Evaluating Taste Differences in Korean Soju Through Electronic Tongue Analysis

Chang-Hwan Oh, Min-Hyuk Im
School of Bio Food and Nutrition Science, Semyung University, Jecheon, Chungbuk, Korea-27136
Email address: och35@semyung.ac.kr

Abstract— *To analyze the taste differences among common Soju brands available on the market, objective taste measurements were conducted using an electronic tongue (E-tongue). Eight soju samples were diluted to 1, 3, and 5%, and the electronic responses from seven sensors were processed using multivariate analysis, specifically principal component analysis (PCA). The results indicated a promising degree of differentiation among the soju samples at the 1% to 3% dilution levels. The taste profiles plotted in the PCA showed that Soju produced by the same company showed similar taste pattern. Although the NMS sensor, which measures umami, produced consistent responses for samples from the same company, the Soju sample that claimed to contain double the concentration of thaumatin—a natural sweetener—exhibited the lowest response from the NMS sensor. In contrast, the Soju containing glycine seemed like developing higher umami. This experiment confirmed that the E-tongue could effectively differentiate the taste of Soju. For the development of new Soju products and quality control within the company, the E-tongue might be a potent alternative to human tasting panels.*

Keywords— *Electonic tongue, PCA, Soju, Taste, Additives*

I. INTRODUCTION

The name of the distilled liquor 'Soju' was officially designated as a worldwide name by the World Intellectual Property Organization (WIPO) in 2022 under the Nice Agreement and is listed as 330039 in Class 33 of the 2023 WIPO edition (WIPO, 2023). According to trade statistics from the Korea Customs Service, soju exports in 2023 are expected to reach $101.41 million. According to Drinks International's the

Millionaires' Club, Jinro increased its sales figures by nearly 20 million 9-litre cases between 2017 and 2021. This impressive growth is equivalent to approximately 240 million 750ml bottles (Drinks International, 2023). The main ingredient of Soju is ethanol; however, subtle differences in taste can arise depending on the raw materials, aging methods, and additives used. Unlike traditional distilled Soju, the ethanol in diluted Soju (hereinafter referred to as just Soju) is high-purity ethanol (95%) obtained by fermenting plant-based carbohydrates extracted from cassava, sweet potatoes, and similar sources, which are then continuously distilled (Jee et al., 2008). Soju is a popular alcoholic beverage consumed by people of many different ages due to its reasonable price. In the early days of production in 1965, diluted soju with an alcohol content of 20-35% was released, but in the 1970s, the alcohol content was standardized to 25%. However, due to consumer preferences for lower alcohol content, an alcohol level of about 16% is currently favoured. Taste preference for soju is highly subjective, making it challenging for individuals who do not enjoy it to distinguish differences in flavour. Recently, due to health-related concerns, the use of traditional sugars such as fructose is declining, with a growing trend toward 'ZERO' products that incorporate low-calorie alternative sugars like stevioside in soju. Therefore, while differences in taste may be expected between Soju brands due to variations in alternative sweetners used, securing objectivity in evaluating these taste differences remains difficult. Recently, Park et al. (2022) measured the relative sweetness of sugars, fructose, glucose, and xylitol using an electronic tongue (E-tongue). This experiment focused to provide an objective evaluation of the actual taste differences of the popular Korean Soju samples by an instrument with the electronic sensor array complex unit, E-tongue.

II. MATERIALS AND METHODS

Soju is popular in any mart in Korea. Sampling was planned considering the ingredients (additives) in Soju to retain the diversity of samples. Sample analysis was performed using E-tongue without any involvement of human sensory function.

