning a mass range of 28–400 m/z. Chemical constituents were identified by comparing the obtained mass spectra with those available in the National Institute of Standards and Technology (NIST-17) mass spectral library. Compounds were determined based on similarity indices, molecular weights, and structural data.

2.2.3. Soap Prototype Formulation

Soap was prepared using the cold process method with modifications (24). Sodium hydroxide (NaOH) was dissolved in distilled water to prepare the lye solution, which was allowed to cool at room temperature. Palm oil was then added and blended with the lye to form soap batter, which was poured into moulds. The moulds were covered with cling film and insulated with a towel. The soaps were cured for 28 days before use. To develop prototype formulations, ground cascara and spent coffee grounds were incorporated at 2, 4, 6, and 8 g per 100 g of soap base. The soaps were dissolved in 50% ethanol at a concentration of 10 mg/mL for subsequent analyses.

2.2.4. Determination of Total Phenolic Content (TPC)

The total phenolic content of soap extracts was determined using the Folin–Ciocalteu method (25). Gallic acid (GA) served as the reference standard. A stock solution of GA (1 mg/mL) was prepared by dissolving 0.1 g in 100 mL of distilled water. Working standards at 0, 0.00625, 0.0125, 0.025, 0.05, and 0.1 mg/mL were prepared for the calibration curve. Soap extracts were prepared at 0.1 mg/mL. For analysis, 1 mL of each sample was mixed with 0.75 mL Folin Ciocalteu reagent and allowed to stand for 5 minutes at room temperature.

Subsequently, 0.75 mL of 6% sodium carbonate (Na_2CO_3) solution was added, and the mixture was incubated for 45 min. Absorbance was measured at 725 nm using a UV–visible spectrophotometer. All analyses were performed in triplicate. The calibration curve (R^2 = 0.9901) was used to calculate TPC, expressed as mg gallic acid equivalents per gram of sample (mg GAE/g).

2.2.5. Determination of Total Flavonoid Content (TFC)

The total flavonoid content of soap extracts was determined by the aluminium chloride ($AlCl_3$) colorimetric method (26). Quercetin served as the reference standard. A stock solution of quercetin (1 mg/mL) was prepared by dissolving 0.1 g in 100 mL of ethanol, and diluted to obtain concentrations of 0, 0.0625, 0.125, 0.25, 0.5, and 1 mg/mL for calibration. Soap extracts were prepared at 1 mg/mL. For each analysis, 0.125 mL of the sample or standard solution was mixed with 0.075 mL of 5% sodium nitrite ($NaNO_2$) solution and left for 6 min. Then, 0.150 mL of 10% $AlCl_3$ solution was added, followed by 0.750 mL of 1 M sodium hydroxide (NaOH) after 5 min. The mixtures were incubated for 15 min, during which a reddish-pink colour developed. Absorbance was measured at 510 nm using a UV–visible spectrophotometer. All measurements were carried out in triplicate. The calibration curve of quercetin (R^2 = 0.9968) was used to calculate TFC, expressed as mg quercetin equivalents per gram of sample (mg QE/g).

2.2.6. Antioxidant Activity (DPPH Assay)

Antioxidant activity of soap extracts was evaluated using the DPPH radical scavenging assay with modifications (27). A 0.1 mM DPPH solution was prepared by dissolving 39.4 mg of DPPH in 100 mL of methanol. The blank solution consisted of 1 mL DPPH solution mixed with 1 mL methanol. For analysis, 1 mL of each soap extract was mixed with 1 mL DPPH solution and incubated for 30 min at room temperature. Absorbance was measured at 517 nm using a UV–visible spectrophotometer. The percentage of inhibition was calculated as:

$$\text{Percentage of inhibition (\%)} = \left[1 - \left(\frac{\text{Abs}_{\text{Sample}}}{\text{Abs}_{\text{Control}}}\right)\right] \times 100 \quad (1)$$

Abs_{sample} is the absorbance of each triplicate samples with DPPH in methanol while $Abs_{control}$ is the absorbance of the DPPH with DPPH. Sample was further diluted to obtain the percentage inhibition at different concentration, and a linear graph was constructed to obtain the inhibition concentration at 50 % (IC_{50}).

