



Gen Z sensory perspective on turmeric-based *jamu* transformed into kombucha through convolutional neural network approach

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Abstract

Jamu, an Indonesian traditional herbal drink, is widely consumed for health maintenance but is often perceived as bitter, pungent, and outdated by younger generations. To preserve this cultural heritage, transforming *jamu* into kombucha offers both improved sensory appeal and functional benefits. This study examined the characteristics and sensory perception of kombucha made from turmeric and a mix of turmeric–tamarind leaves, evaluated at serving temperatures of 25°C and 9°C. Sensory evaluation employed Rate-All-That-Apply (RATA) and Temporal Dominance of Sensations (TDS), validated using Facial Emotion Recognition (FER) and Facial Landmarks Distance (FLD) analyses via a Convolutional Neural Network (CNN). Results showed that, despite pungent or bitter notes, sourness was the dominant attribute across samples ($p < 0.05$). Sourness was perceived for a longer duration in kombucha served at 9°C compared to 25°C. Although GC–MS detected bitterness, it did not significantly affect preference ($p > 0.05$). FER results were dominated by positive expressions ($p < 0.05$), confirming overall acceptance, while FLD analysis revealed significant changes in five facial landmarks associated with positive emotions. Male participants exhibited more positive expressions than females ($p < 0.05$). These findings suggest that converting *jamu* into kombucha effectively enhances its palatability and emotional acceptance, making it a promising strategy to modernize traditional beverages. *Jamu* based kombucha can thus serve as a culturally rooted, functional drink suitable for Gen Z consumers and adaptable to various serving temperatures.

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1. Introduction

From the Mataram Empire to date, Indonesians have been consuming the herbal drink called *jamu* to maintain body health. *Jamu* treatment and blends are portrayed in the Karmawibhanga relief on the 8th-century Borobudur Temple, and herbal medicinal plants are depicted in the reliefs of the Prambanan, Penataran, Sukuh, and Tegawangi Temples established in Majapahit by Prabu Hayam Wuruk, indicating careful oversight of healing. The Majapahit Empire archaeological heritage location map is displayed in Figure 1. The Balawi inscription (1305 AD) mentions *tuha nambi*, *kdi*, and *walyan* as professions in medicine (1). Meanwhile, the Bendosari inscription (1360 AD) calls the village healer '*janggan*,' and the Madhawapura inscription names the herbal drink compounder '*acaraki*.' Before producing any herbal drinks, fasting, prayers, and meditation are performed upon the plants from which the ingredients are obtained for direction and healing. These herbal drinks, or *jamu*, have the capability of preventing and soothing several diseases. Plant extracts are used in *jamu*

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processing. Usually, *jamu* contains turmeric, ginger, galangal, aromatic ginger or *kencur*, and cinnamon, with rock sugar, lime juice, and brown sugar providing sweetness (2).

Jamu has been authorized as an Intangible Cultural Heritage of Humanity by UNESCO. It has been utilized by Indonesians since the eighth century. Hot illnesses are believed to be cured by cold medicines, and cold diseases are cured by hot medicines, with a healthy body balancing heat and cold elements. The color and shape of plants play a role in enhancing organ health. *Jamu* is intended to boost immunity and retain well-being. *Jamu* distributors, cultivators, and consumers bear the roles as practitioners of the *jamu* culture. Anyone can take and make *jamu*, but most are adult women. *Jamu* producers cultivate herbs and spices to create recipes suited to each customer's age, lifestyle, and health issues. The process of *jamu* making is handed over through families and fellow residents, but some people are self-taught. *Jamu* is also taught at universities. *Jamu* fosters trust, and unity in society (3).



Figure 1. Historical location of the Majapahit Empire in East Java, Indonesia.

Traditional Javanese medicines take the form of "*empon-empon*," "*botekan*," "*jamu cekok*," and "*jamu gendong*." *Empon-empon* and *botekan* are still widely consumed in Javanese rural communities. *Jamu gendong*, too, is still commonly taken, but it is now well-known not only in various regions of Indonesia, but also overseas. *Jamu gendong* is prepared, whether pure or mixed, to maintain health, boost the body's resistance to diseases, cure illnesses, and serve other purposes. *Jamu gendong* literally refers to decoctions sold by women on their backs. However, *jamu gendong* is now also produced by simple, traditional, home-based enterprises. Traditional *jamu* producers consider cleanliness, sanitation, and biological and non-biological chemical pollutions. They strive to protect raw materials and finished products against contamination, but they do not observe worldwide industrial standards. The raw material selection, sorting, grating, scraping, crushing, mixing, heating, and hygienic boiling involved in making *jamu* varies from producer to producer (4).

Before the word "*jamu*" became popular, ancient Javanese manuscripts referred to it as "*oesada*" or "*jampi*". The word "*oesada*" focused more on health, while the word "*jampi*" incorporated the element of prayers for healing with concoctions of medicinal plants. The word "*jamu*" is derived from the word "*jampi*" and was used outside the royal palace circle by "*wiku*" and "*dukun*" (priests). The term "*jamu*" has roots in Indonesian culture, especially among the Javanese ethnic community. The tradition of *jamu* concoction focuses on physical health and reflects a deep connection between nature, spirituality, and healing. The *jamu* made of rice and aromatic ginger or *kencur* is used to treat various physical diseases. It also prevents post-workout pain. Many say aromatic ginger enhances health and appetite.

Curcumin, the main compound in turmeric, ginger, and aromatic ginger, has been clinically tested for its ability to cure inflammatory diseases or protect the skin from inflammation and such skin problems as red spots, improve stamina by increasing estrogen levels and antioxidant activity, and reduce heart disease risk by neutralizing free radicals and saturated fatty acids. In addition to active components, fresh and dried *simplisia* from roots, rhizomes, stems, leaves, flowers, and fruits are used at standard dosages. *Jamu godog* literally means bringing water with fresh and dried *simplisia* to a boil. Other ingredients such as Indonesian bay leaf or *daun salam*, green chiretta or *sambiloto*, turmeric, red ginger, ginger, guava, and Javanese chili have been scientifically evaluated (5).

