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Research Article

Comparison of Characterization of Cold Brew and Hot Brew Coffee Prepared at Various Roasting Degrees

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This investigation is aimed at elucidating the effects of roasting degree and extraction method on coffee beverages prepared with beans from Asia. According to the results with the improvement of the roasting degree, a decrease in titratable acidity, total phenolic compounds, the concentrations of chlorogenic acid and trigonelline, and total antioxidant capacity was observed. Cold coffee beverages showed higher total sugar and trigonelline. The volatile components, such as pyridine, furan-2-yl-methyl acetate, 2-furanemethanol, and 5-methylfurfural, were also affected by roasting degree and extraction methods. Cold brew coffee exhibited higher intensities of enzymatic flavor and sweetness. Furthermore, the principal component analysis revealed a distinct difference in coffee characterization in roasting degree in cold coffee brews than in hot ones. The results indicate that roasting degree affects physicochemical and sensory properties more than extraction temperature. Additionally, there were significant differences in coffee characteristics between cold and hot brew coffee.

1. Introduction

Coffee is one of the most widely consumed beverages in the world. Approximately 166.63 million bags (60 kilograms) of coffee were consumed globally in 2020/2021 (with a slight increment in 2019/2020) [1]. Because of the "third wave of specialty coffee," the coffee market demands a higher quality of coffee beverages. Specialty coffee is produced with high-grade coffee beans extracted from coffee plants grown under ideal conditions and climates. Furthermore, the light roasting is optimized to exhibit intrinsic flavors and high sensory quality [2].

Recently, the coffee market has undergone significant changes [3]. With the increasing demand for high-quality coffee, cold brew has become more popular. Market analysis reveals that, in 2017, the cold brew coffee market was worth $321 million and is estimated to rise by $1.37 billion by 2023 [1]. Normal cold brew coffee is generally obtained by extracting water at room temperature or lower, over an extended period of 8 to 24 hours [4]. The sensory attributes of cold brew coffee include medium bitterness and acidity with intense sweetness, chocolaty, fruity, and floral notes [5], whereas titratable acidity (TA) and total antioxidant capacity (TAC) are low. Cold drip coffees are another type of cold extraction method known for their higher levels of bitterness, caffeine, and chlorogenic compounds [5]. New technology, the vacuum cycle method, has recently been applied to cold brew coffee, which speeds up the extraction process. The yield and sensory profile of the final beverage can be influenced by adjusting the number of cycles and the pressure used in the vacuum pressure cycle method. Previous research has shown that low-pressure conditions are optimal for extracting phenols and that 2 and 7 vacuum cycles produce the most flavorful extracts. In the sample of 16 cycles, caffeine and TA were both significantly higher, while acidity as measured by sensory analysis was higher only in 2 cycles [6, 7]. However, normal cold brew coffee by soaking is more convenient and widely used than the decompression cycle extraction method because it does not necessitate any specialized equipment.

Despite the growing coffee market and increased cold coffee drink consumption, only a few studies have been addressed. Previous studies have shown that extraction conditions, such as particle size, powder/water ratio, and water temperature, affected the physicochemical and sensory properties of coffee drinks. Some studies suggest that the degree of grinding has no significant effect on caffeine and chlorogenic acid (CGA) in cold coffee brews; however, finely ground coffee has higher total dissolved solids (TDS), extraction yield (EY), total phenol compound (TPC), volatile components, and TAC contents [8–11]. It was also revealed that higher powder-to-water ratios were more bitter in sensory properties [12]. Several investigations proved that coffee extraction temperature and time had little effect on its physicochemical properties, such as in cold brew coffee, higher temperature not only raised the extraction components like caffeine, CGA, and melanoidins but also improved acidity and antioxidant activity [5, 10, 13, 14].

Roasting can extremely affect the quality of coffee brew [15]. Higher temperatures during roasting cause several chemical reactions which release various volatile compounds [16]. Therefore, coffee roasting conditions are also an important factor affecting cold brew coffee. Unfortunately, only a few studies describe the effect of roasting on cold brew coffee. Rao et al. measured physicochemical parameters (pH, TA, melanoidin, TDS, CGA, TAC, and caffeine) of cold brew coffee beverages at three roasting conditions (194°C, 203°C, and 209°C) [4]. Yu et al. analyzed the influence of three different roasting temperatures (235°C, 240°C, and 245°C) on the volatile components of cold brew coffee drinks [11]. The previous investigations usually included dark- or medium-roasted beans as research objects, whereas, in the third wave of specialty coffee, light-roasted (below 200°C) coffee is more in demand due to its unique flavor.

Furthermore, previously, the coffee beans selected for the study were usually from South America, such as Colombia or Brazil. The coffee beans from Asia have not been studied yet for their cold brew form; however, their market potential is huge. Therefore, this investigation was performed to evaluate the physicochemical including volatile components and sensory properties of coffee brew prepared with coffee beans from Asia, under different roasting degrees (light, medium, and dark).

2. Materials and Methods

2.1. Chemicals and Coffee Samples. Yuanye Biotechnology Co. Ltd. (Shanghai, China) provided the caffeine (99%), chlorogenic acids (99%), trigonelline (99%), and DPPH (1,1-diphenyl-2-picrylhydrazyl radical). 2-Octanol and ABTS (2,2′-azinobis-(3-ethylbenzothiazoline-6-sulphonate)) were acquired from Titan Technology Co., Ltd. (Shanghai, China), Folin phenol (2 M) from Sigma-Aldrich Chemical Co. Ltd. (Shanghai, China), and light-, medium-, and dark-roasted Arabica coffee beans from Yunnan (China) and Sumatra (Indonesia) from Yanbei Coffee Co. Ltd. (Shanghai, China). Light, medium, and dark roasts were achieved by setting the roaster's temperature to 195°C, 208°C, and 220°C for 12 minutes. The color parameters (*L* value) for light-, medium-, and dark-roasted coffee beans were 31 ± 1, 28 ± 1, and 24 ± 1, respectively.

2.2. Preparation of Coffee Brews. Roasted beans were ground in a coffee grinder (EK43s, Mahlkonig, Italy); then, the coffee powder was sieved to retain particles of size between 400 and 600 μm. Fifteen grams of ground coffee were extracted using deionized water (240 mL) at 92°C for 3 min in a brewer. For cold brew coffee, 15 grams of coffee grounds were left in 240 mL of deionized water at 5°C for 16 h. Coffee samples were filtered using filter paper.

2.3. Total Dissolved Solid (TDS) and Extraction Yield (EY). Pal-Coffee Handheld Digital Refractometer (Pal-Coffee, ATAGO, Japan) was used to measure the TDS (°Brix) in coffee brews [17]. The EY was analyzed based on the relationship between the TDS, total weight of extract obtained (W_b), and ground coffee weight used in the extraction (W_{gc}), calculated by the following equation [18]: $\text{EY}(\%) = (\text{TDS} \times W_b / W_{gc}) \times 100$.

2.4. Total Titratable Acidity (TTA), Total Sugars (TS), and Total Phenol Compound (TPC). The TTA of each coffee was determined by titration with 0.1 M NaOH to a pH of 6.5 [9]. The coffee brew TS concentration was analyzed via the 3,5-dinitrosalicylic acid method (DNS) [19], whereas coffee TPC was evaluated by Folin-Ciocalteu method based on Bilge's method [20]. For TPC, 0.5 mL of 0.25 M Folin-Ciocalteu reagent was combined with 0.5 mL of diluted coffee brews (1 : 50) and then left for 3 min of incubation before the addition of 1 mL of 15% Na_2CO_3. This mixture was centrifuged at 120 rpm and 25°C in the dark for 60 min. Lastly, with the help of a spectrophotometer (UV-1800, Shimadzu, Japan), the absorbance at 765 nm was measured. Quantification was performed in light of a calibration curve of gallic acid (μg/mL).

2.5. Antioxidant Capacity. The DPPH and ABTS scavenging capacity was determined for evaluating the antioxidant activities in the coffee brews. DPPH was determined via the Bilge method [20] and ABTS via the method given by Gorecki and Hallmann [21]. The absorbance values were calibrated with Trolox solution (10–100 μmol/L), and the data were expressed as mmol/L Trolox.

2.6. Caffeine, Trigonelline, and Chlorogenic Acid (CGA). Caffeine, trigonelline, and CGA (including 3-O-Caffeoylquinic acid, 4-O-Caffeoylquinic acid, and 5-O-Caffeoylquinic acid) components of coffee brews were measured by following the method of Córdoba et al. [22] with minor modifications. Quantitative analyses were performed using an LC-20A HPLC (Shimadzu, Japan) with a photodiode array detector (PDA). The caffeine separation was achieved by a WondaSil™ C-18 column (150 mm × 4.6 mm × 5 μm, Shimadzu, Japan) at 30°C. The methanol and water ratio of 24 : 76 (*v*/*v*) was selected as the mobile phase. The trigonelline was separated by a WondaCract ODS-2 column (150 mm × 4.6 mm × 5 μm, Shimadzu, Japan) at 30°C, with mobile phase = methanol and water (ratio = 12 : 88 (*v*/*v*)).

The separation of CGA was achieved in a WondaCract ODS-2 column (150 mm × 4.6 mm × 5 μm, Shimadzu, Japan) at 30°C, mobile phase = acetonitrile and 1%acetic acid (ratio = 15 : 85 (v/v)). The flow rate of the mobile phase was set at 1.0 mL/min, and the injection volume was 10.0 μL. Trigonelline and CGA were determined at 260 nm, and caffeine was determined at 272 nm. The concentrations of caffeine, trigonelline, and CGA were qualified based on a regression equation of their concentrations as HPLC standard references.

2.7. Volatile Compounds. Volatile compounds in the coffee beverage after brewing were quantified by optimizing Sun et al. method [23]. Gas chromatography/mass spectrometry (GC-MS) and headspace solid-phase microextraction (HS-SPME) were used for analyzing these volatile compounds. The volatiles of vials in the headspace were extracted via a divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) SPME fiber of 50/30 μm film thickness with the manual SPME holder (Supelco, USA). A 4 mL of sample was added to the GC vial. The internal standard 2-octanol was added. The sample was equilibrated in a water bath at 60°C for 15 minutes and absorbed for 30 minutes, followed by 2 min desorption in the GC injector at 200°C in splitless mode. After desorption, the compounds were further separated by GC-MS. A gas chromatograph coupled with a mass spectrometer (Shimadzu, TQ-80, Japan) was equipped with a capillary RTX-WAX column (Shimadzu, 30 m × 0.25 mm × 0.25 μm film thickness, Japan). The column oven was programmed to increase the temperature from 40 (after 2 min) to 130 at a rate of 2/min, then increase to 220 at a rate of 4/min, and finally, increase to 250°C at 10°C/min; final temperature was maintained for 5 min. Helium was selected as a carrier gas and incorporated at a 1.6 mL/min flow rate, and energy voltage was kept at 70 eV. The peak area ratio of each compound was calculated based on the peak area of the internal standard.