2.2.7. Preparation for Cascara Tea Samples

Sarawak Liberica coffee cascara was processed following the procedure consisting of washing, depulping, grading, grinding, drying, dipping, and brewing (25). For product variation, a natural sweetener, commercially obtained dried stevia leaves was incorporated into the cascara tea as a flavour enhancer. Both the original and flavored cascara teas were packed into tea sachets and stored at −20 °C until analysis.

2.2.8. Sensory Evaluation

Sensory evaluation of cascara tea was conducted using a cupping protocol adapted for coffee beverages (28). Samples were prepared by infusing 30 g of cascara in 1000 mL of boiling water. Each sample was evaluated for fragrance, concentration, aftertaste, acidity, and sweetness using a 9-point hedonic scale, where higher scores represented greater intensity or preference (29,30). A minimum of 81 untrained panellists participated in the evaluation. This number was based on consumer acceptability study requirements, which recommend at least 81 panellists to detect a 10% difference between sample means at an acceptable standard error (31).

2.2.9. Data Collection and Analysis

Each panellist recorded their evaluation on standardized forms containing attribute definitions. The attributes and their descriptions are shown in Table 1. Data were expressed as mean scores and analysed using analysis of variance (ANOVA). Significant differences among treatments were further examined using appropriate post-hoc tests.

Table 1. Description of each attribute shown to panellists.

Attributes	Description
Fragrance	Evaluation on the smell through sniffing the sample.
Concentration	Overall impression given by the sample from the first slurp to its final aftertaste.
Aftertaste	The positive flavour and aroma remaining after the sample is swallowed.
Acidity	Sourness and fruitiness experienced during the first slurp of sample.
Sweetness	Overall taste of sweet or pleasing fullness of flavours.

3. Results and Discussion

3.1. GC-MS Analysis of Cascara Extract

Gas chromatography–mass spectrometry (GC-MS) identified 30 bioactive compounds in the ethanolic extract of Sarawak Liberica coffee cascara (Table 2), with major peaks corresponding to 3-hydroxydodecanoic acid (37.86%), 5-hydroxymethylfurfural (17.58%), and n-hexadecanoic acid (9.06%) (Table 3).

3-hydroxydodecanoic acid, a surfactant-like fatty acid, has applications in soap and cosmetic formulations due to its foaming and cleansing properties (32,33). 5-hydroxymethylfurfural, derived from sugar degradation during drying, contributes to antioxidant capacity and flavour enhancement (34,35). n-Hexadecanoic acid (palmitic acid), commonly found in palm oil, is a key soap-forming fatty acid with emulsifying and moisturizing properties, as well as anti-inflammatory potential (36,37). Polar compounds such as aldehydes, ketones, carbohydrates, and alkaloids exhibit relatively higher water solubility and are therefore more likely to migrate into the aqueous infusion during brewing, contributing to the chemical composition, flavour characteristics, and potential antioxidant properties of cascara tea.

In contrast, long-chain fatty acids and their derivatives with low water solubility and limited volatility will have a minimum transfer into the tea infusion. However, these lipid-soluble compounds may contribute to the overall phytochemical profile of cascara and support its potential utilization in lipid-based applications such as soap and personal care formulations. These findings highlight cascara's dual functionality as a beverage with bioactive health benefits and as a raw material for personal care applications.

Table 2. Bioactive compounds found in the ethanolic extract of Sarawak Liberica coffee cascara.

