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Research Article

Physicochemical, Electronic Nose and Tongue, Sensory Evaluation Determination Combined with Chemometrics to Characterize *Ficus hirta* Vahl. (*Moraceae*) Beer

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Ficus hirta Vahl. (FHV) is widely consumed because of its functional and aromatic compounds. The incorporation of adjuncts contributes to the functional and flavor properties of beers. This study aims to enrich FHV extractions to develop beers with satisfactory physicochemical, antioxidant, and sensory characteristics. As a result, beers with 0.1 g/mL (P1) and 0.067 g/mL (P3) FHV extraction showed the highest values of physicochemical properties including °Brix, antioxidant activity, foam, lightness, and color intensity. Electronic nose and tongue results show that the aroma of P1 and taste of P3 were quite different from those of other FHV beers, resulting in substantially high consumer preference. The liking drivers of FHV beers were color appearance, hop and malty odor, sweet and malty flavor, thickness, and carbonation mouthfeel. However, the astringency flavor attribute was the disliking factor for beers. The results of this study may provide some references and guidelines for the development of *Ficus hirta* Vahl. functional beer to control the physicochemical, antioxidative, and sensory properties of the beer.

1. Introduction

Beer is one of the most popular and most consumed alcoholic beverages [1]. It has a long history of use all over the world [2, 3]. Beer is made from mainly four basic materials: malted barley, yeast, hops, and water. Sometimes, beer is supplemented with other cereals or sources of sugar known as adjuncts [4]. According to the difference in fermentation, beers are grouped into two types: lager (bottom fermented) and ale (top fermented) [5]. Beer is considered a nutritious and refreshing carbonated beverage, which is rich in amino acids, vitamins, minerals, carbohydrates, and bioactive compounds [1, 6]. Nowadays, with an increasingly healthy lifestyle, demands for healthy beverages and foods are growing. Today's beer consumers commonly prefer to reduce the amount of alcohol, sugar, gluten, and carbohydrates

in beer products without affecting their original taste [7]. To satisfy the increasingly diversified needs of consumers, the beer industry is expanding and is constantly making progress to provide more functional and enriched flavorful beers.

Ficus hirta Vahl. (FHV), which belongs to the *Moraceae* family, is also known as *Hairy fig* or *Wuzhimaotao*. It is mainly distributed in Guangdong, Yunnan, Guangxi, Guizhou, and Hainan provinces of China [8]. FHV is widely consumed as an edible functional food with reported tonic effects because it is rich in functional compounds including flavonoids, coumarins, steroids, benzoic acid derivatives, phenylpropanoids, phenolic acids, fatty acids, and triterpenoids [8, 9]. FHV has antibacterial, hepatoprotective, antitumor, anti-inflammatory, and improved memory activities [9, 10]. In recent years, FHV has been widely added to

diverse health products, including beverages, wines, teas, and porridge [9]. FHV is both a medicinal herb and aromatic plant containing a treasury of bioactive components, making it a valuable functional and potential raw material for beer brewing. However, to the best of our knowledge, FHV has not been used in the production of functional beer products. The quality of beers is often evaluated by considering the four major characteristics of beer: the appearance, aroma, flavor, and mouthfeel [3]. The aroma and flavor of beer products are mainly influenced by the ingredients, roasting malt and boiling wort, yeast metabolism byproducts during fermentation, microorganism contamination, and inappropriate storage conditions [11]. The complex composition of FHV can affect the quality of beer in many ways, ranging from the physicochemical properties, color, flavor, aroma, mouthfeel, and foaming ability to whether or not consumers accept it. There is currently a lack of information on derived FHV beers, and no quality standard has been set for FHV beer.

In routine brewing operations, advanced analytical techniques including LC-MS, HPLC-MS, GC-MS, CE, IC, and assays are used to help in the selection of high-quality brewing ingredients, control of fermentation processes, and quality control of beer products [12]. Although advanced analytical techniques provide greater consistency for quality control, they are expensive, involve a lot of chemistry and biochemistry, and need skilled technicians. Therefore, it is essential to develop less costly and simpler techniques that provide comparable information, are more available to brewers, and add a more unique marketing approach.

The electronic nose (e-nose) and electronic tongue (e-tongue) methods are new automated nondestructive methods that offer fast and low-cost aroma and flavor information. These methods are used to characterize the components that contribute to the compositional or sensory profiles of foods and beverages, helping to evaluate the freshness and monitor the processes of food and beverages products from ripening to harvest and from raw material storage to packaging and consumption, thus controlling the qualities of food and beverages, as well as allowing complex sensory information to be processed (stimuli for the human sensory system) [13]. The e-nose and e-tongue methods have become popular because of many advantages including high sensitivity, convenient construction, and cost-effectiveness [14]. E-nose and e-tongue mimic human's nose and tongue senses using a combination of gas or chemical sensors [15, 16]. Sensor arrays have been widely applied in the evaluation of food qualities including the microbiological properties, processing quality, and sensory attributes [17]. In the brewing industry, e-nose and e-tongue have been already widely used in the classification, characterization, discrimination, fermentation control, investigation, and monitoring of the aging fingerprint [18–23].

Therefore, this study aimed to (1) evaluate the effects of adding different quantities of FHV into a pale lager malt syrup during the prefermentative step of the brewing process on the physicochemical properties, sensory properties, and sensory acceptance of the resulting FHV fruit beer samples and (2) integrate the automatic data of e-nose and e-tongue

with physicochemical and people's sensory acceptance data to characterize FHV beer. This is the first report on the effects of the use of FHV fruit in beer production. The results will help to illustrate the main quality characteristics and guide the development of FHV fruit beer.

2. Materials and Methods

2.1. Materials. The raw materials including Pale Ale malt (CHÂTEAU) were purchased from Hezhong Trading Co., Ltd. (Shenzhen, China). Mandarina Bavaria hops were purchased from Barth Haas (Beijing) Trade Co., Ltd. (Beijing, China). FERMOALE AY3 yeast was purchased from AEB (Shanghai) Trading Co., Ltd. (Shanghai, China). FHV (Moraceae) was purchased from Anhui Guanghe Chinese Herbal Medicine Co., Ltd. (Bozhou, China). Jing A Workers Pale Ale Craft Beer (Beijing First Brewing Golden Wheat Trading Co., Ltd., Hebei Province) was bought and set as a reference beer (P7). The materials used for sensory analysis were all food-grade materials.

2.2. Beer Processing. A flowchart of the beer brewing process is shown in Figure 1. First, the malt was milled and filtered through a 70-mesh bag to obtain the malt powder. Then, the filtered malt powder (2.5 kg) was mixed with 20 L of water in a saccharification pot (BEERBREW Brewing Equipment Co., Ltd) to saccharify the malt for 60 min at 67 °C and 10 min at 78 °C to obtain the wort. FHV was ground and filtered through a 70-mesh bag. Then, the filtered FHV powder (500 g, 400 g, 333 g, 285 g, 250 g, and 222 g) was soaked in 7 L of water for 1 h and then boiled for 1 h to obtain 5 L of different concentrations of FHV extractions. Then, a mixture of wort (20 L) and FHV extractions (5 L) was first boiled for 15 min, and then 30 g of dry hops were added and boiled for another 15 min. Activated yeast (0.5 g/L) was added to the cooled mixture (25 °C) to ferment the mixture for three days at 25 °C. After the fermentation, the beer samples were stored at 4 °C for 48 h for precipitation and then stored at 25 °C for 24 h for reducing the amount of diacetyl. Then, the beer sample was poured into a keg barrel to carbonize the beer at 4 °C for 24 h. After the carbonization, the temperature was increased to 21 °C for the second fermentation (two days). The final beer sample was produced and stored at 4 °C for further analysis.

