An Approach Sensory Analysis Using Targeted Sensors in Electronic Nose for Assessing Green Tea Quality

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Abstract— **The aroma greatly influences tea's character. Recent advances in techniques have led to numerous studies on volatile organic compounds in tea. Different green tea grades have distinct aromas, with premium grades having a stronger scent. Key factors in assessing tea quality are its chemical aroma substances. Various methods like GC-MS are used to identify volatile aroma compounds (VOCs). Nevertheless, these processes are time-consuming and costly for green tea producers. On the contrary, sensory analysis by tea experts is another way to evaluate tea quality, though subjectivity may arise. The electronic nose (e-nose) is a sensor-based instrument concerning tea quality assessment inspired by the human olfactory system. It, combined with statistical analytics, can enhance the performance of quality testing accuracy. Sensors are selected based on dominant compounds like hydrocarbons, alcohol, ketones, and aldehydes. Using targeted sensors and an appropriate statistical analysis should simplify prediction computation. Notably, green tea's pleasant aroma may not be very intense, necessitating a comprehensive sensor array. Integrating tasting assessments can enhance the accuracy of electronic nose predictions.**

Keywords—aroma, e-nose, green tea, sensors, VOCs

I. Introduction

Tea consumption per capita rose by 2.5% in the past decade in the world, as stated by the United Nations under the Food and Agriculture Organization (FAO) of. with notable expansions among tea-producing countries. Because of its delightful flavor, alluring scent, and benefits for health [1].

One of the most significant elements influencing the character of tea is its aroma. The aroma of green tea impacted by a multitude of elements including the grade of tea, processing stages, and fertilization techniques. There have been many studies on volatile compounds in tea due to recent developments in techniques and tools for identifying and isolating these compounds. Different grades of green tea have distinct aroma profiles, with premium grades often exhibiting a higher intensity of pleasant scent[1].

During the assessment of tea quality, it is essential to consider the chemical substance found in its aroma[2]. GC-MS, GC-O-MS, GC-TOFMS, and GC-IMS are commonly used methods to determine the specific volatile aroma compounds[3]. However, if these methods are applied to every production, they are expensive, time-consuming, difficult for green tea producers to implement, and inappropriate for real-time quality monitoring[3]. On the other hand, utilizing sensory analysis conducted by tea experts to visually inspect, perceive aromas, and experience the flavors of different green tea samples represents an alternative method for expedited evaluation of tea quality[2]. However, it might be subjective due to a few things, like emotion, tiredness, and infection, leading to inconsistency[4].

The electronic nose is a sensor-based tool for assessing tea quality that is embedded with the ability to perform predictive analysis, inspired by the olfactory system of humans[4]. The combination of an electronic nose with intelligent pattern recognition and statistical methods is a potential tool for assessing tea quality. This integration has the capability to minimize errors, enhance detection accuracy, and ensure consistency during quality testing[5]. Two types of electronic noses are used to define the quality of green tea: commercial-developed (such as PEN2, PEN3, FOX3000, FOX4000, Heracles II, etc.) and lab-developed[2]. The commercial-developed system is more general since it has a fixed sensor array. Whereas for specific ones, researchers can create their systems according to the characteristic aroma found in certain green teas.

Nevertheless, the utilization of sensors utilizing compounds associated with GC-MS has not been addressed; for instance, GC-MS serves as a ground truth. The present study aims to investigate the application of sensors in electronic noses that were laboratory-made by a scientific institution and correlated with the organic compounds in green tea. Assessing methodologies on electronic noses that are commercially available is not within the scope of this paper.

II. Design Study

Recent publications, primarily issued after 2014 to 2024, have been chosen for this examination, alongside some articles from the preceding year that have been referenced. Specific keywords such as electronic nose, e-nose, artificial nose, aroma compound, odor compound, gas sensors, quality of green tea were utilized to explore relevant journal articles across SpringerLink, IEEE Xplore, Science Direct, and Scopus databases. This led to the identification of approximately 1200 papers. Subsequently, a selection of 62 papers was made based on predefined criteria: removal of duplicates, exclusion of certain additional records, and assessment of the eligibility of abstract articles (including journal articles and conference proceedings). Given the central focus of this review on electronic nose systems for assessing the quality of green tea, studies that focused solely on black tea, flavor, or other unrelated aspects concerning the identification of green tea quality from its aroma were omitted. According to a search using those keywords, the Scopus database has yielded data as shown in *Fig. 1*.

