Application of E-tongue, E-nose, and MS-E-nose for discriminating aged vinegars based on taste and aroma profiles

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Abstract The combined approach of E-senses was undertaken to discriminate the taste and aroma profiles of aged vinegars, including Chinese Shanxi extra aged vinegar (EX, 5–8 years), Japanese black vinegar (BL, 1–5 years), and Italian balsamic vinegar (BA, 8–25 years). The principal component analysis plot for E-tongue revealed that EX, BL, and BA formed individual groups with clear distinctions. The volatile compounds detected in E-nose based on Kovats indices represented that a major component in all vinegars was matched to acetic acid, which showed a strong relationship with the aging period ($R=0.8186–0.9998$). The discriminant function analysis plot accompanied by the MS-E-nose indicated that more volatiles were produced during prolonged aging in cereal vinegar, whereas the aging process degraded volatile constituents in fruit vinegar. Categorization with respect to aging years was possible using both E-noses. The approach using E-senses indicated a better discrimination for distinguishing the complex sensory information in aged vinegars.

Keywords: aged vinegar, electronic tongue, electronic nose, mass spectrometry-E-nose, multivariate analysis

Introduction

Vinegar can be easily prepared by alcoholic and acetic fermentation of a carbohydrate source such as cereals and fruits (1,2) and has versatile and distinct organoleptic properties. As a widely favored condiment, large quantities of vinegar prepared from different raw materials are produced and consumed worldwide. Chinese black vinegar is categorized as traditional aged vinegar product being made up of different cereal grains, i.e., glutinous rice, wheat, sorghum, and millets, and has an ink-like black color and complex flavor. Traditionally, no specific recipe of black Chinese vinegar is in existence; therefore, Chinese black vinegars comprise some accessory ingredients such as spice condiments, caramel as colorant, and table sugar. In Japan, a somewhat lighter form of black vinegar synthesized from rice is widely available and being marketed as a health drink. Medicinal significance of black vinegar was reported in recent literature, such as anticancer properties in *in vivo* mice model (3,4) and *in vitro* anti-carcinogenic activity in human cancer cells (5). European vinegars are typically produced from fruits such as balsamic vinegar from Italy (6) and wine vinegar from France (7). The choice of raw material and production and aging techniques are very important for the development of taste and aroma in vinegar (8).

Vinegars have particularly sharp and acidic tastes, and contain

complex volatile compounds such as acids, esters, and aldehydes, and sensory assessment of vinegar is challenging because of non-repeatability or inaccuracy (9). Recently, modifications in taste and flavor profiles were reported by various studies. Notable changes comprised moisture loss through pores in wood, rise in acetic acid concentration, recovery of phenolic compounds from wood surface, and development of aromatic compounds, i.e., esters, (10). Products were classified based on different parameters such as origin, type, variety, and quality attributes (11,12). Multivariate statistical and sophisticated fingerprinting (involving chemical characterization) techniques were employed for the purpose of classification. Moreover, volatile compounds can be used to distinguish high-quality vinegars from adulterated and substandard vinegars (13).

Electronic tongue (E-tongue) and electronic nose (E-nose), which are simulations of the human taste buds and nose, respectively, have been introduced as effective alternatives to conventional approaches used for the taste and odor analyses of food (14). E-tongue is used as a chromatographic technique to analyze food characteristics. Wide variety of E-tongues has been used to perform successful characterization and discrimination and quality assurance (evaluation and control). Moreover, they were also utilized for monitoring processes, and foodstuffs and beverage products were also evaluated by means of quantitative analysis. E-nose possesses several advantages. Prominent