2.3. Determination of Physicochemical Properties

2.3.1. Acidity. Using the method reported by Attchelouwa et al. [6], the total titratable acidity of the beer sample was determined by titrating 5 mL of the sample against 0.1 M of NaOH using phenolphthalein as the indicator.

2.3.2. Brix. The total soluble solids (TSS) content, expressed as °Brix degree of beer samples, was determined using a pocket Brix Acidity meter PAL BXACID F5 (ATAGO Co., Ltd., Tokyo, Japan). Before conducting the test, the instrument was first calibrated with deionized water. After the calibration, 2 mL of sample was placed at the sensor, and the
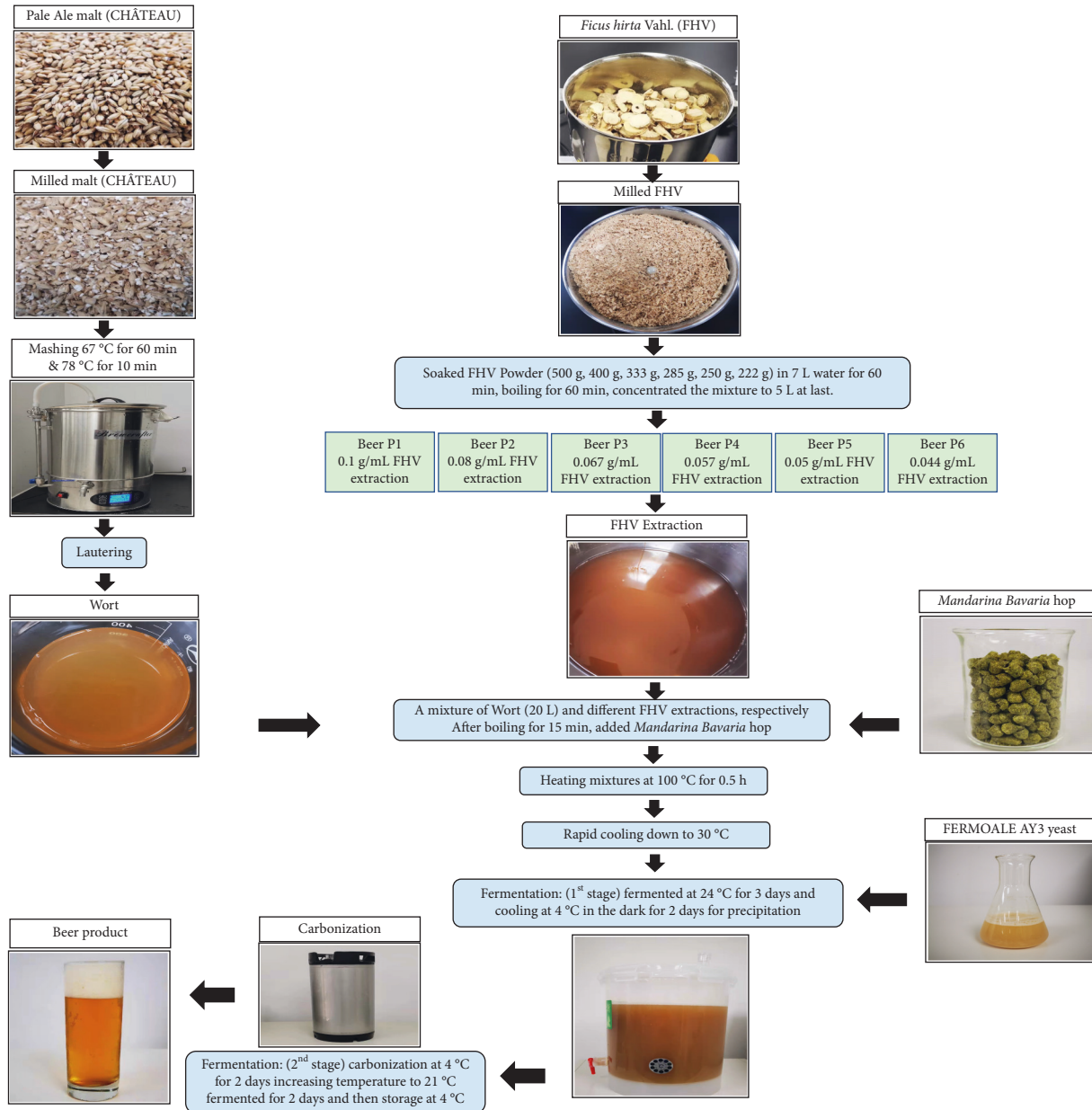
FIGURE 1: Flowchart of *Ficus hirta* Vahl. (FHV) beer production process.

°Brix of each sample was tested and documented. All the beer samples were analyzed six times.

2.3.3. Alcohol Content, Relative Density, and Original Extraction of Beer Samples.

Following the methods reported by Li et al. [24], the alcohol content, relative density, and original extraction of beer samples were determined according to the Chinese beer standard GB/T 4928-2008. The alcohol content was recorded as % vol; the amount of original extraction was recorded as °P.

2.3.4. Color.

The color attributes of beer samples were measured using a Chromameter CR-410 (Konica Minolta, Sensing Inc., Tokyo, Japan) and the CIE2000 method. Before the measurement, the chromameter was calibrated with a calibration plate. The beer samples were decarbonated in an ultrasonic bath for 15 min until the foam disappeared, indicating that the beer samples did not contain CO_2. Then, the beer samples were placed in a light projection tube CR-A33e (Konica Minolta, Sensing Inc., Tokyo, Japan); L^*, a^*, and b^* values of the samples were measured with a calibration plate background. In addition, the C^* and $h°$ values were calculated using

$$C^* = \left(a^{*2} + b^{*2} \right)^{1/2}, \tag{1}$$

$$h^o = \frac{b^*}{a^*}. \tag{2}$$

2.3.5. Turbidity. The beer samples were first decarbonated in an ultrasonic bath for 15 min until the foam disappeared, indicating that the beer samples did not contain CO_2. After the decarbonization, the turbidity of beer samples was measured using a calibrated nephelometer (WZS-185A INESA Scientific Instrument Co., Ltd., Shanghai, China) and turbidity standard solutions.

2.3.6. Foam Ability. According to the method reported by Neugrodda et al. [25], the foam height and foam stability of beer samples were tested using a standardized pouring procedure. The beer samples with original packages were first incubated at 20 ± 0.5 °C for 30 min. After the incubation, the beer samples were immediately poured into a 100 mL cup till the foam reached the rim of the cup in 3-4 s. The foam height was calculated, and the foam holding time was recorded immediately till the foam collapsed.

