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Identifying sensory attributes of Korean rice wine (*makgeolli*) using sensory evaluation and chemical analysis

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Abstract: *Makgeolli* is a traditional alcoholic beverage in Korea; however, research on *makgeolli* is limited in foreign markets such as New Zealand. This study seeks to identify sensory descriptors that best describe *makgeolli* among New Zealand consumers. Four methods of making *makgeolli* have been identified based on different processing times and the number of fermentation stages. Chemical analysis and sensory evaluation were carried out to establish the different sensory and flavor properties of the four different *makgeolli* samples. Chemical analysis using SPME–GC–MS was employed to understand the volatile compounds present in the four *makgeolli* samples, while two sensory tests were carried out simultaneously using Check-All-That-Apply (CATA) and Just-About-Right (JAR). A total of 45 volatile compounds were identified using SPME–GC–MS, and examples of major volatiles include 2-methyl-1-propanol (alcoholic flavor), limonene (citrus-like flavor), and hexanal (green/grass-like flavor). One hundred and twenty-nine subjects (n = 68 females) completed the sensory evaluation and were analyzed for this study. Female subjects tend to rate overall acceptance of *makgeolli* higher than male subjects; both subjects preferred 1SF-YN with the highest mean hedonic score, and the least preferred *makgeolli* was 1SF-N. From CATA, attributes such as apple, apricot, peach, sweet taste, and bubbly texture were statistically significant when describing *makgeolli*. For JAR, a high proportion of subjects indicated that sourness was too much in three of the four *makgeolli* samples.

KEYWORDS
Makgeolli, Korean rice wine, SPME, Sensory

Practical Application: Research on rice wine in Western markets such as New Zealand is limited, and this study gives insight into how New Zealand consumers perceive Korean rice wine (*makgeolli*). Sensory participants in this study indicated that *makgeolli* is too sour and lacks sufficient sweetness in the majority of the samples examined. When launching *makgeolli* to the New Zealand market, practitioners need to optimize sweetness and reduce sourness to increase overall liking. Sensory terms used by subjects describing *makgeolli* include cider, apple, and sour.

1 | INTRODUCTION

Research on alcoholic beverages such as wine and beer is popular among Western scientific literature; however, ethnic beverages like *makgeolli* (Korean rice wine [KRW]) are limited.

Makgeolli is made from glutinous rice, water, and a starter culture called *nuruk* (see Supporting Information S1 for more details of *nuruk*) (Kim et al., 2015; Lee et al., 2015; Son et al., 2018). *Nuruk* plays an important role in the overall flavor of *makgeolli* because it contains a variety of microorganisms such as bacteria, fungi, and yeast—notably, *Bacillus amyloliquefaciens*, *Bacillus subtilis*, *Enterococcus faecium*, *Pediococcus pentosaceus*, and *Lichtheimia corymbifera* were found in *nuruk* (Song et al., 2013). Compounds such as 2,3-butanediol (buttery odor), 2-cyclohexen-1-ol, phenyl ethyl alcohol (floral odor), benzyl alcohol (fruity odor), and 3-methylbutanoic acid (cheese odor) were identified in the *nuruk* samples using gas chromatography–mass spectrometry (GC–MS), which are likely contributors to the flavor profile of *makgeolli* (Lee et al., 2016). Other rice wine studies have shown that the starter culture determines the concentration of flavor compounds such as ethyl octanoate (apple-like aroma) and phenyl ethyl alcohol (rose aroma) (Chen, Ren, et al., 2021) and varying levels of polyphenolic content (Cai et al., 2019).

In terms of flavor compounds in *makgeolli*, Jung et al. (2014) identified 45 volatile compounds using gas chromatography coupled to time-of-flight mass spectrometry. The 45 major volatile compounds include 33 esters, eight alcohols, one aldehyde, one acid, one phenol, and one terpene (Jung et al., 2014). Three esters closely perceived as having fruity flavor—ethyl decanoate (grape flavor), ethyl octanoate (floral, banana, pear, and pineapple flavor), and ethyl dodecanoate (fruity flavor)—were observed in the *makgeolli* samples (Jung et al., 2014). In another study, Kang et al. (2016) identified high levels of ethyl esters in *makgeolli* using solid-phase microextraction (SPME) coupled with GC–MS. Fruity and flower/floral flavor compounds (ethyl acetate, isoamyl acetate, ethyl decanoate, and phenyl ethyl acetate) were observed by Kang et al. (2016).

In recent years, there have been a few published studies on the sensory perception of KRW in Western literature. KRW is an umbrella term for alcoholic beverages that originates from Korea and the primary ingredient for fermentation is rice. Examples of KRW include but are not limited to *yakju*, *makgeolli*, *takju*, *cheongju*, and *dongdongju*. These studies include Kwak et al. (2015) investigating the sensory attributes of KRW among consumers in the United States for their acceptability, Heo et al. (2020) identifying specific sensory attributes of KRW such as apple and sweet taste where it was found to be positively correlated with overall consumer liking, and Wong et al. (2023) comparing different *makgeolli* products using polarized projective mapping against three basic tastes including sourness, sweetness, and bitterness.

The purpose of this study is to determine the sensory profile of *makgeolli* from different processing methods. This research is novel because there is limited research on the flavor perception of *makgeolli* and sensory preferences in non-Korean markets such as New Zealand. This study aims to contribute to the growing area of cereal alcoholic beverages such as rice wine by exploring the flavor and sensory perception of rice wine outside of Asia. The main objectives of this paper include (a) using chemical techniques (SPME–GC–MS) to identify volatiles that are currently present in different *makgeolli* processing methods, (b) understanding the sensory characteristics of *makgeolli* by New Zealand consumers using CATA, and (c) understanding the intensity of specific attributes that contributes to the overall liking of *makgeolli* and how *makgeolli* samples can be optimized to increase consumer acceptance.

2 | MATERIALS AND METHODS

The following section is a description of the methods and materials used in the sensory evaluation and volatile compound analysis using SPME–GC–MS experiments. The specific tests and methods in the sensory evaluation will be discussed in Section 2.2.4.

2.1 | *Makgeolli* samples

Four different *makgeolli* processing methods were examined in the sensory evaluation and SPME–GC–MS experiment. The *makgeolli* processing methods were identified

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from scientific literature (Jeon et al., 2010; Kim et al., 2015; Nile, 2015) and the researchers used Wong et al.'s (2023) method of producing *makgeolli* for experimentation. The *makgeolli* samples will be referred to as 1SF-N, 1SF-YN, 2SF, and 3SF in this article. All *makgeolli* samples were prepared in the Food Laboratory of Auckland University of Technology. All materials were purchased from the Auckland CBD area.

In summary, the preparation of single-stage-fermented (1SF-N) *makgeolli* with *nuruk* involved washing 2 kg of glutinous rice (Wang Ltd.) until the water ran clear (around 10 min of continuous washing) and soaking for 3 h before draining for 1 h. The glutinous rice is then steamed for 120 min and then cooled to 25°C followed by mixing with 3 L of de-ionized (DI) water and 500 g of ground nuruk (Wang Ltd.). The 1SF-N mixture was then fermented at 25°C for 7 days. 1SF-N samples were then filtered and stored in an amber-colored bottle in a refrigerator at 4°C until it was used for sensory evaluation and chemical analysis (within a week).

Preparation of single-stage-fermented (1SF-YN) *makgeolli* with yeast and *nuruk* followed a similar procedure as 1SF-N; however, 500 g of ground *nuruk* was replaced with 40 g of ground *nuruk* and 11 g of dry yeast (Safale US-05 dry ale yeast, Fermentis, S.I. Lesaffre).