2.8. Sensory Evaluation. The sensory evaluation was conducted by 6 experienced SCA members in the sensory analysis room following the methodology proposed by the Association of Special Coffees (SCA). Two sessions (2 hours each) were performed to familiarize the panel with the sensory vocabulary selected, its definitions, and intensities (WorldCoffee Research, 2017). All samples were presented in random order and served at $20 \pm 3 \circ C$ in clear glasses. A trained member was asked to sip each sample and rate the odor intensity perceived retronasally. Then, a second sip was allowed to rate the taste and mouthfeel attributes. A list of specific descriptors and constants was chosen and used in the sensory analysis (Table 1). Flavor attributes included enzymatic flavor (flowery, fruity, and herby), sugar browning flavor (nutty, caramelly, and chocolatey), dry distillation flavor (carbon, spicy, and resinous), astringency, acidity, sweetness, bitterness, body, aftertaste, and overall intensity. The intensity of the attributes was determined using a 0- to 15-point scale with 0.5 increments (0 = none; 15 = extremely intense) [24].

2.9. Statistical Analysis. SPSS 23.0 software was applied to analyze the data statically. The variance was analyzed using Duncan's multiple range test. Significant difference levels were judged at 0.05. GraphPad Prism 9.0 was used for constructing column graphs. PCA was performed via SIMCA 14 software. All data are expressed as the average value of standard deviations. All experiments were performed in triplicates.

3. Result and Discussion

3.1. Physicochemical Characteristics. Table 2 shows the physicochemical characteristics of coffee beverages. There was no significant difference observed between the coffee brewed with Sumatra and Yunnan beans, and it is suggested unless otherwise stated that these results applied to all the coffee drinks brewed with Sumatra and Yunnan beans. The value of EY and TDS showed a significant ($p < 0.05$) increase, regardless of the cold or hot brewing, with light roasting to dark roasting. The EY in the cold brews was higher than that in the hot brew counterparts ($p < 0.05$). This finding is consistent with previous studies where the TDS values were raised with an increased roasting degree regardless of the brew methods, and the TDS values of hot brew coffees were higher than that of cold brew coffees at the same roasting degree [4]. Córdoba et al. reported no significant differences in TDS between hot brew and cold brew coffee [22]. TDS and EY exhibited linear correlation, having similar behavior as a function of roasting degree [25]. During roasting, the porosity of the bean and the structure of its cell walls also changed, making the extraction process easier. This could explain why TDS and EY increased with a roasting degree. The extraction of certain compounds was less efficient in cold water due to the solubility affected by temperature.

Conversely, TA, TS, TPC, and TAC (ABTS and DPPH) significantly ($p < 0.05$) reduced with the increase of roasting degree. Cold brew coffees present a greater ($p < 0.05$) concentration of TS, while a lower concentration of TA, TPC, and TAC (DPPH and ABTS) compared with hot brew coffee beverages; this data is consistent with the findings of Rao et al., who reported that the cold brews exhibited a significantly higher TA and TAC. A recent study by Turan Ayseli et al. revealed that coffee beverages brewed with medium-roasted beans displayed a higher TAC compared to coffee drinking brewed with dark-roasted beans [4, 16]. Many chemical reactions occur in coffee beans during the process of roasting such as components with poor thermal stability and coffee matrix being degraded and new substances forming.

The Maillard reaction is important in the roasting process of coffee beans. Sugar is consumed as a substrate in this reaction, explaining why the TS levels decreased as the degree of roast increased [15]. The thermal stability of phenolic substances, which act as one of the main antioxidant components, is relatively poor, and high-temperature roasting accelerates the decomposition of phenolic substances [26]. TA reflects the content of acidic substances in coffee, mainly organic acids such as formic, acetic, glycolic, and lactic; chlorogenic acid also contributes slightly [3]. It is

Table 1: List of specific attributes and definitions used in the sensory analysis of brewed coffee.

Specific attributes	Definition	Reference
Enzymatic flavor (flowery, fruity)	A sweet, floral, aromatic blend of a variety of ripe fruits. A sweet, light, slightly fragrant aromatic associated with fresh flowers. An aromatic characteristic of fresh, plant-based material. Attributes may include leafy, unripe, grassy, and peapod.	Juice kiwi strawberry (100%). Strawberry coffee flavor map ref. #015 Rose coffee flavor map ref. #067 Fresh parsley in water
Sugar browning flavor (nutty, caramelly, and chocolatey)	A slightly sweet, brown, woody, oily, musty, astringent, and bitter aromatic commonly associated with nuts, seeds, beans, and grains. A round, full-bodied, medium brown, sweet aromatic associated with cooked sugars and other carbohydrates. A blend of cocoa, including cocoa butter and dark roast aromatics at varying intensities.	Hazelnut coffee flavor map ref. #040. Puree the almonds and walnuts separately Caramel coffee flavor map ref. #051 Dark chocolate coffee flavor map ref. #056. Chop dark chocolate
Distillation flavor (carbon, spicy, and resinous)	The somewhat sharp, acrid notes associated with a dark brown impression of an overcooked, almost scorched product.	One drop of liquid smoke on a cotton ball in a large snifter
Astringency	A drying, puckering, or tingling sensation, on the surface and/or edge of the tongue and mouth.	0.05% alum solution
Acidity	The fundamental taste factor associated with a citric acid solution.	0.015–0.05% citric solution
Sweetness	A fundamental taste factor of which sucrose is typical.	1.0% sucrose solution
Bitterness	The fundamental taste factor associated with a caffeine solution.	0.01–0.04-0.05% caffeine solution
Body	Tactile feeling of the liquid in the mouth, especially as perceived between the tongue and roof of the mouth.	Samples of hot and cold brew coffee
Aftertaste	Length of positive flavor qualities emanating from the back of the palate and remaining after the coffee is expectorated or swallowed.	Samples of hot coffee and cold brew coffee
Balance	How all the various aspects of flavor, aftertaste, acidity, and body of the sample work together and complement or contrast to each other.	Samples of hot coffee and cold brew coffee
Overall	The maximum overall sensory impression. It reflects the holistically integrated rating of the sample as perceived by the individual panelist.	Samples of hot and cold brew coffee

(World Coffee Research, [24]).

suggested that less acidic molecule degradation is associated with light roasting, where acidic molecules remain in the final coffee cup. High water temperature facilitates the extraction of poorly soluble and polar substances [27], further supporting the higher TA, TAC, and TPC concentrations in hot brewed coffee. TS behavior was interesting, as cold brew had higher content than hot brew, possibly because longer cold extraction time is beneficial for the sugar extraction process.

3.2. Nonvolatile Compositions. The concentrations of CGA and trigonelline displayed a significant ($p < 0.05$) decrease trend (Figure 1), while the caffeine levels remained constant with an increasing degree of roasting. Regarding the brewing method, cold brewing coffee had trigonelline in significantly higher levels with a light roasting degree compared to its hot brew counterparts. These findings are in line with prior studies, demonstrating a higher concentration of CGA in medium-roasted than dark-roasted coffee brews while caffeine levels had no significant difference [16]. A recent study showed that chlorogenic acid was sensitive to the roasting process and caffeine concentrations fluctuated with an increase in the degree of roasting [28]. However, light-roasted coffee has not been addressed based on the roasting temperature in previous studies.

Trigonelline values also had no difference in both hot or cold brew coffees [22]. CGA is an important precursor of many flavor components, and it breaks down and produces new substances such as caffeic acid and quinic acid as the roasting process progresses [29]. Trigonelline also decomposed into pyrroles during this process [30].

It is known that the intragranular pore diffusion processes limit the CGA with excellent solubility in water, which favors its extraction at not only high temperatures but also low temperatures. The longer brewing times lead to complete caffeine extraction, allowing time for completing the rate-limiting mass transfer step during the extraction process [8]. These effects could also explain why the caffeine and CGA levels have no significant difference in hot and cold brews.

3.3. Sensory Properties of the Coffee Brew Sample. As shown in Table 3, regardless of brew method, the intensities of sugar browning flavor, dry distillation flavor, astringency, and bitterness of coffee beverages increased significantly, whereas the intensities of enzymatic, acidity, balance, overall, and sweetness decreased with increasing degree of roasting. The intensity of the body showed higher concentrations in medium roast coffee drinks. The aftertaste in medium and dark roasts was more intense than in light ones. These

Table 2: Physicochemical index of coffee beverages by cold and hot brewing with beans of different roasting degrees.