2.4. DPPH Antioxidant Capacity (AA) Assay. According to the method reported by Brand-Williams et al. [26], the AA of beer samples was determined using the DPPH scavenging method and a spectrophotometer (UV5 Bio, METTLER TOLEDO International Trading Co, Ltd., Shanghai, China). The percentage inhibition of remaining DPPH was calculated using the method reported by Liguori et al. [27]. The Trolox standard calibration curve was used; the results are expressed as Trolox equivalent (TE) μmol/L beer.

2.5. E-Nose Determination of Beers. To measure the odor responses of beer samples, a PEN-3 e-nose (Airsense Analytics Inc., Schwerin, Germany) equipped with a MOS-based sensor array with 10 sensors (W1C, W5S, W3C, W6S, W5C, W1S, W1W, W2S, W2W, and W3S), a sampling system, and a data collection and analysis software (Winmuster, Version 1.6.2) was used at room temperature. To perform the e-nose assay, 20 mL of beer sample was poured into a 50 mL headspace glass vial with a Teflon/silicon septum in the screw cap. Based on the sampling and headspace generation parameters reported by Bonah et al. [28], one Luer lock needle connected to a Teflon tubing (3 mm) was used to perforate the seal of the vial and absorb the air inside the vial and 3 cm above the beer sample surface. The sampling and headspace generation parameters were set as flush time of 200 s, presampling time of 5 s, zero-point trim time of 10 s, chamber flow rate of 400 mL/min, initial injection flow of 400 s, and measure time of 120 s. The sensor response was defined as the ratio of conductance $G0/G$ or $G/G0$ (where $G0$ and G are the conductance of the sensor before and after the exposure to the gas samples, respectively) [29]. The signals of the sensors during the measurement of a sample-formed pattern were analyzed randomly.

2.6. E-Tongue Determination of Beers. The beer samples were analyzed using a potentiometric e-tongue (Isenso, Shanghai Ruifen International Trading Co., Ltd., Shanghai, China) with cross-selective six taste sensors made of metallic

electrodes, platinum, gold, palladium, titanium, tungsten, and silver, along with a reference electrode (Ag/AgCl) and a platinum counter electrode; the applied pulse waveform is made up of three frequencies: 1, 10, and 100 Hz. In addition, the potential of -1.0 V and 1.0 V was used as the minimal and maximal values, respectively. The current between the taste sensors and counter electrode was determined when the voltage between the working and reference electrodes with the amplitude of each pulse reached 0.2 V [30, 31].

The sensor was first conditioned with a reference potassium chloride solution (30 mmol/L) at room temperature and then rinsed with deionized water. The detecting and the electric potential measured for each sensor were defined as Vr. After the rinsing, 10 mL of beer samples at room temperature was poured into a specialized e-tongue test beaker (25 mL) for measurements, and the measured potential was defined as Vs. Based on the method reported by Han et al. [30], each beer sample was analyzed six times, and the data were collected and analyzed.

2.7. Sensory Evaluation of Beer Samples. Sensory evaluation panels were recruited from the campus of Beijing Normal University-Hong Kong Baptist University United International College. The selection criteria were the availability and motivation to participate in experiments, and the panels were not allergic to beer. All the participants provided written informed consent to participate in the study. After the screening, 50 panels (44% women and 56% men) aged 18 to 22 were selected to conduct the sensory acceptance evaluation.

The beer samples were stored at 4 °C before the test. For acceptance evaluation, 30 mL of beer samples was added to 50 mL of disposable plastic cups labeled with three random numbers at refrigeration temperature ranging from 4 °C to 8 °C. The beer samples were provided following a balanced complete block design and evaluated by the assessors in individual cabins under white light.

Sensory profile tests of beer samples were conducted using a given list of descriptors of beers including the appearance (color, clarity, and foam), aroma (alcohol, malty, hop, floral, and fruity), texture (carbonation mouthfeel and thickness), and flavor (bitter, sour, sweet, alcohol, flora, fruity, malty, and astringency). A nine-point category scale was used to measure the intensity of the corresponding descriptors.

At the same time, a nine-point hedonic scale was used to evaluate the level of sensory acceptance as follows: (1) dislike extremely, (5) neither dislike nor like, and (9) like extremely. The acceptance data of beer samples regarding the appearance, aroma, texture, flavor, and overall acceptability were collected and analyzed.

2.8. Statistical Analysis. One-way analysis of variance (ANOVA) was performed to determine statistically significant differences in the physicochemical and sensory properties among the beer samples. Duncan's multiple range test was conducted to compare the means using SPSS version 17.0 (SPSS, Chicago, IL, USA) at a significance level of $P < 0.05$.

TABLE 1: Physiochemical properties of beer.

Sample	P1	P2	P3	P4	P5	P6	P7
Original extraction (°P)	3.62 ± 0.00^f	4.77 ± 0.00^d	4.98 ± 0.01^c	5.02 ± 0.00^b	2.80 ± 0.01^g	4.56 ± 0.01^e	12.50 ± 0.00^a
Alcohol content (% vol.)	1.63 ± 0.00^f	2.37 ± 0.00^d	2.50 ± 0.00^c	2.53 ± 0.00^b	1.11 ± 0.00^g	2.23 ± 0.00^e	5.00 ± 0.00^a
Alcohol by weight (%)	1.28 ± 0.00^f	1.87 ± 0.00^d	1.97 ± 0.00^c	2.00 ± 0.00^b	0.88 ± 0.00^g	1.76 ± 0.00^e	3.95 ± 0.00^a
Turbidity (NTU)	50.78 ± 0.29^b	72.78 ± 0.47^a	36.55 ± 0.10^c	18.83 ± 0.06^e	22.41 ± 0.12^d	3.21 ± 0.04^g	8.58 ± 0.13^f
°Brix	4.03 ± 0.05^b	3.60 ± 0.00^e	3.95 ± 0.05^c	3.20 ± 0.00^g	3.71 ± 0.04^d	3.43 ± 0.05^f	6.66 ± 0.12^a
Density (g/cm³)	1.0194 ± 0.00^c	1.0107 ± 0.00^g	1.0110 ± 0.00^f	1.0135 ± 0.00^e	1.0200 ± 0.00^b	1.0190 ± 0.00^d	1.0305 ± 0.00^a
Acidity	0.36 ± 0.02^{bc}	0.39 ± 0.02^a	0.39 ± 0.01^a	0.39 ± 0.01^a	0.35 ± 0.02^c	0.37 ± 0.01^{ab}	0.36 ± 0.01^{bc}
pH	4.22 ± 0.00^b	4.08 ± 0.00^c	3.98 ± 0.00^d	3.82 ± 0.00^f	4.30 ± 0.00^a	3.88 ± 0.00^e	4.20 ± 0.00^b
Foam (mm)	5.1 ± 0.17^e	4.61 ± 0.15^d	6.98 ± 0.18^a	3.03 ± 0.16^f	7.15 ± 0.15^a	3.45 ± 0.22^e	6.46 ± 0.16^b
Foam (s)	85.33 ± 4.97^b	59.16 ± 3.49^d	85.16 ± 3.43^b	41.66 ± 4.46^e	128.16 ± 7.73^a	70.5 ± 5.82^c	83.5 ± 4.04^b
L^*	71.76 ± 0.13^d	71.99 ± 0.54^d	79.21 ± 0.79^a	77.45 ± 0.36^b	74.45 ± 0.12^c	77.73 ± 0.13^b	65.43 ± 0.17^e
a^*	7.83 ± 0.06^b	5.65 ± 0.04^c	2.69 ± 0.07^e	4.01 ± 0.04^d	5.73 ± 0.02^c	2.62 ± 0.03^e	20.62 ± 0.18^a
b^*	45.90 ± 0.28^d	43.93 ± 0.35^f	47.27 ± 1.00^b	47.34 ± 0.34^b	46.71 ± 0.16^c	45.23 ± 0.20^e	57.48 ± 0.16^a
h^0	5.86 ± 0.07^e	7.77 ± 0.09^d	17.57 ± 0.72^a	11.80 ± 0.04^b	8.16 ± 0.05^c	17.30 ± 0.29^a	2.79 ± 0.02^f
C^*	46.56 ± 0.28^c	44.29 ± 0.34^e	47.35 ± 1.00^b	47.51 ± 0.34^b	47.06 ± 0.16^{bc}	45.31 ± 0.20^d	61.06 ± 0.20^a
DPPH (mol TE/L)	0.41 ± 13.89^a	0.34 ± 6.59^b	0.33 ± 4.32^{bc}	0.33 ± 1.02^{bc}	0.31 ± 3.96^c	0.24 ± 4.39^d	0.12 ± 56.64^e