TABLE I. Soju list

Soju Code	Manufacturer	Ethanol%	Ingredients
J	H	16.0	Enzymatically modified Stevia, Erythritol, Thaumatin
T	H	16.5	High purity Fructose, Enzymatically modified Stevia, Erythritol, Thaumatin
W	L	16.5	Low purity Fructose, Enzymatically modified Stevia, Steviol glycoside
Bird	L	16.0	Enzymatically modified Stevia, Erythritol, Steviol glycoside
D	M	16.5	Enzymatically modified Stevia, Erythritol, Glycine, Steviol glycoside, Thaumatin
G	G	16.5	Enzymatically modified Stevia, Erythritol, Thaumatin, Asparagine, Xylitol
C1	D	19.0	High purity fructose, Enzymatically modified Stevia, Thaumatin, Asparagine, Arginine, Glycine
Big	D	16.5	Enzymatically modified Stevia, Erythritol, Steviol glycoside, Thaumatin

A. *Materials*

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Soju samples, including J and T (Manufacturer H), D (Manufacturer M), W and Bird (Manufacturer L), C1 and Big (Manufacturer D), and G (Manufacturer G), were purchased from local marts in Jecheon and Busan (Table 1). Purified water for dilution (Daehan Pharmaceutical Co., Ltd., Ansan) was obtained from a pharmacy in Jecheon. E-tongue used for taste analysis was the ASTREE Electronic Tongue V5 (sensor set #6) from Alpha MOS (France) (Fig. 1). The E-tongue consists of seven sensors, with AHS, NMS, and CTS representing sourness, umami, and saltiness, respectively; the other four sensors (PKS, CPS, ANS, and SCS) are known to react in a complex manner. High-purity solutions, such as HCl (0.1 M and 1 M) and NaCl (0.1 M) for stabilizing the sensors of the device, were purchased from Alpha MOS, and MSG powder was acquired from Glentham Life Sciences (Corsham, UK).

Fig. 1: Astree Electronic tongue

B. Method of Analysis

To stabilize E-tongue sensors, conditioning, calibration, and diagnostic processes were performed just before using the device according to the method of Park et al. (2022). The temperature was 23°C and the humidity was 57%. The soju samples were diluted to 1, 3, and 5% by adding purified water. No any further treatment was performed before analysis. The acquisition duration of the electronic tongue was set to 120 seconds, the acquisition period was set to 1 second. The sensors were washed by individual purified water right after completing the analysis of each sample. All samples were analysed six times consecutively to enhance precision.

C. Statistical analysis

The acquired sensor responses were statistically processed by the software installed in E-tongue system (Alpha Soft 14.1 ver., Alpha MOS, Toulouse, France"). Principal component analysis (PCA) was applied to the E-tongue data treatment and the Sojus were grouped by hierarchical cluster analysis (HCA).

III. Results and Discussion

Among the five human senses, taste and smell are highly subjective, with preferences varying based on individual personality and health status. Therefore, to accurately evaluate taste and smell—assessments that can only be made by people—statistical reliability could be achieved just in case of a large number of human panels are involved. While instrumental analysis of fragrance components using gas chromatography has been performed frequently for a long time, allowing for scientific and objective evaluations, taste is limited to a smaller range of components compared to odor. Moreover, current scientific analysis methods often struggle to match the highly sensitive sensory capabilities of humans. The E-tongue is a sensor array instrument analyzing liquid samples to generate multidimensional data, combining a powerful statistical processing tool to extract meaningful interpretation of the complex data (del Valle, 2010). Each sensor of E-tongue is lack of enough selectivity for determining of one or more analytes, stand-alone. However, when the multiple sensors react to a group of analytes, they can provide cross-response as an electronic tongue unit (Bastos-Arrieta et al., 2024). The multiple sensor responses could not be interpreted without aid of statistical processing. The most frequently used statistical tool is PCA, a multivariate analysis. Through PCA, multiple dimensions of the data are transformed into a few characteristic dimensions for analysis and can be represented as an image. PCA was first designed by Karl Pearson in 1901. It was later introduced by Harold Hotelling in 1933 and further developed in 1936 in a solitary manner. The calculation process involves a new collection of variables, known as principal components, which are each derived as linear combinations of the original variables. (McKenzie et al., 2011). The principal components are selected to retain the important information in the data and are transformed into a few new variables; therefore, the information is effectively summarized for the samples or observations.

