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A Fuzzy Kansei Engineering for Evaluating Comfort and Sensory Preferences in Robusta Coffee Intake

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Coffee provides a comforting experience that varies among individuals, making fuzzy logic a suitable method for evaluating perceived comfort. This study aimed to assess the comfort experienced after the intake of Robusta coffee processed through different postharvest methods (wet, semi-wet, and hybrid), using Kansei Engineering and sensory preference analysis. Thirty panellists (13 women, 17 men), aged 17–65 years and regular coffee consumers, participated in the study. Descriptive analysis was conducted using XLStat, and comfort modelling was performed using a Mamdani-type Fuzzy Inference System via Python Scikit-Fuzzy. The results showed that: (1) significant heart rate changes occurred after the intake of hybrid- and semi-wet-processed coffee, while significant blood pressure changes were found only after the intake of hybrid-processed coffee; (2) postharvest processing affected Kansei physiological responses, with heart rate and oxygen saturation as key indicators of comfort; (3) increased heart rate and decreased oxygen saturation were associated with reduced comfort; (4) the intake of hybrid-processed coffee resulted in the highest comfort and sensory preference; and (5) aroma showed the strongest association with perceived comfort. These findings suggest that Kansei physiological responses can be applied as a reliable tool for evaluating comfort in coffee intake. Coffee that induces positive physiological responses may enhance emotional well-being, providing valuable input for product development aligned with consumers' affective needs.

Keywords: Affective needs, Bodily responses, Coffee processing, Consumer preferences, Flavour

Introduction

Coffee is valued for its complex sensory characteristics and psychostimulant effects, making it one of the most commonly consumed beverages globally. These attributes are shaped by numerous variables, notably postharvest methods including dry, wet, semi-wet processing, and other innovative methods.[1,2] These methods affect the chemical composition of coffee, including key compounds such as potassium, chlorogenic acid, and caffeine, which contribute to its physiological and sensory properties.[3,4]

Caffeine is known to enhance alertness and promote calming effects, whereas chlorogenic acid has been linked to improved sleep quality. Additionally, potassium acts as a vasodilator that improves blood flow, indirectly influencing mood regulation.[5] These components determine flavor and aroma and affect how coffee influences comfort, mood, and fatigue in consumers.[6,7] Increased coffee intake has been associated with reduced stress levels, contributing to a greater sense of comfort.[8]

Kansei Engineering offers a powerful approach to understand how coffee intake influences emotional and physiological comfort. Kansei Engineering is a design methodology that translates emotional responses into product features, helping manufacturers develop products aligned with consumer needs by capturing the verbal and non-verbal Kansei parameters.[9] Non-verbal parameters in coffee products are derived from physiological responses, such as blood pressure[10–12], heart rate[13,14], and oxygen saturation.[15,16] These physiological responses serve as indicators of comfort, an emotional state reflecting well-being and pleasantness, influenced by psychological balance.[5,17]

Comfort in beverage consumption refers to a mentally relaxed and pleasant state shaped by sensory perceptions such as taste, aroma, texture, or other sensory attributes, with positive experiences enhancing comfort and unfavourable attributes causing discomfort.[18–20] While coffee often evokes

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feelings of relaxation and pleasure[18], individual responses to coffee intake can vary, making comfort a subjective and complex experience.[8] Consequently, subjective rating tools, such as the Likert scale, are commonly used to assess comfort in studies.[21]

Fuzzy logic can be used alongside Kansei Engineering to interpret these subjective and physiological responses better. This combination has proven effective in modelling physiological data and decision-making under uncertainty.[22–24] Prior studies have applied this approach in contexts such as ergonomics in Small and Medium-sized Enterprises (SMEs)[25], furniture design[26], sub-grade coffee product development[27], and coffee capsule machine design.[28] However, there is a gap in research that integrates coffee intake, physiological responses, sensory preferences, and comfort levels into a single study.

This research addresses this gap by applying Kansei physiological measurements to evaluate the comfort level after intake of coffee processed using different postharvest processing methods, and sensory preferences were analysed to understand their relationship with comfort perception.

Materials and Methods

Materials

This study examined three types of Menoreh Robusta coffee from different postharvest processes: wet, semi-wet, and hybrid (Supplementary Material, Fig. S1). All samples were roasted to a medium-dark level and brewed using the *tubruk* method, following the Specialty Coffee Association (SCA) standard preparation for Robusta coffee cupping tests[29] to analyse the sensory preferences. The caffeine content varied according to the processing method: 2.21% for wet, 2.45% for semi-wet, and 2.80% for hybrid, resulting in caffeine levels of 182 mg, 202 mg, and 231 mg per 150 mL, respectively, all below the 400 mg/day maximum intake.[30] Chlorogenic acid content was 17.33 mg, 33.83 mg, and 39.60 mg for wet, semi-wet, and hybrid processing, respectively

Methodology

The conceptual model of the research methodology is shown in Fig. 1.