Turmeric (*Curcuma longa*) is a rhizomatous plant with a yellowish color and a distinctive aroma that is used as an ingredient of herbal drinks in Indonesia due to its ability to alleviate several diseases such as liver damage and cancer, boost the body's immune system, and serve as an antibacterial agent (6). However, the bioactive compounds in turmeric are low in bioavailability because they are still limited by other components. The bioavailability of these bioactive compounds can be increased by fermentation, for example, by converting the compounds into kombucha (7). Kombucha is a traditional beverage produced from the fermentation of tea and sugar solutions using a mixed culture of acetic acid bacteria and several types of yeasts. Given the antioxidant and anti-inflammatory activity of the compounds that it contains, turmeric can be processed into kombucha (8).

Many Indonesian merchants have formulated useful herbal treatments. People usually have preferences for *jamu paitan* (bitter *jamu*), *jamu kunir-asem* (a concoction of turmeric and tamarind), *jamu beras-kencur* (a concoction of rice and aromatic ginger), *jamu temulawak*, and *gula asem* (a drink made of sugar water and tamarind). *Jamu* has the ability to promote health. Its composition may comprise *kedawung* seeds, cumin, *pandan* leaves, lemongrass, lime, cinnamon, and/or ginger, and it can be taken in addition to medical ingredients. Javanese sugar, or palm sugar, sweetens the drink. Ginger, tamarind, palm sugar, *pandan* leaves, and cumin can also be added. *Jamu* can treat dizziness, nausea, and the common cold in children and elderly people, respectively. *Tinospora cordifolia* is an ingredient that makes *jamu paitan* the most difficult to enjoy, but people still consume it because it helps with pain, swelling, inflammation, and arthritis. *Lempuyang*, or bitter ginger, when combined with Javanese chili, can fight the common cold, promote energy, and lower flatulence. It is also helpful in decreasing women's blood pressure, constipation, and menstrual pain (9).

Members of younger generations dislike *jamu* due to its bitter taste and pungent rhizome-like aroma (10). The sensory acceptance of *jamu* is limited to them, especially Gen Z'ers. To overcome the weaknesses of traditional *jamu* in these respects, we propose the transformation of traditional *jamu* into kombucha for a rich, pleasant taste and health benefits. The proposed transformation is illustrated in Figure 2.

Kombucha's growing market targets health-conscious members of younger generations. Sugar and tea ferment into kombucha with the infusion of SCOBY colonies (11). This drink has long been consumed globally. Its origin might date back to approximately 220 BC in China or Manchuria. The drink is called "*chájūn*" (茶菌) in Chinese, meaning "tea mushroom". From "*kombu*" and "*cha*" the name "*kombucha*" is obtained. Kombu, a fifth-century AD Korean physician, cured Inkyo in 414 BC. The doctor used fermented tea to relieve the emperor's constipation. The monarch then named the tea blend "*kombucha*" after the medical expert Kombu. The ancient Chinese people dubbed kombucha "*the tea of immortality*" and "*immortal health elixir*." Asia, Eastern Europe, and Russia later also enjoy kombucha. Russians

call this drink "tea kvass," while Latin Americans do "hongo de té." Kombucha started to become popular in Russia and Germany in the late 19th century. In the early 1900s, Eastern European immigrants brought kombucha to America. Herbalists and alternative medicine fans subsequently fell in love with kombucha for its health benefits. The early 21st century also witnessed kombucha's rise in popularity. As with their predecessors, health-conscious people during this period flocked to it for its many health benefits. Anyone can make kombucha with a SCOBY, resulting in many kinds of kombucha (12).

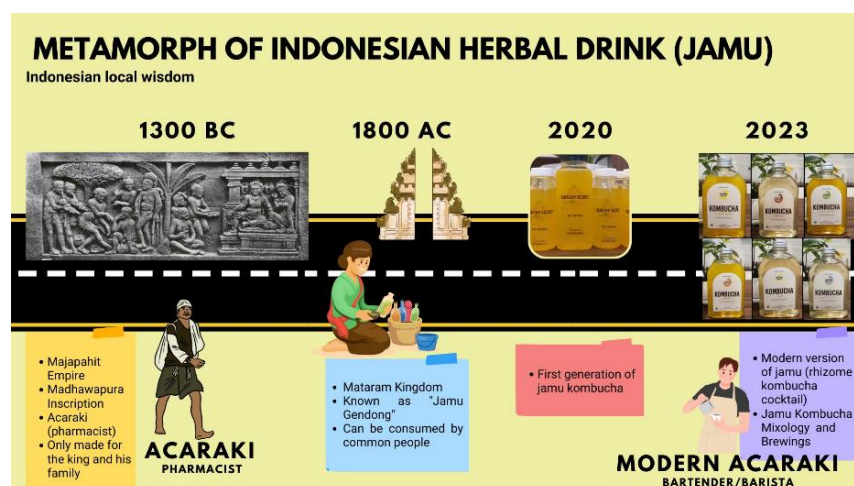


Figure 2. Historical transformation of traditional *jamu*.

In an earlier study, turmeric and black tea kombucha were found to improve the adaptive immune response, as shown by increased CD4⁺, TNF α , and IFN- γ levels. They were also able to strengthen the innate immune response, as indicated by decreased CD68 and IL-6 levels (8). While both samples exhibited significant beneficial outcomes, the *in vivo* immunomodulatory efficacy of turmeric kombucha was more evident than that of black tea kombucha. Fermentation enhanced the hepatoprotective action of turmeric kombucha by releasing chemicals and generating new bioactive molecules, resulting in a favorable impact. Consequently, the hepatoprotective activity was more pronounced in Balb/C mice when they were given fermented turmeric kombucha rather than turmeric essence beverage (13).

However, there are concerns about kombucha beverage products in Indonesia because they contain alcohol. In the fermentation process of kombucha, the yeast *Saccharomyces cerevisiae* converts sugar (sucrose) in the media into alcohol and other compounds. Although the alcohol formed will also be oxidized into acetic acids by *Acetobacter xylinum* bacteria, there will still be alcohol compounds left behind and not oxidized into acetic acids (14). Therefore, an effort was made to reduce the alcohol content in turmeric kombucha using low-pressure evaporation technology.