Beans origins	Brewing	Roasting	TDS (%)	EY (%)	Titratable acidity (mL of 0.1 M NaOH)	Total sugar (mg/mL)	Total phenolic compounds (mg/mL)	DPPH (mmol Trolox/L)	ABTS (mmol Trolox/L)
Sumatra	Cold	Light	1.20 ± 0.01^{a}	18.40 ± 0.13^{a}	15.51 ± 0.18^{c}	5.66 ± 0.23^{b}	0.83 ± 0.03^{b}	6.75 ± 0.12^{c}	2.14 ± 0.07^{c}
		Medium	1.26 ± 0.02^{b}	18.90 ± 0.09^{b}	14.53 ± 0.15^{b}	5.32 ± 0.10^{b}	0.68 ± 0.08^{a}	6.01 ± 0.11^{b}	1.74 ± 0.09^{b}
		Dark	1.31 ± 0.02^{c}	19.39 ± 0.11^{c}	12.96 ± 0.19^{a}	4.85 ± 0.19^{a}	0.58 ± 0.02^{a}	4.03 ± 0.13^{a}	1.44 ± 0.08^{a}
	Hot	Light	1.17 ± 0.01^{a}	$18.04 \pm 0.14^{a*}$	$17.09 \pm 0.17^{c*}$	$5.21 \pm 0.15^{c*}$	$0.95 \pm 0.05^{c*}$	$7.61 \pm 0.17^{c*}$	$2.25 \pm 0.05^{c*}$
		Medium	1.22 ± 0.02^{b}	$18.37 \pm 0.16^{b*}$	$16.34 \pm 0.16^{b*}$	$4.83 \pm 0.22^{b*}$	$0.80 \pm 0.03^{b*}$	$6.89 \pm 0.12^{b*}$	$2.03 \pm 0.07^{b*}$
		Dark	1.28 ± 0.01^{c}	19.25 ± 0.10^{c}	$15.69 \pm 0.07^{a*}$	$4.49 \pm 0.16^{a*}$	0.67 ± 0.03^{a}	$5.54 \pm 0.14^{a*}$	$1.62 \pm 0.07^{a*}$
Yunnan	Cold	Light	1.24 ± 0.02^{a}	19.01 ± 0.11^{a}	16.28 ± 0.23^{c}	4.61 ± 0.23^{b}	0.75 ± 0.03^{b}	6.41 ± 0.15^{c}	1.93 ± 0.03^{c}
		Medium	1.30 ± 0.05^{ab}	19.50 ± 0.17^{b}	15.19 ± 0.12^{b}	4.28 ± 0.09^{ab}	0.66 ± 0.02^{b}	5.66 ± 0.12^{b}	1.57 ± 0.06^{b}
		Dark	1.34 ± 0.01^{b}	19.98 ± 0.08^{c}	14.07 ± 0.18^{a}	3.96 ± 0.14^{a}	0.51 ± 0.03^{a}	3.13 ± 0.23^{a}	1.08 ± 0.05^{a}
	Hot	Light	1.18 ± 0.04^{a}	$18.25 \pm 0.12^{a*}$	$18.52 \pm 0.24^{c*}$	$4.05 \pm 0.11^{b*}$	$0.86 \pm 0.02^{b*}$	$7.22 \pm 0.12^{c*}$	$2.23 \pm 0.08^{c*}$
		Medium	1.23 ± 0.02^{ab}	$18.84 \pm 0.13^{b*}$	$17.26 \pm 0.17^{b*}$	$3.77 \pm 0.14^{b*}$	$0.81 \pm 0.04^{b*}$	$6.45 \pm 0.12^{b*}$	$1.88 \pm 0.06^{b*}$
		Dark	1.29 ± 0.01^{b}	$19.41 \pm 0.22^{c*}$	$15.93 \pm 0.33^{a*}$	$3.43 \pm 0.17^{a*}$	0.58 ± 0.07^{a}	$5.33 \pm 0.21^{a*}$	$1.32 \pm 0.11^{a*}$

Values are expressed as mean ± standard deviation. The superscript letters (a, b, and c) represent statistically significant differences ($p < 0.05$) between roasting degrees for the same brewing method, as determined by a one-way ANOVA. * indicates significant differences ($p < 0.05$) based on a one-way ANOVA analysis between cold and hot brewing methods for the same degree of roasting.

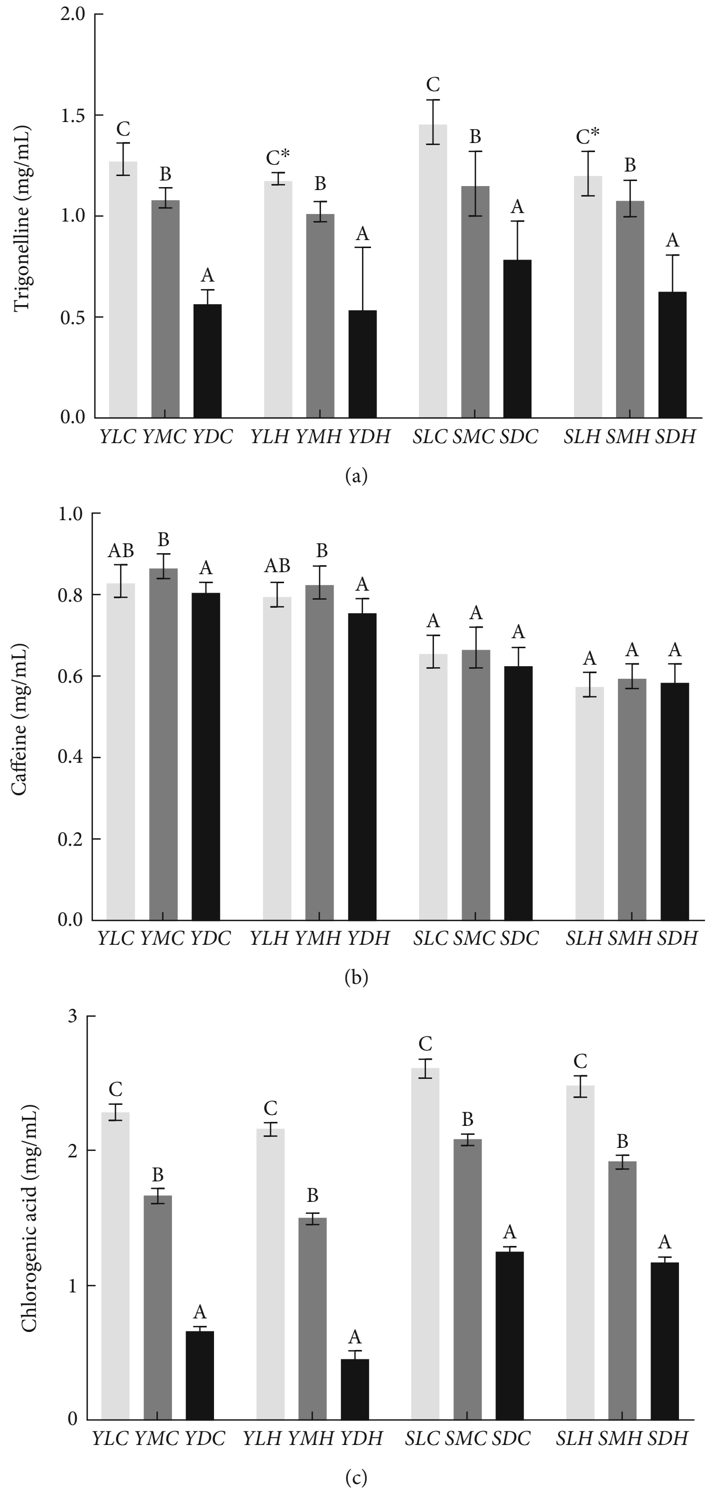


Figure 1: The total concentration of trigonelline (a), caffeine (b), and CGA (c) of cold and hot brew coffee as a function of the degree of roast. The superscript letters (A, B, and C) represent statistically significant differences ($p < 0.05$) between roasting degrees for the same brewing method, as determined by a one-way ANOVA. * indicates significant differences ($p < 0.05$) based on a one-way ANOVA analysis between cold and hot brewing methods for the same degree of roasting.

results are corroborated by Turan Ayseli et al., who found that the medium-roasted coffee brews (Arabica coffee beans, Brazilian originating) had better positive sensory characteristics [16].

Regardless of the roasting degree, enzymatic flavor, sweetness, and overall showed a significant intensity in cold brew coffee than in hot ones. Sugar browning flavor, dry distillation flavor, astringency, and bitterness were perceived as

Table 3: Comparisons in the mean intensity ratings for sensory attributes.

Beans origins	Brewing	Roasting	Enzymatic	Flavor Sugar browning	Dry distillation	Astringency	Acidity	Sweetness	Bitterness	Body	Aftertaste	Balance	Overall
Sumatra	Cold	Light	7.62 ± 1.19^{c}	7.01 ± 0.83^{a}	3.50 ± 0.71^{a}	2.13 ± 1.10^{a}	7.88 ± 1.35^{b}	7.38 ± 0.51^{c}	3.26 ± 0.71^{a}	6.12 ± 0.51^{a}	6.63 ± 0.51^{a}	10.88 ± 0.38^{b}	12.12 ± 0.51^{b}
		Medium	5.88 ± 0.80^{b}	8.00 ± 0.83^{b}	4.62 ± 1.1^{a}	3.38 ± 0.72^{b}	7.20 ± 1.02^{b}	6.26 ± 0.36^{b}	4.01 ± 0.36^{a}	6.87 ± 0.51^{b}	7.62 ± 0.29^{b}	10.62 ± 0.51^{b}	11.25 ± 0.75^{ab}
		Dark	4.13 ± 0.57^{a}	8.75 ± 0.36^{b}	6.26 ± 1.04^{b}	5.00 ± 0.56^{c}	4.76 ± 0.93^{a}	5.51 ± 0.56^{a}	5.51 ± 0.56^{b}	6.50 ± 0.56^{ab}	7.62 ± 0.68^{b}	10.01 ± 0.36^{a}	10.62 ± 0.68^{a}
	Hot	Light	$6.26 \pm 0.36^{c*}$	$8.63 \pm 0.84^{a*}$	$5.37 \pm 0.68^{a*}$	3.12 ± 0.51^{a}	9.12 ± 1.26^{b}	6.75 ± 1.07^{b}	$5.88 \pm 1.10^{a*}$	$7.50 \pm 0.44^{a*}$	$8.63 \pm 0.38^{a*}$	$10.01 \pm 0.56^{*}$	10.62 ± 0.51
		Medium	5.25 ± 0.62^{b}	$9.75 \pm 0.75^{b*}$	$6.87 \pm 0.68^{b*}$	4.38 ± 0.80^{b}	7.88 ± 0.95^{ab}	5.63 ± 1.13^{ab}	$7.01 \pm 0.83^{ab*}$	$8.51 \pm 0.56^{b*}$	$9.63 \pm 0.29^{b*}$	10.13 ± 1.13	10.50 ± 0.75
		Dark	3.87 ± 0.92^{a}	$10.25 \pm 0.83^{b*}$	7.01 ± 1.49^{b}	5.63 ± 0.57^{c}	$6.87 \pm 1.10^{a*}$	5.25 ± 0.62^{a}	$8.00 \pm 0.71^{b*}$	$7.62 \pm 0.51^{a*}$	$9.75 \pm 0.62^{b*}$	$9.38 \pm 0.38^{*}$	10.01 ± 0.71
Yunnan	Cold	Light	5.13 ± 0.80^{b}	7.25 ± 0.71^{a}	4.50 ± 0.75^{a}	3.38 ± 0.84^{a}	6.38 ± 0.72^{c}	$8.51 \pm 0.56^{c*}$	3.87 ± 0.68^{a}	5.63 ± 0.38^{a}	6.50 ± 0.83^{a}	9.50 ± 0.83^{b}	10.50 ± 1.44^{b}
		Medium	4.38 ± 0.68^{b}	9.00 ± 0.75^{b}	6.26 ± 0.93^{b}	4.88 ± 0.38^{b}	4.88 ± 0.38^{b}	6.26 ± 0.71^{b}	5.37 ± 0.92^{b}	6.26 ± 0.36^{ab}	7.38 ± 0.51^{b}	8.75 ± 0.71^{b}	9.50 ± 0.83^{b}
		Dark	1.76 ± 0.93^{a}	9.87 ± 0.51^{b}	8.51 ± 1.28^{c}	7.76 ± 1.28^{c}	3.26 ± 0.36^{a}	4.01 ± 0.56^{a}	7.38 ± 0.80^{c}	6.63 ± 0.80^{b}	7.76 ± 1.35^{b}	6.63 ± 1.19^{a}	7.88 ± 1.20^{a}
	Hot	Light	6.12 ± 0.80^{c}	$9.00 \pm 0.98^{b*}$	$5.75 \pm 0.71^{a*}$	4.40 ± 0.83^{a}	$8.75 \pm 0.71^{c*}$	$6.87 \pm 0.68^{c*}$	$6.50 \pm 0.83^{a*}$	$7.25 \pm 0.71^{a*}$	$8.13 \pm 0.68^{a*}$	10.13 ± 0.57^{a}	10.25 ± 0.71^{a}
		Medium	4.13 ± 1.20^{b}	10.01 ± 1.35^{ab}	$7.76 \pm 0.71^{b*}$	$6.12 \pm 0.51^{b*}$	$7.25 \pm 0.71^{b*}$	5.63 ± 0.84^{b}	$8.13 \pm 0.68^{b*}$	$8.88 \pm 0.29^{a*}$	$9.12 \pm 0.51^{ab*}$	9.12 ± 0.68^{b}	9.63 ± 0.51^{b}
		Dark	1.76 ± 1.04^{a}	$11.37 \pm 0.80^{a*}$	$10.13 \pm 0.72^{c*}$	8.13 ± 0.68^{c}	$5.37 \pm 1.10^{a*}$	4.01 ± 0.83^{a}	$9.26 \pm 0.93^{c*}$	$7.88 \pm 0.57^{b*}$	8.75 ± 0.83^{b}	7.38 ± 0.51^{c}	8.00 ± 0.56^{b}