advantages comprise ease of handling, cost-effectiveness, easy establishment of analytical setup, and rapidity of analysis. The main advantages of E-tongue include the low cost, easy-to-handle measurement set-up, and speed of the measurements (15,16). The E-nose is a promising technique that has been recently used for monitoring the aging of several foods, including wine (17) and beer (18), showing good agreement with chemical analysis and sensory panel evaluations. Recently, mass spectrometry (MS) application has been reported as a sensing element for E-nose. Each ion generated by the mass spectrometer is considered as a virtual sensor, and the whole system functions as an E-nose (19). MS-E-nose has been applied for various purposes such as efficient determination of differences in quality attributes, aroma, and flavor profiles detection, and identification of country of origin of foodstuff (20). The applications of E-senses (E-tongue and E-nose) are promising for discriminating the taste and smell of different types of foods, although the human olfactory system has very sophisticated organs and many receptors (21). Therefore, the simultaneous use of these sensory systems will increase the efficiency of obtaining information from food samples according to different factors.

This study was conducted with the main objective of investigating the potential of E-tongue, E-nose, and MS-E-nose for discriminating the aged vinegars made with different raw materials based on the analysis of their taste and aroma profiles using multivariate analytical techniques: principal component analysis (PCA) and discriminant function analysis (DFA).

Materials and Methods

Samples The vinegar samples comprised 3 types of products commercially available in markets, including Chinese Shanxi extra aged vinegar (EX, 5, 6, and 8 years), Japanese black vinegar (BL, 1, 3, and 5 years), and Italian balsamic vinegar (BA, 8, 12, and 25 years), prepared with different raw materials and aging years. Three sets of commercial bottles of each product were obtained from a wholesale market in Daegu, Korea, and the product information regarding raw materials, fermentation period, and total acidity were acquired from the bottle labels; the corresponding information is listed in Table 1.

E-tongue analysis The sample was analyzed using an ASTREE Electronic Tongue system (Alpha M.O.S., Toulouse, France). The detection system comprised 7 electrochemical sensors (SRS, GPS, STS, UMS, SPS, SWS, and BRS) and one reference electrode (Ag/AgCl). The main taste attributes to each sensor can be summarized

as follows: SRS sensor (sourness, astringency, bitterness), GPS sensor (sourness, saltiness, metallic), STS sensor (saltiness, spiciness, metallic), UMS sensor (umami, saltiness, astringency), SPS sensor (metallic, spiciness, umami), SWS sensor (sweetness, sourness), and BRS sensor (bitterness, astringency). Each sample (25 mL) was measured for 120 s and the raw data was expressed as voltage versus time. Samples were evaluated five times and the sensors were rinsed in water following each measurement to prevent cross-contamination between samples. PCA was used to determine sample patterns, grouping, similarities, or differences in the E-tongue data set.

E-nose analysis The HERACLES Electronic Nose (Alpha M.O.S.) was applied to monitor the volatile compounds in each sample. This instrument was integrated with classical gas chromatography functionalities and E-nose olfactory fingerprint software. This instrument included a sampling system and two flame ionization detectors (FID) detector systems, including two short columns with different polarities (2 m×0.18 mm DB-5/DB-1701). The sample (1 mL) was placed in a 20-mL headspace vial and capped with a polytetrafluoroethylene/silicone septum (Supelco, Bellefonte, PA, USA). Each vial was incubated at 40°C for 1 min under agitation at 500 rpm. The accumulated gas in the headspace was then injected into gas chromatography instrument. The carrier gas, nitrogen, was circulated at 1 mL/min in the constant flow mode. The injected volume was 1,000 µL and the injector temperature 200°C. The oven temperature program was as follows: 40°C for 5 s; 3°C/s ramp to 150°C holding for 50 s; 3°C/s ramp to 270°C, and holding for 30 s. The temperature of the two flame ionization detectors was 270°C. The parameters were optimized and each analysis was repeated five times. To globally compare volatile components, a general odor map based on PCA was generated using chromatogram peaks. Retention indices of all the constituents were determined by the Kovat method (22) using n-alkanes as standards for C6-C16. The volatile constituents were identified by a comparison of Kovats indices and their identification was confirmed by computer matching of their mass spectral fragmentation patterns.