Note. The data are shown as mean value ± SD. The mean values were averaged from the triplicate results of the corresponding parameters. Significant differences in physiochemical parameters among different beer samples were measured at the $P = 0.05$ level of confidence by one-way ANOVA. Different letters (a, b, c, etc.) labeled on the mean values indicate the differences between two samples in a row. Different beer samples P1–P6 were prepared with different volumes of FHV extraction, and P7 represents a commercial beer.

The previously mentioned statistical analyses, principal component analysis (PCA), agglomerative hierarchical clustering (AHC) analysis, and PREFMAP, were performed using XLSTAT version 2020.3.1.17 (Addinsoft, New York, USA). The e-nose data were analyzed using PCA and linear discriminant analysis (LDA) and Winmuster version 1.6.2 (AIRSENSE ANALYTICS, Germany). PCA and LDA of taste attributes of beer samples were conducted using MATLAB software version R2013a (MathWorks, USA). All the statistical analysis was set at a 95% confidence level.

3. Results and Discussion

3.1. Physiochemical Properties of Beer. The physicochemical properties of six beer samples (P1–P6) made with different volumes of FHV and one commercial ale beer (P7) are shown in Table 1. The original extraction is the number of soluble solids before starting the fermentation [32]. The produced FHV beers (P1–P6) had an original extraction content in the range of 2.8–5.02 °P, which were significantly different ($P < 0.05$) from each other due to different amounts of FHV added in P1–P6. In addition, they were substantially lower than the original extraction content (12.5 °P) of commercial beer (P7). This is probably because a lower grist/water ratio was used when producing wort compared with commercial beer (P7). For example, Liguori et al. [33] fermented beer from wort prepared with a 1 : 4 grist/water ratio, which had the original extraction range from 15.3 wt% to 16.2 wt%, higher than the 1 : 8 grist/water ratio used for producing beers in this study. In addition, original extraction (about 14.2 °P) of beers produced using a 1 : 4 grist/water ratio and produced wort in a study conducted by Yin et al. [34] were also higher than those in our study. Thus, it can be concluded that the grist/water ratio used to prepare wort substantially affected the original extraction of beers.

Table 1 shows that the alcohol content of FHV beer samples ranged from the lowest of 1.11% vol. (P5) to the highest of 2.53% vol. (P4), substantially different from commercial beer products of 5% vol (P7). In addition, the alcohol by weight (%) had the same trend as the alcohol content of beer samples. Beer is primarily produced with yeast strains' metabolism of a fermentable carbohydrate source, producing alcohol and carbon dioxide [35]. Thus, the concentration of wort as a carbohydrate source caused substantial differences in the alcohol content between FHV beers and commercial beer. Liguori et al. [32] reported, the greater the amount of sugar, the higher level of alcohol produced. The substantial differences in alcohol content among P1–P6, mainly originating from different concentrations of FHV extractions, may influence the metabolism of yeast strains [33]. In addition, Mehra et al. [36] also reported that the differences in the composition of wort and conditions during fermentation may influence the alcohol content of beers. Alcohol fermentation is an essential step in brewing, which helps in achieving the beverage's typical quality and sensory characteristics [11, 35]. As a result, different alcohol contents of beer samples may influence their typical quality and sensory properties.

°Brix is a parameter to estimate the total reduced soluble sugar of beers [37]. Density is also an essential parameter to estimate the alcohol content of the final product [38]. Table 1 shows significant differences in the °Brix and density of beers. The commercial P7 sample had the highest °Brix (6.66%) and density (1.0305 g/cm³). Among the FHV beer samples, the °Brix of P1 (4.03%) was substantially higher than that of other FHV beers. However, the density of P1 (1.0194) was substantially lower than that of P5 (1.02). The higher the °Brix of the FHV beer sample, the lower the alcohol content and the relatively higher density of the FHV beer sample. This is probably because a higher concentration of FHV extraction affected the yeast metabolites during fermentation, thus affecting the transformation of sugars into ethanol. As a result, a lower ethanol content may lead to

a lower density of beer. However, a higher amount of sugar left in the beer may also increase the density of the beer sample. Baigts-Allende et al. [37] also proved that the transformation of sugars to ethanol can result in different alcohol content-Density-°Brix combinations of beer samples.

In general, the pH of samples ranged from 3.82 (P4) to 4.22 (P1), consistent with the titratable acidity of beers. The pH and titratable acidity among the beer samples were substantially different. This is probably caused by the quality and quantity of raw materials used to make wort [36]. The pH in corroboration with the titratable acidity of beer is an important parameter for shelf-life, chemical stability, color, flavor, and resistance to microbial contaminations [36, 39]. Thus, the differences in pH and titratable acidity may also influence beer's typical qualities and sensory attributes.

Color is one of the main physical properties of beer assessed by a beer consumer besides clarity, viscosity, and foam, providing information about its style [39, 40]. The measured color properties of beers show that the commercial beer (P7) had the lowest lightness (L^* 65.43) and color intensity ($h^°$ 2.79); however, it had the highest redness (a^* 20.62), yellowness (b^* 57.48), and color saturation (C^* 61.06). This indicates that the color of the commercial beer was the darkest with the highest proportion of red and yellow color. Significant differences in color attributes were also observed among FHV beers. P1 was observed to be the darkest (L^* 71.76) with the highest redness (a^* 7.83) among FHV beers. P3 (b^* 47.27) and P4 (b^* 47.34) had similar yellowness. The color intensities of P3 ($h^°$ 17.57) and P6 ($h^°$ 17.30) had no substantial difference and were higher than other FHV beers. The color saturation values of P3 (C^* 47.35), P4 (C^* 47.51), and P5 (C^* 47.06) were similar and had no substantial difference. These results indicate that beers with a higher concentration of FHV extraction had higher lightness and redness; however, those with a lower concentration of FHV extraction had higher yellowness, color saturation, and intensities. This is probably caused by increasing the concentration of FHV extraction, contributing to the formation of colored Maillard reaction products and increased extraction of colored compounds from FHV [40, 41]. Also, the main components of malts and adjuncts could be modified during the malting or wort boiling through caramelization or Maillard reaction also affected the color of beers [33]. In addition, Psota [42] also reported that beer composition and the technical and technological conditions of brewing may affect the color attributes.