Values are expressed as mean ± standard deviation, corresponding to the evaluation given by 8 evaluators for each coffee sample evaluated in duplicate. The superscript letters (a, b, and c) represent statistically significant differences ($p < 0.05$) between roasting degrees for the same brewing method, as determined by a one-way ANOVA. * indicates significant differences ($p < 0.05$) based on a one-way ANOVA analysis between cold and hot brewing methods for the same degree of roasting.

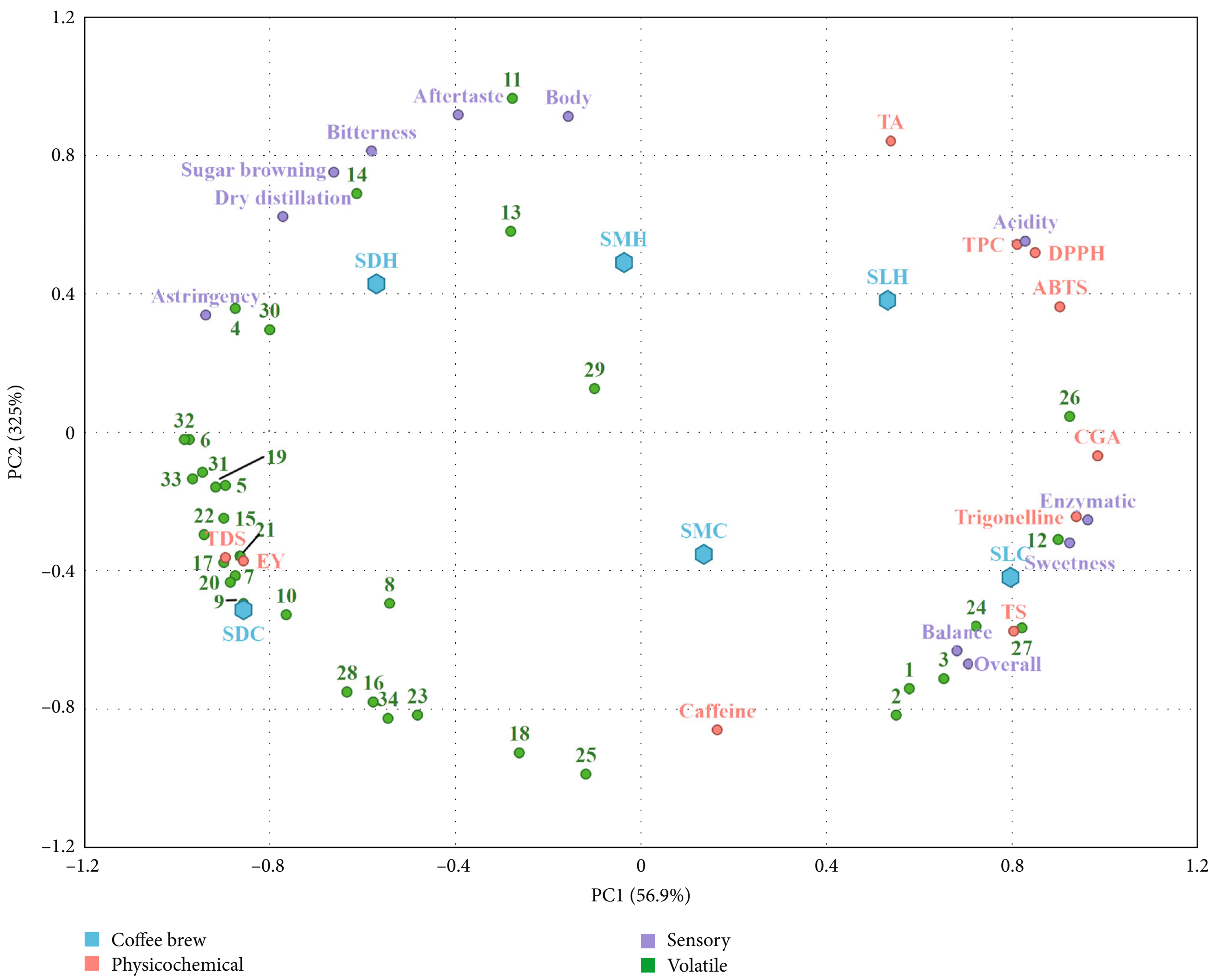
Table 4: Volatile compounds in coffee beverages prepared with cold and hot brewing at different roasting degrees (μg/L).