The preparation of two-stage-fermented (2SF) *makgeolli* deviates from 1SF-N and 1SF-YN where the fermentation base was first produced before being incorporated into the glutinous rice and DI water mixture. The fermentation base is processed by first soaking 400 g nonglutinous rice (Wang Ltd.) for 3 h and then draining for 1 h. The nonglutinous rice is then milled into a fine powder using a blender (Russell Hobbs). The nonglutinous rice powder is cooked for 15 min with 1.25 L of DI water and then cooled to 25°C before incorporating 200 g of ground *nuruk*. The fermentation base is then left to ferment for 1 day at 25°C. The fermentation base is then filtered and 1 L of the fermentation base is incorporated into the 2-kg glutinous rice mixture with 1 L of DI water following a similar procedure as described for 1SF-N.

Three-stage-fermented (3SF) *makgeolli* followed the same procedure as 2SF; however, the fermentation base was fermented twice. For example, the fermentation base follows the same procedure as described in 2SF; however, after 1 day, the fermentation base is filtered and 1 L of this base is added into another set of 400 g of washed, drained, milled, and cooked nonglutinous rice. The fermentation base was left to ferment without additional *nuruk* for 1 day at 25°C and this second fermentation base was added to the steamed glutinous rice for the main fermentation as described in 1SF-N.

2.2 | Sensory evaluation and wine knowledge assessment

2.2.1 | Study protocol

The sensory evaluation was presented as a questionnaire format including a 9-point hedonic category scale, Check-All-That-Apply (CATA), Just-About-Right (JAR), subjective and objective wine scale, and sociodemographic questions (this will be discussed in detail in Section 2.2.4). A code to differentiate the subjects was printed on the right-hand corner of each page of the questionnaire (seven pages of the questionnaire in total). During the sensory evaluation, an information sheet about the experiment, a consent form, and a questionnaire about the sensory evaluation were presented to the subject upon arriving at the Food Science Laboratory (AUT). Subjects were instructed to answer the questions according to the order presented on the questionnaire. For each *makgeolli* sample, a randomized three-digit code was printed on the top of the first four pages of the questionnaire and subjects were required to answer the questions specifically to the *makgeolli* sample with the corresponding three-digit randomized codes. The subjects first answered the 9-point hedonic category scale regarding the overall liking of the m*akgeolli* sample, then subjects were instructed to select the CATA terms that best describe the sensory attributes of the *makgeolli* sample. Lastly, subjects were instructed to use the JAR scale to evaluate the *makgeolli* sample. After completing all four *makgeolli* samples in the order instructed by the researcher, subjects answered questions to the objective wine knowledge scale followed by the subjective wine knowledge scale. Sociodemographic questions were placed on the last page of the questionnaire.

2.2.2 | Subjects

Subjects were recruited from the Auckland city area by means of posters, social media, and word-of-mouth. Subjects were screened for the following criteria: (1) the subject does not suffer from food allergies such as wheat, rice, and alcohol, (2) the subject is not pregnant or trying to conceive a child, (3) the subject is not operating heavy machinery or driving within 2 h after completing the sensory evaluation, and (4) subjects being or over the legal age of 18 were allowed to take part in the sensory evaluation. Subjects were invited to participate in the sensory evaluation based on their interest in the *makgeolli* study, and the information sheet states that the subject should be a regular consumer of alcoholic beverages, for example, beer and wine. Regular consumption of rice wine was not a prerequisite for subjects participating in the sensory evaluation. One hundred and thirty-two subjects attended the sensory evaluation; however, three subjects were removed due to the subjects not being responsive or submitting an incomplete sensory evaluation. One hundred and twenty-nine subjects participated in the study, with 52.7% female subjects taking part in the sensory evaluation. Most of the subjects were aged between 21 and 29 years old (58.9%), and the largest self-identified ethnic group in this experiment was New Zealand European (29.5%) followed by East Asian subjects (27.9%). Forty percent of subjects consume rice more than once a week, followed by 28.7% of subjects who consume rice at least once a week, and only 12.4% of subjects seldom consume rice. Researchers used the self-prioritization method as part of the sociodemographic questions to categorize subjects into specific ethnic groups. Subjects can only identify one specific ethnic group that they strongly associate themselves with (Kukutai & Callister, 2009). New Zealand Europeans are defined as individuals who have a strong affiliation with New Zealand (e.g., citizenship or cultural identity) with European ancestry. A summary of the subjects' sociodemographic details is presented in Table 1. This sensory test was reviewed and approved by the AUT Ethics Committee number 19/241.

TABLE 1 Sociodemographic information of subjects with percentage including age, gender, ethnicity, rice consumption frequency, and alcoholic consumption frequency that participated in the sensory evaluation.

Characteristics		**Sample *n* (%)**
Age	18–20	7 (5.4%)
	21–29	76 (58.9%)
	30–39	23 (17.8%)
	40–49	10 (7.8%)
	50+	13 (10.1%)
Gender	Male	61 (47.3%)
	Female	68 (52.7%)
Ethnicity	East Asian[a]	36 (27.9%)
	European[b]	9 (7.0%)
	Maori/Pacifika[c]	13 (10.0%)
	Middle Eastern[d]	7 (5.4%)
	New Zealand European[e]	38 (29.5%)
	South Asian[f]	21 (16.3%)
	Other[g]	5 (3.9%)
Rice consumption	More than once a week	52 (40.3%)
	Least once a week	37 (28.7%)
	Every second week	14 (10.9%)
	Once a month	10 (7.7%)
	Seldom	16 (12.4%)
Alcohol consumption	More than once a week	26 (20.1%)
	Least once a week	32 (24.8%)
	Every second week	25 (19.4%)
	Once a month	46 (35.7%)

[a]East Asians category consists of subjects with East and Southeast Asian ancestry, for example, Chinese, Japanese, South Korean, Thai, Filipino, and Vietnamese.
[b]Europeans consist of subjects that have strong affiliation to European countries such as Greece, the United Kingdom, France, Germany, and Spain that do not identify as New Zealand European.
[c]Maori and Pacifika category consists of subjects with Maori, Tongan, and Samoan ancestry.
[d]Middle Eastern category consists of subjects with Iranian or Jordanian ancestry.
[e]New Zealand European is defined as individuals who have European ancestry but with strong affiliation with New Zealand (e.g., New Zealand citizenship).
[f]South Asian category consists of subjects with Indian or Sri Lankan ancestry.
[g]Other category consists of subjects from African, Latin American, and American ancestry.

2.2.3 | Sample presentation and sensory evaluation procedure

The sensory evaluation took place in the Food Laboratory at the AUT city campus with the temperature set at 22°C. White fluorescent light was used in the Food Laboratory, and prior knowledge or training in rice wine or alcoholic beverages such as beer or wine was not necessary. Before starting the sensory evaluation, a researcher explained the nature of the experiment and how to answer the questionnaire to the subjects. Subjects were instructed to consume the *makgeolli* sample one at a time following the order of the three-digit randomized codes printed on the questionnaire and answer the survey questions accordingly. A 1-min break was enforced between each sample by a timer with a counting down function and subjects were asked to consume one cracker (Arnotts) and a sip of water as a palate cleanser. All samples were prepared at least 4 h before the experiment took place. A total of 15 mL of *makgeolli* was pipetted to a 30-mL transparent portion cup and was stored in the refrigerator at 4°C before the sensory evaluation.