After analyzing Soju samples with different concentrations (1, 3, and 5%) using E-tongue, the entire seven sensor measurements (responses) were utilized for PCA. Among the diluted samples by stages, the 1 and 3% diluted samples showed the best discrimination efficiencies with the discrimination index (DI) of 85~88 (the closer the DI is to 100, the easier it is to discriminate). The following PCA results are from 3% diluted sample analysis data.

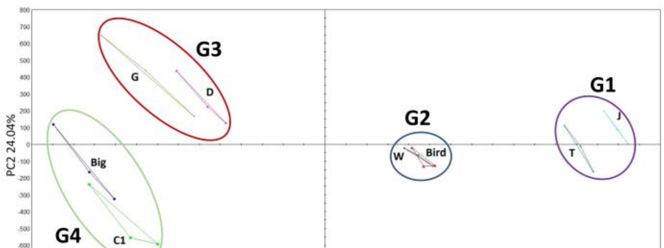

Fig. 2: PCA plot of eight Soju samples analysed by E-tongue

As shown in Fig. 2, the eight Soju samples were divided into four clusters. The common ingredient noted in these samples was enzymatically modified stevia. Erythritol and thaumatin were present in six samples, while steviol glycoside and fructose were labeled in four and three samples, respectively. An interesting observation from Fig. 2 is that,

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except for group G3, which includes Soju G and D from two different manufacturers, the other three manufacturers composed three different clusters. Soju J and T of cluster G1 produced from manufacturer H. The difference of them were a slightly different ethanol % and the existence of fructose. However, cluster G4 of Soju C1 and Big from manufacturer D showed more ingredients differences, such as asparagine, arginine, glycine, erythritol and steviol glycoside. It could be also explained as the distance of Soju samples in Table 2. The distance between Soju J and T of cluster G1 is 183.29, though the distance between Soju C1 and Big is 366.37. That means Soju C1 and Big are showing more different taste characters than Soju J and T. The closest distance 76.65 of two Soju samples was observed in cluster G2 where Soju W and Bird showed only difference of fructose and erythritol. The fructose described in Soju W is the low percentage of fructose under 35%, mixed with other form of mono and disaccharides. Erythritol in Bird Soju and the low percentage fructose in W Soju looked like counteracting their taste character with each other. That's why the two forms of Soju may representing very similar taste pattern. The distance of Soju D and G from different manufacturers was 548.62 almost 7 times larger than 76.65, the closest distance. The difference of additives observed in cluster G3 were glycine, asparagine and xylitol. Soju G was the only one containing xylitol. The distance is a practical mean of evaluating the similarity of two set of samples while pattern discrimination index (PDI) % also considering dispersion of each sample set. The closer the PDI is to 100%, the larger the distance between the centers of gravity and the lesser the dispersion within the sample set (Alpha MOS, 2020). The tendencies of distance and PDI in Table 2 are similar with each other.

TABLE 2: Distance and pattern discrimination index (PDI) of Soju samples belong to each cluster

Cluster	Soju code		Distance	PDI (%)
G1	J	T	183.29	42.76
G2	W	Bird	76.65	29.43
G3	D	G	548.62	68.66
G4	C1	Big	366.37	48.81

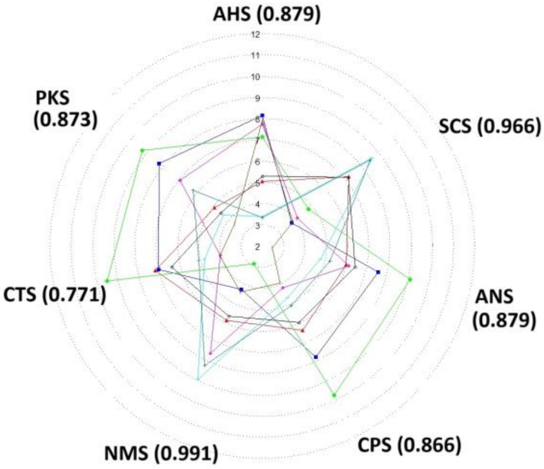

Fig. 3: Radar pattern of seven sensors' normalized responses to eight Soju samples analysed by E-tongue. The values in parenthesis are discrimination power of each sensor.