MS-E-nose analysis A 0.3-g sample was placed in a 20 mL vial (La-Pha-Pack GmbH, Langerwehe, Germany). The vial was immediately sealed with a silicone septum and conditioned for 10 min at 70°C with agitation at 350 rpm prior to sampling. Volatile compounds from the samples were analyzed using an MS-E-nose (SMart Nose 300; SMart Nose, Marin-Epagnier, Switzerland) equipped with a programmable auto sampler (Combi PAL, CTC Analytics, Industriestrasse, Zwingen, Switzerland) and mass spectrometer (ThermoStar™ GSD

Table 1. Details of Shanxi extra aged vinegar, black vinegar, and balsamic vinegar

Sample type/label	Raw materials	Aged year (year)	Total acidity (%)	Production country
Shanxi Extra aged vinegar/EX	Sorghum, bran, rice bran, barley, pea, salt, water	5, 6, 8	>3.5	China
Black vinegar/BL	Rice, water	1, 3, 5	>4.5	Japan
Balsamic vinegar/BA	Grape puree, wine vinegar	8, 12, 25	>5.0	Italy

320 T2; Balzers Instruments, Masin-Epagniger, Switzerland). Headspace (2.5 mL) of the sample was taken using a headspace system (SMart Nose300; SMart Nose) and thermostatted tray holder (Combi PAL, CTC Analytics) and then injected into the E-nose at 130°C. Ionization was performed at 70 eV over a mass range of 10–200 atomic mass unit (amu) at 0.5 s/amu. The samples were randomly placed in the autosampler trays to avoid biases because of external factors, and each sample was injected. All samples were analyzed in triplicate and peaks between 40 and 200 amu were considered for DFA.

Statistical analysis PCA and DFA are the most often used multivariate analysis methods. PCA was performed by a statistical analysis software (version 11.0, Alpha M.O.S.), and DFA was performed using a software (SMart Nose 151; SMart Nose). The relationships among data were analyzed using the 2 dependent variables and the significance was established at $p < 0.05$.

Results and Discussion

E-tongue discriminates the taste profiles of different aged vinegars

E-tongue analysis was performed to classify commercial vinegars based on raw materials and aging periods (Fig. 1A). The intensities of SRS, one of the basic tastes of vinegar, increased with aging period in all samples ($p < 0.05$). STS showed an inverse correlation with UMS and increased STS intensity was observed with increasing aging years of cereal vinegars (EX and BL) ($p < 0.05$). No differences were found in GPS, SWS, and BRS sensor scores among samples. Figure 1B displays PCA plots on the sensor pattern for the aged vinegars analyzed by E-tongue. The variance contribution rates of PC1 and PC2 were 87.34% and 11.34%, respectively, accounting for 98.68% of the cumulative proportion of two PCs. EX, BL, and BA samples were grouped in different PCA score plots based on taste profiles. Liu *et al.* (23) reported that the four groups of vinegars prepared using different materials were well-divided into three regions and that 12 brands of aromatic vinegars showed differences in electronic tongue analysis, indicating that E-tongue analysis is suitable for discriminating the vinegar taste. In the PC1 direction, all samples were slightly moved to the left plane with increased aging years, indicating that the taste pattern of vinegars changed during the aging process. Shu *et al.* (24) reported that electronic tongue can distinguish vinegars from different areas and different brands and can also reflect taste differences among various brands, enabling consumers to purchase goods according to their preferences. This discrimination performance of E-tongue was similar to that obtained by Yu *et al.* (25), where the discrimination of wine sourced from different vintage years could be explained by the fact that enzymatic reactions and microbial degradation processes gradually slowed with increasing fermentation time. All commercial vinegars could be distinguished reliably using PCA in two-dimension principal components according to their raw materials and aging periods (Fig. 1B).

Fig. 1. Comparison of E-tongue sensor responses (A) and taste profiles based on PCA (B) of Shanxi extra aged vinegar, black vinegar, and balsamic vinegar (BRS: bitterness, SWE: sweetness, UMS: umami, STS: saltiness, SRS: sourness).