2.2.4 | Scales and questionnaire

The sensory evaluation consists of a 9-point hedonic category scale labeled from "*dislike extremely*" to "*like extremely*" for determining the overall liking of *makgeolli*, CATA, JAR, and sociodemographic questions. Objective and subjective wine knowledge questions were also included to understand the subject's degree of knowledge, attitude, and behavior toward wine (Ellis & Caruana, 2018; Flynn & Goldsmith, 1999; Forbes et al., 2008). The use of the objective and subjective wine knowledge scale is only for exploratory purposes and both scales are not specifically designed for rice wine. However, the researchers' intention was to see whether group clustering existed among subjects and whether this would affect the taste and flavor perception of *makgeolli*. Research previously published by Kwak et al. (2015) indicates that KRW (including *makgeolli*) may have similar attributes to rosé or white wine. This is to test whether different levels of objective and subjective wine knowledge would perceive *makgeolli* differently. The objective wine knowledge questions, consisting of five questions, were taken verbatim for this study (Ellis & Caruana, 2018; Forbes et al., 2008). However, four questions from the subjective wine knowledge were used instead of the nine presented in Flynn and Goldsmith (1999). A focus group consisting of four researchers and students from the Department of Food Science and Microbiology (AUT) noted that the five other questions from the subjective wine knowledge scale were repetitive and as a result, those questions were subsequently removed from the questionnaire. Subject wine knowledge scale required subjects to select the answer that best describes their situation on a 7-point category scale from "*disagree strongly*" to "*agree strongly*." The four questions include (Q1) "Among my circle of friends, I'm one of the 'experts' on wine," (Q2) "Compared to most other people, I know a lot about wine," (Q3) "I am quite familiar with wine," and (Q4) "I feel very knowledgeable about wine." Two of the four questions—Q1 and Q2—were taken from Ellis and Caruana (2018), Flynn and Goldsmith (1999), and Forbes et al. (2008).

The CATA method was selected due to its ease of use and the minimal training required for subjects to yield meaningful sensory information about the food product. CATA is relatively simple to carry out as subjects only need to "check" or "mark" specific sensory attributes that are relevant or perceived by the subjects. CATA has been used in alcoholic beverages and the products include *Syrah* (Alencar et al., 2019), Sangiovese wine (Rinaldi et al., 2021), and *yakju* (Lee et al., 2021). Terms used in the CATA questionnaire were formulated by previous literature that performed descriptive sensory analysis on *makgeolli*, KRW, and rice (Jung et al., 2014; Kwak et al., 2015; Lee & Lee, 2008; Pramudya & Seo, 2018). In addition, two focus groups were convened to ascertain the most fitting terms for describing the *makgeolli* samples. Two focus groups with four subjects in each were recruited from AUT, however, socio-demographic details were not collected. All participants had previous experience with sensory evaluation; however, they are not regular consumers of rice wine. Seven participants were students (n = 5 from the Department of Food Science and Microbiology; n = 2 from the Department of Chemistry) and one was a staff member from AUT. Four *makgeolli* samples were presented with random three-digit numbers in the focus groups, and the focus groups were set up in a semistructural format describing the *makgeolli* samples by sight, taste, flavor, and texture.

Based on the results from published literature (1) and two focus groups (2), 20 terms were selected for this study that best describe the *makgeolli* samples including apple, apricot, astringent, bitter, bubbly, cider, cream, dairy, floral, hay-like, metallic, nutty, peach, pear, rancid, sour, sweet, watery, yellow, and yeasty. During the sensory evaluation, subjects were asked to review the terms listed on the CATA questionnaire to ensure their understanding of all the terms. A list of terms and their corresponding definition were provided to subjects during the sensory evaluation for the CATA questionnaire. Subjects were asked to select all the terms that they consider best describe the *makgeolli*. All the CATA terms were placed in a random order to reduce answering bias throughout the sensory evaluation.

The JAR scale was selected as part of this study because the JAR scale allows researchers to determine which sensory attribute should be reformulated or adjusted to increase product overall liking of *makgeolli*. Other features of the JAR scale that appealed to the researchers include (1) the ability to calculate the penalty score that identifies which specific attributes are affecting *makgeolli*'s hedonic score and (2) to quickly ascertain the perception of the intensity of specific attributes (e.g., sweetness and sourness) in *makgeolli* by the subjects partaking in this study. Seven attributes including sweetness, sourness, astringency, color, alcohol strength, fruitiness, and smoothness were assessed on a 5-point JAR scale (1 = *Not enough*, 3 = *Just about right*, and 5 = *Too much*). All the JAR attributes were placed in a random order to reduce answering bias on the questionnaire. Sensory terms with definitions were provided to the subjects alongside CATA terms; subjects were encouraged to ask the researcher if they did not understand the terms.

2.3 | Chemical analysis (SPME–GC–MS)

Headspace SPME for volatile analysis of *makgeolli* used a similar methodology reported by Diep et al. (2021). A volume of two milliliters of *makgeolli* sample was placed in each headspace vial with 0.5 g of NaCl. A total of 10 µL of internal standard (5 µL/L solution of 1,2 dichlorobenzene in ultra-purified water) was added to the headspace vial and vortexed for 30 s. The headspace vial was heated at 50°C and was incubated for 15 min at an agitator speed of 250 rpm. The SPME fiber used for this study was Supelco 50 mm/30 µm DVB/CAR/PDMS, Stableflex, 24GA Fiber Assembly (Sigma Aldrich 57,329-U). The extraction period was 25 min, and the desorption time was 5 min at a desorption temperature of 50°C. SPME volatile analysis was performed on an Agilent GC-MS system, 7890B GC and 5977B MSD, equipped with a Gerstel autosampler. The column used was an Agilent J&W DB-Wax UI column

(122-7032UI) (0.25 µm film thickness, 0.25 mm ID × 30 m length). The carrier gas was helium with a constant flow rate of 1.1 mL/min. The injection was splitless, with the inlet temperature for the injection port set at 250°C. For the chromatographic conditions, the temperature was set at 40°C, held for 2 min, and raised to 240°C at the rate of 8°C/min and held for 3 min. The total run time of mass spectrometry (MS) was 30 min. The MS conditions were set at a source temperature of 250°C and a quad temperature of 150°C, with the electron ionization energy set at 70 eV. The total MS total ion chromatogram scanned masses range from 38 to 450 m/z.

To aid in the identification of unknown compounds, a series of alkane standards (C7–C30; Supelco) was run using the same GC–MS method as used in the sample analysis. The retention times for alkanes from heptane to triacontane were uploaded to the MassHunter Unknowns software program to augment the NIST14 library compound identification with retention index (RI) values. The semipolar column RI values for the NIST-identified compounds were compared with the experimentally obtained RI values. If the values were within 20 points, this was identified as a positive hit, and if not, the RI values of similar NIST matching compounds were compared to the experimentally obtained RI value to help verify a hit. Once a compound hit was obtained, the compound was added to the MassHunter Library that would be run against the entire sample set to obtain relative concentrations. The GC–MS response of the volatile compounds was normalized to the response of the internal standard. GC–MS quantification was not performed, and absolute concentration was not obtained. The SPME–GC–MS results are semiquantitative in nature as the relative concentrations were normalized against 1,2-dichlorobenzene as the internal standard. The volatile compound responses in Table 3 include the mean of *makgeolli* samples in triplicate ($n = 3$) and their standard deviation.

2.4 | Statistical analysis

Hierarchical cluster analysis (HCA) was employed to determine the consumer groups present in this study in combination with objective wine knowledge, subjective wine knowledge, *makgeolli* overall liking, alcoholic consumption pattern, and rice consumption pattern data. Ward's method was employed with Euclidean distances to calculate cluster groups among the subjects.