Compound	Odor description	Sumatra						Yunnan					
		Light roasting	Cold brew Medium roasting	Dark roasting	Light roasting	Hot brew Medium roasting	Dark roasting	Light roasting	Cold brew Medium roasting	Dark roasting	Light roasting	Hot brew Medium roasting	Dark roasting
Furans													
2-Acetylfuran	Sweet, amaretto, cocoa	29.63 ± 1.13^{a}	50.16 ± 1.06^{b}	86.83 ± 3.52^{c}	43.13 ± 3.06^{a*}	59.37 ± 1.60*	76.16 ± 0.85^{c*}	19.58 ± 1.67^{a}	40.26 ± 1.31^{ab}	42.86 ± 2.27^{b}	17.92 ± 1.03^{a}	35.75 ± 0.43^{b}	46.62 ± 0.94^{b}
2,2-Methylenebisfuran	Roasted	9.16 ± 0.26^{a}	10.51 ± 0.73^{a}	30.75 ± 1.52^{b}	5.16 ± 0.09^{a*}	12.18 ± 0.43^{b}	20.65 ± 2.65^{c*}	5.19 ± 0.17^{a}	8.37 ± 0.52^{a}	28.18 ± 0.36^{b}	4.92 ± 1.55^{a}	9.62 ± 0.86^{a}	31.16 ± 1.15^{b}
Difurfuryl ether	Nutty, earthy	18.02 ± 0.56^{a}	15.84 ± 1.06^{a}	67.86 ± 3.37^{b}	12.41 ± 1.16^{a*}	23.15 ± 2.36^{b*}	45.06 ± 0.58^{c*}	4.29 ± 0.32^{a}	13.63 ± 1.18^{b}	50.37 ± 4.13^{c}	8.16 ± 0.62^{a}	15.95 ± 0.84^{b}	55.71 ± 1.75^{c}
2-Propionylfuran	Fruity	14.22 ± 0.85^{a}	17.82 ± 0.42^{b}	41.22 ± 1.83^{c}	16.44 ± 0.67^{a}	25.31 ± 2.74^{b}	26.27 ± 1.60^{b*}	8.5 ± 0.43^{a}	11.81 ± 0.12^{b}	18.39 ± 0.42^{c}	6.19 ± 0.25^{c}	2.46 ± 0.13^{a*}	3.92 ± 0.29^{b*}
2-Vinylfuran	Phenolic	1.29 ± 0.20^{a}	1.71 ± 0.13^{a}	2.14 ± 0.72^{a}	0.86 ± 0.09^{a}	0.91 ± 0.12^{a*}	1.22 ± 0.26^{a}	0.85 ± 0.19^{a}	1.10 ± 0.08^{a}	1.54 ± 0.10^{a}	0.39 ± 0.12^{a}	0.46 ± 0.09^{a*}	0.68 ± 0.14^{a*}
Furfuryl methyl sulfide	Onion, garlic, sulphury	3.77 ± 0.34^{a}	11.27 ± 1.07^{b}	19.60 ± 1.39^{c}	n.d.	n.d.	n.d.	2.55 ± 0.36^{a}	15.68 ± 1.42^{b}	35.86 ± 1.38^{c}	n.d.	4.03 ± 0.58^{a*}	10.54 ± 0.96^{b*}
Methyl furfuryl thiol	Roasted	n.d.	n.d.	n.d.	n.d.	16.43 ± 1.18^{a*}	17.63 ± 0.81^{a*}	1.41 ± 0.26^{a}	10.33 ± 0.74^{b}	18.67 ± 1.35^{b}	0.68 ± 0.15^{a*}	7.95 ± 0.81^{b}	14.64 ± 0.98^{b}
2-Furanemethanol	Caramel	624.43 ± 1.46^{c}	523.23 ± 5.39^{b}	424.88 ± 3.17^{a}	589.45 ± 8.73^{c*}	461.08 ± 2.97^{b*}	321.89 ± 1.15^{a*}	288.54 ± 3.73^{c}	239.65 ± 2.61^{b}	128.74 ± 3.10^{a}	293.15 ± 2.59^{c}	250.63 ± 1.88^{b}	110.58 ± 3.53^{a}
Furan-2-yl-methyl acetate	Sweet, fruity, banana	156.35 ± 2.63^{a}	404.19 ± 2.86^{b}	563.72 ± 4.52^{c}	126.16 ± 3.63^{a*}	239.00 ± 5.65^{b*}	424.22 ± 3.28^{c*}	90.83 ± 2.09^{a}	165.49 ± 1.58^{b}	317.3 ± 2.46^{c}	67.02 ± 1.48^{a*}	110.60 ± 3.05^{b*}	265.46 ± 5.19^{c*}
5-Methylfurfural	Perfume, caramel	199.31 ± 1.60^{a}	231.23 ± 2.59^{b}	192.12 ± 2.67^{a}	188.87 ± 1.49^{a}	271.33 ± 1.28^{b*}	258.10 ± 4.68^{a*}	186.47 ± 3.51^{b}	215.09 ± 3.65^{c}	140.35 ± 2.91^{a}	150.18 ± 2.4^{b*}	231.83 ± 2.06^{c*}	138.46 ± 2.35^{a}
Total		1057.8 ± 9.03^{b}	1263.62 ± 15.31^{a}	1422.38 ± 22.71^{a}	983.44 ± 18.92^{c*}	1105.24 ± 18.33^{b*}	1178.07 ± 15.86^{a*}	612.66 ± 12.73^{a}	714.4 ± 13.21^{a}	786.17 ± 18.48^{a}	545.98 ± 10.19^{b}	660.93 ± 10.73^{b}	654.7 ± 17.28^{a*}
Pyrazines													
2-Ethylpyrazine	Peanuts, butter, nutty	16.85 ± 0.58^{a}	22.83 ± 1.32^{a}	25.44 ± 1.73^{a}	18.62 ± 0.64^{a}	24.24 ± 0.39^{a}	27.31 ± 1.43^{a}	12.71 ± 0.85^{a}	19.53 ± 0.68^{b}	23.76 ± 0.85^{c}	11.39 ± 1.03^{a}	14.27 ± 0.48^{a*}	25.96 ± 0.77^{b*}
2,5-Diethylpyrazine	Nutty	4.69 ± 1.33^{a}	5.54 ± 0.67^{a}	5.62 ± 0.49^{a}	2.92 ± 0.26^{a}	3.45 ± 0.68^{ab}	4.55 ± 0.16^{b}	4.28 ± 0.52^{a}	5.54 ± 0.15^{a}	8.65 ± 0.61^{b}	2.86 ± 0.18^{a*}	3.08 ± 0.32^{a*}	3.39 ± 0.2^{a*}
2,6-Diethylpyrazine	Nutty	11.66 ± 0.23^{a}	18.35 ± 0.75^{b}	43.49 ± 3.73^{c}	8.44 ± 0.92^{a*}	8.91 ± 0.58^{a*}	37.44 ± 1.76^{b*}	51.66 ± 1.87^{a}	54.94 ± 2.81^{a}	62.7 ± 1.36^{b}	36.01 ± 0.83^{a*}	41.13 ± 1.39^{ab*}	58.76 ± 0.76^{b*}
2-Methylpyrazine	Nutty, cocoa, roasted	40.25 ± 0.29^{a}	45.23 ± 1.42^{ab}	50.81 ± 0.49^{b}	36.96 ± 0.78^{a*}	41.50 ± 1.02^{bc}	45.33 ± 2.48^{c}	26.78 ± 0.66^{a}	31.94 ± 0.36^{b}	37.27 ± 1.16^{c}	25.11 ± 1.51^{a}	31.44 ± 0.69^{ab}	37.37 ± 1.33^{b}
2,5-Dimethylpyrazine	Cocoa, nutty, meaty	27.41 ± 0.57^{bc}	18.10 ± 0.95^{a}	30.08 ± 1.3^{c}	27.56 ± 1.12^{ab}	29.17 ± 0.83^{c*}	23.70 ± 0.63^{a*}	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
2-Ethyl-6-methylpyrazine	Roasted, potato	45.79 ± 0.86^{a}	54.19 ± 1.85^{bc}	56.76 ± 1.09^{c}	36.89 ± 2.63^{a*}	46.29 ± 1.07^{bc*}	47.88 ± 1.31^{c*}	31.93 ± 0.39^{a}	35.38 ± 0.27^{ab}	41.45 ± 0.98^{b}	27.89 ± 0.85^{a*}	30.63 ± 0.46^{a*}	31.88 ± 1.08^{a*}
2-Ethyl-5-methylpyrazine	Nutty, green, roasted	28.09 ± 0.53^{ab}	30.11 ± 0.37^{bc}	33.46 ± 0.78^{c}	22.95 ± 0.36^{a*}	28.03 ± 0.53^{bc*}	30.56 ± 0.49^{c*}	21.72 ± 0.58^{a}	23.43 ± 0.86^{ab}	26.35 ± 0.75^{b}	18.97 ± 0.29^{a*}	20.54 ± 0.65^{a*}	23.63 ± 0.30^{a*}
2-Ethyl-3-methylpyrazine	Nutty, corn, bread	12.32 ± 1.63^{a}	14.44 ± 0.34^{a}	15.29 ± 0.29^{a}	23.34 ± 0.37^{a*}	26.73 ± 0.18^{ab*}	28.32 ± 0.43^{b*}	20.88 ± 1.16^{a}	23.30 ± 0.25^{ab}	28.27 ± 0.17^{b}	19.13 ± 0.40^{a}	21.64 ± 0.32^{ab*}	25.47 ± 0.46^{b*}
3,5-Diethyl-2-methyl pyrazine	Nutty, meaty	22.23 ± 1.36^{a}	25.11 ± 0.83^{ab}	28.55 ± 1.54^{b}	5.77 ± 0.96^{a*}	7.22 ± 1.03^{a*}	7.69 ± 0.27^{a*}	16.81 ± 0.97^{a}	20.49 ± 0.72^{a}	21.78 ± 0.79^{a}	8.25 ± 0.84^{a*}	9.66 ± 0.79^{a*}	10.34 ± 0.51^{a*}
Ligustrazine	Nutty	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.27 ± 0.46^{a}	1.35 ± 0.17^{a}	2.14 ± 0.65^{a}	0.81 ± 0.14^{a}	0.96 ± 0.21^{a}	1.8 ± 0.30^{a}
Total		210.24 ± 7.38^{a}	256.66 ± 12.48^{b}	261.18 ± 9.00^{c}	214.46 ± 8.88^{b}	212.14 ± 6.31^{a*}	219.09 ± 8.12^{c*}	189.86 ± 8.00	213.61 ± 8.70	250.03 ± 7.57	152.45 ± 5.93^{a*}	172.83 ± 6.60^{a*}	208.98 ± 6.41^{b*}
Phenols													
Phenol	Plastics, caoutchouc	6.26 ± 0.57^{a}	9.24 ± 1.28^{ab}	16.79 ± 1.37^{b}	3.75 ± 0.83^{a*}	9.11 ± 1.63^{b}	12.80 ± 0.49^{bc}	1.44 ± 0.27^{a}	3.61 ± 0.63^{b}	12.64 ± 0.43^{c}	1.48 ± 0.26^{a}	4.94 ± 0.29^{b}	12.70 ± 0.47^{c}
4-Ethylguaiacol	Spicy, smoky, bacon	5.34 ± 0.38^{a}	13.49 ± 1.07^{b}	46.54 ± 2.18^{c}	9.56 ± 0.5^{a}	19.79 ± 0.58^{b*}	30.04 ± 1.26^{c*}	4.31 ± 0.68^{a}	11.09 ± 0.51^{b}	38.71 ± 1.53^{b}	3.66 ± 0.60^{a}	11.08 ± 0.18^{b}	34.54 ± 0.32^{c*}
p-Cresol	Phenolic	2.06 ± 0.73^{a}	2.53 ± 0.85^{a}	2.42 ± 0.73^{a}	0.66 ± 0.16^{a}	0.88 ± 0.21^{a}	1.70 ± 0.35^{a}	1.46 ± 0.15^{a}	1.62 ± 0.18^{a}	1.46 ± 0.31^{a}	0.98 ± 0.11^{a}	1.13 ± 0.14^{a}	1.23 ± 0.28^{a}
Total		13.66 ± 1.68^{a}	25.26 ± 3.20^{b}	65.75 ± 4.28^{c}	13.97 ± 2.04^{a}	29.78 ± 2.42^{b}	44.54 ± 2.10^{c*}	7.21 ± 1.10^{a}	16.32 ± 1.32^{b}	52.81 ± 2.27^{c}	6.12 ± 0.97^{a}	17.15 ± 0.61^{b}	48.47 ± 1.07^{c*}
Pyrroles													
2-Acetylpyrrole	Nutty, walnut, bread	15.85 ± 1.39^{b}	7.43 ± 0.53^{a}	20.42 ± 0.81^{c}	5.06 ± 1.43^{a*}	11.33 ± 0.95^{b*}	12.83 ± 0.38^{bc*}	3.93 ± 0.45^{a}	6.62 ± 0.73^{ab}	9.24 ± 0.87^{b}	2.91 ± 0.25^{a}	9.22 ± 0.49^{b*}	16.02 ± 0.91^{c*}
1-Methylpyrrole	Herbs, wood	2.69 ± 0.34^{a}	3.53 ± 0.29^{ab}	9.34 ± 0.75^{c}	0.82 ± 0.17^{a*}	1.58 ± 0.45^{a*}	2.18 ± 0.21^{a*}	2.82 ± 0.12^{a}	4.63 ± 0.26^{a}	11.59 ± 0.59^{b}	1.25 ± 0.22^{a}	1.53 ± 0.28^{a*}	4.81 ± 0.32^{b*}
1-Methylpyrrole-2-carboxaldehyde	Roasted, nutty	33.42 ± 1.08^{a}	42.14 ± 0.79^{b}	51.24 ± 2.41^{c}	42.41 ± 1.17^{a*}	76.60 ± 2.64^{b*}	86.32 ± 3.37^{bc*}	24.33 ± 0.84^{a}	44.07 ± 1.65^{b}	50.22 ± 0.80^{c}	21.34 ± 1.09^{a}	37.85 ± 1.22^{b*}	40.33 ± 1.97^{b*}
1-Furfurylpyrrole	Plastics, waxiness	37.53 ± 1.84^{a}	34.07 ± 1.31^{a}	74.54 ± 2.49^{b}	24.78 ± 1.21^{a*}	36.12 ± 1.06^{b}	55.79 ± 2.63^{c*}	24.57 ± 0.69^{a}	42.91 ± 1.48^{b}	67.53 ± 0.72^{c}	24.92 ± 0.45^{a}	38.69 ± 0.79^{b*}	62.08 ± 1.58^{c*}
Total		88.69 ± 4.65^{a}	86.47 ± 2.92^{a}	153.41 ± 6.46^{b}	72.9 ± 3.98^{a}	125.36 ± 5.10^{b*}	156.62 ± 6.59^{c}	55.09 ± 2.10^{a}	97.04 ± 4.12^{b}	137.52 ± 2.98^{c}	50.18 ± 2.01^{a}	87.12 ± 2.78^{b}	122.59 ± 4.78^{c}
Pyridine	Sour, pourri	27.26 ± 1.43^{a}	55.22 ± 2.73^{b}	126.77 ± 0.60^{c}	22.53 ± 0.92^{a*}	42.93 ± 1.35^{b*}	64.72 ± 1.63^{c*}	16.85 ± 0.36^{a}	36.51 ± 1.25^{b}	106.68 ± 2.07^{c}	10.34 ± 1.13^{a*}	31.7 ± 1.83^{b*}	72.65 ± 2.59^{c*}

TABLE 4: Continued.