Fig. 3 is representing the normalized sensor responses to the Soju samples. NMS sensor scored the highest value of discrimination power (DP), 0.991 followed by 0.966 of SCS sensor. The lowest DP (0.771) was observed in CTS sensor designated as sensing saltiness, that could be interpreted as the saltiness may be the weakest variable. Other sensor's DPs are in the range of 0.866 (CPS) to 0.879 (AHS).

NMS sensor is designated to umami and AHS sensor is assigned to sourness. The relative strength of the two tastes of the eight Soju samples are presented in Fig. 4. As expected, samples belong to cluster G1 and G2 showed very close value of umami and sourness, respectively. Otherwise, Soju G and Big showed very similar umami and sourness patterns unexpectedly, while they are quite different with Soju D and C1 in the view of umami and sourness. The high value of umami of Soju D comparing Soju G (in cluster G3) may be caused by the existence of the amino acid, glycine. In the research of Bachmanov et al. (2016), glycine was used as representative sweet tasting amino acid while L-glutamate used as umami tasting amino acid. Therefore, glycine might enhance the response of NMS sensor for Soju D if we consider the receptor T1R3 detects umami and sweet tastes together in the human tongue (Immohr, 2016). However, C1 Soju showed the lowest umami strength (about 2.8) though it claimed glycine, arginine, asparagine and thaumatin. Moreover, the added amount of thaumatin was claimed twice than other Soju products. A natural sweetener, thaumatins is a polypeptide with 207 residues isolated from the katemfe fruit (*Thaumatococcus daniellii*) of West Africa. It is known 100,000 times sweeter than sucrose (Edens et al., 1982). The low umami flavor of Soju C is likely due to its higher ethanol content (19.0%) compared to the other soju samples, which have ethanol percentages ranging from 16.0 to 16.5%. A larger amount of purified water was added to Soju C to dilute it to the same concentration of 3%. As a result, the taste impact of the more diluted ingredients may be less pronounced than that of the other Soju samples. Therefore, the higher alcohol content in Soju C may be contributing to its lower umami flavor. Nonetheless, the low umami value of soju C1 appears to warrant further study.

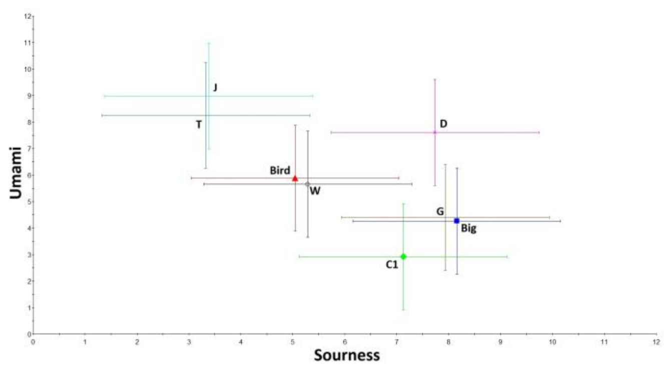

Fig. 4: Relative umami and sourness strength of eight Soju samples

IV. CONCLUSION AND RECOMMENDATIONS

Soju, the most popular liquor in Korea, was analyzed by E-tongue. The similar taste characteristics were found among

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Soju samples produced by the same manufacturer. However, even among soju classified into the same cluster in the PCA plot, there were cases of the large differences in umami, etc. It is guessed that this is due to dissimilarities in the amount, ratio, or form of the added ingredients. Specifically, the quantitative impact of thaumatin, which is known to be 100,000 times sweeter than sugar, is area that warrants further research in the future. Given that costly human taste tests often yield results with significant variability due to individual preferences and health conditions, it is likely that objective analysis using E-tongue technology will become increasingly popular in the food industry. In particular, E-tongue is anticipated to play a larger role in taste difference testing and QA/QC of high-alcohol beverages, where the strong alcohol flavor can obscure the intrinsic taste.

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