Nine-point hedonic category scale of *makgeolli* overall liking was analyzed by one-way analysis of variance (ANOVA) and the post hoc test was performed by Tukey's Honestly Significant Difference (HSD) test when statistically significant differences were observed. Two-way ANOVA was also performed between male and female subjects for the overall liking of *makgeolli* on the 9-point hedonic category scale. Statistical significance was defined to exist at $p < 0.05$ for both the one-way ANOVA and two-way ANOVA tests.

Each CATA term was calculated by counting the number of times subjects marked the term that best describes the *makgeolli* samples. Cochran's Q test was performed to evaluate the statistical differences among the four *makgeolli* samples (1SF-N, 1SF-YN, 2SF, and 3SF). If statistical differences among the variables were observed, post hoc multiple pairwise comparisons were performed using McNemar's test. Alpha was set at 0.05 to determine statistical significance. Correspondence analysis (CA) was used to visualize the interactions between different sensory attributes of the CATA terms and *makgeolli* samples. Significant terms determined by Cochran's Q test were used in CA.

Mean drop was calculated by the mean overall liking for the JAR attribute minus the mean overall liking of "not enough" and mean overall liking of "too much" (Narayanan et al., 2014). This was performed for each attribute that was stated in Section 2.2.4. The mean drop values were then plotted against the percentage of subjects giving each attribute a response that is either "not enough" or "too much" (Narayanan et al., 2014).

Principal component analysis (PCA) was conducted to understand the interactions of volatiles in the *makgeolli* samples. The volatiles were standardized using scale.unit function from FactoMineR package in R.

All data analyses were performed in R version 4.1.0 (R Core Team, New Zealand). JAR data were analyzed and visualized using "SensoMineR" (Le & Husson, 2008) and "FactoMineR" (Lê et al., 2008). CAs were visualized using "FactoMineR." Nonparametric analyses such as Cochran's Q test and McNemar's test were performed by "rcompanion" R package.

3 | RESULTS AND DISCUSSION

3.1 | Hierarchical cluster analysis

From the HCA, four groups were identified—Cluster 1 with 28 subjects, Cluster 2 with 70 subjects, Cluster 3 with eight subjects, and Cluster 4 with 20 subjects. Three subjects were removed from HCA due to incomplete answers in sensory evaluation. Cluster 1 subjects rated 2SF (5.6 ± 1.9) with the highest mean hedonic score, while they rated 3SF (3.9 ± 2.1) as the lowest among the four *makgeolli* samples. Over 75% of the subjects consume rice at least once a week, and the consumption frequency of alcoholic beverages is distributed evenly between the four categories of once a month, every second week, at least once a week, and more than once a week. In Cluster 2, subjects rated 1SF-YN (5.8 ± 2.0) the highest on the mean hedonic scale, while 1SF-N (4.4 ± 1.8) is rated the lowest. The majority of the subjects are between the ages of 21 and 34 (80.0%), and subjects tend to consume alcoholic beverages at a lower frequency compared to the three cluster groups. Cluster 3 consists of eight subjects, and they rated 1SF-N (5.4 ± 2.7) the highest on the mean hedonic score and 2SF (4.1 ± 1.9) the lowest among the four *makgeolli* samples. Interestingly, Cluster 3 had the highest correct answers on the objective wine knowledge scale and scored moderately on the subjective wine knowledge scale. Cluster 4 consists of 20 subjects—1SF-YN (5.7 ± 1.3) scored the highest on the mean hedonic score for overall liking of the *makgeolli* and 1SF-N (3.3 ± 1.6) scored the lowest. Cluster 4 subjects scored high on the subjective wine knowledge scale relative to the other cluster groups; however, their answers were less correct compared to Cluster 3 for objective wine knowledge.

In this study, objective wine knowledge and subjective wine knowledge were used as an exploratory technique to categorize different subjects into different customer segments by employing HCA. Of course, objective wine knowledge and subjective wine knowledge cannot be directly related to rice wine and KRW. However, behavioral questions exclusively about rice wine or KRW would not yield much information in a Western context, given the limited availability and presence of rice wine products. Research from Kwak et al. (2015) indicates that Western consumers perceive KRW as belonging to the wine category. From Kwak et al.'s (2015) study, Western consumers tend to rate KRW samples with higher overall liking when the KRW has a higher resemblance to semisweet white wine. More research is needed on Western consumers' attitudes and behaviors toward rice wine as information regarding this topic is limited.

3.2 | Hedonic rating of *makgeolli* samples

Statistical differences were observed between *makgeolli* samples for the mean hedonic rating ($F = 40.09$; $p < 0.001$) (see Supporting Information S2 for the graphing of hedonic score of the four *makgeolli* samples and Supporting Information S3 for the one-way ANOVA results of the hedonic score of the four *makgeolli* samples). 1SF-YN was observed to be the most liked *makgeolli* sample with an overall mean hedonic score of 5.5 ± 2.0 followed by 2SF (5.1 ± 2.1); however, both are not statistically significant. 3SF has a hedonic score of 4.5 ± 2.0, and 1SF-N was the least liked *makgeolli* sample with a hedonic score of 4.3 ± 1.9. Both 3SF and 1SF-N were not statistically significant; however, 1SF-N is significantly different from 1SF-YN.

ANOVA showed statistical differences among genders in mean hedonic scores of the four *makgeolli* samples ($F = 17.533$; $p < 0.001$) (see Supporting Information S4 for the overall liking of *makgeolli* between genders and Supporting Information S5 for the two-way ANOVA results of overall liking of *makgeolli* between male and female participants). The mean hedonic scores for male subjects of *makgeolli* tend to be lower than female subjects; however, female subjects tend to rate overall liking of *makgeolli* with a greater range (e.g., greater standard deviation). Female subjects rated the 1SF-YN sample with the highest overall mean of 5.6 ± 2.0 followed by 2SF (5.2 ± 2.2); however, the difference was not statistically significant. 1SF-YN (5.5 ± 2.0) was also the highest rated among male subjects followed by 2SF (5.0 ± 2.0). Both male and female subjects rated 1SF-N as the least liked *makgeolli* with an overall hedonic rating of 4.3 ± 2.1 and 4.2 ± 1.8, respectively.

The hedonic score of *makgeolli* overall liking is relatively low (e.g., the mean hedonic score of overall liking is below 6). A possible explanation of the moderate low overall liking of *makgeolli* among the subjects may be the result of limited prior experience before the sensory evaluation and being unfamiliar with Korean alcoholic beverages. Studies show that previous experience with ethnic food products helps consumers to form positive expectations of the food product, consequently increasing overall liking (Choe & Hong, 2018). In terms of familiarity, evidence suggests that familiarity with the food product is often correlated with higher hedonic scores during consumer testing (Hong et al., 2014; Park et al., 2020).

3.3 | Check-All-That-Apply

Thirteen terms were cited 20% or more by subjects, while 14 terms were statistically significant between *makgeolli* samples using Cochran's Q test. These terms include apple, apricot, astringent, bitter, bubbly, cider, creamy, dairy, hay-like, peach, sour, sweet, watery, and yellow. The most used term by subjects to describe *makgeolli* was sour. The perceived attribute of astringency by subjects increased as the length of fermentation time increased in *makgeolli*. In contrast, more subjects noted bubbliness as a perceived trait in single-stage fermentation such as 1SF-YN, and this trait reduced as the length of fermentation time increased such as 2SF (11.6%) and 3SF (5.4%). Table 2 shows the usage frequency and statistical significance of terms used to describe *makgeolli*. Post hoc test was performed using McNemar's test to identify terms with statistical significance at $p < 0.05$. There are similarities between the attributes identified in this study and those described by

TABLE 2 A contingency table of the fraction of consumers selecting the 20 terms from the Check-All-That-Apply questionnaire to describe *makgeolli*.

