Discrimination and geographical origin prediction of washed specialty Bourbon coffee from different coffee growing areas in Rwanda by using electronic nose and electronic tongue

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Abstract The study aimed at discriminating washed specialty Bourbon coffee from major coffee growing areas in Rwanda and evaluating the feasibility of using flavor to predict the geographical origin of Arabica coffees from different origins. Discrimination was achieved by performing a principal component analysis, and a discriminant factorial analysis (DFA) model was used to predict the geographical origin of coffee samples based on their intrinsic flavor. Discrimination results from both e-nose and e-tongue indicated clear grouping of coffee samples from areas within the same geographical sub-regions. A DFA model using e-nose was successful in predicting the geographical origin of coffee samples but not with e-tongue. Therefore, the study demonstrated that aroma could reliably be used to predict the geographical origin of coffee samples from different origins than their taste profile.

Keywords Coffee flavor · Rwanda · Washed Bourbon · Electronic nose · Electronic tongue

Introduction

Coffee grown in Rwanda is dominated by “Bourbon” variety of Arabica coffee [1–4]. Arabica coffee is mainly grown in the western region along Lake Kivu, central

plateau and southeast. These regions are characterized by soils and weather favorable for Arabica coffee growth [5, 6]. Until 2001, Rwanda produced only semi-washed Arabica coffee, but today the country produces both semi-washed and specialty grade, fully-washed (FW) Arabica coffee as its major export commodity. Almost all coffee produced in Rwanda is exported, with the domestic consumption not exceeding 2%.

In recent years, there has been an increasing world demand and competition for high-quality/specialty Arabica coffee beans. The major determinant of coffee quality is its flavor in the cup [7, 8]. Coffee flavor as well as other qualities is influenced not only by variety and geographical origin (that is, variation in soil types, farm practices, and weather conditions) but also the processing and storage conditions and time [9–11]. Therefore, the uniqueness of coffee from each origin need to be known, which may determine its value on the market since coffee in the cup is nothing but the intrinsic quality of the raw beans.

Raw (green) Arabica coffee is characterized by a peasy odor note caused by alkyl-methoxy pyrazines such as 3-isobutyl/3-isopropyl-2-methoxypyrazine. Higher concentrations of these compounds cause an undesirable peasy off-flavor, also referred to as potato taste defect when detected in the cup [12]. Methoxypyrazines are normally present even after roasting [8, 12, 13], but in low concentrations, and have other sensory attributes such as roasty and earthy. The problem occurs when their concentration is high (possibly due to improper sorting).

The general characteristic coffee flavor is a result of chemical reactions (mainly Maillard reaction and Strecker degradation) that occur during roasting. It is also influenced greatly by the roasting conditions. Although different roasting conditions (150–250 °C for 3–30 min) have been studied, the typical ones were reported to be 180–240 °C

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for 8–15 min [8–13]. These conditions may vary depending on the roaster type and the amount of coffee that is being roasted. Light to light-medium roasted coffees bring out the most original character of particular coffees, while the darker the roast, the more the coffee has a burnt flavor [14]. Therefore, for better discrimination, coffee should not be roasted beyond the light-medium degree of roast.

Roasted ground and brewed coffee contains many flavor compounds, both volatile (for aroma) and non-volatiles (for taste), but a few of the volatiles are considered to be the drivers or key contributors of coffee aroma [7, 8, 12–19]. However, as the characteristic flavor varies among varieties and geographical origins, the key odorants also vary. In addition, different cultivars should also be considered.

Preliminary processing methods of raw beans (washing/wet, semi-wet, or dry) influence coffee flavor. Washed coffee is said to possess full aroma and pleasant acidity as a result of the fermentation process, whereas the corresponding dry processed coffee exhibits full body [20]. Washing is said to improve the quality, particularly for Rwandan coffee, where the fully washed coffee has a higher value on the market since it is also produced from selected good quality cherries (by sorting) and its production is being encouraged compared to the medium quality, semi-washed (ordinary) coffee.