Experimental Protocol

Written informed consent was obtained from all participants after a briefing on the experimental procedures, which included the study objectives, the type and amount of coffee to be consumed, the sequence of physiological and sensory measurements, potential risks, and the right to withdraw at any time. Each participant was instructed to avoid coffee, tea, or cocoa products for 24 hours prior to the session. On the day of the experiment, baseline measurements were taken, followed by coffee consumption, and physiological responses were recorded at 0, 15, 30, 45, and 60 minutes after intake. The study received ethical approval from Universitas Gadjah Mada (No. KE/UGM/028/EC/2023).

Panelists

Sensory and physiological response analyses involved 30 untrained coffee-drinking panellists (13 women and 17 men), aged 17 to 65 years, with no history of heart disease, diabetes, and not pregnant or breastfeeding (women). All participants consumed coffee at least once a week.

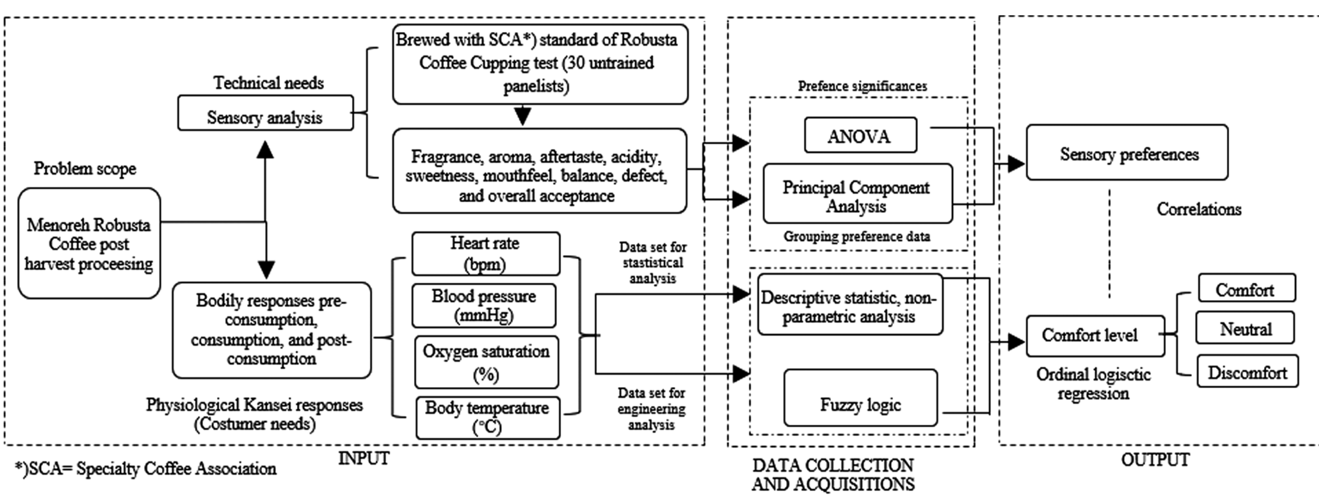

Fig. 1 — Conceptual model of research methodology

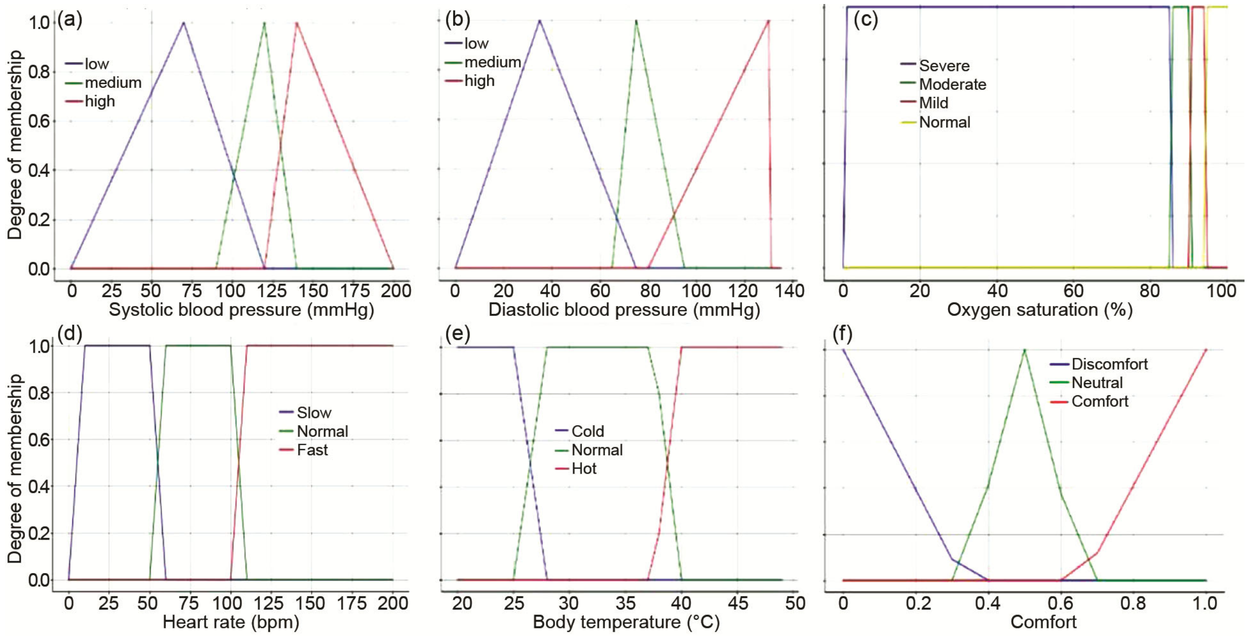

Fig. 2 — Membership functions of systole (a), diastole (b), oxygen saturation (c), heart rate (d), body temperature (e), and (f) the comfort level after intake Robusta coffee

Kansei's Engineering Physiological Responses

The panellists were instructed to avoid cocoa, tea or coffee products 24 hours before measurements. Kansei's physiological responses included heart rate (HR measured in bpm), oxygen saturation (SpO_2 measured in %), Systolic Blood Pressure (SBP measured in mmHg), Diastolic Blood Pressure (DBP measured in mmHg), and body temperature (TR measured in °C), which are the physiological responses of coffee intake from different postharvest processing collected on different days. Blood pressure and heart rate were monitored by an OMRON HEM 6200, with standard accuracy of 0–299 mmHg for pressure and 40–180 (±5%) bpm for pulse. Body temperature was measured using an infrared thermometer, and oxygen saturation was assessed using a pulse oximeter. In each measurement session, participants were asked to sit and were prohibited from moving or talking during data collection.

Fuzzy Model Building