Attribute	Significance	1SF-YN	1SF-N	2SF	3SF
Apple	0.000***	0.403^{a}	0.326^{a}	0.333^{a}	0.132^{b}
Apricot	0.018*	0.07^{b}	0.194^{a}	0.132^{ab}	0.109^{ab}
Astringent	0.004**	0.217^{b}	0.264^{ab}	0.357^{a}	0.388^{a}
Bitter	0.000***	0.178^{a}	0.341^{b}	0.333^{b}	0.403^{b}
Bubbly	0.000***	0.411^{b}	0.147^{b}	0.116^{a}	0.054^{a}
Cider	0.000***	0.527^{d}	0.457^{c}	0.481^{b}	0.24^{a}
Creamy	0.000***	0.085^{b}	0.147^{b}	0.31^{a}	0.271^{a}
Dairy	0.008**	0.116^{ab}	0.07^{b}	0.163^{ab}	0.202^{a}
Floral	0.538^{NS}	0.054^{a}	0.085^{a}	0.062^{a}	0.093^{a}
Hay like	0.005**	0.07^{a}	0.155^{ab}	0.109^{ab}	0.202^{b}
Metallic	0.550^{NS}	0.085^{a}	0.085^{a}	0.07^{a}	0.116^{a}
Nutty	0.117^{NS}	0.054^{a}	0.07^{a}	0.101^{a}	0.132^{a}
Peach	0.027*	0.116^{b}	0.116^{b}	0.093^{ab}	0.031^{a}
Pear	0.437^{NS}	0.116^{a}	0.132^{a}	0.155^{a}	0.093^{a}
Rancid	0.819^{NS}	0.116^{a}	0.155^{a}	0.132^{a}	0.132^{a}
Sour	0.000***	0.612^{b}	0.775^{a}	0.667^{ab}	0.287^{c}
Sweet	0.018*	0.271^{a}	0.14^{b}	0.279^{a}	0.233^{ab}
Watery	0.000***	0.318^{a}	0.155^{b}	0.093^{b}	0.302^{a}
Yeasty	0.463^{NS}	0.31^{a}	0.372^{a}	0.372^{a}	0.318^{a}
Yellow	0.000***	0.031^{a}	0.403^{b}	0.037^{a}	0.031^{a}

Note: Letter within each row represents a statistical difference between each sample. "NS" represents statistical significance was not reached.*Statistical significance was reached at $p < 0.05$.
**Statistical significance was reached at $p < 0.01$.
***Statistical significance was reached at $p < 0.001$.

Kwak et al. (2015) and Lee and Lee (2008). American subjects identified attributes such as apple, pear, peach, nutty, yeasty, and apricot to describe KRW (Kwak et al., 2015).

Further analysis of CATA terms was performed by using CA to visualize the association between sensory attributes and *makgeolli*, as shown in Figure 1. The CA biplot map explains 87.47% of the total variance (48.45% in the first dimension and 39.02% in the second dimension). Each *makgeolli* was distributed on each of the four quadrants of the biplot map. The first dimension was defined by fruity flavor attributes such as apple, peach, cider, apricot, and pear in the negative values, compared to textural attributes such as creamy, watery, and astringent in the positive values. The results displayed in Figure 1 show that 2SF and 3SF are closely grouped together in the positive values of the first dimension, while 1SF-YN and 1SF-N are in the negative values. The differences between the *makgeolli* samples and sensory attributes in Figure 1 are likely to be influenced by the processing method such as the fermentation time and starter culture. For example, 3SF had the longest fermentation time and required a three-stage fermentation process, thereby enhancing the creamy texture of the rice wine. In contrast, 1SF-YN and 1SF-N had 7 days of single-stage fermentation; therefore, the creamy texture was not properly developed. From the CA biplot map, 1SF-YN shares similar flavor attributes such as apple, peach, cider, and apricot described by Kwak et al. (2015) as favorable traits of rice wine. In comparison, 1SF-N was associated with negative sensory attributes such as bitter and sour, both of which are negative drivers of rice wine (Kwak et al., 2015).

3.4 | JAR and penalty analysis

Figure 2a summarizes the penalty analysis for 1SF-YN. Overall, four attributes including too much sourness, not enough sweetness, not enough smoothness, and not enough fruitiness contributed a big part of the hedonic score in 1SF-YN.

For 1SF-N, sensory attributes including too much sourness, not enough smoothness, not enough fruitiness, and too much astringency exceed the mean drop score of 1 as shown in Figure 2b. This indicates that reformulation should be considered for 1SF-N; however, some of the attributes tend to contradict each other with a mean

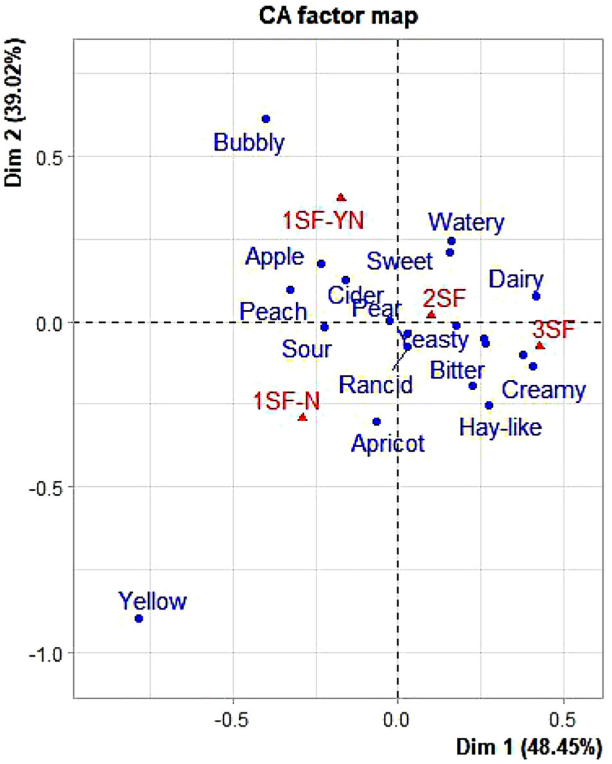

FIGURE 1 Correspondence analysis of the Check-All-That-Apply (CATA) terms and the cluster distribution of *makgeolli* samples.

drop score over 1 for both too much and not enough. For example, 62% of subjects cited sourness to be too much for SF-N with a mean drop score of 1.88, while 10% of subjects cited sourness as not enough for 1SF-N with 1.82. Similar issues can be observed for both 2SF and 3SF as shown in Figure 2c and Figure 2d, respectively, where contradictory information was observed. For 2SF, six attributes of interest excluding color had a mean drop score of more than 1. The contradictory results may have been caused by two factors: differing consumer groups within the subjects in this study and subjects not knowing an ideal product to compare *makgeolli* with or being unfamiliar with the product itself. From Section 3.1, four clusters of consumer groups were identified in this study using HCA. The four consumer groups may have perceived the four *makgeolli* samples differently as the level of subjective wine knowledge, objective wine knowledge, hedonic scores of different *makgeollis* samples, alcohol consumption frequency, and rice consumption frequencies were different. For example, Lee and Lee (2008) identified three consumer groups during their consumer testing for KRW, and Wong et al. (2023) noted that males and females tend to perceive *makgeolli* differently when comparing sweet, sour, and bitter tastes. Although the JAR scale provides the benefit of penalty analysis for product optimization, *makgeolli* is not a common product within New Zealand. Subjects may have found the JAR task difficult during sensory evaluation because the JAR scale assumes that they are familiar with the terms (e.g., sourness, sweetness, and color) being examined and have an ideal product (e.g., rice wine) for comparison (Lawless, 2013).