Foam and foamability are important characteristics of beer which help to avoid O_2 and CO_2 intake as well as aroma release from the beer, also a determinant factor for consumers [33, 43]. Consumer preference for beer foam varies but can be characterized in terms of foam quantity, foam stability, concentration, whiteness, and creaminess (bubble texture) [44]. In this study, P5 showed the highest foam quantity (7.15 mm) and foam stability (128.16 s), probably because of its higher pH compared to other beers. This indicates that a high pH may contribute to the chemical stability of the beer [36, 39]. A low pH of other beers possibly causes protein degradation, thus leading to lower foam

stability. An increase in protein modification may lead to a lower foam stability [44]. No substantial difference in foam stability was observed among P1 (85.33 s), P3 (85.16 s), and P7 (83.5 s). Regarding foam quantity, substantial differences were observed among all the beer samples. Foam formation could be affected by raw materials, namely, malt and FHV extractions, and the brewing process. The visual appearance of beer foam greatly influences the consumers' expectations of the flavor and mouthfeel of the beer [25].

Turbidity, arising due to the refraction of insoluble particles, is perceived as a subjective and visual impression, which should satisfy consumers' expectations because of its importance for visual reasons and as an indicator of serious contamination of the beer [45]. In the case of beers with reduced FHV extraction added to P1–P6, a decreased trend in turbidity was observed. Beer P2 had the highest turbidity of 72.78 NTU, caused by the suspended FHV fragments and yeasts [40]. The turbidity of beer was substantially affected by the addition of FHV extraction and no filtration procedure, leading to substantial differences in turbidity between FHV beer and commercial beer. The polysaccharides, especially pectins, released from FHV lead to the flocculation [41]. The reactions between protein and tannins contribute to the turbidity in the beer [33]. Turbidity provides a first visual impression of the quality of beer to the consumer [39]. This property might lead to a low consumer acceptance of P2 beer.

The AA of beer samples measured using the DPPH method showed that the AA of commercial beer (0.12 mmol TE/L) was substantially lower than that of all FHV beers at the same shelf-life time (two months). P1 showed the highest AA (0.41 mmol TE/L), indicating significant statistical differences ($P < 0.05$) with other FHV beers. All FHV beer samples showed higher AAs than the commercial beer (P7), suggesting that the FHV extraction added to the beer could increase the AA compared with that of commercial beer. The different AAs between FHV and commercial beer can be attributed to the raw ingredients, brewing techniques, beer filtrations, beer style, and fermentation conditions, as well as packaging and storage conditions [46]. The phenolic compounds mainly originating from barley malt and hops contributed to AAs of beers [46]. In this study, we also found that a higher concentration of FHV leads to a higher AA. Thus, the antioxidant compounds in FHV compounds could better inhibit the lipid peroxidation, which helped in stabilizing the flavor and aroma; foam stability and longer shelf-life during processing and storage also increased the number of functional components in the beer [1, 47].

A biplot of PCA and bootstrap ellipse on the physicochemical characteristics of beers is shown in Figure 2. The first two-dimension F1 and F2 explain 80.31% of the total variance with F1 and F2 accounting for 57.97% and 22.34%, respectively. As shown in the biplot of PCA (Figure 2(a)), the seven beer samples were separated into three groups. It was observed that P1 and P5 were nearly located in the second quadrant and were positively correlated with the turbidity and DPPH, indicating that they had similar physicochemical properties. Thus, P1 has relatively high turbidity and DPPH, while P5 has relatively higher foam, foam stability, and pH,
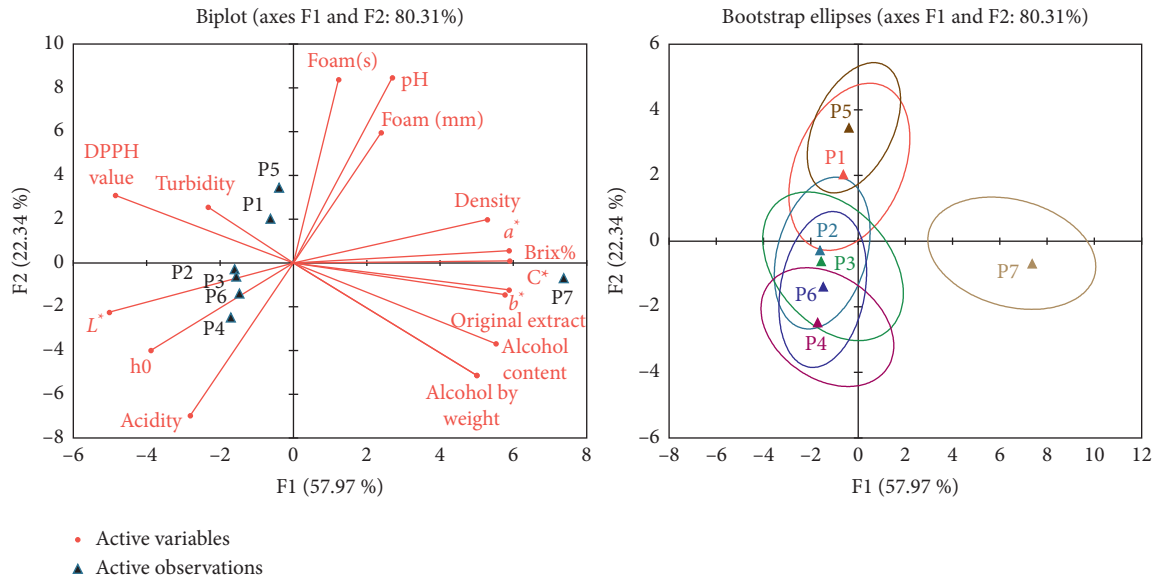
FIGURE 2: Principal component analysis of physicochemical properties of beers. Notes: F1 and F2 represent the first and second principal components of principal component analysis (PCA). P1–P6 represent the beer samples with 0.1 g/mL, 0.08 g/mL, 0.067 g/mL, 0.057 g/mL, 0.05 g/mL, and 0.044 g/mL FHV extraction, respectively. P7 represents the commercial beer.