The fuzzy inference system (FIS) comprises a set of fuzzy logic components, including fuzzification, a knowledge base, rule evaluation, and defuzzification, as illustrated in Supplementary Material, Fig. S2.

This system predicts panellists' comfort levels using rules based on predefined criteria. This study focuses on stress levels as an indicator of discomfort.[19,24] The study utilized Python's Scikit-fuzzy library to create a Mamdani-type fuzzy inference system, employing 324 rules that link input variables using the 'AND' connector. Kansei's Engineering physiological responses used as inputs are presented in the Supplementary Material, Table S1.[22,24,31] The output, Body Response (BR), discomfort (0–0.3), neutral (0.3–0.6), and comfort (0.6–1)[23,24] (Fig. 2).

Generally, the formula calculates the input membership function as follows[22,24]:

$$\text{Low} = \begin{cases} 1, x \leq a \\ \frac{b-x}{b-a}, a \leq x \leq b \\ 0, x \geq b \end{cases} \qquad \ldots (1)$$

$$\text{Normal} = \begin{cases} 0, x \leq aataux \geq c \\ \frac{x-a}{b-a}, a \leq x \leq b \\ \frac{c-x}{c-b}, b \leq x \leq c \end{cases} \qquad \ldots (2)$$

$$\text{High} = \begin{cases} 0, x \leq a \\ \frac{x-a}{b-a}, a \leq x \leq b \\ 1, x \geq b \end{cases} \qquad \ldots (3)$$

where, a = the minimum limit, b = the transition/middle limit, c = the maximum limit, and x = the data being evaluated in the fuzzy system. This study applies the centroid of area approach to evaluate the panelists' comfort[24], Z = the defuzzified result, q = the number of rules, uc = the membership value for class c at output Zj.

$$Z = \frac{\sum_{j=1}^{q} z_j u_c(z_j)}{\sum_{j=1}^{q} u_c(z_j)} \quad \dots (4)$$

Sensory Analysis

Coffee samples' sensory evaluation was carried out using a structured 7-point hedonic scale to quantify panellists' preference levels, where a score of 1 signified intense disliking, and 7 indicated a high degree of liking. The 7-point hedonic scale was chosen as a widely used method in sensory evaluation, offering simplicity for untrained panellists and adequate sensitivity to detect differences in consumers' preferences.[32–35] Panellists rated fragrance before coffee tasting and then evaluated aroma, aftertaste, acidity, sweetness, mouthfeel, balance, defects, and overall acceptance after tasting the coffee samples.