The purpose of this study was to examine the sensory characteristics of *jamu*-based kombucha taking into account the Gen Z respondents' perspectives, the chemical contents of the drink, the respondents' acceptance level, and the respondents' facial expressions after consuming the drink. Rate-all-that-apply (RATA) and temporal dominance of sensations (TDS) methods were employed in a sensory evaluation to assess the intensity and duration of sensory attributes. Meanwhile, an analysis of facial expressions was conducted using a Convolutional Neural Network (CNN) approach for facial emotion recognition (FER) and facial landmarks distance (FLD). FER has the capability to analyze and understand facial expressions.

It can identify positive emotions, such as happiness, and negative emotions, such as sadness, anger, and disgust (15). Panellists might show signs of happiness if they took a liking in the *jamu*-based kombucha, or expressions of disgust and anger if they rejected it. FER was expected to enhance the sensory analysis. FLD was used to analyze the facial features that strongly indicated positive or negative expressions based on the previous FER responses, enhancing the sensory evaluation of the *jamu*-based kombucha.

2. Materials and Methods

2.1. Materials

Turmeric (*Curcuma longa*) and tamarind (*Tamarindus indica*) leaves were obtained from a traditional market in Malang, East Java, Indonesia. These raw materials were washed and cut into small sizes. They were then dried using a cabinet dryer (60°C, 5 h), powdered, and put into a teabag at 6 g each. The commercial kombucha starter culture/colony was purchased from a local distributor, and 10% (w/v) was added. Kombucha was fermented for 7 days at room temperature (25°C). The substrate used in the kombucha fermentation process was sucrose (C₂₂H₂₂O₁₁). Sucrose is a substrate for microbial cultures. The ideal sugar concentration for making kombucha is approximately 10% (w/v) (16).

2.2. Soluble Sugar Content

The total sugar content was tested according to previous methods (17), using anthrone reagent and H₂SO₄. A kombucha sample was mixed with aquadest solution and CaCO₃ and then homogenized. The mixture was heated at 95 °C for 30 minutes and then cooled to room temperature (25°C). After that, a saturated Pb-acetate and Na-oxalate mixture, as well as aquadest, was added to the sample. The sample was then homogenized and filtered using a piece of filter paper. The filtrate obtained was diluted, and 1 ml was added to 5 ml of anthrone reagent. The sample solution was homogenized and then heated in a water bath for 12 minutes at 95°C. Next, the absorbance of the cooled sample solution was measured spectrophotometrically at 630 nm. The process was repeated three times for each sample.

2.3. Total Organic Acid Content

The total organic acid content measurement was guided by previous methods (18) with some modifications. For each of the turmeric kombucha and turmeric-tamarind leaf kombucha, phenolphthalein (PP) was added at 3 drops, and the mixture was titrated with NaOH solution (0.1 N) until a constant pink color change occurred. The color of the blank solution was subsequently compared, and the volume of NaOH used for titration was recorded. The process was repeated three times for each sample, and the results are expressed as % titratable acidity.

2.4. Flavor Aromatic Compound Analysis

A qualitative method with the Wiley library database was utilized for GC-MS analysis. In the present study, similar to a previous study (19), distillation was used to prepare GC-MS samples, but with some changes. A 2:1 distilled water to sample ratio was required. After distillation, 10 cm³ of the distillate was removed. Diethyl ether (2 ml) was added to 10 ml of distillate to help separate the complex components. The distillate-diethyl ether mixture was gently stirred. The two ingredients were shaken, and the layers were separated. Finally, the agitated top layer was removed. The upper layer contained lighter or more soluble diethyl

ether components, whereas the lower layer contained heavier or more soluble mineral water distillate components. This study used the following GC-MS parameters: the column oven temperature was 40°C, the injection temperature was 200°C, and the injection mode was split. The flow control mode was achieved by regulating the column flow at 49.5 kPa and 6 ml/min. The column flow rate was 1 ml/min, resulting in a 36.1 cm/sec linear velocity. The split ratio was 2, and the purge flow rate was 3 ml/min.

2.5. Sensory Evaluation

A total of 82 Gen Z (21–26 years old) untrained panellists participated in evaluating the sensory attributes of the *jamu*-based kombucha for temporal dominance of sensations (TDS) methods. The sensory attributes evaluated using the RATA method were sweet aroma, sour aroma, rhizome-like aroma, sweet taste, sour taste, sour sensation, alcoholic sensation, and sparkling sensation. The RATA test was performed using Google Forms, enabling convenient administration of the online assessment. The participants were presented with a comprehensive compilation of sensory attributes related to the taste qualities of bitterness, sourness, sweetness, and astringency in the RATA test. Each attribute was assigned a scale of intensity ranging from 1 to 15, with 1 representing a very low intensity and 15 representing a very high intensity. This sensory study has been approved by Polkesma Ethic Committee No.DP.04.03/F.XXI.31/0107/2024.

A total of 11 Gen Z (21–26 years old) trained panellists also evaluated the *jamu*-based kombucha using the temporal dominance of sensations (TDS) method using the Sensomaker application. The sensory attributes evaluated using TDS included sweet taste, sour taste, astringent sensation, sparkling sensation, turmeric taste, tamarind leaf taste, sweet aroma, sour aroma, and turmeric aroma. To determine the eligibility of the panellists, a series of threshold tests were conducted to evaluate their perceptions of sweet taste and aroma (sucrose solution), sour taste and aroma (citric acid), and bitter taste (tea solution). The selection of panellists aimed to ensure their ability to accurately perceive and discriminate the sensory attributes relevant to this study. Experienced panellists screened the test samples' taste threshold using the 3-AFC method. Three different concentrations of each compound were randomly placed on the table, and each was combined with two mineral water samples (blank samples). The panellists were trained to evaluate and recall the aroma of tamarind leaves and fresh turmeric. The TDS testing lasted 45 seconds for each aroma and taste evaluation session of the *jamu*-based kombucha.