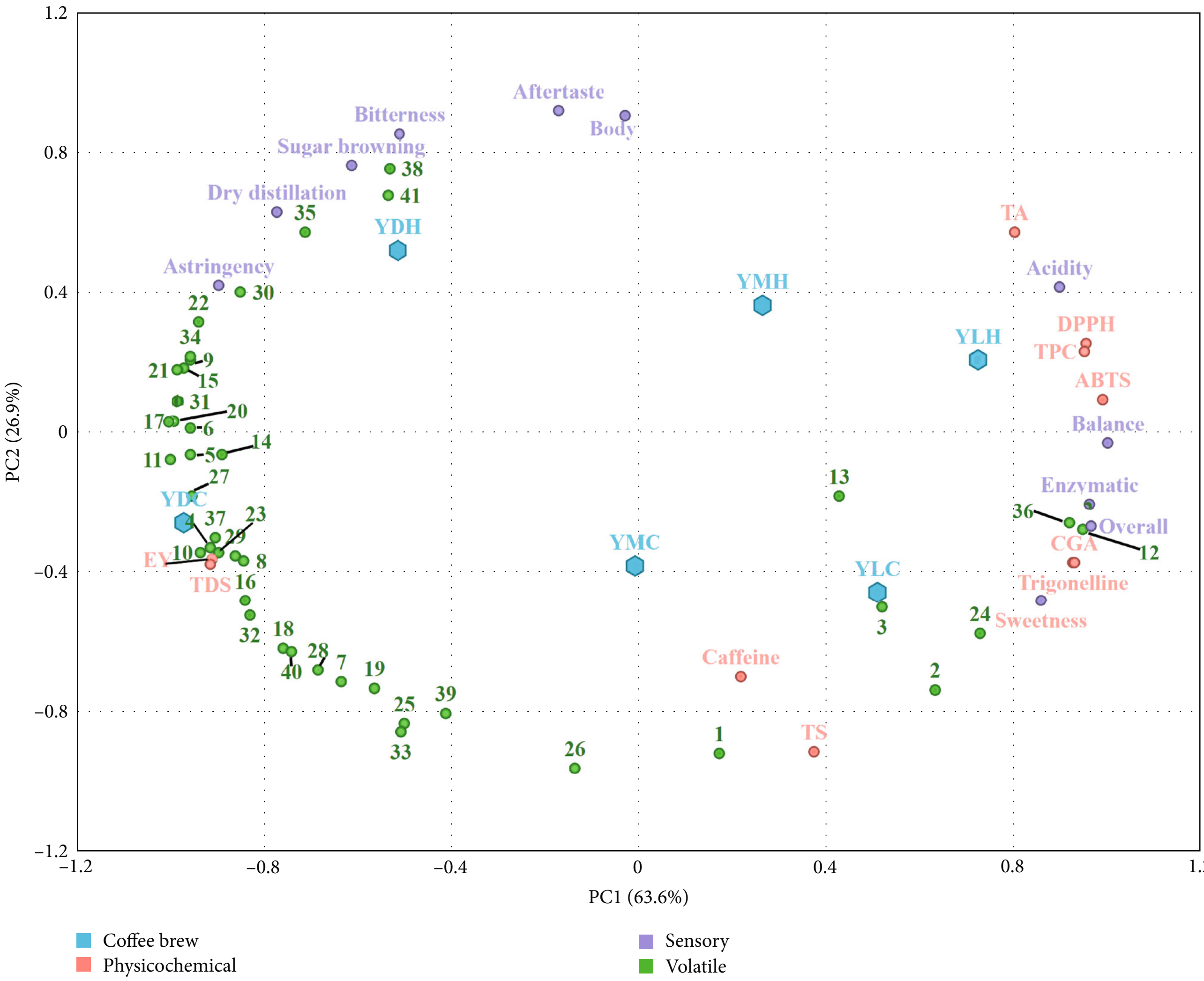
Compound	Odor description	Sumatra						Yunnan					
		Cold brew			Hot brew			Cold brew			Hot brew		
		Light roasting	Medium roasting	Dark roasting	Light roasting	Medium roasting	Dark roasting	Light roasting	Medium roasting	Dark roasting	Light roasting	Medium roasting	Dark roasting
Alkones													
2-Butanone	Fruity	7.35 ± 0.36^{c}	3.82 ± 0.18^{b}	3.16 ± 0.65^{a}	$1.62 \pm 0.28^{b*}$	$1.27 \pm 0.43^{ab*}$	1.06 ± 0.47^{a}	3.61 ± 0.89^{b}	2.28 ± 0.08^{b}	1.68 ± 0.19^{a}	$0.42 \pm 0.22^{a*}$	n.d.	n.d.
2,3-Pentanedione″	Sweet, cream	25.18 ± 0.63^{b}	19.56 ± 1.56^{a}	17.83 ± 1.38^{a}	$14.86 \pm 0.85^{b*}$	$13.09 \pm 1.02^{b*}$	$8.89 \pm 0.86^{a*}$	8.06 ± 0.26^{b}	7.27 ± 0.11^{b}	4.06 ± 0.18^{a}	$5.41 \pm 0.43^{b*}$	$5.27 \pm 0.21^{b*}$	2.81 ± 0.12^{b}
3,4-Hexanedione	Butter, amaretto, nutty	1.28 ± 0.26^{a}	3.16 ± 0.43^{b}	4.82 ± 0.46^{c}	$2.27 \pm 0.19^{a*}$	2.92 ± 0.51^{a}	3.53 ± 1.18^{b}	1.46 ± 0.18^{a}	2.74 ± 0.22^{a}	3.29 ± 0.59^{a}	1.26 ± 0.27^{a}	1.85 ± 0.13^{a}	3.61 ± 0.17^{b}
2,3-Butanedione	Butter, sweet, cream	7.27 ± 0.95^{a}	9.39 ± 1.36^{ab}	11.33 ± 1.05^{b}	$4.94 \pm 0.40^{a*}$	$5.62 \pm 1.21^{ab*}$	$7.95 \pm 0.57^{b*}$	2.67 ± 0.51^{a}	3.09 ± 0.16^{a}	4.47 ± 0.35^{a}	2.05 ± 0.14^{a}	$2.24 \pm 0.21^{a*}$	$3.09 \pm 0.19^{a*}$
3-Hexanone	Sweet, fruity, grape	1.30 ± 0.16^{a}	1.59 ± 0.23^{a}	3.40 ± 0.56^{b}	$0.46 \pm 0.12^{a*}$	$0.68 \pm 0.17^{a*}$	0.88 ± 0.23^{a}	0.83 ± 0.14^{a}	1.34 ± 0.15^{a}	2.64 ± 0.21^{b}	0.33 ± 0.17^{a}	$0.59 \pm 0.14^{a*}$	$0.89 \pm 0.11^{a*}$
2,3-Hexanedione	Sweet, caramel, butter	5.07 ± 0.46^{a}	6.86 ± 0.29^{ab}	7.36 ± 0.19^{b}	$2.62 \pm 0.21^{a*}$	3.03 ± 1.15^{a}	$2.96 \pm 0.76^{a*}$	1.59 ± 0.39^{a}	2.36 ± 0.26^{a}	3.07 ± 0.50^{a}	0.98 ± 0.13^{a}	$1.25 \pm 0.11^{a*}$	1.44 ± 0.20^{a}
3-Ethyl-2-hydroxy-2-cyclopenten-1-one	Sweet, caramel, maple	n.d.	1.65 ± 0.26^{a}	40.73 ± 2.31^{b}	$16.80 \pm 0.78^{a*}$	$32.3 \pm 1.43^{c*}$	$25.55 \pm 0.80^{b*}$	n.d.	n.d.	27.83 ± 1.79^{a}	n.d.	$2.22 \pm 0.48^{a*}$	29.63 ± 0.75^{b}
2-Hydroxyacetophenone	Phenolic, tobacco, herbs	n.d.	3.32 ± 0.32^{a}	7.07 ± 0.66^{b}	$1.87 \pm 0.26^{a*}$	3.77 ± 0.24^{b}	5.00 ± 0.19^{c}	1.22 ± 0.35^{a}	2.46 ± 0.72^{ab}	5.32 ± 0.38^{b}	1.01 ± 0.43^{a}	2.37 ± 0.18^{a}	5.00 ± 0.59^{b}
Total		46.97 ± 2.82^{a}	49.08 ± 4.63^{a}	95.31 ± 7.26^{b}	46.11 ± 3.09^{a}	$62.82 \pm 6.16^{b*}$	$55.72 \pm 5.06^{ab*}$	20.67 ± 2.72^{a}	21.32 ± 1.7^{a}	52.23 ± 4.19^{b}	$11.37 \pm 1.79^{a*}$	15.18 ± 1.46^{a}	45.74 ± 2.13^{b}
Aldehyde													
2-Methylbutyraldehyde	Cocoa, coffee, nutty	21.23 ± 0.85^{a}	24.22 ± 0.36^{ab}	27.37 ± 0.21^{b}	$18.71 \pm 0.18^{a*}$	$22.57 \pm 0.63^{ab*}$	$24.87 \pm 0.86^{b*}$	20.26 ± 1.26^{a}	24.83 ± 0.35^{a}	24.47 ± 0.38^{a}	$12.54 \pm 1.43^{a*}$	15.35 ± 1.18^{a4}	$18.23 \pm 0.92^{a*}$
Benzaldehyde	Bitter almond odor, nutty	8.36 ± 0.51^{a}	12.22 ± 0.61^{b}	24.45 ± 1.31^{c}	10.00 ± 0.56^{a}	16.36 ± 0.41^{b}	$16.52 \pm 0.92^{b*}$	5.77 ± 0.43^{a}	8.55 ± 0.39^{a}	14.08 ± 0.84^{b}	4.10 ± 0.62^{a}	6.79 ± 0.40^{ab}	$10.86 \pm 0.75^{b*}$
Crotonaldehyde	Flowery	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.37 ± 0.23^{a}	0.84 ± 0.28^{a}	n.d.	1.02 ± 0.33^{a}	n.d.	n.d.
Hexanal	Green, fruity	12.04 ± 0.73^{c}	8.63 ± 0.45^{b}	4.02 ± 0.26^{a}	$4.80 \pm 0.21^{a*}$	$4.77 \pm 0.52^{a*}$	3.86 ± 0.16^{a}	1.06 ± 0.18^{a}	0.93 ± 0.41^{a}	0.77 ± 0.14^{a}	0.87 ± 0.33^{a}	0.62 ± 0.16^{a}	0.44 ± 0.21^{a}
2-Methyl-3-(2-furyl)propenal	Perfume, cinnamon, wood	4.49 ± 0.22^{a}	4.70 ± 0.28^{a}	8.81 ± 0.56^{b}	n.d.	n.d.	5.93 ± 0.96^{a}	2.52 ± 0.72^{a}	4.58 ± 0.75^{ab}	6.13 ± 0.44^{b}	1.08 ± 0.39^{a}	$10.39 \pm 0.58^{b*}$	$14.54 \pm 0.94^{c*}$
Total		245.43 ± 3.91^{a}	281.00 ± 5.29^{b}	256.77 ± 7.01^{ab}	$222.38 \pm 3.24^{a*}$	$315.03 \pm 3.84^{b*}$	$309.28 \pm 7.58^{b*}$	217.45 ± 6.33^{b}	254.82 ± 5.83^{c}	185.8 ± 4.71^{a}	$169.79 \pm 5.50^{a*}$	264.98 ± 4.38^{b}	182.53 ± 5.17^{a}
Alcohols													
2-Heptanol	Lemon, green, flowery	2.18 ± 0.19^{a}	2.46 ± 0.42^{ab}	3.86 ± 0.16^{b}	1.93 ± 0.18^{a}	n.d.	n.d.	1.31 ± 0.29^{a}	1.08 ± 0.29^{a}	2.17 ± 0.38^{a}	n.d.	n.d.	n.d.
3-Octanol	Oranges	3.14 ± 0.36^{a}	3.15 ± 0.29^{a}	4.27 ± 0.43^{a}	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
(Z)-linalool oxide	Flowery, sweet	30.84 ± 1.07^{b}	21.29 ± 0.95^{a}	17.47 ± 1.32^{a}	31.10 ± 0.57^{b}	21.09 ± 1.28^{a}	19.01 ± 0.69^{a}	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
(E)-linalool oxide	Flowery	17.04 ± 0.59^{a}	13.9 ± 0.19^{a}	11.23 ± 0.46^{a}	$13.46 \pm 0.66^{a*}$	$10.46 \pm 0.26^{a*}$	$8.66 \pm 0.31^{a*}$	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Linalool	Oranges, flowery, sweet	48.90 ± 2.53^{a}	44.88 ± 1.78^{a}	44.91 ± 2.19^{a}	$14.57 \pm 0.49^{a*}$	$15.77 \pm 0.43^{a*}$	$15.73 \pm 0.28^{a*}$	11.93 ± 0.89^{a}	13.19 ± 0.18^{a}	10.29 ± 0.73^{a}	$5.03 \pm 0.48^{a*}$	$5.17 \pm 0.35^{a*}$	$5.08 \pm 0.70^{a*}$
Geraniol	Sweet, flowery, fruity	14.22 ± 0.55^{b}	7.28 ± 0.26^{a}	5.77 ± 0.28^{a}	$6.65 \pm 0.75^{a*}$	n.d.	n.d.	4.91 ± 0.53^{a}	n.d.	n.d.	$1.05 \pm 0.31^{a*}$	n.d.	n.d.
Hydroxyacetone	Sweet, caramel	2.46 ± 0.16^{a}	2.21 ± 0.45^{a}	n.d.	1.44 ± 0.29^{a}	n.d.	n.d.	1.22 ± 0.38^{a}	1.11 ± 0.25^{a}	n.d.	1.18 ± 0.33^{a}	1.13 ± 0.28^{a}	n.d.
Total		118.78 ± 5.45^{b}	95.17 ± 5.34^{ab}	87.51 ± 4.84^{a}	$69.15 \pm 2.94^{b*}$	$47.32 \pm 1.97^{a*}$	$43.40 \pm 2.28^{a*}$	19.37 ± 2.09^{a}	15.38 ± 0.72^{a}	12.46 ± 1.11^{a}	$7.26 \pm 1.12^{a*}$	$6.30 \pm 0.63^{a*}$	$5.08 \pm 0.70^{a*}$
Other													
2,4,5-Trimethyloxazole	Nutty, roasted	1.18 ± 0.41^{a}	1.17 ± 0.28^{a}	2.71 ± 0.36^{b}	1.5 ± 0.22^{a}	1.09 ± 0.09^{a}	$1.08 \pm 0.16^{a*}$	0.77 ± 0.14^{a}	1.29 ± 0.36^{a}	3.01 ± 0.51^{a}	0.63 ± 0.19^{a}	0.75 ± 0.28^{a}	$1.02 \pm 0.22^{a*}$
Methyl disulfide	Sulphury, vegetables, onion	1.42 ± 0.23^{a}	3.59 ± 0.96^{a}	3.41 ± 1.15^{a}	$0.40 \pm 0.11^{a*}$	$0.45 \pm 0.13^{a*}$	0.59 ± 0.20^{a}	1.35 ± 0.22^{a}	1.38 ± 0.21^{a}	2.71 ± 0.18^{a}	$0.45 \pm 0.09^{a*}$	$0.53 \pm 0.16^{a*}$	$0.91 \pm 0.26^{a*}$
Indole	Animal, faeces	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.87 ± 0.35^{a}	1.89 ± 0.46^{a}	3.41 ± 0.62^{a}	$3.01 \pm 0.29^{a*}$	2.87 ± 0.93^{a}	$5.62 \pm 0.24^{a*}$
Total		2.60 ± 0.64^{a}	4.76 ± 1.24^{a}	6.12 ± 1.51^{a}	1.90 ± 0.33^{a}	1.54 ± 0.22^{a}	$1.67 \pm 0.36^{a*}$	5.26 ± 1.17^{a}	5.91 ± 1.2^{a}	11.27 ± 1.96^{a}	4.90 ± 0.71^{a}	5.11 ± 1.58^{a}	9.35 ± 1.02^{a}
Total compounds		1612.12 ± 35.39	1886.01 ± 50.55	2283.08 ± 61	1457.97 ± 42.85	1670.83 ± 44.42	1815.01 ± 44.90	956.68 ± 33.09	1158.87 ± 34.40	1455.75 ± 42.95	807.40 ± 26.95	1030.37 ± 28.71	1212.56 ± 39.21