contributing to their nearer location on PCA (Figure 2(a)). The other group included P2, P3, P4, and P6 because of their narrow distance and location in the same third quadrant. The acidity, $h°$, and L^* values positively correlated with the four FHV beers, indicating that these four beer products' acidities, $h°$, and L^* were their typical characteristics. The last group contained only P7 located on the fourth quadrant of the PCA biplot. P7 positively correlated with most of the physicochemical characteristics, making it significantly different from other FHV beer samples. The ellipse constructed with sample loadings showed that P7 was substantially different from other FHV beer samples as its ellipse has no overlap with those of other FHV beer samples [48]. The high overlap degree of the ellipse of P2, P3, P4, and P6 indicates that they were similar. Thus, P1 and P5 were also similar because their ellipse highly overlapped. Regarding the correlation among the variables (physicochemical properties), a positive relationship was observed between the pH and foamability; however, a negative relationship was observed between the acidity and foamability, indicating that a higher pH and lower acidity contributed to foam formation and its stability. Moreover, positive relationships were observed among the density, °Brix, original extraction, and alcohol content. A higher amount of original extraction indicated a higher amount of sugar resources in the beer, leading to a higher °Brix and density of beer. After sugar transformation, a higher amount of alcohol would be produced. For the color attributes shown in the biplot (Figure 2(a)), the original extraction positively correlated with a^* (redness), b^* (yellowness), and C^* (color saturation); on the other side, it negatively correlated with L^* (lightness) and $h°$ (color intensity). This again indicates that the original extraction had a high concentration of wort that would increase the darkness and color saturation and decrease the lightness and color intensity of beer. All the results obtained

from PCA are consistent with the previous data shown in Table 1, indicating that different concentrations of FHV extraction added to beers substantially affected their physiochemical properties, making FHV beers different from commercial beers (P7).

In conclusion, physicochemical properties and PCA analysis data of beers show that, among the FHV beers, P1 had the highest °Brix and AA but a medium level of the rest of the properties. P3 had the highest foam, lightness, and color intensity but a medium level of other attributes.

3.2. Beer Classification by Electronic Nose and Tongue.

Flavor features of beer consist of volatiles and tastes that decide beer's quality and thus affect consumers' preference [22]. To test the capability of e-nose and e-tongue in classifying and evaluating the qualities of beers, the data obtained from e-nose and e-tongue were analyzed using PCA and LDA.

3.2.1. Volatile Discrimination of Beers.

The PCA results (Figure 3(a)) of the volatiles of beers obtained by e-nose explained 99.92% of the total variance with the first principal component (PC1), accounting for 98.64%, and the second principal component (PC2), accounting for 1.28%, indicating that the two-dimensional (2D) PCA model is sufficient enough to explain the total variance of the e-nose dataset [49]. Chen et al. [49] reported that if the sample locations on the score plot were close to each other or overlapped, the samples have similar volatile profiles. Thus, the long distance between P1 and P7 or their long distance from the left beer samples (P2, P3, P4, P5, and P6) on the PCA score plot (Figure 3(a)) indicates that the volatiles of P1 and P7 were significantly different from each other and the left beer samples. This is probably because P1 had the highest
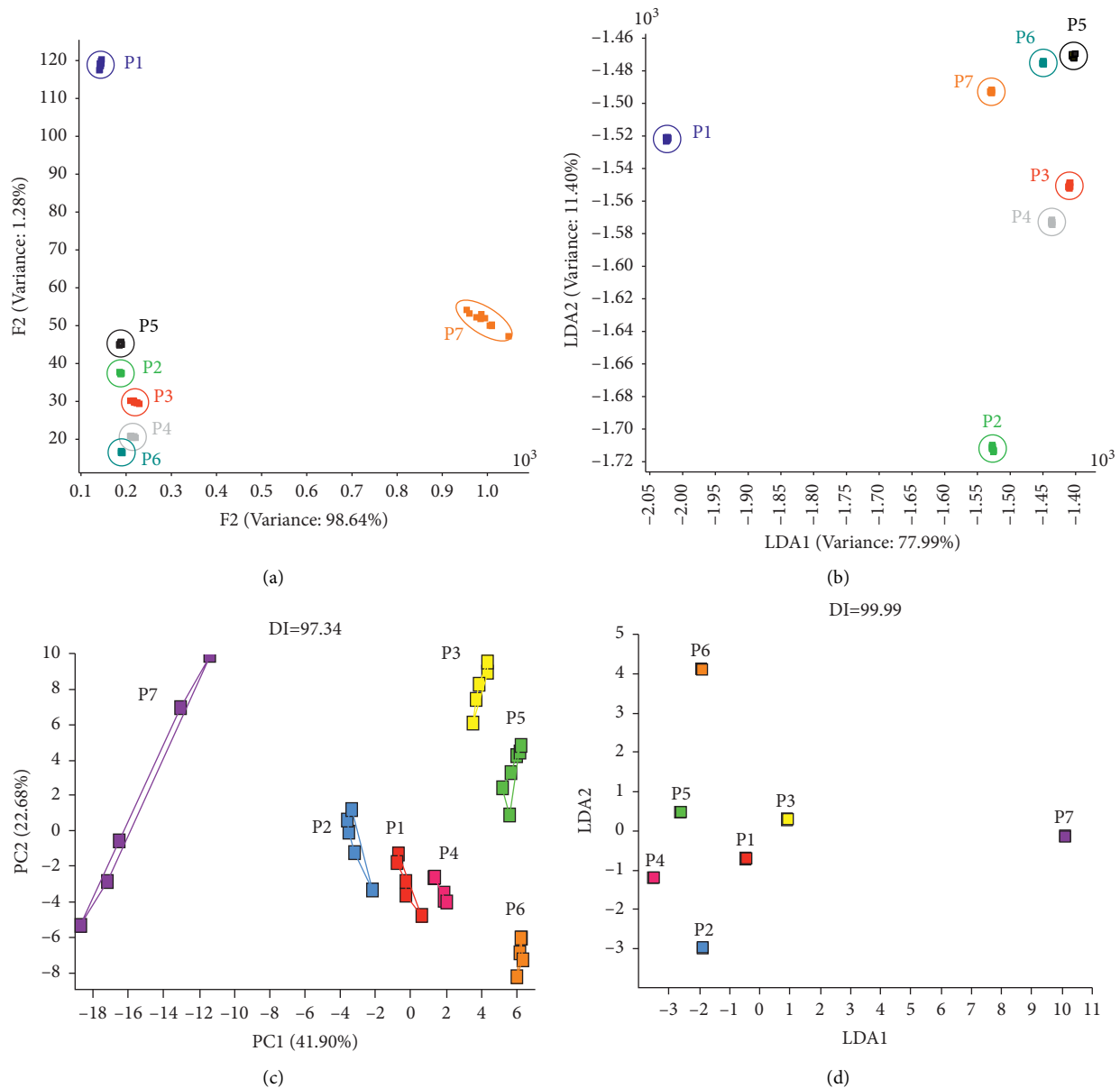
(a)

(b)

(c)

(d)

FIGURE 3: Visualization of beer samples' distribution based on e-nose and e-tongue determination. (a) Score plot of principal component analysis (PCA) performed on beers using the e-nose. (b) Score plot of linear discriminant analysis (LDA) performed on beers using the e-nose. (c) Score plot of PCA performed on beers using the e-tongue. (d) Score plot of LDA performed on beers using the e-tongue.

concentration of FHV extraction, and fermentation, as well as the differences in the ingredients of P7, made their volatiles quite different from the left five beer samples. On the other hand, the volatiles of P2, P3, P4, P5, and P6 were similar because of their close location on the PCA score plot (Figure 3(a)).