To date, several studies have been reported on discrimination and characterization of coffees from different origins such as Kenya [7], Philippine [10], Indonesia [15, 16], Colombia [21, 22], Ethiopia, Tanzania and Guatemala [23, 24]. However, to the best of our knowledge, there is no report about the flavor profiles of Rwanda's washed specialty Bourbon Arabica coffee. Thus, this study aimed at applying electronic nose and tongue technologies to discriminate the intrinsic flavor profile of the brews from a commercial Bourbon cultivar from different major coffee growing areas in Rwanda in comparison with Arabica coffee from other origins. In addition, the study provided a simple approach of using flavor to identify the geographical origins of coffee samples.

Materials and methods

Materials

Fully washed (FW) Arabica coffee beans of a commercial cultivar, Bourbon Mayaguez 139 (BM 139), were investigated in this study. Eight samples from seven coffee growing areas in the four provinces of Rwanda, selected based on where Arabica coffee growth is suitable [2], were ordered directly from the coffee washing stations (CWS).

The four provinces (northern, southern, eastern, and western) were considered in this study as geographical sub-regions of Rwanda. Two other samples, a fully washed Typica from Yirgacheffe, Ethiopia, and a dry/natural Red Bourbon from Fazenda Bau, Brazil, were bought from GSC International (Seoul, Korea). Both Bourbon and Typica are varieties belonging to *Coffea Arabica*. Crop year for all samples was 2015. Analyses were conducted in Food Engineering Laboratory and Center for Scientific Instruments, Gangneung-Wonju National University, Korea. The growing areas, CWS, and producers are indicated in Table 1.

Hydrochloric acid (0.1 M HCl and 1 M HCl), monosodium glutamate (0.1 M MSG), and sodium chloride (0.1 M NaCl) used for e-tongue were purchased from Chem-Lab (Zedelgem, Belgium). Kovats standard was purchased from Restek Corporation (110 Benner Circle, Bellefonte, PA, USA).

Roasting

All coffee samples were roasted, ground, and brewed following the cupping protocol by the Specialty Coffee Association of America (SCAA) [25]. Samples were roasted to a light-medium degree ($L^* = 31.1\text{--}39.3$) using a 500 g capacity drum roaster (Namgaver, Korea) with a roast profile monitoring software (Artisan-win-0.7.4) and the same conditions were applied to avoid the roasting effect (sample weight: 200 g, preheating temperature 180 °C, roasting time: 10 min). Roasted beans were air cooled at ambient temperature, packed in stand-up foil pouches, and left to stand for 12 h prior to brewing.

For geographical origin prediction, two additional roasting batches comprising one sample from each country (Rwanda, Ethiopia, and Brazil) were prepared as training samples (reference) to recognize test samples. Training samples were roasted and analyzed after test samples, using the same procedures and analytical conditions, except for the Brazilian coffee, which was roasted 11 min in the first batch and 12 min in the second, because the model constructed using a Brazilian sample roasted for 10 min was invalid.

Brewing

Roasted samples were ground using R-220 coffee grinder (Fuji Royal, Japan) which was set so that 74% of the grounds pass through the 20 mesh sieve. Brews were then prepared using aero-press coffee makers (Aerobie Inc. Palo Alto, CA, USA) by pouring hot water (93 °C) over the ground coffee in a ratio of 8.25 g of the grounds to 150 mL

Table 1 Information about the geographical origin, weather conditions, and labeling of coffee samples