3.5 | Volatile and flavor analysis

From the scientific literature, researchers have observed rice (Chen et al., 2020) and fermentation culture (*nuruk*) significantly impact the flavor and volatile compounds produced in rice wine (Chen, Ren, et al., 2021; Kang et al., 2020; Shin et al., 2017). Esters tend to be the most abundant volatile compound found in different rice wines including Hong Qu glutinous rice wine (Chinese rice wine) (Liu et al., 2022), sake (Japanese rice wine) (Kang et al., 2016), and *makgeolli* (Jung et al., 2014; Park et al., 2014). In Hong Qu glutinous rice wine, specific esters that were identified include isoamyl acetate and ethyl acetate (Liu et al., 2022). In sake, isoamyl acetate and ethyl decanoate play an important role in the overall quality of the product (Kang et al., 2016).

A total of 45 aroma compounds were detected from the four *makgeolli* samples by SPME–GC–MS, including 10 alcohols, 25 esters, four aldehydes, one terpene, one ether, one heteroaromatic compound, and three other compounds. The majority of the volatile compounds identified from the SPME–GC–MS for *makgeolli* are esters that are derived from alcohols and aldehydes. Esters are important aromatic compounds that that influences the quality of alcoholic beverages such as rice wine (Kang et al., 2016). Examples of esters include phenethyl acetate, ethyl butanoate (pineapple-like flavor), and ethyl octanoate. In general, 2SF and 3SF have more ethyl esters than the single-stage-fermented makgeolli samples (1SF-N and 1SF-YN) due to a higher concentration of acyl-coenzyme A (acyl-CoA) produced by *Saccharomyces cerevisiae* (Saerens et al., 2008). The double and triple prefermentation steps to produce 2SF and 3SF *makgeolli* samples, respectively, produce a starter culture that has significantly higher microbial counts before the primary fermentation step (Kim et al., 2015). This means that *S. cerevisiae* can quickly reach peak activity during primary fermentation. Acyl-CoA produced by *S. cerevisiae* is a precursor for the formation of ethyl esters by enzymatic condensation of organic acids and ethanol via anabolism during fermentation (Pires et al., 2014). Other aroma compounds found in the *makgeolli* samples were consistent with the literature, as benzaldehyde (almond flavor) (Chen, Wang, et al., 2021), 1-octanol, 2-octanol (earthy/must aroma), ethyl acetate (fruity aroma) (Chen, Ren, et al., 2021), and

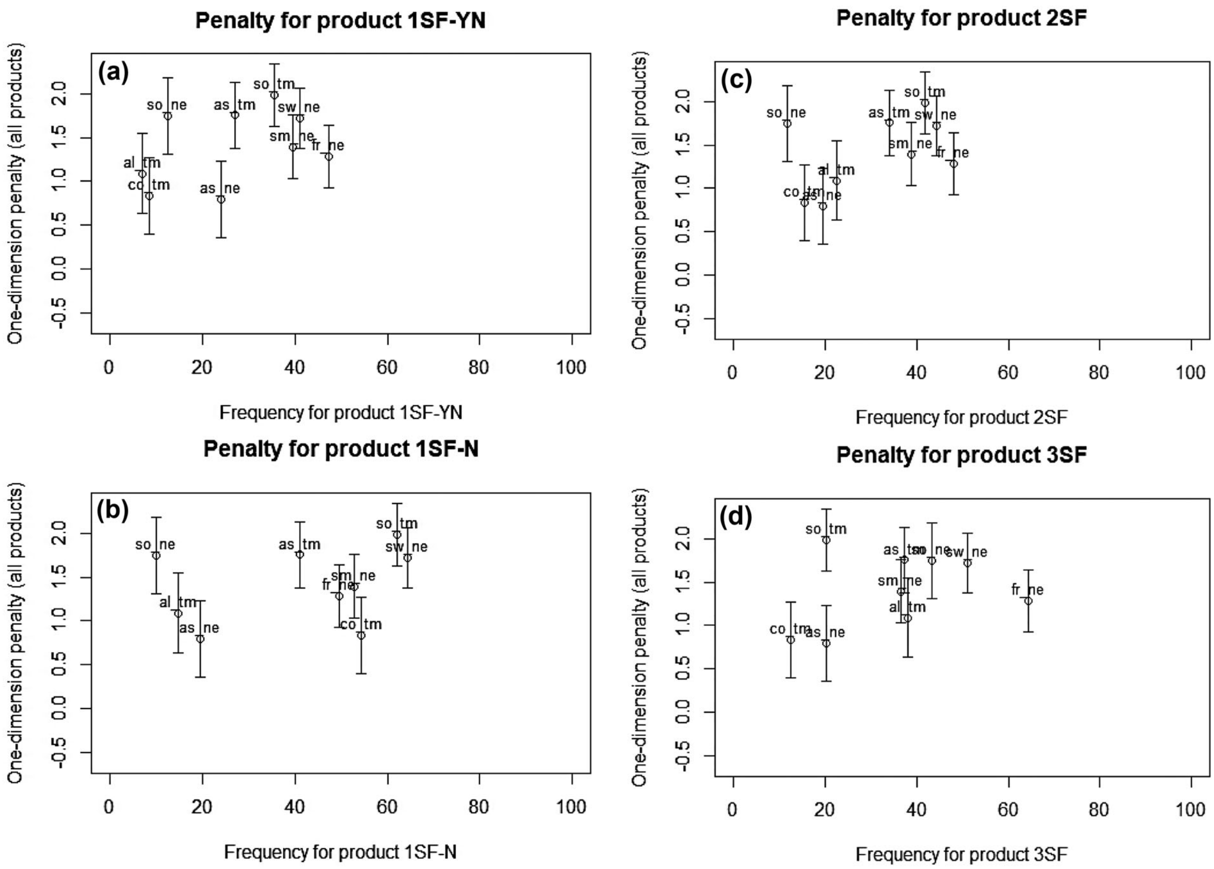

FIGURE 2 Panels (a), (b), (c), and (d) are the penalty analyses performed on 1SF-YN, 1SF-N, 2SF, and 3SF, respectively. The *y*-axis represents the penalty score, and the *x*-axis represents the frequency of subjects citing the sensory attribute either "Not enough" or "Too much." The sensory attribute is abbreviated in the left part of the underscore: so = sourness, al = alcoholic strength, sm = smoothness, sw = sweetness, fr = fruitiness, as = astringency, and co = color. The right side of the underscore denotes the intensity of the attribute either not enough (= ne) or too much (= tm).

phenylethyl alcohol (rose and floral aroma) (Yu et al., 2019) were previously identified in the literature and also present in this study. Table 3 shows the volatile compounds identified from the SPME–GC–MS. PCA was conducted and is represented in Figures 3 and 4. A scree plot (see Supporting Information S6) was constructed, and the first three dimensions explain 86.28% of the total variance; however, only Dimension 1 and Dimension 2 will be used for further analysis. Both Figure 3 (*makgeolli samples only*) and Figure 4 (variable correlation circle of volatiles) contain Dimension 1 and Dimension 2 where the graph explains 63.58% of the total variance (36.73% and 26.85%, respectively). From Figure 3, both 2SF and 3SF samples tend to cluster together, while 1SF-N and 1SF-YN are distinctively different. This can be explained by the different processing methods of making *makgeolli* where 1SF-N had the highest concentration of *nuruk* among the four different processing methods and 1SF-YN had the lowest concentration of *nuruk*, but yeast was added to reduce the amount of *nuruk* required during the fermentation process. This practice is used to reduce