Data Analysis

The body response data were summarized by descriptive statistics, and fuzzy logic was applied using the Scikit-Fuzzy Python library in a Mamdani-type system to analyse the comfort index.[36,37] The relationships between independent and dependent variables were assessed using Friedman, Spearman Rank Correlation, and Kruskal-Wallis tests. To evaluate the impact of coffee type and Kansei-related physiological changes over time on comfort levels, Ordinal Logistic Regression (OLR) was applied to determine their statistical significance. Principal Component Analysis (PCA) was used to identify coffee sensory preferences. All statistical analyses were performed using XLStat software.

Results and Discussion

Kansei Physiological Responses Changes

The Kansei physiological response outcomes, including percentage changes pre- and post-intake of coffee from the three processing methods, are detailed in Table 1. Corresponding trends in physiology are depicted in

As shown in Table 1, systolic blood pressure occurs during heart contraction, whereas diastolic pressure occurs during relaxation.[38] Coffee intake affects blood pressure due to caffeine, which peaks in the bloodstream within 45–60 minutes, raising blood pressure through sympathetic activation and increased cortisol levels.[10,12] This study demonstrated that the intake of Robusta coffee from hybrid processing led to significant changes in both systolic and diastolic blood pressure ($p < 0.05$, Friedman test). A post-hoc analysis using the Nemenyi test ($\alpha = 0.05$) revealed a significant rise in diastolic and systolic blood pressure 60 minutes after coffee intake compared to pre-intake levels ($p = 0.030$ and 0.015, respectively). Meanwhile, Robusta coffee from semi-wet and wet processing did not produce significant effects on diastolic and systolic blood pressure.

Studies have shown that coffee intake affects the heart rate differently among panellists. It can either reduce the heart rate[39] or increase it up to 60 minutes post-intake.[40] In this study, there was a significant decrease in heart rate between the baseline and 15th to 60th minutes after intake of coffee from hybrid and semi-wet processing ($p < 0.05$, Friedman test). The most notable decrease occurred at 15th minutes post-intake and persisted until the 60th minute. Additionally, the highest percentage change in heart rate (ΔHR) was observed at the 45th minute for hybrid-processed coffee (9.50%) and at the 15th minute for semi-wet processed coffee (10.13%). Meanwhile, coffee from wet processing significantly affects heart rate, despite the Friedman test ($p = 0.043 < 0.05$). However, post-hoc analysis by Nemenyi test found no significant differences in % ΔHR ($p = 1.00$), indicating consistency in the panellists' heart rates during the observation period or limited variation, with the correction in subsequent tests reducing the sensitivity to small changes in heart rate.

Coffee intake also affects oxygen saturation due to caffeine.[41] However, the Friedman test results in this study showed that oxygen saturation was not significantly affected by coffee from any of the three processing types ($p > 0.05$).

Caffeine can boost metabolism and raise body temperature, with varying effects based on individual habits and genetics.[42] Based on the Friedman test results, coffee intake from hybrid and semi-wet processing did not have a significant effect on body temperature changes. Nevertheless, a significant elevation in body temperature was observed 30 minutes after intake of wet-processed coffee ($p < 0.05$), although no significant differences were observed at 45th and 60th minutes. Overall, changes in body temperature were not significantly affected by the type of coffee ingested ($p > 0.05$).

Sensibility of Kansei Physiological Responses to Comfort Level

Comfort during coffee intake is a positive experience, as caffeine enhances alertness and readiness.[8,43,44] In this study, comfort levels were

Table 1 — Kansei physiological response and the changes before and after intake of Robusta coffee from 3 processing methods (wet, semi-wet, and hybrid)