Results are presented as the mean of measurements ± standard deviation as μg/L; n.d.: not detected. The superscript letters (a, b, and c) represent statistically significant differences ($p < 0.05$) between roasting degrees for the same brewing method, as determined by a one-way ANOVA. * indicates significant differences ($p < 0.05$) based on a one-way ANOVA analysis between cold and hot brewing methods for the same degree of roasting.



(a)

Figure 2: Continued.



(b)

FIGURE 2: Principal component analysis (PCA) biplot of physicochemical and sensory property in cold and hot brew coffees obtained from Sumatra (a) and Yunnan (b) coffee beans. SCL: light-roasted Sumatra bean cold brews; SCM: medium-roasted Sumatra bean cold brews; SCD: dark-roasted Sumatra bean cold brews; SHL: light-roasted Sumatra bean hot brews; SHM: medium-roasted Sumatra bean hot brews; SHD: dark-roasted Sumatra bean cold brews; YCL: light-roasted Yunnan bean cold brews; YCM: medium-roasted Yunnan bean cold brews; YCD: dark-roasted Yunnan bean cold brews; YHL: light-roasted Yunnan bean hot brews; YHM: medium-roasted Yunnan bean hot brews; YHD: dark-roasted Yunnan bean cold brews; TDS: total dissolved solids; EY: extraction yield; TPC: total phenolic compounds; TA: titratable acidity, titratable acid; TS: total sugar; CGA: chlorogenic acid (1: 2-butanone; 2: 2,3-pentanedione″; 3: geraniol; 4: 2-ethylpyrazine; 5: 3,4-hexanedione; 6: 2-acetylfuran; 7: 2-methylbutyraldehyde; 8: 2,4,5-trimethyloxazole; 9: 2-methylpyrazine; 10: 2-ethyl-5-methylpyrazine; 11: 2-ethyl-3-methylpyrazine; 12: 2-furylmethanol; 13: 5-methylfurfural; 14: 1-methyl-2-formylpyrrole; 15: difurfuryl ether; 16: 3-hexanone; 17: furan-2-ylmethyl acetate; 18: 2,3-hexanedione; 19: 2-propionylfuran; 20: pyridine; 21: 1-furfurylpyrrole; 22: phenol; 23: furfuryl methyl sulfide. For Sumatra coffee beans, 24: hexanal; 25: 3-octanol; 26: (z)-linalool oxide; 27: (e)-linalool oxide; 28: 2,3-butanedione; 29: 2,5-dimethylpyrazine; 30: 3-ethyl-2-hydroxy-2-cyclopenten-1-one; 31: benzaldehyde; 32: 2′-hydroxyacetophenone; 33: 4-ethylguaiacol; 34: 2-vinylfuran. For Yunnan coffee beans, 24: crotonaldehyde; 25: 2-heptanol; 26: linalool; 27: tetramethylpyrazine; 28: 2,5-diethylpyrazine; 29: 2,6-diethylpyrazine; 30: cinnamyl isovalerate; 31: methyl furfuryl thiol; 32: 2-ethyl-6-methylpyrazine; 33: 3,5-diethyl-2-methyl pyrazine; 34: 2,2-methylenebisfuran; 35: 2-acetylpyrrole; 36: hydroxyacetone; 37: 1-methylpyrrole; 38: indole; 39: p-cresol; 40: methyl disulfide; 41: 2-methyl-3-(2-furyl)propenal).

higher in hot brew coffees, and this finding is in agreement with the report of Córdoba et al., who analyzed the coffee beans (*Coffea arabica*) produced by growers from Colombia and found that some attributes, such as bitterness, acidity, and astringency, exhibited significantly higher intensities in hot brew coffees than that in the cold brew coffee, while floral aroma was perceived as highest in cold brew coffees [22]. It is suggested that desirable flavor would be perceived as higher in cold brew coffee using lightly roasted coffee beans.