Province (geographical sub-region)	District (growing area)	Washing station/farm	Producer/seller ^a	Cultivar/genotype	Grade/screen	Altitude (m)	Rainfall ^b (mm)	Labeling ^c
North	Gakenke	Muhondo	MCC	BM 139 ^d	15+	1700	1600	NGK
	Rulindo	Rulindo		BM 139	15+	1800–2000	1200–1300	NRL
South	Kamonyi	Nyamiyaga	RWACOF	BM 139	15+	1410	1609	SKN
	Kamonyi	Kayumbu	RWACOF	BM 139	15+	1450	1600	SKK
East	Rwamagana	Karenge	RWACOF	BM 139	15+	1395	800	ERW
West	Rutsiro	Kirorero	COOPAC Ltd	BM 139	15+	1800–2000	1300–1400	WRT
	Rusizi	Nzahaha	RWACOF	BM 139	15+	1616	1200	WRS
	Rubavu	Nyamyumba	RWACOF	BM 139	15+	1800	1600–2000	WRB
Ethiopia	Yirgacheffe		GSC	Typica	G2	1770–2200	–	ETH
Brazil	Cerrado	Fazenda Bau	GSC	Red Bourbon	NY2	1050	–	BRA

^a MCC Muhondo coffee company Ltd, RWACOF RWACOF exports Ltd, GSC GSC international

^b All data were provided by the supplier except those of NRL and WRT, which were obtained from the website of alliance for coffee excellence (ACE)

^c For Rwandan coffees, the first two letters stand for the first letter of the province and district, respectively

^d Bourbon Mayaguez-139

of water and allowed to stand for 5 min before pressing [25]. Five brews were prepared for each sample.

Odor (aroma) profile analysis

The aroma profiles of coffee brews were studied using Heracles II e-nose system (Alpha M.O.S, Toulouse, France). This device is equipped with an HS-100 autosampler, two capillary columns in parallel (MXT-5; polar and MXT-1701; slightly polar) of 10 m long and internal diameter of 180 µm, each connected to a flame ionization detector (FID).

Before running the sample analysis, 20 µL of Kovats standard (a mixture of C₆–C₁₆ alkanes) were injected into the e-nose and analyzed under the same chromatographic conditions as the samples. This is done to obtain retention indices calculated using the AroChemBase module in Alpha Soft software (Alpha M.O.S, Toulouse, France) according to the equation shown below. This also offsets instrumental variations whereby during identification of aroma compounds for characterization, a compound is qualified by its relative position in a series of analyzed alkanes and not by its retention time.

$$RI_X = 100n + \frac{100(t_X - t_n)}{(t_{n+1} - t_n)}$$

Here RI, retention index of compound X; n and n + 1, number of carbon atoms of the two alkane peaks flanking compound X; t, retention time.

Five milliliters of each brew was immediately put into 20 mL vials and capped in order to keep the fresh aroma.

The headspace was generated by an autosampler for 15 min at 60 °C with agitation at 500 rpm. Five mL from the headspace were then injected into the injector at 200 °C and a speed of 250 µL/s. The valve, trap, and desorption temperatures were set at 250, 40 and 250 °C, respectively. The column temperature increased from 40 to 270 °C at a rate of 3 °C/s in a splitless mode, whereas the acquisition time was 120 s and FID temperature was 270 °C. For each column, a chromatogram indicating the intensity of each aroma compound against its retention time for each sample was recorded and the average peak areas were calculated by the software for data analysis.

Taste profile analysis

Astree II e-tongue (Alpha M.O.S, France) equipped with seven cross-selective sensors: SRS, GPS, STS, UMS, SPS, SWS, and BRS for sourness, metallic, saltiness, umami, spiciness, sweetness, and bitterness, respectively, a Ag/AgCl reference electrode, an electronic unit with Alpha Soft software and a 48-position autosampler was used.

Passive hydration of the sensors was first performed by placing them in distilled water for 30 min, followed by conditioning, calibration, and diagnostic using 0.01 M aqueous solution of HCl, MSG, and NaCl standards. The three steps were explained in details by Ousama et al. [26], Woertz et al. [27] and Raithore et al. [28].

The same five brews per sample from which 5 mL were taken for aroma analysis were cooled at ambient temperature and filtered through Whatman filter paper No. 1. Twenty-five milliliters per brew was then poured into

beakers and placed onto the autosampler tray with two beakers containing distilled water placed before each sample for cleaning the sensors between sample measurements. For each sample, two beakers of the first brew in the sequence were placed right after beakers containing water to avoid dilution effect. The acquisition time was set to be 120 s. The potential difference between each sensor and the reference electrode against acquisition time was then recorded by the software.