From an analysis of the Scopus database, we observe a rising trend in the discourse surrounding the application of electronic nose for assessing green tea quality spanning the years 2014 to 2024. Fig. 2 shows the examination of the data, reveals that China emerges as the leading contributor to research in this field, with over 800 scholarly works published within this timeframe. Following China, the United States, India, Iran, Spain, Australia, Brazil, South Korea, Italy, and Indonesia are among the top countries engaged in studies pertaining to the utilization of electronic nose devices for assessing quality of green tea. While the academic disciplines

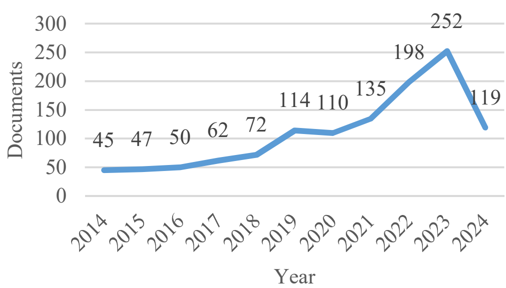

Fig. 1. Trends in the use of electronic nose in identifying quality of green tea from 2014 to 2024.

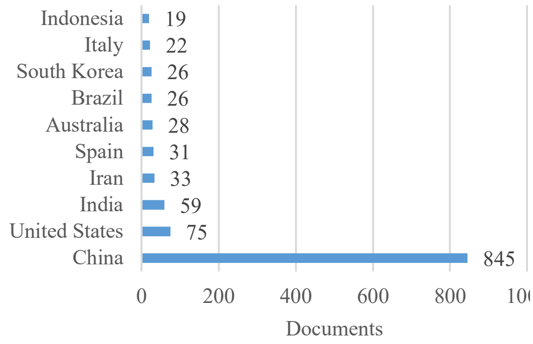

Fig. 2. Top 10 countries that contributed to the study of the electronic nose in identifying green tea quality.

that primarily focus on examining the quality of green tea through electronic nose are agricultural and biological sciences (36.6%), followed by engineering (14.7%); biochemistry, genetics, and molecular biology (7.4%); chemistry (12.7%); physics and astronomy (5.3%), computer science (4.8%), and other related fields as seen in Fig. 3.

III. Key Volatile Organic Compounds in Green Tea

Many research have used different methods to assess the volatile organic compounds (VOCs) found in green tea. In general, samples of green tea are extracted using HS-SPME (headspace solid-phase micro extraction) then segregated using a gas chromatograph, then the mass is measured using mass spectrometry[6].

According to analysis of gas chromatography-olfactometry (GC-O), a preliminary aroma recombination experiment, and odor activity value (OAV) calculations, in Longjing green tea there are fourteen VOCs were presented as the critical aroma compounds including benzaldehyde, methyl ethyl acetaldehyde, benzene acetaldehyde, dimethyl sulphoxide, heptanal, nonanal, 1-vinylhexanol, linalool, geraniol, trans,trans-2,4-heptadienal, (E, E)-3,5-octadien-2-one, linalool oxide I, β-ionone, and methyl salicylate[6].

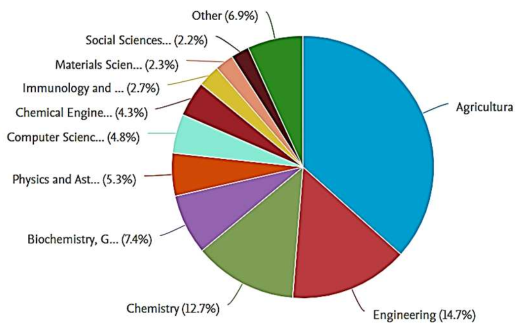

Fig. 3. The utilization percentage of electronic nose for assessing green tea quality has been explored across diverse scientific disciplines.