2.6. Face and Emotion Analysis Using Facial Emotion Recognition (FER) and Facial Landmarks Distance (FLD)

Following the successful selection of trained panellists, a series of expression training sessions were conducted to enhance the participants' facial expressions. The training sessions encompassed replicating facial expressions associated with positive emotions (happiness) and negative emotions (sadness, disgust, and anger). A relaxed state or emotion was considered a happy emotion. Photographs extracted from prior research papers were used to instruct and familiarize the panellists with facial expressions. The training sessions were documented and archived in a database that was not representative of the overall population.

The researchers recorded the facial expressions of the expert panel members during the sensory evaluation sessions. These expressions were captured on video and subsequently analyzed using screenshots extracted from the complete video recordings of each panel

member. The facial expressions obtained through various processing methods were compiled into a database of trained panellists' responses. The database was used to enhance the precision of the sensory evaluation sessions and to guarantee the panellists' uniformity in their facial expressions throughout the evaluation process.

The FER and FLD analysis procedures were developed on Phyton 3.11 and executed by command prompt (CMD) according to prior research (20) with some modifications. The coding approach commenced with importing essential modules and libraries, including *imutils*, *numpy*, *argparse*, *dlib*, *cv2*, *csv*, *os*, *scipy.spatial*, *exifread*, and *math*. Subsequently, the command line arguments were acquired by employing the ``argparse.ArgumentParser()`` function and processed through ``ap.parse_args()`` to be saved within the ``args`` variable. Face detection and landmark prediction were executed on every image contained within the designated ``input`` directory. Significant findings were recorded in a comma-separated values (CSV) file, which contained data on the landmark numbers and the corresponding x and y coordinates. Subsequently, the distance between specific landmarks was measured using the ``dist.euclidean`` function and later appended to the pre-existing CSV file.

The landmark information was used to capture certain regions of the face, which were subsequently extracted as individual photos. These images were then stored in the designated ``output`` directory with associated names. The deepFace model was employed to perform an emotion analysis of facial appearances, where the outcomes were subsequently added to the image, alongside an accompanying text that denotes the prevailing emotion.

The output folder contained stored result images and data, encompassing images featuring landmarks and distances, cropped photographs for individual facial components, and images displaying information regarding the prevailing emotion exhibited on the face. We normalized the data by subtracting the distance of each facial landmark from the neutral facial landmark when the subject was not consuming the sample (baseline face). FLD points were specific points on a face used to identify and track facial features. The FLDs included the distances between the outer left and right corners of the lips, the left corner of the lips and the nose, the right corner of the lips and the nose, the nose and the outer corner of the right eye, the nose and the outer corner of the left eye, the nose and the inside corner of the left eye, the outer corner of the right eye and the right corner of the lips, the outer corner of the left eye and the left corner of the lips, the outer right corner of the lips and the middle of the upper lip, the outer left corner of the lips and the middle of the upper lip, the outer left corner of the lips and the middle of the lower lip, the outer right corner of the lips and the middle of the lower lip, and the middle of the upper and lower lips and the outer corners of the left and right eyes. Example of an image with emotional analysis is shown in Figure 3.

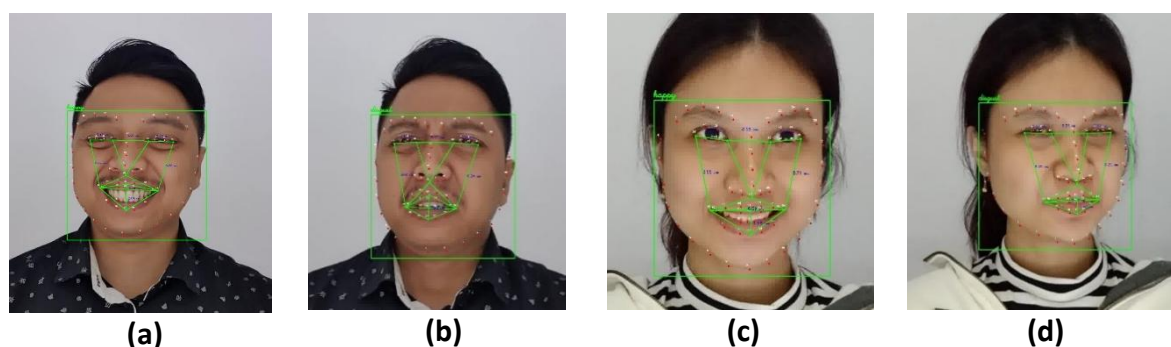


Figure 3. (a) Typical male positive emotion; (b) Typical male negative emotion; (c) Typical female positive emotion; (d) Typical female negative emotion.

2.7. Statistical Analysis

Minitab 21 was utilized to analyze all the significant treatments and responses.

3. Results and Discussion

3.1. Kombucha's Sourness and Sweetness Chemical Characteristics

As shown in Table 1, the significant differences between turmeric kombucha and turmeric and tamarind leaf kombucha were observed only in total phenolic content and final pH (p-value <0.05).

Table 1. Chemical characteristics of *jamu*-based kombucha after 7 days of fermentation.

Kombucha type	Final sugar content (%)	Final titratable acidity (%)	Total phenolic content (µg GAE/ml)	pH	
				Initial	Final
Turmeric kombucha	8.09 ± 0.25	0.16 ± 0.03	132.89 ± 14.59 ^a	5.25±0.27	4.73±0.18 ^a
Turmeric and tamarind leaf kombucha	7.50 ± 0.59	0.20 ± 0.03	240.90 ± 05.14 ^b	4.71±0.25	3.81±0.15 ^b

*The values represent mean± standard deviation

*Different superscript letter within the same column indicates a significant difference at the 95% confidence level

The sugar contents of both types of kombucha were not significantly different, as the amounts of sugar added for the pre-fermentation subtraction were equal at 10% (w/v). The amount of sugar added before fermentation affected the total sugar content in kombucha. An increase in the added sugar concentration led to a higher total sugar content after fermentation (21). Furthermore, the temperatures and durations of fermentation were the same (25°C, 7 days).