Classification	Compound name	Area (%)
Alkane	1-methyl-1-(1-methylethyl)-2-nonyl-cyclopropane	0.95
Alkene	1-Heptadecene	0.45
	1-Nonadecene	2.17
	1-Hexacosene	1.31
Carbohydrates	D-Allose	1.01
Carboxylic acid	3-hydroxydodecanoic acid	37.86
	4-oxo-pentanoic acid	0.85
	Tetradecanoic acid	0.62
	n-Hexadecanoic acid	9.06
Ketone	2-hydroxy-2-cyclopenten-1-one	2.13
	3-butyl-3-octen-2-one	1.04
Cyclic Amide	N-Hydroxymethyl-2-pyrrolidone	1.01
Pyranones	2,3-dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one	2.53
Aldehyde	5-Hydroxymethylfurfural	17.58
	Furfural	0.76
Orthoester	Ethyl orthoformate	1.13
Alcohol	2,3-Butanediol	0.46
	1,2,3-propane-triol monoacetate	1.11
Ether	1,1-diethoxyethane	1.11
Ester	Succinic acid, 3-methylbutyl pentyl ester	1.19
	methyl hexadecanoate	0.49
	ethyl docosanoate	1.61
	Ethyl Oleate	1.19
	methyl (Z)-6-Octadecenoate	0.48
Alkaloid	Caffeine	0.44
	Theobromine	1.03
Fatty Acid	10(E),12(Z)-Conjugated linoleic acid	2.35
	Oleic Acid	4.57
	Octadecanoic acid	2.17
Pyrimidine	2,4-diamino-6-methyl-5-nitropyrimidine	1.33

Table 3. Major compounds in the extracts of Sarawak Liberica coffee cascara.

No	Name	Retention Time	Molecular Formula	Molecular Weight	Peak area (%)
1	3-hydroxydodecanoic acid	21.047	$C_{12}H_{24}O_3$	216	37.86
2	5-hydroxymethylfurfural	15.203	$C_6H_6O_3$	126	17.58
3	n-Hexadecanoic acid	23.835	$C_{16}H_{32}O_2$	256	9.06

3.2. Soap Formulation and Appearance

After 28 days of curing, soaps formulated with cascara and spent coffee grounds formed solid brown bars with visible specks (Figures 1a-h). In contrast, the control soap (without additives) was pale cream in colour (Figure 1i). The darker coloration of supplemented soaps is attributed to natural pigments (e.g., anthocyanins, tannins) present in coffee by-products. This demonstrates the feasibility of incorporating cascara and spent coffee grounds into soap formulations without impairing physical stability.