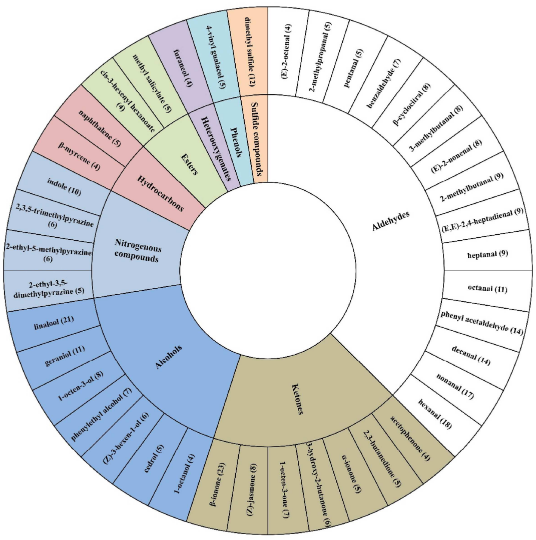

Fig. 4. Key odorants identified in green tea [14]

Furthermore, in 21 samples of green tea grown in Hangzhou and Ya'an, several compounds including 27 hydrocarbons, 17 aldehydes, 11 ketones, 9 alcohols, 9 nitrogen compounds, 7 esters, 2 furans were found[7]. In the other hands, the similar compounds are also produced by Rizhao green tea[8]. It emphasized the significance of a pleasant and aromatic floral scent in determining the green tea quality.

Based on the key odorants that were proficiently extracted by flavor dilution (FD) and odor activity values (OAVs) found that hydrocarbons, aldehydes, alcohols, ketones, nitrogenous chemicals, phenols, esters, hetero-oxygenates, and sulphide compounds are among the molecules that contribute to the green tea aroma [6].

There is a relationship on health advantages and volatile compounds that play a role in fostering a favorable perception; these compounds exhibit antimicrobial, anticarcinogenic, and antioxidant activities[9].

Moreover, the principal volatile compound found in green tea, including benzyl alcohol, linalool, and furfural, have been proved to possess noteworthy antioxidant activities. It can be observed that the tea samples with a high grade obtained the most elevated rating in terms of pleasant aroma attributes, such as purity, persistence, maltiness, sweetness, citrus notes, fruitiness, floral flavors, refreshment, and hints of seaweed [10].

IV. ORGANOLEPTIC TEST

According to multiple green tea assessment criteria, including ISO11287-2011 concerning the definition and fundamental necessities of green tea; (GB/T 23776-2018) about a systematic approach for assessing the sensory attributes of tea on the Chinese national guideline; and the Indonesian national regulation (SNI3945:2016) regarding green tea; aroma represents a critical parameter consistently included in all sensory assessments of different forms of green tea (dry, infused, and infused residues). The assessment was conducted by multiple panellists with diverse gender and age[2].

V. ELECTRONIC NOSE (E-NOSE)

Electronic nose, the machine olfaction system, is capable of imitating the human nose, enabling it to perform intricate pattern recognition tasks that mimic the olfactory system present in humans[10], [11], [12]. The E-nose is made up of three components, illustrated in Fig. 5,: (1) a system for handling the aroma of sample, (2) a system for detection, which consists of a specific gas sensors array and (3) a system for data processing and pattern recognition for the aroma [3].

Sensor array, a crucial and intricate element for detecting gas/odor in electronic nose, is arranged of a diverse array of sensors exhibiting extensive response characteristics and significant cross-sensitivity to a variety of gases. These sensors are responsible for converting gas concentrations into electrical signals, which in turn are utilized for conducting analysis of qualitative or quantitative on the samples being observed. In order to enhance the e-nose system's monitoring of the chosen samples, choosing a proper gas sensor array is one of the main design requirements [13].

The detection system in electronic nose is typically paired with various sensing elements, such as MOS (such as: iron oxides, titanium, nickel, cobalt, zinc, and tin) sensors, EC, CP, quartz crystal microbalance, etc. Therefore, the selection of materials and sensors employed influences the specificity, sensitivity, speed of response, and efficiency of each electronic gas detector[13].