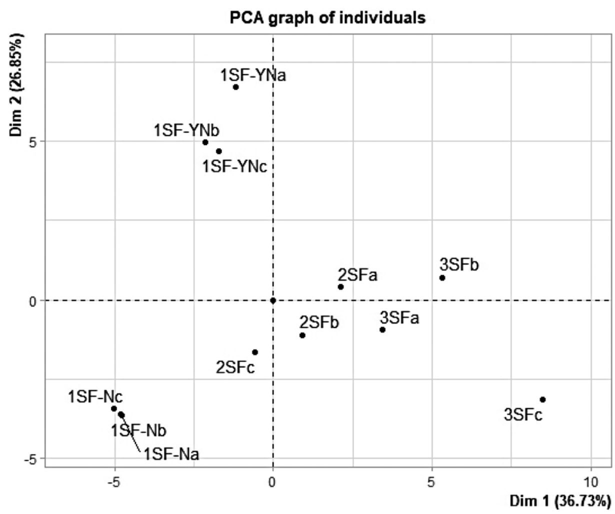

FIGURE 3 The graph represents the results of the principal component analysis (PCA) of four makgeolli samples with triplicates from the SPME–GC–MS analysis. The triplicates are denoted as a, b, or c, which refers to the sequence of the analysis that took place in the SPME–GC–MS.

TABLE 3 Normalized GC–MS response ratio of volatiles with mean values and standard deviation identified from *makgeolli* samples ($n = 3$).

	1SF-N	1SF-YN	2SF	3SF
2-Ethoxy-2-methyl-propane	0.005 ± 0.000	0.009 ± 0.001	0.006 ± 0.000	0.006 ± 0.002
Ethyl acetate	1.406 ± 0.025	1.493 ± 0.139	2.146 ± 0.233	1.630 ± 0.337
Isobutyl acetate	0.064 ± 0.005	0.230 ± 0.016	0.136 ± 0.015	0.125 ± 0.070
Ethyl butanoate	0.145 ± 0.010	0.095 ± 0.006	0.230 ± 0.020	0.175 ± 0.061
Hexanal	0.018 ± 0.000	0.038 ± 0.004	0.029 ± 0.002	0.035 ± 0.015
2-Methyl-1-propanol	0.320 ± 0.019	0.889 ± 0.117	0.571 ± 0.106	0.616 ± 0.229
Isoamyl acetate	0.303 ± 0.010	0.381 ± 0.061	0.503 ± 0.075	0.377 ± 0.094
Ethyl pentanoate	0.033 ± 0.001	0.033 ± 0.003	0.041 ± 0.004	0.043 ± 0.014
Limonene	0.002 ± 0.000	0.003 ± 0.000	0.005 ± 0.001	0.004 ± 0.002
2-Pentyl-furan	0.014 ± 0.000	0.011 ± 0.002	0.053 ± 0.004	0.032 ± 0.032
Ethyl hexanoate	0.719 ± 0.028	2.315 ± 2.105	0.925 ± 0.080	1.876 ± 2.158
3-Methylbutanol	0.810 ± 0.018	3.107 ± 1.809	1.129 ± 0.155	2.910 ± 2.998
Ethyl heptanoate	0.622 ± 0.026	1.251 ± 0.138	1.784 ± 0.107	1.409 ± 0.560
(*Z*)−2-Heptenal	0.006 ± 0.000	0.056 ± 0.027	0.007 ± 0.001	0.030 ± 0.033
2-Methylpropyl hexanoate	0.044 ± 0.004	0.203 ± 0.027	0.062 ± 0.005	0.094 ± 0.071
1-Hexanol	0.172 ± 0.007	0.568 ± 0.056	0.925 ± 0.079	0.504 ± 0.296
Ethyl octanoate	1.899 ± 0.048	2.762 ± 0.294	3.356 ± 0.229	2.794 ± 0.616
2-Octanol	0.285 ± 0.006	0.233 ± 0.169	0.055 ± 0.008	0.185 ± 0.156
Isopentyl hexanoate	0.212 ± 0.014	0.298 ± 0.037	0.216 ± 0.014	0.288 ± 0.094
1-Octen-3-ol	0.040 ± 0.001	0.149 ± 0.004	0.105 ± 0.016	0.010 ± 0.041
Acetic acid	0.591 ± 0.116	1.899 ± 0.464	1.773 ± 0.314	1.176 ± 0.738
1-Heptanol	0.047 ± 0.004	0.135 ± 0.013	0.186 ± 0.019	0.123 ± 0.053
2-Ethyl-1-hexanol	0.039 ± 0.006	0.046 ± 0.003	0.053 ± 0.029	0.048 ± 0.015
Ethyl nonanoate	0.724 ± 0.099	1.112 ± 0.147	1.880 ± 0.112	1.366 ± 0.502
Benzaldehyde	0.031 ± 0.002	0.043 ± 0.001	0.037 ± 0.018	0.040 ± 0.011
Isobutyl octanoate	0.017 ± 0.001	0.066 ± 0.007	0.031 ± 0.002	0.035 ± 0.020
Ethyl (*E*)−2-octenoate	0.020 ± 0.001	0.022 ± 0.002	0.030 ± 0.001	0.029 ± 0.010
1-Octanol	0.047 ± 0.001	0.164 ± 0.016	0.196 ± 0.016	0.138 ± 0.060
Ethylidene diacetate	0.063 ± 0.006	0.261 ± 0.030	0.061 ± 0.016	0.112 ± 0.092
2-Decanol	0.014 ± 0.001	0.030 ± 0.003	0.029 ± 0.004	0.022 ± 0.009
Ethyl decanoate	0.014 ± 0.001	0.030 ± 0.003	0.029 ± 0.004	0.021 ± 0.009
Benzeneacetaldehyde	0.024 ± 0.004	0.023 ± 0.001	0.024 ± 0.003	0.029 ± 0.010
3-Methylbutyl octanoate	0.148 ± 0.006	0.127 ± 0.013	0.143 ± 0.011	0.139 ± 0.012
Ethyl trans-4-decenoate	0.023 ± 0.001	0.020 ± 0.002	0.039 ± 0.003	0.028 ± 0.008
1-Nonanol	0.037 ± 0.001	0.073 ± 0.007	0.089 ± 0.009	0.072 ± 0.023
Ethyl 9-decenoate	0.015 ± 0.000	0.079 ± 0.009	0.013 ± 0.001	0.029 ± 0.031
Phenylethyl acetate	0.308 ± 0.012	0.220 ± 0.014	0.374 ± 0.034	0.261 ± 0.094
Ethyl decanoate	0.756 ± 0.031	0.665 ± 0.061	1.058 ± 0.080	0.863 ± 0.176
Phenylethyl alcohol	2.772 ± 0.091	1.705 ± 0.243	2.792 ± 0.256	2.620 ± 0.614
Ethyl tetradecanoate	0.585 ± 0.033	1.008 ± 0.102	1.790 ± 0.159	1.336 ± 0.597
Ethyl hexadecanoate	2.384 ± 0.096	1.824 ± 0.180	2.467 ± 0.128	2.508 ± 0.593
Ethyl 9-hexadecenoate	0.033 ± 0.002	0.054 ± 0.004	0.034 ± 0.004	0.036 ± 0.011
Ethyl octadecenoate	0.080 ± 0.006	0.037 ± 0.005	0.047 ± 0.001	0.055 ± 0.017
Ethyl oleate	0.196 ± 0.013	0.131 ± 0.045	0.228 ± 0.030	0.193 ± 0.043
Ethyl linoleate	0.281 ± 0.043	0.126 ± 0.020	0.298 ± 0.041	0.231 ± 0.077