The turmeric and tamarind leaf kombucha had significantly lower pH than that of the turmeric kombucha. This could be attributed to the addition of tamarind leaf. Tamarind leaves that are extracted using chloroform have various acid contents, including malic acid, tartaric acid, benzene-1,2-dicarboxylic acid, methyl 3,5-d-tert-butyl-4-hydroxybenzoate, hexadecenoic acid, and 10-Octadecenoid acid. Tartaric acid is the acid compound with the highest content in tamarind leaves, and it imparts the characteristic sour taste (22). These organic acids may result in higher acidity or lower pH in the fermented product.

The total phenolic content of kombucha ranged from 132.89 to 240.90 µg GAE/ml. Phenolic compounds have functional effects, such as cardiovascular inhibition, anticancer activity, and chronic disease prevention. Fermented turmeric kombucha was reported to increase hepatoprotective activity in Balb/C mice by releasing compounds and producing new bioactive compounds (13). The total phenolic content in turmeric can block the NF-kB and TLR2 pathways, regulate inflammatory responses that cause cell apoptosis, and inhibit IL-6 expression (8). Previous research found that black tea kombucha acted as an immunomodulatory agent for mice infected with *S. typhi* by increasing CD4+, CD8+, CD4 + IFNγ, CD4 + TNFα, CD8 + IFNγ, and CD8 + TNFα cells (21).

3.2. Flavor Volatile Compounds

There were 18 flavor aromatic compounds identified from the GC-MS analysis. The turmeric and tamarind leaf kombucha likely contained several compounds with a bitter

aroma, bitter taste, and pungent aroma, as shown in Table 2. The most similar metabolite found in GC-MS was 3-furaldehyde, which was also found in tamarind (23). Graphic chromatogram of GC-MS analysis results is shown in Figure 4.

Table 2. Flavor-aroma characteristics of turmeric-tamarind leaf kombucha

Peak#	R. Time	Area%	Similarity	Flavor aromatic volatile compounds	Flavors
1	8.40	0.18	95	3-furaldehyde	Pungent aroma and bitter taste (24)
2	16.08	0.02	75	1-methyl-2- phenoxyethylamine	Bitter taste (25)
5	22.66	0.04	68	cis-aconitic anhydride	-
6	25.72	0.02	74	N'-isopropylureidoacetic	-
14	33.23	0.31	73	Pentane, 3-ethyl-	Bitter taste and aroma (26)
22	40.46	5.75	66	2,3,6-trifluorobenzyl alcohol, 3-methylbutyl ether	-
24	41.66	11.35	77	2,4-pentadien-1-ol, 3-ethyl-, (2Z)-	-
26	45.64	7.79	77	Benzenemethanol, .alpha.-(1-aminoethyl)-	-
27	47.96	5.59	70	Norpseudoephedrine	-
29	49.63	3.79	68	Propanamide, 3-(3,4-dimethylphenylsulfonyl)-	-
30	50.19	1.89	62	N,N- dimethylethanesulfonamide	-
32	52.87	3.14	74	Benzeneethanamine, 4- fluoro-.beta.,3-dihydroxy-N-methyl-	-
34	54.26	1.33	76	Acetic acid, [(aminocarbonyl)amino]oxo-	-
35	55.00	1.35	70	Meglumine	Bitter taste (27)
38	57.60	0.74	70	Pentafluoropropionamide	-
39	58.71	0.57	71	2-[(2- Aminoethyl)sulfanyl]acetic acid, N-methyl-, methylester	-
40	59.54	0.23	70	DL-cystine	Bitter taste (28)
41	60.38	0.07	71	Benzeneethanamine, 2- fluoro-.beta.,3-dihydroxy-N- methyl-	-

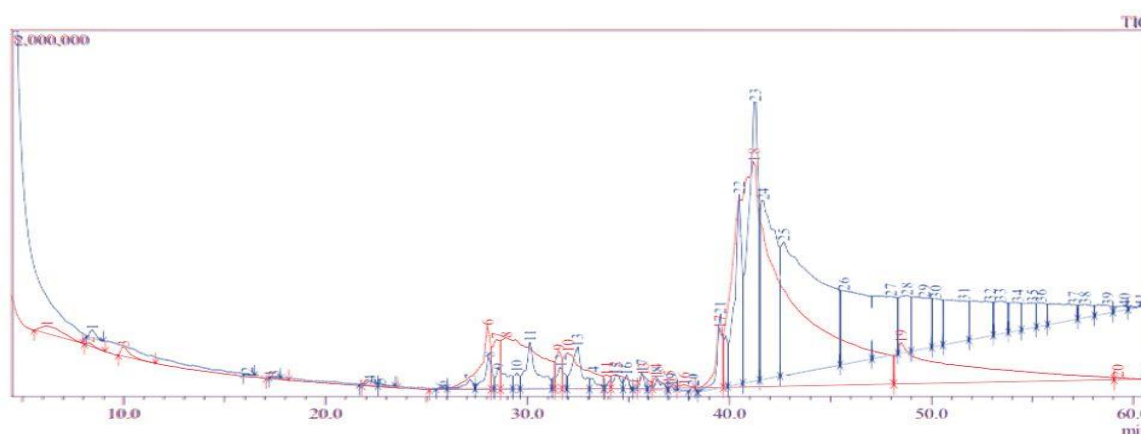


Figure 4. Graphic chromatogram (red is turmeric kombucha and blue is turmeric-tamarind leaf kombucha).

Seven flavour aromatic compounds were identified from the GC-MS analysis. The turmeric kombucha possessed a sweet, woody, and strong aroma, as shown in Table 3. The most similar compound found in GC-MS was 2-methyl-5-(1-methylethyl)-phenol, also known as carvacrol, which was also found in *Origanum*, *Thymus*, *Satureja*, *Thymbra*, and

Coridothymus (29). Tamarind leaf *jamu* alone has a bitter, sour, and sweet taste and a sour aroma (30). Compared with the turmeric kombucha, the turmeric and tamarind leaf kombucha might have a significantly more sour taste.

Table 3. Flavor and aroma characteristics of turmeric kombucha.