Body responses	OT	Coffee postharvest processes					
		Wet ± SD	Δ ± SD	Semi-wet	Δ ± SD	Hybrid	Δ ± SD
SBP (mmHg)	BC	123.20 ± 14.56	0.00 ± 0.00a	120.79 ± 12.83	0.00 ± 0.00a	119.37 ± 11.65	0.00 ± 0.00a
	C0	124.63 ± 18.97	0.35 ± 8.98a	122.36 ± 11.31	1.51 ± 8.55a	123.57 ± 14.09	2.97 ± 7.43ab
	C15	123.63 ± 14.97	−0.32 ± 12.63a	125.00 ± 14.59	2.59 ± 8.04a	122.60 ± 13.33	2.42 ± 4.80ab
	C30	122.27 ± 14.73	−1.34 ± 10.94a	122.04 ± 14.33	0.68 ± 6.97a	124.20 ± 12.58	3.48 ± 8.33ab
	C45	121.83 ± 14.07	−1.34 ± 7.35a	123.07 ± 12.74	1.67 ± 7.26a	123.93 ± 12.13	3.37 ± 7.82ab
	C60	122.50 ± 13.53	−0.95 ± 9.44a	124.21 ± 12.23	2.10 ± 6.19a	125.97 ± 12.48	4.94 ± 7.54b
p-value			0.901		0.257		0.004
DBP (mmHg)	BC	81.36 ± 8.69	0.00 ± 0.00a	80.21 ± 8.72	0.00 ± 0.00a	77.97 ± 8.93	0.00 ± 0.00a
	C0	84.10 ± 11.70	2.36 ± 10.8a	80.79 ± 8.14	0.67 ± 6.06a	79.33 ± 10.61	10.40 ± 10.40ab
	C15	82.23 ± 8.38	0.83 ± 7.87a	82.97 ± 9.03	2.75 ± 7.62a	81.83 ± 9.62	7.66 ± 7.66ab
	C30	80.67 ± 8.00	−1.13 ± 8.72a	81.90 ± 9.06	1.46 ± 7.40a	81.43 ± 8.74	8.83 ± 8.83ab
	C45	81.67 ± 7.53	0.22 ± 7.71a	80.25 ± 9.24	−0.81 ± 8.68a	81.80 ± 9.40	9.13 ± 9.13ab
	C60	79.87 ± 9.74	−2.59 ± 10.92a	81.18 ± 8.19	0.93 ± 6.29a	83.30 ± 8.45	9.74 ± 9.74b
p-value			0.120		0.080		0.003
O_2 (%)	BC	97.13 ± 1.61	0.00 ± 0.00a	97.29 ± 1.59	0.00 ± 0.00a	97.03 ± 1.47	0.00 ± 0.00a
	C0	96.97 ± 1.21	−0.18 ± 1.61a	97.07 ± 1.43	−0.28 ± 1.25a	97.00 ± 1.50	−0.04 ± 1.40a
	C15	97.17 ± 1.60	0.01 ± 2.29a	97.54 ± 1.35	0.13 ± 1.31a	97.17 ± 1.56	0.13 ± 1.33a
	C30	97.40 ± 1.83	0.25 ± 1.98a	97.46 ± 1.14	0.20 ± 0.20a	96.97 ± 1.71	−0.08 ± 1.57a
	C45	97.36 ± 0.93	0.24 ± 1.54a	97.50 ± 1.14	0.23 ± 0.23a	97.03 ± 1.52	−0.01 ± 1.67a
	C60	97.83 ± 1.18	0.71 ± 1.70a	97.50 ± 1.32	0.09 ± 0.09a	96.97 ± 1.61	−0.08 ± 1.41a
			0.053		0.370		0.980
HR (bpm)	BC	74.27 ± 9.44	0.00 ± 0.00a	74.96 ± 8.20	0.00 ± 0.00b	75.67 ± 11.25	0.00 ± 0.00ab
	C0	72.80 ± 9.90	−2.52 ± 9.86a	73.57 ± 9.63	−3.07 ± 10.93ab	72.83 ± 8.85	−4.08 ± 10.78a
	C15	69.37 ± 7.75	−7.60 ± 12.69a	68.61 ± 9.77	−10.13 ± 14.37a	70.57 ± 10.12	−7.52 ± 9.73a
	C30	69.90 ± 8.50	−6.88 ± 12.43a	68.82 ± 8.00	−3.70 ± 8.98ab	70.97 ± 9.34	−6.81 ± 9.84b
	C45	69.87 ± 8.38	−6.93 ± 12.81a	69.71 ± 8.14	−8.62 ± 11.34a	69.07 ± 8.13	−9.50 ± 9.67a
	C60	70.80 ± 8.68	−5.59 ± 13.47a	68.34 ± 11.37	−12.82 ± 24.56a	70.33 ± 10.41	−7.92 ± 9.34a
p-value			0.043		<0.0001		0.0001
T (°C)	BC	36.60 ± 0.29	0.00 ± 0.00a	36.60 ± 0.24	0.00 ± 0.00a	36.59 ± 0.26	0.00 ± 0.00a
	C0	36.56 ± 0.27	−0.10 ± 0.65	36.72 ± 0.25	0.67 ± 6.06a	36.68 ± 0.28	0.24 ± 0.73a
	C15	36.66 ± 0.28	0.18 ± 0.89	36.65 ± 0.25	2.75 ± 7.62a	36.60 ± 0.29	0.01 ± 0.72a
	C30	36.76 ± 0.29	0.44 ± 0.72	36.66 ± 0.25	1.46 ± 7.40a	36.66 ± 0.26	0.20 ± 0.75a
	C45	36.71 ± 0.25	0.32 ± 0.74	36.66 ± 0.25	−0.81 ± 8.68a	36.68 ± 0.30	0.25 ± 0.72a
	C60	36.72 ± 0.33	0.34 ± 0.79	36.68 ± 0.26	0.93 ± 6.29a	36.67 ± 0.25	0.21 ± 0.55a
p-value			0.00001		0.042		0.148