Data analysis

Multivariate statistics was employed to discriminate and predict the geographical origins of coffee samples by performing principal component analysis (PCA) score plot and discriminant factorial analysis (DFA) model using Alpha Soft software. Both PCA score plot and DFA model were constructed using the most discriminating peaks (those that showed discrimination power $\geq 95\%$) selected as important odorants that contribute to the discrimination and origin character of coffee samples.

Discrimination was achieved by comparing the distances and pattern discrimination indices between sample groups on a PCA score plot, whereas geographical origins were predicted by projecting test samples onto the DFA model and recognized by the training samples. Five replicates (brews) were analyzed for each sample.

Results and discussion

Aroma discrimination

For coffee samples from Rwanda, the discussion was directed toward geographical sub-regions rather than growing areas due to similarities observed in the flavor profiles between samples from coffee growing areas in the same sub-region. Discrimination of aroma profile of coffee samples is presented on the PCA score plot (Fig. 1) constructed using 21 selected peaks (discrimination power $\geq 95\%$) as inputs. Discrimination power explains the contribution of each peak in differentiating the samples.

On a PCA score plot, samples were well separated into groups representing their geographic origins. A clear difference between Group 1 (western and southern sub-regions) and Group 2 (northern and eastern sub-regions) was evident. This separation occurred along the first principal component (PC1), which accounted for 92.1% of the information on the variation between samples. However, regardless of higher discrimination power considered, differentiation between washed Bourbon coffee from western and southern sub-regions of Rwanda (Group 1) was not possible due to similarity in their aroma intensities as

indicated by overlapping and a negative sign on the average discrimination index (-19%). Discrimination index explains how samples on the PCA map are well separated.

Since the sensor arrays of e-nose produce an integral response of the volatile components detected, samples with similar intensities of the volatile components result in similar pattern [11] and such samples may overlap on the PCA map. The opposite is true for samples with different intensities of the volatile compounds. In fact, the difference in type or proportion of intensities of the odorants present in different samples is what contributes to their aroma pattern discrimination.

The similarities observed among coffees from some regions of Rwanda can be more attributed to being of the same variety and cultivar, whereas differences may be attributed to the origin, i.e., variations in environmental factors such as altitude, temperature, rainfall, soils, farm practices, and postharvest handling of coffee beans in each area.

Among the environmental factors, altitude and rainfall (provided by the supplier) were compared among the four provinces (Table 1). Altitude of east (Group 2) was 1395 m which was close to that of south (Group 1), but not north (Group 2). Furthermore, rainfall of east was the lowest, 800 mm and the rest were in the range of 1200–2000 mm. Neither altitude nor rainfall was the factor leading to regional differences in PCA plot. Therefore, it might be a combination of environmental factors for each area that contribute to a given area specific character.

The separation along the second principal component (PC2) between Groups 1 and 2 and between Groups 2 and 3 (samples from Brazil and Ethiopia) was least as this component accounted for 5.3% of the variance. Short distances and small pattern discrimination indices (data not shown) observed between coffee samples from northern and eastern sub-regions of Rwanda as well as between Brazilian and Ethiopian coffee samples indicated that there might be a similarity in their aroma characteristics.

PCA was effective in discriminating coffee samples based on origin (growing area and countries) as reported in literature for discrimination and characterization of coffee samples of different qualities, varieties, processing, and brewing methods [10, 11, 21].

Prediction of the geographical origin

After discrimination, a DFA model (Fig. 2) consisting of one sample from each country was constructed to predict the geographical origin of the test samples. DFA is used to define an unknown sample as belonging to a well-known sample (origin, cultivar, or processing batch such as degree of roast).