LDA, a class-modeling technique, can provide a better classification than PCA. It was also used to discriminate beer samples according to their volatiles. As shown in Figure 3(b), PC1 accounts for 77.99% of the data variability, and PC2 accounts for 11.40%, a total of 89.4%. Locations of P1 and P2 were far away from other beers. Among the left beer samples, three groups (P3 and P4, P5

and P6, and P7 alone) were classified according to their close locations. This indicates that the volatiles of P1 and P2 were quite different from other beer samples because they had a higher concentration of FHV extraction than other beers. Compared with P1 and P2, samples P3, P4, P5, and P6 were quite similar to sample P7. It can be concluded that a decrease in the concentration of FHV extraction in beer samples made them much more similar to the commercial beer sample.

The PCA and LDA results of volatiles of beers obtained from e-nose analysis indicate that P1 had quite different volatiles than other FHV beers and the commercial beer product.

3.2.2. Taste Discrimination of Beers. In the e-tongue analysis, Figure 3(c) shows the score plot of PCA results of taste compounds of beers. The first two principal components account for 97.34% of the total information with PC1 accounting for 41.90% and PC2 accounting for 22.68%. All the beer samples were separated well on the plot, indicating that the PCA classified the beer samples using the e-tongue data. Similar to the PCA e-nose results (Figures 3(a) and 3(b)), the taste of P7 was substantially different from other FHV beers due to its long distance from other beers observed on the PCA score plot (Figure 3(c)). Also, it was observed in Figure 3(c) that the signal shifts in P7 were more significant than in other beer samples which may be because higher alcohol content in P7 leads to shifts of e-tongue signals [50, 51]. Along the second dimension of the PCA plot in Figure 3(c), P3 was located farthest on the plot, indicating its strongly different taste from other FHV beers. However, P6 was the farthest along the first dimension of the PCA plot indicating that P6 was different from other FHV beers. Thus, the tastes of P1, P2, and P4 were much more similar owing to their close location on the plot. In addition, Figure 3(d) indicates that a good separation between beer samples was obtained by applying LDA. Also, Kovacs et al. [51] reported that the LDA method applying drift correction methods significantly improved the long-term measurement results of the electronic tongue and could be adapted for industrial purposes. Compared with the PCA plot of e-tongue (Figure 3(c)), a similar distribution of beer samples was observed with the LDA models. It also indicates that the taste of P7 was quite different from FHV beers due to the long distance between P7 and FHV beers. Along the first dimension of the LDA model, P3 was located far away from other FHV beers, indicating that the taste of P3 was quite different from others. Along the second dimension of the LDA model, P6 showed the most taste difference from other FHV beers due to its long distance from others. In conclusion, PCA and LDA results indicate that the tastes of P3 and P6 were different from other FHV beers and commercial beers.

3.3. Sensory Profile and Acceptance of Beers. The main quality characteristics of beer are appearance, aroma, flavor, and mouthfeel [3]. Concerning the quality and consumers' preference of beers, the PCA results of sensory profile and hedonic tests are shown in Figures 4(a) and 4(b). Visualization of correlation between the sensory profiles of beer samples is shown in Figure 4(a) using a 2D plot of PCA with 74.78% of the total variance. Four groups (G1: P1 and P3, G2: P2 and P4, G3: P5 and P6, and G4: P7) were observed based on the distance difference between the beer samples on the plot. According to the factor loadings of descriptors (Figure 4(a)), the first principal component (F1) accounting for 55.08% of the total variance was mainly represented by the most sensory attributes on the positive side of the axis [43]. In addition, a positive correlation was observed between the descriptors and the three beers, namely, P1, P3, and P7, indicating that the three beer samples were characterized by a high concentration of volatiles, strong taste, and mouthfeel texture sensory intensity. However, only the appearance, clarity, and astringency flavor were located along the negative side of F1 and positively correlated with P2, P4, P5, and P6 beers, indicating that the appearance and astringency sensory properties could discriminate them from other beers. It was also shown that P2 and P4 were similar owing to their similar appearance and clarity sensory properties. Also, P5 and P6 were similar owing to their astringency taste. The PCA of physicochemical results (Figure 2) also showed that P2, P4, and P6 were similar because of their narrow location. The results are consistent with the previous LDA results for e-nose (Figure 3(b)); the LDA results of e-tongue (Figure 3(d)) showed a narrow distance between P2 and P4 and P5 and P6. The bootstrap ellipses of sample loadings conducted on their sensory profile data are shown in Figure 4(b). Overlap of the ellipses of P1 and P3 once again proved that P1 and P3 had similar sensory properties. Thus, P2, P4, P5, and P6 were similar to each other because of the same reason. P7 was different from other FHV beers because its ellipse had only a small or no overlap with those of other FHV beers.