*) SBP = systolic blood pressure; DBP = diastolic blood pressure; O_2 = oxygen saturation; HR = heart rate; T = body temperature; OT = observation times; BC = before coffee intake; C0 = shortly after coffee intake; C15 = 15 min after coffee intake; C30 = 30 min after coffee intake; C45 = 45 min after coffee intake; and C60 = 60 min after coffee intake. The data are expressed as the mean ± standard deviation (SD) (sample size = 30). Means sharing the same letter within a row indicate no significant difference (Nemenyi test, $p < 0.05$).

inversely related to stress, which can elevate heart rate and blood pressure[10–12,23], heart rate[13,14], and oxygen saturation.[15,16] Although comfort is difficult to measure directly, it can be linked to bodily responses such as Kansei physiological responses. The FIS effectively predicted comfort indices without overlapping, showing the variance in panellists' comfort percentages over time, reflecting both comfort levels and indices (Fig. 3).

As illustrated in Fig. 3, comfort responses recorded over a 60-minute period varied according to the postharvest processing of the Robusta coffee samples, each distinguished by different levels of caffeine and chlorogenic acid. Wet processing experienced a 3%

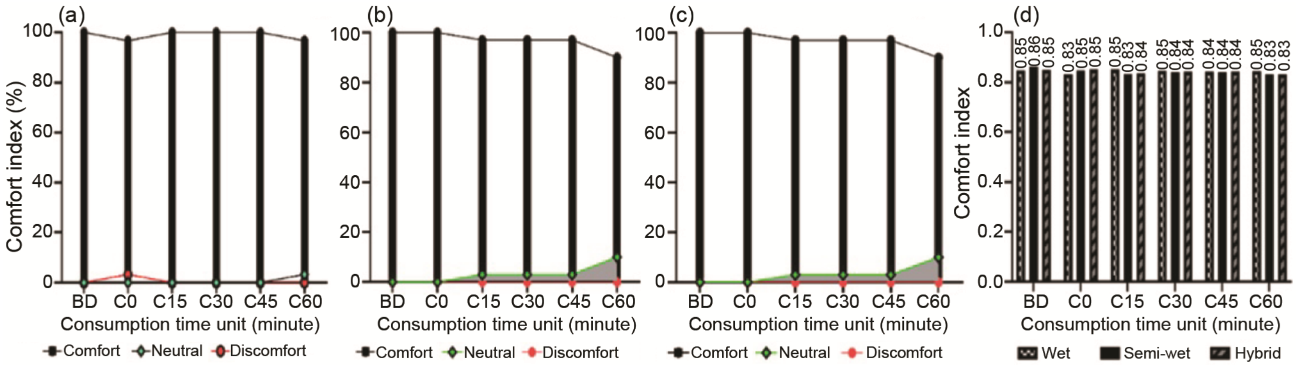

Fig. 3 — Comfort distribution analysis of Robusta coffee intake using the FIS model for coffee produced by three different postharvest (wet, semi-wet, and hybrid) processes: (a) wet-processed, (b) semi-wet-processed, (c), hybrid-processed, and (d) changes in respondents' comfort levels based on the comfort index; [Note: BD = before coffee intake, C0 = shortly after coffee intake, C15 = 15 min after coffee intake, C30 = 30 min after coffee intake C45 = 45 min after coffee intake C60 = 60 min after coffee intake; sample size = 30]

decrease in comfort after intake (Fig. 3a), likely due to increased blood pressure and decreased body temperature and oxygen saturation, although all remained within normal ranges. Semi-wet processing saw a decrease in comfort after 15 minutes (97% of panellists felt comfortable and 3% neutral) of coffee intake (Fig. 3b). Notably, the hybrid-processed coffee demonstrated the highest comfort levels, with all panellists (100%) consistently reporting a sense of comfort throughout the entire observation period (Fig. 3c). This variant contained the highest concentrations of caffeine (231 mg/cup) and chlorogenic acid (39.60 mg/cup), surpassing those found in coffees processed by wet and semi-wet methods. Higher levels of caffeine and chlorogenic acid have been associated with a greater ability to reduce the stress hormone cortisol.[3,45,46] In the context of this study, this physiological response corresponds to an enhanced sense of comfort after coffee intake. Overall, hybrid processing consistently provided the highest comfort levels. For all the methods, the average comfort index remained above 0.66 for all methods, indicating comfort.