The findings of the research have demonstrated the effectiveness of MOS sensors within the field of food applications for extended periods of continuous

TABLE I. ORGANOLEPTIC TEST PARAMETERS BASED ON SNI3945:2016

	Dried greentea appearances	Brewed greentea appearance	Tea grounds appearance
How to express the result	A = excellent; B = good; C = sufficient; D = bad; E = unsatisfactory;	• There are 2 test results from steeping, namely the color of steeping water and taste (briskness, strength, flavor, and foreign taste elements). • *Briskness*: fresh tea; *strength*: concentrated, biting, not bitter; *flavour*: specific taste and aroma; foreign flavor: tainted	• Assessment includes the evenness of the color

Characteristic	Grading A	B	C	D	E
Colors	Blackish green	greenish black	Yellowish Green/ Yellowish	Blackish	Brownish Yellow
Form	Perfectly rolled	Rolled	Less rolled	Not rolled	Powdered, trunk, fiber
Aroma	Normal typical green tea	Normal typical green tea	Normal typical green tea	less typical of green tea	Not-normal / unfamiliar aroma
Texture	Solid	Solid / not fragile	Less solid	Not Solid	Not solid / Fragile
Uniformity size	Uni-form	Uni-form	fairly uniform	Less uniform	Not uniform
Foreign objects	unavailable	unavailable	unavailable	unavailable	unavailable

Score	Color of Brewed Tea
5	Yellowish green and very bright
4	Greenish yellow and bright
3	Reddish yellow and moderately bright
2	Red and dull
1	Brownish red and very dull

Score (Odd)	Flavour of Brewed Tea
21 - 29	bad until unsatisfactory
31 - 39	fairly good until good
41 - 49	good until very good

Score	Color of Tea Grounds
a	Very bright green
b	Bright green
c	Slightly bright green
d	Brownish green
e	Dull/dark

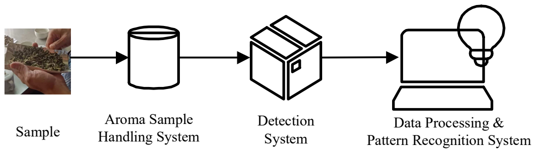

Fig. 5. General diagram of electronic nose system

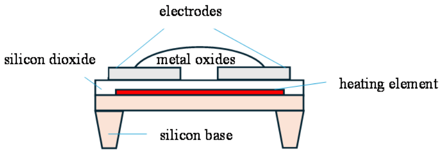

Fig. 6. Metal oxide semiconductor schematic

operation[13]. For example, MOS sensors effectively differentiated among the five distinct classifications, highlighting the capability of the device to differentiate between the flavor profiles of the various teas produced using different processing techniques. Consequently, it could be employed for discriminatory purposes and for evaluating changes in quality.

VI. DISCUSSION

Hydrocarbon, aldehydes, alcohols, phenols, ketones, nitrogenous compounds, esters, hetero-oxygenates, and sulphide compounds are a variety of the molecular constituents that contribute in the characteristic of green tea aroma, as determined through the effective extraction of key odorants, for example GC-MS[6].

TABLE II is a summary of information derived from GC-MS that has been performed on different green teas and certain electronic noses designed to distinguish each green tea both in quality and origin which are distinguished by the type of green tea, sensor array used, class of compounds detected, analysis method, and the performance achieved. Hydrocarbons and alcohols represent the predominant compounds of interest in every e-nose system designed for the analysis of each types of green tea. Reporting from PubChem from the National Center for Biotechnology Information under the National Institues of Health (NIH), phenol is an acidic alcohol-derived organic compound that has antioxidant characteristics contained in plants. Hence, the process of sensing is focused on alcohol, as illustrated in TABLE II.

The performance of quality detection is the predicted result of gas sensing using sensor array, which correlates with the results of organoleptic parameter tested as specified in

TABLE I. shows amount of sensors utilized in the e-nose consists of 6 to 8 gas sensors. The e-nose built for quality classification on West Lake Longjing green tea uses eight gas sensors that detect more compounds and has the highest performance of 99.42% by using Random Forest (RF). On the other hand, Fu et al succeeded in building an e-nose using six gas sensors, resulting in 99.38% prediction with a Quantum Neural Network (QNN).