Peak#	R. Time	Area%	Similarity	Flavor Aromatic Volatile Compounds	Flavor and Aroma
5	22.01	0.03	73	Cathinone	Aromatic odor, pungent aroma, and flavor (31)
10	32.02	3.84	75	Alpha,alpha,4- trimethylbenzyl carbanilate	-
12	34.33	1.14	79	Acorenone B	Sweet aroma, Cinnamon aroma, herbal aroma (32)
14	36.38	0.45	87	Phenol, 2-methyl-5-(1 methylethyl)-	Phenolic and spicy aroma (33)
15	37.03	0.13	72	5-cis-methyl-1R,3-cis- cyclohexanediol	-
17	39.53	2.31	73	1,3- Bis(cinnamoyloxymethyl)adamantane	-
20	59.27	0.12	62	3-chloro-N-[2-(3-chloro-N-methylpropanamido)ethyl]-N-methylpropanamide	-

3.3. Sensory Attributes of Jamu-based Kombucha

The entirety of the *jamu*-based kombucha sensory attribute preference level and sensory attribute intensity based on the RATA test are displayed in Table 4. The turmeric and tamarind leaf kombucha exhibited a wide variety of sensory attributes, which could be modified by the fermentation temperature and the type of raw material used. The RATA test revealed that the turmeric and tamarind leaf kombucha, served at 9°C, exhibited the greatest level of acid intensity. Conversely, when served at 25°C, the rhizome-like flavor exhibited the greatest intensity. Nevertheless, the panellists found both variations satisfactory since there was no statistically significant difference in the total acceptance response according to Tukey's additional test. The research has shown that turmeric kombucha had the highest overall preference score (9.0) in sensory evaluation, with a pH value of 3.1.

Table 4. Sensory characteristics of *jamu*-based kombucha.

Kombucha Type	Serving Temperature	Sweet Taste	Sour Taste	Turmeric Taste	Astringent Sensation	Sparkling Sensation	Turmeric Aroma	Sweet Aroma	Sour Aroma	Overall Preference
(a) Preference Level										
Turmeric	25°C	3.52 ± 0.87	3.39 ± 0.97	3.74 ± 1.00	3.49 ± 0.84	3.04 ± 0.95	3.52 ± 0.88	3.45 ± 0.79	3.52 ± 0.79	3.59 ± 0.94
	9°C	3.50 ± 0.87	3.45 ± 0.86	3.47 ± 1.17	3.26 ± 0.86	3.20 ± 1.05	3.50 ± 0.88	3.50 ± 0.85	3.43 ± 0.77	3.61 ± 0.84
	25°C	3.68 ± 0.80	3.66 ± 0.81	3.68 ± 1.11	3.49 ± 0.93	3.39 ± 0.93	3.63 ± 0.81	3.52 ± 0.71	3.57 ± 0.74	3.79 ± 0.81
	9°C	3.63 ± 0.94	3.61 ± 0.99	3.50 ± 1.12	3.37 ± 0.95	3.33 ± 0.98	3.41 ± 0.83	3.32 ± 0.84	3.37 ± 0.82	3.66 ± 0.85
(b) Sensory Attributes Intensity										
Turmeric	25°C	7.25 ± 3.24	5.99 ± 3.51 ^b	6.13 ± 0.81	5.13 ± 3.44	3.62 ± 3.34	7.29 ± 3.14 ^a	5.53 ± 3.01 ^a	6.70 ± 3.04	
	9°C	6.58 ± 3.00	6.34 ± 3.28 ^b	6.04 ± 0.84	5.80 ± 3.67	3.93 ± 3.48	6.44 ± 2.95 ^b	4.75 ± 2.70 ^b	6.61 ± 2.77	
	25°C	6.50 ± 3.11	7.43 ± 2.77 ^a	6.03 ± 0.85	6.56 ± 3.68	4.81 ± 3.52	7.89 ± 2.79 ^a	5.41 ± 4.86 ^a	7.07 ± 2.69	-
	9°C	6.46 ± 3.22	7.71 ± 3.50 ^a	5.92 ± 0.84	5.72 ± 3.79	4.09 ± 3.90	6.69 ± 2.98 ^b	4.86 ± 2.76 ^b	7.34 ± 3.00	
(c) TDS DRMax										
Turmeric	25°C	0.52 ± 0.00 ^a	0.45 ± 0.00 ^b	0.45 ± 0.00 ^a	0.18 ± 0.00	0.22 ± 0.00 ^b	0.63 ± 0.000 ^a	0.27 ± 0.00 ^a	0.54 ± 0.00 ^b	
	9°C	0.45 ± 0.00 ^b	0.72 ± 0.00 ^a	0.45 ± 0.00 ^a	0.18 ± 0.00	0.27 ± 0.00 ^a	0.62 ± 0.000 ^a	0.19 ± 0.00 ^b	0.56 ± 0.00 ^a	
	25°C	0.54 ± 0.00 ^a	0.54 ± 0.00 ^b	0.45 ± 0.00 ^a	0.18 ± 0.00	0.27 ± 0.00 ^b	0.42 ± 0.000 ^b	0.27 ± 0.00 ^a	0.54 ± 0.00 ^b	-
	9°C	0.45 ± 0.00 ^b	0.81 ± 0.00 ^a	0.27 ± 0.00 ^b	0.18 ± 0.00	0.36 ± 0.00 ^a	0.42 ± 0.000 ^b	0.09 ± 0.00 ^b	0.61 ± 0.00 ^a	

*The values represent mean ± standard deviation

*Different superscript letter within the same column indicates a significant difference at the 95% confidence level

The overall sensory attributes of the *jamu*-based kombucha based on the TDS analysis are shown in Table 4. Through the TDS DRMax feature, the turmeric and tamarind leaf kombucha served at 9°C exhibited a sour taste, sparkling sensation, and the most intense sour aroma. The turmeric and tamarind leaf kombucha served at 25°C had the greatest sweetness, a turmeric taste, and a sweet aroma. Similar to the turmeric and tamarind leaf kombucha, the turmeric kombucha served at a temperature of 9°C had a sour taste and a highly sour aroma. Turmeric kombucha, served at a temperature of 25°C, had the sweetest taste and aroma. A graphic of TDS test results for taste attributes is shown in Figure 5, while the aroma attributes is shown in Figure 6. Regarding the attributes of turmeric taste and aroma, those of turmeric kombucha were not significantly different. The attributes of turmeric taste and aroma of the turmeric kombucha were not significantly different. The sensation of sweetness emerged when there was an increase in temperature at the tip of the tongue from 20 to 40°C (34). A taste of sourness tended to occur when the tongue's end was cooled to 35 – 5°C.