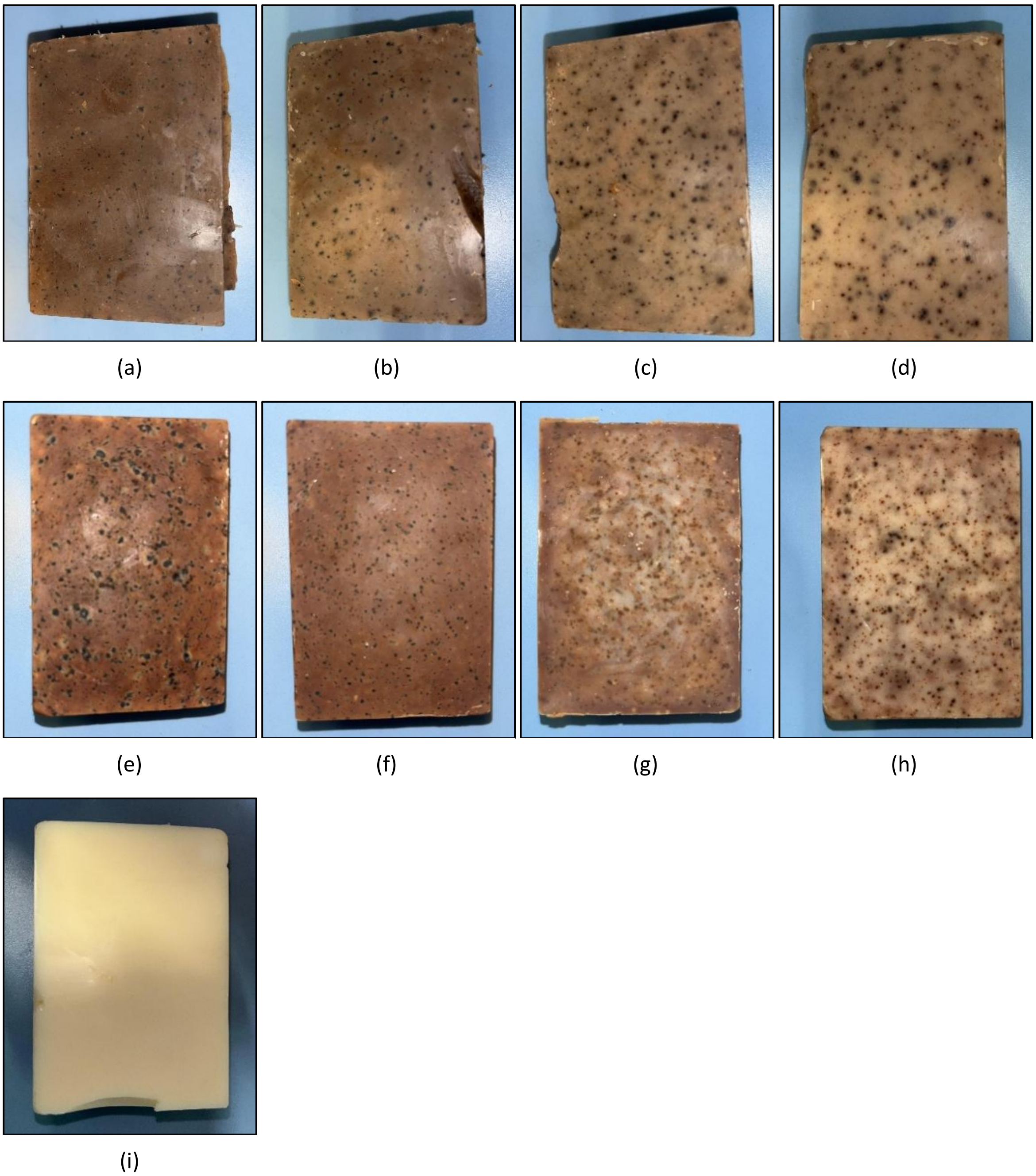

Figure 1. Soap formulated with a known weight of cascara powder per 100 g soap. (a) 2g; (b) 4g; (c) 6g; (d) 8 g. Soap formulated with known weight of spent coffee ground per 100 g soap. (e) 2g; (f) 4g; (g) 6g; (h) 8 g; (i) Soap formed using pure palm oil and lye solution as control.

3.3. Total Phenolic and Flavonoid Content

The incorporation of cascara and spent coffee grounds significantly increased total phenolic content (TPC) and total flavonoid content (TFC) of the soaps (Tables 4 and 5). Cascara addition at 8 g/100 g soap resulted in the highest TPC (214.77 ± 7.39 mg GAE/g) and TFC (27.67 ± 0.85 mg QE/g), while spent coffee grounds also enhanced these values, peaking at 233.40 ± 12.52 mg GAE/g (TPC) and 33.67 ± 0.40 mg QE/g (TFC) at 8 g addition. Components present in the soap matrix after saponification, such as compounds derived from palm oil, may contribute to this reducing capacity and react with the reagent (38). Therefore, the control value was used as a baseline for comparison with soaps containing coffee by-products.

Table **Error! No text of specified style in document.**. Total phenolic content of different weight of cascara and spent coffee ground added into the soap.

Weight	TPC (mg GAE/g)	
	Cascara	Spent coffee ground
0 g	165.87 ± 17.69[a]	161.63 ± 18.54[a]
2 g	191.47 ± 12.30[b]	168.83 ± 17.03[ab]
4 g	199.43 ± 15.99[b]	183.50 ± 16.56[ab]
6 g	204.47 ± 10.69[b]	193.63 ± 13.87[b]
8 g	214.77 ± 7.39[b]	233.40 ± 12.52[c]

Note: All data are expressed as mean ± standard deviation. ANOVA followed by Duncan post hoc test was used to compare the difference in the mean of TPC between different weight of dried cascara and spent coffee ground added at 0.05 significance level. The same alphabet within column indicates the variances do not differ significantly.