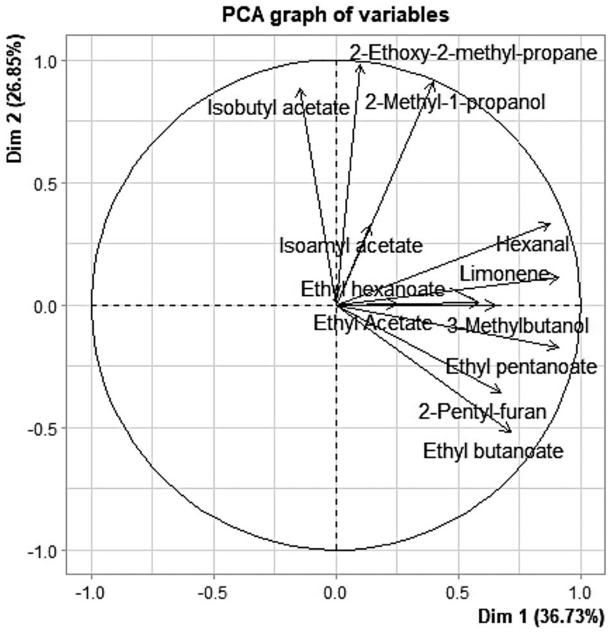

FIGURE 4 The graph represents the variable correlation circle of volatiles from the four makgeolli samples in triplicate. The distance between volatiles represents the quality of the information displayed on the PCA with volatiles further from the center being better represented.

the potential formation of excessive bioamines (histamine, tyramine, and putrescine) that can give *makgeolli* samples an unpleasant odor (Kim et al., 2011). Both 2SF and 3SF required a fermentation base prior to the fermentation process, in which the ingredients consist of nonglutinous rice and *nuruk*. Volatile compounds that had similar relative content between 2SF and 3SF include benzaldehyde (almond flavor), ethyl heptanoate (grape-like flavor), limonene (citrus peel-like flavor), and ethyl tetradecanoate. Volatile compounds that were distinctively unique to 1SF-N based on relative content include 1-heptanol, 1-nonanol, 1-octen-3-ol (mushroom-like flavor), 2-decanol, and ethyl-9-hexadecenoate.

In comparison, three volatile compounds—ethylidene diacetate, ethyl-9-decenoate (fruity-like flavor), and ethyl-trans-4-decenoate—are unique to 1SF-YN based on their relative content. The variable correlation circle of volatiles (Figure 4) shows that 2-ethoxy-2-methyl-propane, 2-methyl-1-propanol, isobutyl acetate, hexanal, limonene, and 2-pentyl-furan are well represented in the factor map, meaning that these volatiles are well correlated in either Dimension 1 or Dimension 2. Volatiles that provided the highest contribution for Dimension 1 are limonene, ethyl pentanoate, and hexanal, while 2-ethoxy-2-methyl-propane, 2-methyl-1-propanol, and isobutyl acetate were the three highest variables in Dimension 2.

Although statistical analysis was not performed when comparing sensory evaluation and chemical analysis, some volatile compounds identified from the SPME–GC–MS and sensory attributes from the CATA questionnaire showed similar sensory characteristics. For example, fruity attributes that were identified in the CATA questionnaire were also identified in the SPME–GC–MS such as isobutyl acetate (pear-like flavor) and isobutyl octanoate (fruity-like flavors) with varying relative content between the *makgeolli* sample. The sensory attribute "hay-like" in the CATA questionnaire was also identified in the SPME–GC–MS, with hexanal (hay-like flavor) being identified as the volatile compound.

3.6 | Implications and limitations

The current study is the combination of sensory science and chemistry to understand the sensory and flavor attributes that best describe *makgeolli* in a New Zealand context. CATA allowed researchers to capture the sensory attributes that describe *makgeolli*, while the JAR scale was used to calculate the penalty analysis regarding sensory attributes and the effects it has on hedonic scores of specific *makgeolli* samples. SPME–GC–MS identifies the volatile compounds within the different *makgeolli* processing methods described by Wong et al. (2023). The benefit of using the CATA questionnaire is the ease of use for subjects (Fleming et al., 2015). However, the CATA term selected by the researchers for this study may not capture all the sensory attributes that describe *makgeolli* in a New Zealand context as all the terms are predetermined by the researchers.

JAR scale was included in the study due to its ability for optimizing and identifying attributes that are affecting the overall acceptance of the food product. However, JAR scales require subjects to rate the product against an ideal product while understanding the term being evaluated (Ares et al., 2017), which can be challenging for some subjects. Although this may be a limitation of the JAR scale, researchers have used the JAR scale to assess specific food products such as kimchi (Jang et al., 2016; Park et al., 2020) and Korean traditional cookies (*yackwa*) (Hong et al., 2014), among foreign consumers with low familiarity. Future research on *makgeolli* in a Western context such as New Zealand should incorporate information about the subjects' familiarity, knowledge, understanding, and experience with KRW (specifically *makgeolli*) or rice wine. This will be beneficial to identify different cluster groups among consumers in New Zealand.

SPME–GC–MS provided a qualitative understanding of the different volatiles within the four different *makgeolli* samples. The concentration of the volatile compounds identified in this study can only be expressed relative to the four *makgeolli* samples tested. Absolute concentration measures of volatile compounds would require a different GC–MS method. The performance of sensory evaluation and chemical analysis (SPME–GC–MS) provided good insight into describing *makgeolli* with different processing methods. Both sensory evaluation and chemical analysis have revealed an overlap of sensory attributes and volatiles; 2SF and 3SF tend to share similar attributes that can be explained by their similar processing methods (e.g., fermentation base from nonglutinous rice and *nuruk*). 1SF-N had a higher concentration of *nuruk*, while 1SF-YN requires yeast to enhance the fermentation process due to the low concentration of *nuruk*. The sensory evaluation provided complementary results to the chemical analysis (SPME–GC–MS), such as the identification of acetic acid (vinegar-like taste) for sourness, ethyl pentanoate for apple-like flavor, and hexanal for hay-like flavor.

4 | CONCLUSION

This research paper extends our knowledge of understanding the sensory attributes that best describe *makgeolli* using sensory evaluation and chemical analysis. The CATA technique was implemented to understand how subjects describe different *makgeolli* samples, while the JAR scale provides information on ways to optimize *makgeolli* to increase overall liking on the hedonic category scale. Key attributes that were used to describe all four *makgeolli* samples by subjects include sour, followed by cider, apple, creamy, and bubbly. Fruity attributes such as apple, apricot, and peach were statistically significant among the *makgeolli* samples where 1S-YN had more fruity attributes describing the alcoholic beverage by subjects than 1SF-N, 2SF, and 3SF. In terms of the JAR results, the high penalty score (e.g., greater than 1) for most of the attributes may indicate that subjects may not be accustomed to consuming *makgeolli*. *Makgeolli* is not a common alcoholic beverage in New Zealand, and the higher penalty score is influenced by the low overall liking score accompanied by the "not enough" or "too much" categories of attributes. SPME–GC–MS provided similar insights to the sensory experiment where volatile compounds such as isobutyl acetate (pear-like flavor), isobutyl octanoate (fruity-like flavors), and hexanal (hay-like flavor) were identified. Both sensory evaluation and chemical analysis indicate that terms such as apple, cider, and sourness are good descriptors for describing *makgeolli*.

AUTHOR CONTRIBUTIONS

Barry Wong: Conceptualization; methodology; data curation; investigation; validation; formal analysis; writing—original draft. **Adrian Owen**: Methodology. **Megan Phillips**: Conceptualization; methodology; writing—review and editing; supervision. **Rothman Kam**: Conceptualization; methodology; writing—review and editing; supervision.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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