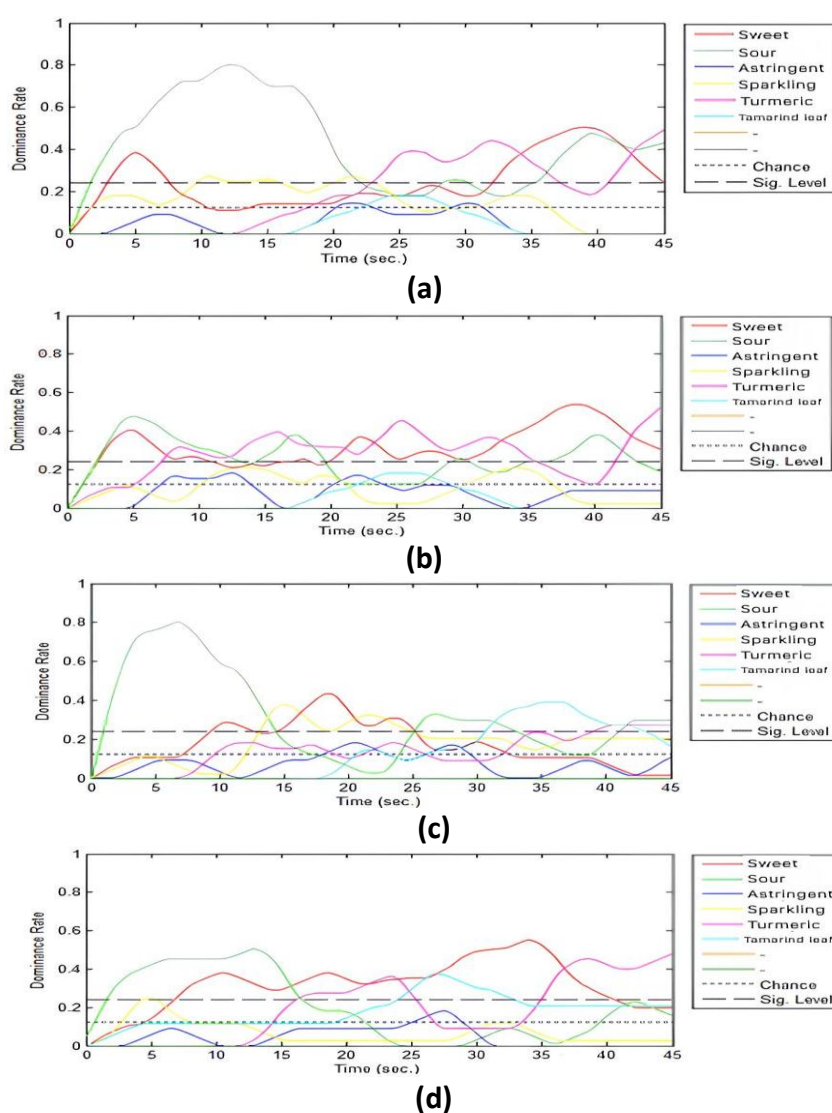


Figure 5. Tastes and mouth-feels temporal dominance of Sensations for: (a) Turmeric kombucha 9°C; (b) Turmeric kombucha 25°C; (c) Turmeric-tamarind leaf kombucha 9°C; (d) Turmeric-tamarind leaf kombucha 25°C.

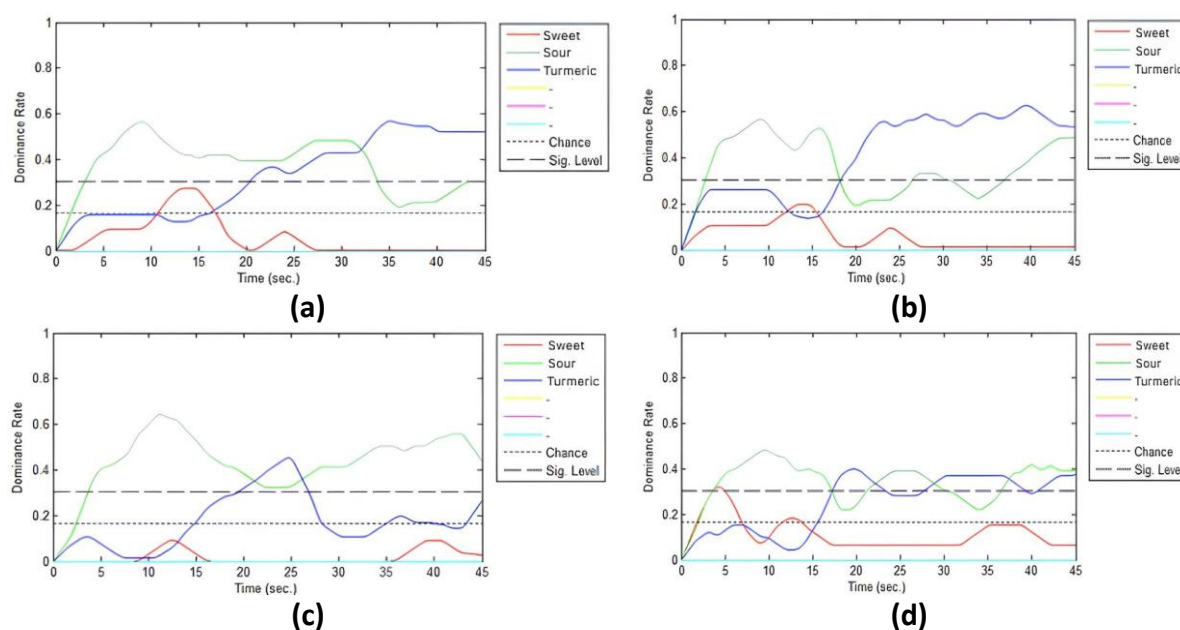


Figure 6. Aromatics temporal dominance of sensations for: (a) Turmeric kombucha 9°C; (b) Turmeric kombucha 25°C; (c) Turmeric-tamarind leaf kombucha 9°C; (d) Turmeric-tamarind leaf kombucha 25°C.