Fig. 1 Principal component analysis (PCA) score plot constructed by e-nose using the most discriminating peaks for discrimination of aroma of coffee samples from different origins. Refer to Table 1 for labeling

As a great separation for coffee samples from Rwanda occurred along PC1 forming two groups, it was found reasonable to construct two DFA models by including a sample from Group 1 in the first and Group 2 in the second. The first model [Fig. 2(A)] used a sample from eastern sub-region, while the second model used a sample from western sub-region [Fig. 2(B)]. The model that included Brazilian coffee roasted for 10 min was not valid due to overlapping with Ethiopian coffee and was therefore eliminated from the model experiment. Instead, Brazilian coffees roasted for 11 and 12 min were respectively included in the first and second models.

Figure 3 (A and B) shows the recognition of test samples by their corresponding groups (same geographical sub-region or group of a similar pattern) when they were projected onto the two models. The unknown score results indicating the recognition groups and values are presented in Table 2. Similar distribution seen with the PCA plot was observed with the DFA models. In the first model, test samples from northern and eastern Rwanda were recognized by the training sample from eastern sub-region, whereas both Ethiopian and Brazilian test samples were recognized by the Ethiopian training sample.

One or two minutes of roasting of the Brazilian training samples beyond the test sample's roasting time led to unrecognition of its test sample. This indicated the effect of slight changes in the roasting conditions, which may produce a pattern different from that of the intrinsic one; this is the reason for applying the same conditions to all test samples. Once high temperatures are reached during roasting, some aroma compounds formed in the early

stages are degraded with roasting time, thus leading to changes in intensity [16]. This could be the factor that led to unrecognition of Brazilian test sample after 1–2 min roasting.

In the first model, coffee samples from western and southern sub-regions were not recognized by Rwanda's training sample, indicating a significant difference between samples from these geographical sub-regions. When test samples were projected onto the second model, which used a sample from the western sub-region, test samples from western and southern sub-regions were recognized, whereas those from eastern and northern sub-regions together with Brazilian coffee were recognized by Ethiopian coffee. This also shows a similarity to some extent in the aroma profile between the samples from Yirgacheffe, Ethiopia, and Group 2 than between Group 1 and Group 2 samples from Rwanda.

Taste discrimination

A combination of taste and aroma is what makes the important perceived coffee flavor. Astree II e-tongue detects dissolved compounds using seven cross-reactive sensors, whose responses are analyzed using AroChem-Base module. After sensor conditioning and calibration, the diagnostic procedure was successful with a discrimination index of 99% indicating that all sensors were operational. These steps were performed before sample analysis to ensure signal stability, adjust the sensors, and test sensors' discrimination ability, respectively [26, 27]. All sensor responses generated for each taste (sweetness, saltiness,

Fig. 2 Discriminant factorial analysis (DFA) models for prediction of the geographical origin of coffee samples by e-nose: the first model (A) included a Rwandan coffee from Group 1, while the second model (B) included a Rwandan coffee from Group 2 (refer to Fig. 1)

bitterness, sourness, umami, metallic, and spiciness) and for each sample were combined and converted into sensory scores that are used to describe the sample's unique taste characteristics [29].

For e-tongue, all 7 sensor values (outputs) were used for PCA. As seen from the discrimination of aroma profiles,

when the taste characteristics of coffee samples were discriminated using PCA, separation of samples along the two principal components (PC1 and PC2) based on origins was evident (Fig. 4). Coffees from western and southern sub-regions of Rwanda again revealed similarity in their flavor patterns and exhibited higher intensities of most taste

Fig. 3 Projection of test samples (in black) onto the DFA models and recognition using the training samples from the same geographical origin by e-nose: the first model (A) included a Rwandan coffee from Group 1, while the second model (B) included a Rwandan coffee from Group 2

characteristics as indicated by their positive correlation, especially sweetness, bitterness, metallic, and spiciness.