Gas sensors exhibit sensitivity that are non-specific and broad cross-sensitivity towards VOCs found in tea. Consequently, within this system, a single sensor may detect multiple VOCs present in green tea, while multiple sensors may detect a single VOC in green tea simultaneously.

TABLE II. LAB-MADE ELECTRONIC NOSE IN RECENT RESEARCH

Type of Green tea	Sensor	Aldehydes	ketones	alcohols	nitrogenous chemicals	hydrocarbons	esters	Hetero-oxygenates	phenols	Sulphide compounds	Analysis Method	Performance	Ref
West Lake Longjing	TGS822		v	v		v					RF	99.42%	[3]
	TGS813					v							
	TGS2600					v							
	TGS2620			v		v				v			
	TGS2602	v			v								
	MQ-6	v											
	MQ-138		v	v		v				v			
	MQ-135				v	v							
Chaoqing	TGS813					v					KNN	90%	[14]
	TGS824				v						ANN	87.5%	
	TGS 821		v	v		v					SVM	95%	
	TGS 822		v	v		v							
	TGS880		v	v									
	TGS 822TF			v									
	TGS812		v										
	TGS 825									v			
Huangshan Maofeng; Xihu Longjing; Enshi Yulu; Mabian Lucha;	TGS832							v			BPNN	82.30%	[15]
	TGS880		v	v							QNN	99.38%	
	TGS800										SVM	98.87%	
	TGS822		v	v		v					k-NN	98.75%	
	TGS826			v	v	v							
	TGS825									v			

Type of Green tea	Sensor	Aldehydes	ketones	alcohols	nitrogenous chemicals	hydrocarbons	esters	Hetero-oxygenates	phenols	Sulphide compounds	Analysis Method	Performance	Ref
Xinyang Maojian	TGS816 TGS812		v v	v		v							

In electronic nose, the sensor array is essential in the process of obtaining high-quality raw data for detection, so sensor array optimization (SAO) become a concentration in several studies [16]. The number of sensors and sensor arrays with optimizations were also developed to show the evidence of the advantages of the suggested approach from different point of view. It offers a more efficient concept and promising idea for the development of a gas sensor array. Additionally, it efficiently removes redundant sensors, contributing to the integrity of the primary data regarding tea aroma. By decreasing the quantity of sensors, the refined sensor array offers to the system cost-saving initiative[16]. Shortly, the objective of the SAO is to utilize a limited quantity of sensors for the acquisition of the most crucial signals to be utilized in the analysis of data. The availability and price of sensors are likely to be taken into consideration in the decision to use sensors.

VII. Conclusion

From the research that has been carried out, to get satisfactory performance, it is not necessary that all classes of compounds are detected by the sensor. The sensor selection is based on the dominance of compounds that are sorted including hydrocarbons, alcohol, ketone, and aldehyde. The use of targeted sensors will produce good data so that the prediction computation can be completed simply. Although if coupled with the use of pattern recognition algorithms may also produce equally high performance so that the number of sensors can be reduced.

The GC-MS method and other similar variants could possibly become the golden standard for e-nose detection systems. So that the concentration of compounds in certain teas can be known and their dominance can then be determined using sensor array optimization. The challenges encountered by researchers in developing a specific device for assessing the quality of a food or beverage product involve the selection of an appropriate sensor. It is feasible for the researcher to evaluate the sensor's reaction to the odor emitted by different types and brands of sensors available in the market. Subsequently, the next consideration pertains to the sensor's specifications for substance detection, specifically, the sensitivity capable of detecting each part per million. It is undeniable that the application of sensor array optimization (SAO) is highly feasible.

However, it is crucial to acknowledge that the aroma of green tea may not be particularly intense, leading to a significant requirement for a considerable sensor array. Moreover, this examination is at risk of being influenced by the presence of other odor like air fresheners, perfumes, body odors, or other odors.

The consistency of predictions generated by the system from repeated use, high durability, or computational time specified by the processor or components used in the system should also be some concern to serve as a reference point for further improvements. The integration of tasting assessments could potentially serve as a means to combine the accuracy of the prediction results generated by an electronic nose.

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