E-nose analysis based on Kovats indices identifies volatile pattern of vinegars

E-nose analysis coupled with PCA was used to identify patterns in volatile components of vinegars aged for different years (Fig. 2A). The PCA plot revealed that the separation along PC1 accounted for 99.44% of the variation, whereas PC2 was 0.44%, showing that the BA samples prepared from fruits were clearly distinguished from the EX and BL samples prepared from cereals. EX and BA samples were distinguished according to their different aging periods, plotting in a fixed direction with aging from 5 to 8 and from 8 to 25 years, respectively (Fig. 2A). A small overlap was observed between cereal vinegars in the early aging stage, including the 5-year EX and 1-year BL samples. The nature of the main volatile compounds detected in the headspace of vinegar samples was investigated using their Kovats retention indices (Table 2). Most compounds included acids, aldehydes, and ethyl esters, which were common to all vinegars but were present at varying concentrations. Acetic acid was present in the highest concentration in all vinegar samples, which was strongly related to the aging period (EX, $R = 0.9998$; BL, $R = 0.8186$; BA, $R = 0.9091$). Ethyl isobutyrate, butyl acetate, ethyl isovalerate, furfural, and beta-pinene increased with maturation in both EX and BL samples, whereas 5-methylfurfural, detected in all samples, indicated a negative correlation with aging years. Furfural and 5-methylfurfural, as well as other furan compounds are derived from the initial cooking of the grape must during which the Maillard

Fig. 2. Odor profiles based on PCA with E-nose (A) and DFA with MS-E-nose (B) of Shanxi extra aged vinegar, black vinegar, and balsamic vinegar.

reaction occurs; these compounds generally increase during aging (26). Pyrazine and methyl ethyl ketone were not identified in BA samples fermented using fruit. Since Anklaam *et al.* (27) reported the

ability of E-nose with polymer sensors to discriminate between two different groups of balsamic vinegars of Modena (a total 21 samples), there have been numerous applications of E-nose to vinegars for origin (28) and type (9,29) classifications. Volatile patterns of vinegars could be separated depending on raw materials and aging periods through E-nose analysis based on Kovats indices, which demonstrates that it is a useful tool for the rapid identification of volatile components profiles in vinegar products.

MS-E-nose analysis separates among groups of aged vinegars

Figure 2B displays the volatile profiles of the aged vinegars resulted from MS-E-nose analysis. More separation for DF1 (F value=6132) than for DF2 (F value=672) was observed based on 7 ion fragments (m/z =58, 61, 70, 73, 74, 88, and 89 amu) selected for discriminating the EX, BL, and BA. The DFA plot revealed that the EX 5 and BL 1 samples positioned near the air (control) exhibit the weakest volatile fingerprint, which was similar to that of E-nose (Fig. 2A). BA samples (fruit vinegar) were separated from EX and BL samples (cereal vinegar) and were found to contain the largest number of volatiles among the 3 types of vinegar samples. BL samples showed the largest increase in volatile levels as aging periods increased.

Figure 3A-C displays the volatile profile changes in the aged vinegars determined by MS-E-nose. Four main ion fragments (m/z =50, 51, 56, and 68 amu) were selected for discriminating the EXs matured for 5, 6, and 8 years (Fig. 3A). The separation according to aging year was found to be in a leftward direction using DF1 (F value=703; R^2 =0.9948) rather than DF2 (F value=210; R^2 =0.9829). The DFA plot revealed that the EX 5 and 6 sample positioned near the air

Table 2. Volatile compounds of Shanxi extra aged vinegar, black vinegar, and balsamic vinegar detected by E-nose and the correlation (r) between relative concentration and aging periods