Robusta coffee intake from different processing methods affects Kansei physiological responses, which determine the panellists' comfort levels. Based on Kruskal-Wallis's analysis results, the percentage change in comfort level did not differ significantly across the observation periods after intake of the three types of coffee ($p > 0.05$). Further analysis using Ordinal Logistic Regression showed that the sensitivity of the comfort level was significantly influenced by Kansei physiological responses, particularly heart rate and oxygen saturation. This was supported by significant percentage changes in oxygen saturation and heart rate ($p < 0.05$) (Table 2).

Wet coffee processing and the 60th minute post-coffee intake were used as baselines for the OLR analysis in the default model based on categorical ordering. An increased heart rate and decreased oxygen saturation were found to significantly reduce the comfort level of the panellists (Table 2). Based on the odds ratio values, a 1% increase in heart rate decreased the comfort level by 19.2%, whereas a 1% decrease in oxygen saturation reduced the comfort level by 9.3%. Although the Friedman analysis indicated no significant differences in heart rate and oxygen saturation across time points, the OLR results revealed that changes in heart rate and oxygen saturation had a significant impact on comfort sensibility.

These findings suggest that the relationship between Kansei physiological responses and comfort levels is influenced not only by the timing of measurements but also by the overall physiological patterns of each panellist. Based on the odds ratios and comfort levels, coffee from hybrid processing provided the highest comfort level compared to coffee from wet and semi-wet processing.

These findings suggest that the Kansei physiological responses approach can be used as an indicator to evaluate the comfort levels after coffee intake. Coffee that elicits significant physiological response sensitivity has the potential to provide customers with positive emotional experiences or a sense of comfort for consumers, thereby contributing to the development of objective and measurable affective need-based products.

Table 2 — Ordinal logistic regression analysis of the effects of percentage changes in Kansei physiological responses, post harvest coffee processing methods, and post-intake time intervals on comfort level

Variables	p-value	β	Odds Ratio (OR)
Kansei Engineering physiological responses			
% ΔSBP	0.079	0.078	1.081
% ΔDBP	0.920	−0.005	0.995
% ΔHR	<0.0001	−0.213	0.907
% ΔO_2	0.023	−0.098	0.808
% ΔT	0.376	0.036	1.037
	Coffee postharvest		
Wet (baseline)	—	—	1
Semi-wet	0.560	−0.028	0.972
Hybrid	0.451	0.037	1.038
	Observation times		
BC	0.502	0.037	1.038
C0	0.579	0.030	1.030
C15	0.386	0.048	1.049
C30	0.198	0.069	1.071
C45	0.212	0.067	1.069
C60 (baseline)	—	—	1

Note: ΔSBP = change in systolic blood pressure; ΔDBP = change in diastolic blood pressure; ΔHR = change in heart rate; ΔO2 = change in oxygen saturation; ΔT = body temperature; BD = before coffee intake; C0 = shortly after coffee intake; C15 = 15 min after coffee intake; C30 = 30 min after coffee intake; C45 = 45 min after coffee intake; and C60 = 60 min after coffee intake.