3.4. Facial Expressions

There were 161 photos of facial expressions obtained from the recording session of the sensory evaluation. There were 0 photos of angry expressions, 37 photos of sad expressions, 7 photos of disgusted expressions, and 117 photos of happy expressions captured from 11 trained panellists. The overall accuracy of the model was 92%. After evaluating each *jamu*-based kombucha sample, the panellists had their negative expressions confirmed by FER. The complete FER data set is presented in Table 5. Even though the positive expressions were not significantly affected by either of the kombucha types, the negative expressions observed when the panellists took a sip of the turmeric and tamarind leaf kombucha served at 9 °C were potentially related to the significant sour flavor attribute. However, the RATA test results showed that the panellists' acceptance did not decrease. The negative expressions observed following the serving of the turmeric and tamarind leaf kombucha at 9 °C were also potentially related to the significant tamarind leaf aroma detected in DRMax and TMax, as well as the turmeric and tamarind leaf flavor caught significantly in the TDS feature of DRMax.

Table 5. Effect of *jamu*-based kombucha and serving temperature on positive expressions based on FER.

<i>Jamu</i> Kombucha	Positive Expressions (photos)	Serving Temperatures (°C)	Positive Expressions (photos)
Turmeric	43*	9	35.5*
Turmeric-tamarind Leaf	15.5	25	23

Note: 11 trained panellists were involved in this FER session. The confidence level was 95% on the General Linear Model.

To extend the expression analysis, we analyzed the FLD. Gender significantly contributed to positive expressions. The panellists' faces tended to be narrowed after they drank the turmeric and tamarind leaf kombucha, as shown in Table 6. Male panellists tended to be more expressive compared to female panellists (34.35).

The integration of Temporal Dominance of Sensations (TDS), facial emotion recognition (FER), and facial landmark distance (FLD) analyses in this study provides a quantitative bridge between subjective sensory perception and objective emotional responses. The TDS profiles revealed that *sourness* was the temporally dominant attribute across all jamu-based kombucha variants, while the *bitter* attribute—although chemically supported by GC–MS detection of compounds such as 3-furaldehyde and meglumine—showed low temporal dominance ($DR_{max} < 0.45$). When these temporal sensory dynamics were compared with the Convolutional Neural Network (CNN)-based FER outputs, no significant temporal overlap was observed between the moments of “bitter” dominance and the detection of negative emotions (e.g., disgust or contempt). The CNN model classified over 70% of captured expressions as positive (happy), and only about 4% as disgusted, indicating that bitterness did not elicit measurable negative affect. Instead, the few negative expressions coincided with the peak of sourness perception, particularly in the turmeric–tamarind kombucha served at 9 °C, suggesting that heightened sourness—rather than bitterness—temporarily triggered mild aversion responses.

In contrast, the FLD analysis provided compelling evidence of an affective–hedonic linkage. Shorter inter-landmark distances around the mouth and lips—indicative of smiling—were strongly associated with higher Rate-All-That-Apply (RATA) scores for “liking” and “richness.” Quantitatively, the relationship was nearly linear ($r \approx -0.95$), implying that as facial contraction increased (smile amplitude), self-reported preference rose proportionally. This correspondence was particularly pronounced in male participants, who exhibited greater expressive range and narrower FLD values when consuming kombucha samples rated higher in liking. Taken together, these findings argue that while *bitter* perception lacked emotional salience in this sensory context, *positive facial expressivity* reliably mirrored hedonic appreciation. The combined TDS–FER–FLD approach thus substantiates the feasibility of using CNN-based facial analytics as an objective complement to conventional sensory methods, bridging physiological expressivity with consumer sensory preference in functional beverage evaluation.

Table 6. Positive expression landmarks of trained panellists caught when drinking turmeric kombucha.

Landmarks Location	Genders	Distances (cm)
Outer Right Corner of the Lips to the Nose	Male	0.8 ± 0.4^a
	Female	0.2 ± 1.1^b
The Middle of the Upper and Lower Lips	Male	1.0 ± 1.0^a
	Female	0.2 ± 0.4^b
Outer Right Corner of the Lips to the Middle of the Upper Lip	Male	1.1 ± 1.0^a
	Female	0.4 ± 0.4^b
Outer Right Corner of the Lips and the Middle of the Lower Lip	Male	1.3 ± 1.3^a
	Female	0.5 ± 0.5^b
Outer Right and Left Corners of the Lips	Male	1.4 ± 0.5^a
	Female	0.6 ± 1.4^b

4. Conclusion

This study demonstrates that integrating AI-driven emotion analytics with sensory profiling enriches the interpretation of consumer perception toward jamu-based kombucha. Temporal Dominance of Sensations (TDS) and RATA confirmed *sourness* as the most dominant

and preferred sensory attribute, while the combination of CNN facial emotion recognition and Facial Landmark Distance (FLD) analysis revealed that *bitterness*, although chemically present, did not elicit negative affective responses. Instead, shorter FLD distances, indicative of smiling, correlated strongly with higher liking and richness scores, reinforcing the product's positive emotional resonance. Although CNN–FLD methods require additional resources, their capacity to objectively validate hedonic experiences offers a significant advantage over traditional sensory testing. Future studies should incorporate shelf-life and stability assessments to ensure that these favorable sensory and emotional attributes persist throughout storage, supporting the long-term sensory integrity and commercial potential of jamu-based kombucha as a culturally inspired functional beverage.

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Author Contributions

K.F. and E.Z.B. conceptualization and methodology; K.F. formal analysis; K.F.; E.Z.B.; I.A.B. ; A.M.; N.A.S. and B.N.P investigation and curation; I.A.B. and A.M. writing-original draft; I.A.B. and A.M. writing-review and editing; K.F. supervision; N.A.S. and B.N.P. collecting primary data. All the authors read and approved the final manuscript.

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Data will be made available on request to the corresponding author.

Conflicts of Interest

No conflict of interest.

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