Table 5. Total flavonoid content of different weight of cascara and spent coffee ground added into the soap.

Weight	TFC (mg QE/g)	
	Cascara	Spent coffee ground
0 g	13.43 ± 0.87[a]	16.07 ± 0.67[a]
2 g	15.97 ± 0.61[b]	16.43 ± 0.21[a]
4 g	19.77 ± 0.21[c]	16.93 ± 0.06[a]
6 g	22.33 ± 0.50[d]	21.80 ± 1.11[b]
8 g	27.67 ± 0.85[e]	33.67 ± 0.40[c]

Note: All data are expressed as mean ± standard deviation. ANOVA followed by Duncan post hoc test was used to compare the difference in the mean of TFC between different weight of cascara and spent coffee ground added at 0.05 significance level. The same alphabet within column indicates the variances do not differ significantly.

This increase aligns with previous reports showing coffee by-products are rich in phenolics and flavonoids (39,40). These compounds contribute antioxidant, anti-inflammatory, and skin-protective properties, supporting cascara's suitability for cosmetic formulations (41).

3.4. Antioxidant Activity

Radical scavenging activity (RSA) assays demonstrated significant enhancement in antioxidant potential with increasing levels of cascara and spent coffee ground (Tables 6 and 7). Soap containing 8 g cascara achieved the highest RSA (70.89 ± 0.70%) with a low IC_{50} (1.19 mg/mL), indicating strong antioxidant activity. Spent coffee ground formulations also showed improved RSA, though with slightly lower potency compared to cascara. In the DPPH assay, a lower IC_{50} value indicates stronger antioxidant activity, as a smaller concentration is required to scavenge 50% of free radicals (42). Previous studies have reported IC_{50} values ranging from 463.36 to 90.34 µg/mL for solid soap containing *Eucheuma spinosum* extract, demonstrating measurable antioxidant activity in herbal soap formulations (43).

Table 6. Antioxidant activity of soap with cascara.

Weight of dried cascara added into the soap (g)	RSA (%)	IC_{50} (mg/mL)
0	32.38 ± 1.22^{a}	6.02 ± 0.15^{a}
2	42.38 ± 0.18^{b}	5.82 ± 0.02^{b}
4	51.04 ± 0.48^{c}	3.85 ± 0.01^{c}
6	60.39 ± 0.13^{d}	1.25 ± 0.01^{d}
8	70.89 ± 0.70^{e}	1.19 ± 0.01^{e}

Note: Data are expressed as mean ± standard deviation. One-way ANOVA followed by Tukey HSD post hoc test was used to compare mean RSA% and IC_{50} between different weights of dried cascara added to soap at a 0.05 significance level. Values sharing the same letter within a column indicate no significant difference.

Table 7. Antioxidant activity of soap with spent coffee ground.

Weight of dried spent coffee ground added into the soap (g)	RSA (%)	IC_{50} (mg/mL)
0	32.38 ± 1.22^{a}	6.02 ± 0.15^{a}
2	41.48 ± 0.40^{b}	7.60 ± 0.02^{b}
4	44.27 ± 0.68^{b}	7.42 ± 0.11^{c}
6	51.38 ± 1.88^{c}	3.54 ± 0.01^{d}
8	63.27 ± 0.71^{d}	2.94 ± 0.06^{e}

Note: Data are expressed as mean ± standard deviation. One-way ANOVA followed by Tukey HSD post hoc test was used to compare mean RSA% and IC_{50} between different weights of spent coffee ground added to soap at a 0.05 significance level. Values sharing the same letter within a column indicate no significant difference.