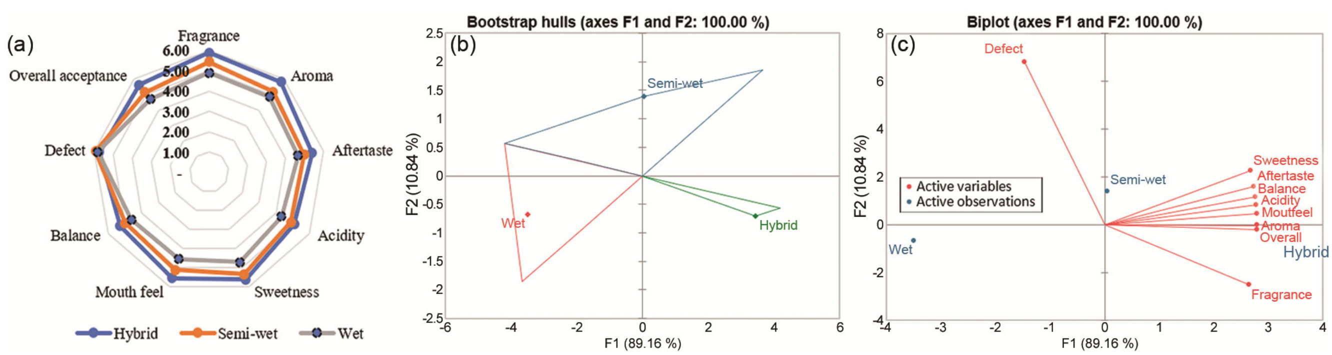

Fig. 4 — The sensory evaluation of panellists in Robusta coffee consumption from wet, semi-wet, and hybrid processing: (a) sensory preference, (b) PCA (Bootstrap hulls), (c) PCA (Biplot)

Sensory Preferences

Panellists favoured hybrid processing coffee for its sensory preferences, showing significant differences except for defects (Fig. 4a and Supplementary Material, Table S2). In this study, higher defect preference scores were correlated with lower flavour defects. Wet processing received the lowest preference compared with semi-wet and hybrid methods. PCA was used to analyse the relationship between coffee postharvest processing and its sensory characteristics (Fig. 4a).

The study found that F1 and F2 explained 100% of the variation in the samples, with F1 explaining the majority (89.67%). Sensory preferences were similar between semi-wet and hybrid processing, with hybrid processing showing high preferences for fragrance, aroma, aftertaste, acidity, sweetness, mouthfeel, balance, and overall acceptance (Fig. 4 (b & c). Overall acceptance was significantly correlated with sensory attributes, except for defect (Spearman correlation, p<0.005).

Correlation between Sensory Preferences and Comfort Level

Sensory preferences impact the individual's comfort experience after drinking coffee. These preferences are subjective and vary among consumers, influencing their perceptions of coffee quality and satisfaction.[47] This perception was closely

Table 3 — Correlation of comfort level and sensory preference by Spearman Rank Correlation (n = 30)

Sensory preferences	ρ	p-value
Aroma	0.301	0.107
Aftertaste	0.197	0.296
Fragrance	0.180	0.339
Overall acceptance	0.031	0.869
Sweetness	0.006	0.974
Acidity	−0.085	0.652
Balance	−0.195	0.301
Defect	−0.219	0.244
Moutfeel	−0.253	0.178

linked to the comfort felt during and after coffee intake. This study explored how sensory preferences relate to comfort levels after drinking coffee from three different postharvest processes, using Spearman's Rank Correlation ($\alpha = 0.05$) (Table 3). In this study, sensory preferences were correlated with comfort levels measured 30 minutes after coffee intake. This point was selected based on the significance of Kansei physiological responses, particularly heart rate, which began to change significantly at 15 min post-intake but remained statistically insignificant up to 60 min. In addition, this observation period (30 min) showed the highest average comfort index across the three coffee types (0.843).

There was no significant relationship between the average sensory preferences from the three types of coffee and the comfort index informed by the Spearman Rank Correlation analysis result ($p > 0.05$) (Table 3). However, aroma appears to have the strongest relationship with the comfort level compared to other sensory attributes (weak positive, $\rho = 0.301$).[48] This finding indicates that if sensory preferences cannot be generalized from the combination of the three types of coffee to reflect the physiological comfort of the panellists, the relationship must be seen from the sensory preferences of each type of coffee. The Spearman rank correlation between comfort level and sensory preference in coffee processing indicated that only the fragrance attribute of semi-wet processed coffee had a significant positive contribution to the comfort level ($p = 0.035$, $\rho = 0.40$) (Supplementary Material, Table S3).

Although basic inclusion and exclusion criteria were applied, we acknowledge that individual differences in caffeine tolerance and habitual coffee consumption may have influenced both sensory and physiological responses, potentially affecting perceived comfort levels. Future studies could address this by controlling for or stratifying participants based on caffeine sensitivity. Nevertheless, these limitations do not diminish the overall quality and relevance of our findings.

Conclusions

Kansei Engineering and fuzzy logic effectively captured physiological comfort responses to Robusta coffee processed through different postharvest processing. Heart rate and oxygen saturation were the most sensitive indicators for comfort, while aroma showed the strongest sensory correlation with comfort. The coffee from hybrid processing achieved the highest sensory preference and a 100% comfort level across all observation periods. Although the findings are encouraging, the study is constrained by a limited sample size and restricted linguistic range. Broader datasets and richer emotional descriptors are recommended to strengthen future applications in coffee product innovation.

Supplementary Matter

Supplementary data of this article is available at https://nopr.niscpr.res.in/handle/123456789/46 and https://or.niscpr.res.in/index.php/JSIR/article/view/18697.

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