RT (sec)	Possible matching compounds based on Kovats Index	Commercial aged vinegar			Odor description
		Shanxi extra aged vinegar	Black vinegar	Balsamic vinegar	
DB5 column					
13.84	Acetaldehyde	0.8555	-0.0329	-0.3829	Pungent, ethereal, fresh
18.18	Isopropyl alcohol	0.9943	0.9254	0.6437	Alcohol, musty, woody
26.68	Methyl isobutyrate	0.9987	-0.8189	-0.2592	Ethereal, diffusive, fruity
30.02	Pyrazine	0.9514	-0.2136	-	Pungent, sweet, roasted hazelnut
32.92	Pyrrole	0.9705	-0.4490	-0.5660	Sweet, nutty, ethereal
36.63	Butyric acid	0.9972	0.2458	-0.9931	Sharp, dairy-like, cheesy
45.29	5-Methylfurfural	-0.9317	-0.9386	-0.9999	Sweet, caramellic, bready
46.29	Hexanoic acid	0.5259	0.0724	0.8525	Sour, fatty, sweaty
DB1701 column					
22.26	Isobutyraldehyde	0.8655	0.1486	0.6333	Fresh, aldehydic, floral
25.55	Methyl ethyl ketone	0.9007	-0.6191	-	Ethereal, diffusive, fruity
27.76	2-Methyl butyraldehyde	0.4077	0.8529	0.8779	Musty, chocolate, nutty
30.70	Acetic acid	0.9998	0.8186	0.9091	Sharp, pungent, sour
33.48	Ethyl isobutyrate	0.9653	0.9829	0.8783	Sweet, ethereal, fruity
37.12	Butyl acetate	0.9846	-0.9081	0.9979	Sharp, ethereal, diffusive
40.04	Ethyl isovalerate	0.9410	0.3474	0.9857	Sweet, diffusive, estry
42.95	Furfural	0.8873	-0.8025	0.9056	Sweet, brown, woody
45.17	beta-Pinene	0.8677	-0.4242	0.8487	Cooling, woody, piney

Fig. 3. Plots of Shanxi extra aged vinegar (A), black vinegar (B), and balsamic vinegar (C) based on DFA with MS-E-nose.

exhibited the weakest volatile fingerprint compared to far-lying EX 8 with the strongest volatile fingerprint. Thus, EX samples showed significant variability (increase) in volatile levels resulting from aging for more than 6 years, whereas EX 5 and 6 could not be easily

distinguished from each other. Similarly, DFA showed a categorical discrimination for BLs aged for 1, 3, and 5 years based on two main ion fragments of 57 and 58 amu as per years (Fig. 3B). The DFA results revealed that the aging years of all BLs could be clearly discriminated using MS-E-nose analysis, i.e., DF1 (F value=3903: $R^2=0.9993$) and DF2 (F value=274: $R^2=9904$). Compared to BL1 and BL3 showing the weakest volatile signals positioned near the air, BL5 showed the strongest volatile fingerprints, which were positioned further away (shifted towards the left side), indicating greater production of volatiles as aging time increased. BAs aged for 8, 12, and 25 years were classified categorically using five ion fragments, including 41, 58, 65, 68, and 74 amu (Fig. 3C). The DFA plot showed divergent F-values, indicating clear discrimination depending on the unique volatile patterns of each sample according to aging years: DF1 (F value=7117: $R^2=0.9995$) and DF2 (F value=1450: $R^2=0.9975$). BA 8 and 12 were located further from air compared to BA 25, which revealed the presence of the strongest volatile fingerprints, whereas BA 25 showed the weakest signal. The categorization with respect to aging years was determined based on a rightward shift toward air. It was considered that volatile levels of BA were evaporated and the amount almost decreased during the aging process in contrast with EX and BL samples.

Different values for ion fragments in the range of 60–98 amu were observed among the 3 samples (EX, BL, and BA), which contributed to a good separation within each group (Fig. 4). Although it was difficult to determine the differences over the entire range of ion fragments in the aged vinegars, all samples were well-separated among groups after discriminant function analysis as displayed in Fig. 2 and 3.

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Fig. 4. Mass spectra of ion fragments from E-nose analysis of Shanxi extra aged vinegar (EX), black vinegar (BL), and balsamic vinegar (BA).