RSA values above 70% represent strong antioxidant activity, confirming the efficacy of cascara-enriched soaps (44,45). The results suggest cascara retains heat-stable antioxidant compounds, while spent coffee grounds may lose some during brewing. Similar trends have been reported in antioxidant-rich soaps formulated with cascara extracts (46). However, portion of antioxidant compounds can remain stable or be retained within complex matrices, allowing measurable antioxidant activity to persist even after processing conditions that may promote degradation (47,48). The incorporation of these coffee by-products aligns with circular economy principles by valorizing agricultural waste into functional skincare products with antioxidant and protective benefits (49,50).

3.5. Sensory Analysis

A total of 81 panelists participated in the sensory assessment of both original and flavored Sarawak Liberica coffee cascara tea. Table 8 presents the mean values of each attribute. The flavored cascara tea obtained higher scores in fragrance, concentration, aftertaste, and sweetness compared to the original version, while acidity values did not differ significantly. This indicates that panelists preferred the flavored version, particularly due to its enhanced fragrance, stronger concentration, smoother aftertaste, and sweeter profile.

The higher fragrance score suggests that the addition of natural sweetener complemented the fruity aroma of Liberica cascara, enhancing its aromatic appeal. The higher concentration and aftertaste scores demonstrate that flavour addition helped mask the bitterness typical of original cascara tea, providing a richer and more pleasant profile. Similarly, the increased sweetness score reflects consumer preference for sweet over tangy flavours, while the unchanged acidity score confirms that flavour addition did not alter the beverage's natural sourness.

Table 8. Attributes of sensory of Sarawak Liberica coffee cascara tea with different flavour.

Attribute	Original	Flavoured	T-Value
Fragrance	5.68 ± 2.06^a	6.33 ± 1.83^b	3.719
Concentration	5.83 ± 1.84^a	6.33 ± 1.63^b	3.017
Aftertaste	5.35 ± 1.86^a	6.17 ± 1.53^b	4.248
Acidity	5.73 ± 1.82^a	6.01 ± 1.66^a	1.731
Sweetness	5.10 ± 2.25^a	6.22 ± 1.64^b	4.504

Note: The data is presented as mean ± standard deviation for 81 panels. Different letter notation indicates a significant different for the degree of freedom of 80 at 0.05 level (1.990).

Both teas achieved mean scores above 5 on a 9-point scale across all attributes (Figure 2), indicating a moderate level of overall acceptability. Interestingly, 87.7% of the panelists had never tried cascara tea prior to this study, yet 79% recommended the flavored version, showing strong consumer acceptance potential. Comparable findings have been reported in cascara beverages from other coffee varieties, where flavour enhancement increased acceptability (51). Beyond sensory attributes, cascara tea is also valued for its antioxidant and anti-inflammatory properties due to the presence of phenolic compounds and caffeine(41,52,53). This supports its potential as a health-oriented functional beverage.