3.4. Volatile Compounds. The concentration of total volatile components, including furans, phenols, ketones, aldehydes, pyrroles, pyridine, and indoles, increased with the roasting degree and had significantly higher levels in cold brew coffee than in hot brew coffee (Table 4). The concentration of alcohols showed a decreasing trend with increasing roasting degree, and the concentration of alcohols in coffee brewed with Sumatran beans was higher than that with Yunnan beans. Indole was also present in higher concentrations in cold brew coffee and was only detected in coffee brewed with Yunnan beans. A trend of increasing pyrazine concentrations was found in cold brew coffee in both Sumatran beans and Yunnan beans, with an increasing roasting degree, and was only observed in Yunnan coffee beans and hot brew coffee.

In this study, it was found that 2-acetylfuran, 2,2-methylenebisfuran, and furan-2-yl-methyl acetate significantly increased with increasing roasting degree. 5-Methyl furfural showed higher concentrations at medium roasting degree levels. While the concentration of 2-furanemethanol decreased with the increase in roasting degrees. Furan-2-yl-methyl acetate, 2-furane-methanol, difurfuryl ether, and 2,2-methylenebisfuran were highly concentrated in cold coffee brews. Similarly, Maksimowski et al. suggested that furan-2-yl-methyl acetate exhibited higher concentration in coffee solution extracted from coffee beans roasted at 220°C compared to 210°C and 230°C [28]. Volatile furans such as furan-2-yl-methyl acetate, 2-acetylfuran, and 5-methyl furfural are associated with the aroma and flavor of sweet, fruity bread-like, caramel, nutty, and malty [31]. Additionally, furan-2-yl-methyl acetate has been recognized as one of the most important furans. 2,2-Methylenebisfuran has been referenced to possess green and medicinal flavor notes [3].

The carbohydrate degradation during Amadori rearrangement produces furans; this reaction occurs relatively early in the coffee roasting process and does not require high temperatures [15]. The highest concentrations of furan-2-yl-methyl acetate, 2-furanemethanol, and 5-methyl furfural were observed in dark-roasted, light-roasted, and medium-roasted cold brew coffee, respectively. The highly abundant furans could explain the higher intensity of sweetness in coffee cold brews.

2-Ethyl-6-methylpyrazine, 2-methylpyrazine, 2-ethyl-5-methylyrazine, 2-ethyl-3-methylyrazine, and pyridine demonstrated an increasing trend with increasing roasting degree. 2-Ethyl-5-methylpyrazine and 3,5-diethyl-2-methyl pyrazine were highly concentrated in cold brews compared with hot brews. 2-Ethyl-3-methylpyrazine had high levels in cold Yunnan coffee bean brews, whereas Sumatra coffee beans showed converse behavior. Maksimowski et al. found that the concentration of pyrazine compounds and their derivatives increased with an increasing degree of roasting [28], which is consistent with our study. There was a huge increase observed in pyridine concentration in cold brew coffee. Pyridine contributes to the nutty aroma. Pyrazines such as 2-ethylpyrazine and 2-ethyl-3-methylpyrazine have been associated with roasted-nutty and earthy odor notes [32], while 2-ethyl-6-methylpyrazine has been associated with a woody or papery and earthy or musty flavor notes [33].

Pyrazines, as well as pyridines, originate mainly from the Maillard reaction. Higher total volatile concentrations of pyrazine and pyridine were detected continuously increasing temperature. It can be speculated that with the increase in roasting degree, pyrazines and pyridines increase while TS decreases. This result could explain the higher intensity of sugar browning flavor in dark-roasted coffee brews.

Most of the pyrroles showed higher concentrations with increasing roasting degrees. 1-Furfuryl pyrrole, 1-methyl-2-pyrrolecarbaldehyde, and 2-acetylpyrrole showed an increasing trend. The high concentration of 1-furfurypyrrole and 1-methylpyrrole was observed in cold brews, while 1-methyl-2-pyrrolecarbaldehyde exhibited an adverse trend. Pyrroles are mainly derived from the thermal trigonelline decomposition, hydroxyproline reaction, and Maillard reaction intermediates during the roasting process. Pyrroles such as 1-furfurylpyrrole have been known to have chief sensory properties described as chocolatey, roasted, green, horseradish-like, and mustard seed [34].

Phenols are associated with undesirable flavors. 4-Ethylguaiacol was reported to have a smoky aroma [31], and the concentration rises with increasing roasting degree. The high concentration of 4-ethylguaiacol was found in cold coffee brewed with Sumatra beans. The main pathway which generates volatile phenolic compounds is CGA degradation during coffee roasting (esters of hydroxycinnamic acids and quinic acid) [29].

From aldehydes, 2-methylbutanal and benzaldehyde increased, while hexanal decreased with the increase in roasting degree. From ketones, 2-butanone and 2,3-butanedione displayed an increasing trend while 2,3-pentanedione showed a decreasing trend with the increased degree of roast. These components were found in a high concentration in cold brews. Aldehydes and ketones come from the Strecker degradation, which is the reaction of amino acids with α-dicarbonyl compounds and proceeds with a loss of CO_2 molecule. Previous studies have indicated that 2,3-butanedione forms a reaction between glucose, glycine, or proline, and 2,3-pentanedione is generated via glucose and alanine reactions [35]. Aldehydes and ketones react with other substances at high temperatures because their carbonyl structure is more active at a higher temperature. Ketones have been recognized as one of the important flavor molecules in coffee. 2,3-Pentanedione, primarily formed by the sucrose fragment recombination during roasting, has been ascribed to buttery and fatty odor notes [36].

Concentrations of cis-linalool oxide, trans-linalool oxide, and geraniol showed a decreasing trend with increasing roasting degrees. A high concentration of trans-linalool oxide, linalool, and geraniol was found in cold brews. Most alcohols have excellent volatility, which partly explains the higher alcohol concentration found in cold light-roasted beans coffee brew. Linalool and its derivative mainly exhibited floral and sweet notes, and geraniol has a rose aroma [37]. The high concentrations of alcohols, aldehydes, and ketones could explain the intensity of enzymatic flavor in coffee cold brews.

3.5. Principal Component Analysis (PCA). PCA was performed to determine the similarities or differences among the characterization of coffee brews (Figure 2). For coffee brewed with Sumatra and Yunnan coffee beans, the first component represented the degree of roasting, with 63.6% and 56.9% variance, respectively. The second component was the temperature, with 32.5% (Sumatra) and 26.9% (Yunnan) variance. Therefore, the effect of roasting degree on coffee beverage quality was stronger than the extraction method. In addition, the distance between points of different roasting degrees in cold brew coffee was greater than that in hot brew coffee, suggesting that cold brew enhanced the effect of roasting degree on the coffee beverages.

Sensory attributes including enzymatic flavor, sweetness, balance, and overall, physicochemical parameters such as trigonelline, CGA, and TS, and volatile compounds including hexanal, 2-furanemethanol, 2,3-pentanedione, and geraniol are present in the fourth quadrant, while sensory attributes of aftertaste, body, bitterness, sugar browning flavor, dry distillation flavor, and astringency are present in the second quadrant. These results suggest that the intensity of enzymatic flavor and sweetness was high in lightly roasted coffee cold brews; in contrast, the intensity of bitterness, sugar browning flavor, dry distillation flavor, and astringency were low. Hot extraction has most of the unpleasant flavors except sugar browning.

Sensory attributes of acidity and physicochemical parameters such as TA, TPC, DPPH, and ABTS are present in the first quadrant, indicating a probable correlation between TA, acidity, and antioxidant activity. The chlorogenic acid, phenolic compounds, hydroxycinnamic acids, and their derivatives, such as ferulic acids and caffeic acid [13], are rich in coffee brews. This could explain why coffee with high acidity also exhibits high antioxidant capacity. Physicochemical parameters such as TDS and EY are in the third quadrant. Most of the volatile components were on the cold extraction side, indicating that cold extraction is more beneficial for generating volatile components. Coffee retained fewer lipids after passing through the filter paper. The longer extraction time of cold brew coffee in comparison to hot brew is responsible for the higher EY and TDS levels. Cold brews benefit greatly from abundant, flavorful compounds like linalool, 3,5-diethyl-2-methyl pyrazine, furfuryl methyl sulfide, and 2-ethyl-6-methylpyrazine. It may have something to do with the polarity of these substances, which causes them to evaporate more readily in hot water at 90°C, resulting in the loss of more volatile components [3]. In contrast to South American coffee, coffee from this study had linalool, ligustrazine, difurfuryl ether, 2-propionylfuran, 2,5-dimethylpyrazine, 2,5-diethylpyrazine, 3,5-diethyl-2-methylpyrazine, 3-hexanone, and 3,4-hexanedione [38]. These variations could be attributable to geographical variations since all bean varieties were Arabica. Overall, intense molecular motion, found at higher extraction temperatures system, facilitates the extraction process of coffee constituents, while the duration of cold brew can compensate for the weaknesses of temperature. Additionally, the extraction of volatile components depends not only on the volatility of compounds but also on solubility, polarity, and other chemical properties, changing the final compounds in the coffee brew [39].

4. Conclusion

This study investigated the volatile and nonvolatile components (CGAs, trigonelline, and caffeine) along with physical and chemical parameters (TA, TS, TPC, DPPH, ABTS, EY, and TDS) and sensory properties of coffee beverages prepared with Asian coffee beans at different roasting degrees (light, medium, and dark roasting degrees) and two extraction methods(cold and hot brewing). The results indicate that TDS and EY values were higher in dark-roasted coffee brews. Higher CGAs, trigonelline, TA, TS, TPC, and TAC were observed in coffee beverages brewed from lightly roasted beans. The concentration of 2-furanemethanol, geraniol, 2,3-pentanedione, and cis-linalool oxide was higher in light-roasted coffee brews. The quantitative difference between the two extraction methods is reflected with lowered EY and TS, high TA, TPC, TAC, total volatile component concentration, and sensory properties such as enzymatic flavor which showed higher intensity in cold brews.

This study concludes that the degree of roasting has a greater impact on coffee quality than the extraction method. The effect of roasting degree on the coffee beverage quality is amplified by cold brewing. The combination of light roast coffee beans and cold brewing techniques resulted in a coffee with better physicochemical properties and sensory characteristics.

Data Availability

The data that support the findings of this study are available from the corresponding authors, upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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