A contrary behavior was seen for coffee samples from the northern sub-region (NGK and NRL), which showed a difference in their taste profiles. This separation occurred along PC2 and resulted from exhibition of a high intensity of sourness by NGK. Sourness indicates the level of acidity, and high values have been associated with the bean quality

(defective bean) and conditions of the fermentation process that coffee beans undergo during the wet processing method [30, 31]. Sourness and sweetness among other taste characteristics of coffee can also be affected by the degree of roast; these tastes decrease with roasting [32]. This is because most acids and sugars are thermally degraded by roasting [33].

Furthermore, coffee from the eastern sub-region of Rwanda showed balanced taste characteristics that were

Table 2 Unknown scores from the projection of test samples onto the DFA models

Sample name	Recognition group	Recognized	Recognition value (%)
First model (A)			
BRA	Ethiopia (10 min)	Yes	86.6 ± 1.3
ETH	Ethiopia (10 min)	Yes	67.9 ± 4.6
NGK	Rwanda (ERW-10 min)	Yes	77.9 ± 1.5
SKK	Rwanda (ERW-10 min)	No	43.9 ± 1.3
SKN	Rwanda (ERW-10 min)	No	57.5 ± 2.8
WRB	Rwanda (ERW-10 min)	No	50.3 ± 3.3
NRL	Rwanda (ERW-10 min)	Yes	75.5 ± 3.4
WRS	Rwanda (ERW-10 min)	No	45.7 ± 2.3
WRT	Rwanda (ERW-10 min)	No	64.6 ± 1.3
ERW	Rwanda (ERW-10 min)	Yes	77.4 ± 2.8
Second model (B)			
BRA	Ethiopia (10 min)	Yes	76.6 ± 1.2
ETH	Ethiopia (10 min)	Yes	84.1 ± 0.9
NGK	Ethiopia (10 min)	Yes	90.7 ± 1.9
NRL	Ethiopia (10 min)	Yes	91.8 ± 0.8
ERW	Ethiopia (10 min)	Yes	98.2 ± 1.1
SKK	Rwanda (WRS-10 min)	Yes	91.6 ± 2.6
SKN	Rwanda (WRS-10 min)	Yes	91.2 ± 3.3
WRB	Rwanda (WRS-10 min)	Yes	88.8 ± 4.4
WRS	Rwanda (WRS-10 min)	Yes	90.7 ± 6.4
WRT	Rwanda (WRS-10 min)	Yes	95.1 ± 2.0

Data represent the mean ± standard deviation (n = 5)

Fig. 4 Principal component analysis (PCA) bi-plot constructed by e-tongue using 7 sensors for discrimination and characterization of taste profiles of coffee samples from different origins. Refer to Table 1 for labeling

closer to those of Brazilian and Ethiopian coffees and NRL from the northern sub-region of Rwanda. The same observation was made from aroma discrimination.

The flavor profile of coffee can be influenced by the roasting conditions as some components are thermally broken down while others are formed. Gloess et al. [34]

reported that changes in roasting profiles influence differently the composition of coffees from different origins. However, since this study applied the same roasting conditions, the discrimination properties observed cannot be related to the roasting conditions but to the roasting properties of coffee from each area, which produce distinct origin characteristics.

Regarding the prediction of the geographical origin using e-tongue, the recognition values were very small due to similarity in the intensity of taste profiles between samples used for the model. Thus, the models were considered to be not valid and results are not included in this article. This may be an indication that taste may not provide reliable data for geographical origin prediction compared to aroma characteristics. Nevertheless, this requires further investigations.

As a conclusion, flavor discrimination of fully washed Bourbon cultivar of *Coffea Arabica* from four geographical sub-regions of Rwanda clearly indicated sub-regional classes among Rwandan coffees. Both e-nose and e-tongue indicated a similarity in the flavor profiles of wet processed Bourbon cultivar from western and southern geographical sub-regions of Rwanda. The same applies to eastern and northern sub-regions of Rwanda as well as natural Bourbon and washed Typica from Brazil and Ethiopia, respectively. In addition, the study revealed the applicability of the DFA model in predicting the geographical origins of different coffees based on their intrinsic aroma. Further investigation is required to test the possibility of origin recognition based on taste characteristics using e-tongue.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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