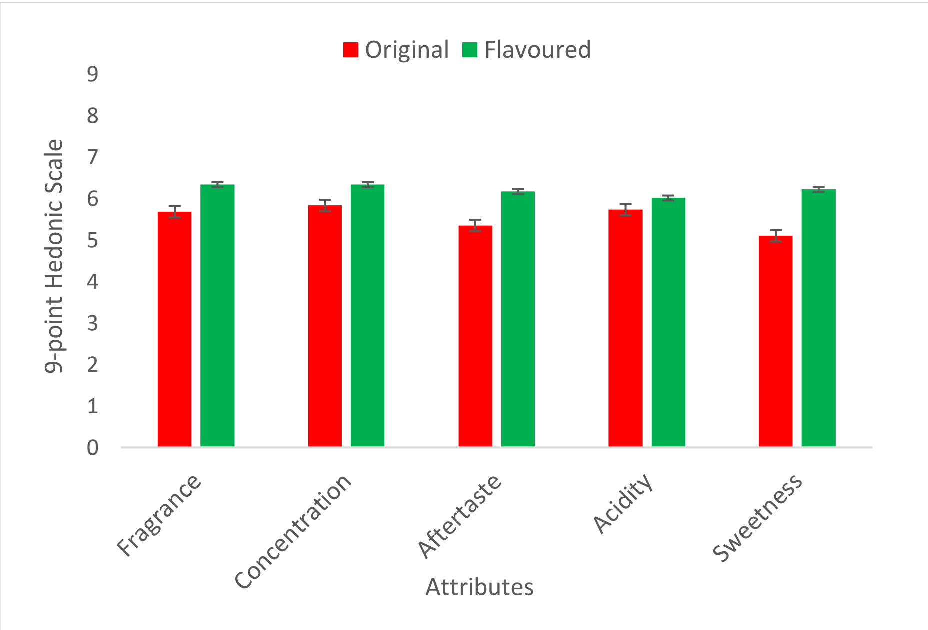

Figure 2. Histogram of comparison on the point given for each attribute between original and flavored version of cascara tea.

4. Conclusions

Cascara tea demonstrated multiple beneficial effects and a moderate level of consumer acceptability, with a higher preference observed for the flavoured cascara tea compared to the original variant. Gas Chromatography–Mass Spectrometry (GC–MS) analysis identified 30 chemical compounds, with three major constituents—3-hydroxydodecanoic acid, 5-hydroxymethylfurfural, and *n*-hexadecanoic acid—extracted using ethanol as the solvent. These bioactive compounds highlight the potential of cascara as a functional ingredient in sustainable product development, including soap and health beverages.

Soap formulated with the addition of 8 g of dried cascara exhibited the highest total phenolic content (TPC) and total flavonoid content (TFC), with values of 214.77 ± 7.39 mg GAE/g and 27.67 ± 0.85 mg QE/g, respectively, at a concentration of 10 mg soap/mL. This formulation also showed the greatest antioxidant activity, with a radical scavenging activity (RSA) of 63.27 ± 0.71% and an IC_{50} value of 2.94 ± 0.06 mg/mL. Similarly, soap formulated with 8 g of spent coffee grounds displayed the highest TPC and TFC values (233.40 ± 12.52 mg GAE/g and 33.67 ± 0.40 mg QE/g, respectively) and antioxidant activity (RSA = 70.89 ± 0.70%, IC_{50} = 1.19 ± 0.01 mg/mL).

The identification of bioactive compounds and the functional evaluation of the developed prototypes provide new insights into the utilisation of cascara in food and cosmetic applications. Overall, the chemical, functional, and sensory characteristics demonstrated in this study emphasize the potential of cascara to be transformed into high-value, sustainable products for both the food and cosmetic industries. However, GC–MS analysis was based on ethanolic extracts, and microbial safety and stability testing were not conducted. Future work should address these aspects to better reflect the compounds in brewed tea and ensure product safety for consumption and topical use.

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Author Contributions

E.N., T.M., W.B.S. and Y.P.P. conceptualized the study and provided project supervision; B.V.L.Q. carried out the experimental work, data analysis, and drafted the initial manuscript; B.V.L.Q., T.M., W.B.S., and Y.P.P. contributed to literature support and manuscript refinement. All authors reviewed and approved the final version of the manuscript.

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Institutional Review Board Statement

This study involved a low-risk sensory evaluation with human participants. In accordance with institutional guidelines, the Human Research Ethics Committee (Non-Medical) of Universiti Malaysia Sarawak (UNIMAS) reviewed and approved the study. All participants provided informed consent before participating. We request all research involving human subjects, freely-given, informed consent to participate in the study must be obtained from participants (or their parent or legal guardian in the case of children under 16). All participants in the sensory evaluation provided informed consent prior to participate and contribute the data for the study.

Data Availability Statement

The datasets generated during the current study, including the data of sensory evaluation responses collected via Google Forms and subsequently analyzed as part of the author's thesis work, are not publicly available but are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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