AHC analysis of beer preference was conducted to segment the consumers to elucidate the perceptions and preferences in the beer samples of consumers [52]. As shown in Figure 4(c), 50 panels were segmented into two clusters with 19 consumers in cluster 1 and 31 consumers in cluster 2. A PREFMAP analysis was conducted on the preference data, and a preference map was constructed as shown in Figure 4(d). The regions with red color indicate the proportion of high preference (80–100%); the regions with green color indicate the proportion of medium preference (40–60%); the regions with blue color indicate the proportion of low preference (0–20%). The preference map (Figure 4(d)) of beer samples shows that all the consumers preferred P1 and P3 beers the most, followed by P7, P2, and P4, and disliked P5 and P6 the most. Between P1 and P3, most people (cluster 2) preferred P1 more because a more positive correlation was observed between P1 and cluster 2. In addition, the consumers in cluster 1 preferred P3 more as a positive correlation was observed. Based on the previous physicochemical, e-nose, and e-tongue results, it can be concluded that P1 and P3 products had higher DPPH and brighter appearance (Figure 2(a)); P1 had a typical aroma (Figures 3(a) and 3(b)); P3 had a typical taste (Figures 3(c) and 3(d)), which are probably the reasons for their higher preference proportions among the consumers. Combining the data shown in the first quadrants in Figures 4(a) and 4(d), it can be concluded that the descriptors A-color, F-sweet, Flavor, F-malty, O-hop, O-malty, texture, T-thickness, and T-carbonation mouthfeel were cited as the factors for the liking of P1 and P3. P6 strongly negatively correlated with clusters 1 and 2, indicating that the consumers did not like P6 the most. Combining the third quadrants of Figures 4(a) and 4(d), it can be concluded that the F-astringency was the disliking factor for P6. Moreover, the previous physicochemical results indicate that the high acidity and lowest turbidity (Table 1 and Figure 2(a)) of P6 might also be the reason for the disliking of P6.
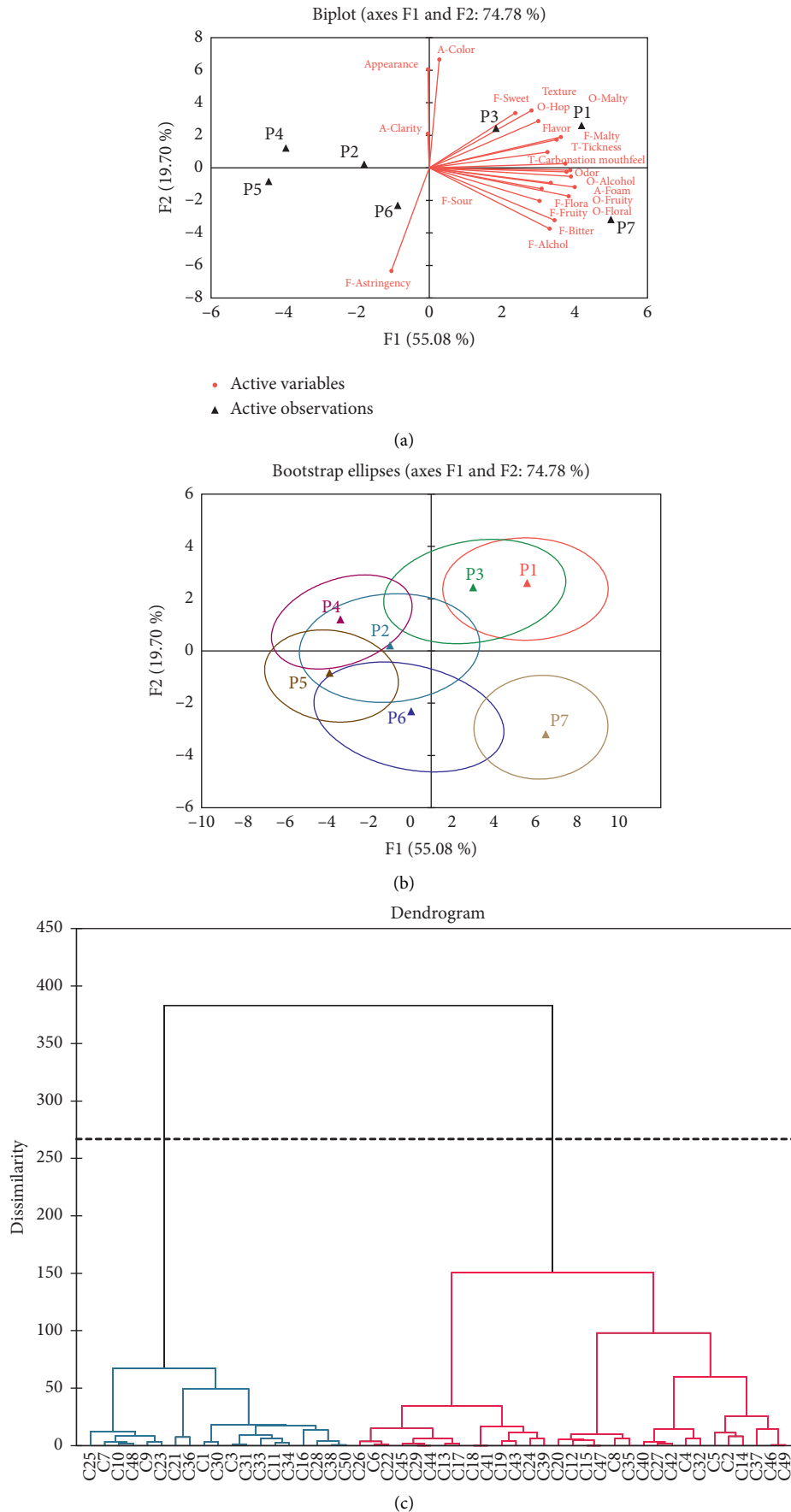
Biplot (axes F1 and F2: 74.78 %)

(a)

Bootstrap ellipses (axes F1 and F2: 74.78 %)

(b)

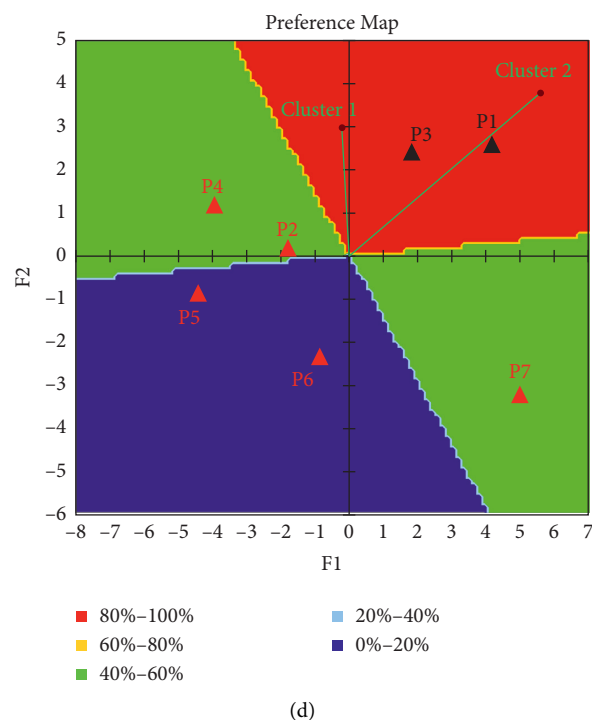Dendrogram

(c)

Figure 4: Continued.

(d)

FIGURE 4: Sensory evaluation results of beers. (a) PCA biplot of quantitative descriptive analysis (QDA) of beers. (b) PCA plot constructed with bootstrap ellipses for the QDA data of beers. (c) Dendrogram of consumer clusters obtained by agglomerative hierarchical clustering analysis. (d) External preference mapping of beers achieved using PREFMAP.

The sensory profile and consumer preference results indicate that the addition of a higher concentration of FHV extraction to the beers will probably increase the consumer preference for FHV beers.

4. Conclusion

Our study indicates that the enrichment of beer with FHV extraction allowed obtaining new flavors and increased the concentrations of bioactive compounds, thus leading to its high quality regarding the physicochemical properties, aroma, and taste profiles, as well as consumers' preferences. In particular, beers with 0.1 g/mL (P1) and 0.067 g/mL (P3) of FHV extraction showed the highest values for physicochemical properties including °Brix, AA, foamability, lightness, and color intensity properties, as well as satisfactory values for the left physicochemical parameters. The identified aroma and taste compounds using e-nose and e-tongue analyses showed that the aroma of P1 and taste of P3 were quite different from those of other FHV beers, resulting in substantially high consumer preference than other beers. The sensory factors for the liking of P1 and P3 include A-color, F-sweet, Flavor, F-malty, O-hop, O-malty, texture, T-thickness, and T-carbonation mouthfeel. On the other hand, the F-astringency attribute was the disliking factor for beers. The results obtained in this study may provide some references and guidelines for future FHV beer product development concerning the physicochemical, functional, sensory, and microstructure properties.

Data Availability

The research data used to support the findings of this study are available from the corresponding author upon request.

Ethical Approval

This study was approved by the Institutional Review Board of Beijing Normal University-Hong Kong Baptist United International College.

Consent

Informed consent was obtained for experimentation with all panels.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

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