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References

- Solieri L, Giudici P. Vinegars of the world. pp. 1-16. In: Vinegars of the World. Solieri L, Giudici P (eds). Springer, Milan, Italy (2009)
- Chinnici F, DuránGuerrero E, Riponi C. Discrimination of some European vinegars with protected denomination of origin as a function of their amino acid and biogenic amine content. *J. Sci. Food Agr.* 95: 2395-2403 (2016)
- Shimoji Y, Kohno H, Nanda K, Nishikawa Y, Ohigashi H, Uenakai K, Tanaka T. Extract of Kurosu, a vinegar from unpolished rice, inhibits azoxymethane-induced colon carcinogenesis in male F344 rats. *Nutr. Cancer* 49: 170-173 (2004)
- Fukuyama N, Jujo S, Ito I, Shizuma T, Myojin K, Ishiwata K, Nagano M, Sakazawa H, Mori H. Kurozu moromimatsu inhibits tumor growth of Lovo cells in a mouse model *in vivo*. *Nutrition* 23: 81-86 (2007)
- Nanda K, Miyoshi N, Nakamura Y, Shimoji Y, Tamura Y, Nishikawa Y, Ohigashi H, Uenakai K, Tanaka T. Extract of vinegar "Kurosu" from unpolished rice inhibits the proliferation of human cancer cells. *J. Exp. Clin. Canc. Res.* 23: 69-76 (2004)
- Cocchi M, Durante C, Grandi M, Lambertini P, Manzini D, Marchetti A. Simultaneous determination of sugars and organic acids in aged vinegars and chemometric data analysis. *Talanta* 69: 1166-1175 (2006)
- Callejón RM, Tesfaye W, Torija MJ, Mas A, Troncoso AM, Morales ML. Volatile compounds in red wine vinegars obtained by submerged and surface acetification in different woods. *Food Chem.* 113: 1252-1259 (2009)
- Ubeda C, Callejón RM, Troncoso AM, Moreno-Rojas JM, Peña F, Morales ML. A comparative study on aromatic profiles of strawberry vinegars obtained using different conditions in the production process. *Food Chem.* 192: 1051-1059 (2016)
- Yin Y, Yu H, Chu B, Xiao Y. A sensor array optimization method of electronic nose based on elimination transform of Wilks statistic for discrimination of three kinds of vinegars. *J. Food Eng.* 127: 43-48 (2014)
- Tesfaye W, Morales ML, Benítez B, García-Parrilla MC, Troncoso AM. Evolution of wine vinegar composition during accelerated aging with oak chips. *Anal. Chim. Acta* 513: 239-245 (2004)
- Robinson AL, Boss PK, Heymann H, Solomon PS, Trengove RD. Development of a sensitive non-targeted method for characterizing the wine volatile profile using headspace solid-phase microextraction comprehensive two-dimensional gas chromatography time-of-flight mass spectrometry. *J. Chromatogr. A* 1218: 504-517 (2011)
- Saurina J. Characterization of wines using compositional profiles and chemometrics. *TrAC-Trend. Anal. Chem.* 29: 234-245 (2010)
- Falcone PM, Verzelloni E, Tagliacucchi D, Giudici P. A rheological approach to the quantitative assessment of traditional balsamic vinegar quality. *J. Food Eng.* 86: 433-443 (2008)
- Escuder-Gilbert L, Peris M. Review: Highlights in recent applications of electronic tongues in food analysis. *Anal. Chim. Acta* 665: 15-25 (2010)
- Gallardo J, Alegret S, del Valle M. Application of a potentiometric electronic tongue as a classification tool in food analysis. *Talanta* 66: 1303-1309 (2005)
- Legin A, Rudnitskaya A, Lvova L, Vlasov Y, Di Natale C, D'Amico A. Evaluation of Italian wine by the electronic tongue: Recognition, quantitative analysis and correlation with human sensory perception. *Anal. Chim. Acta* 484: 33-44 (2003)
- Apetrei IM, Rodríguez-Méndez ML, Apetrei C, Nevares I, Del Alamo M, De Saja JA. Monitoring of evolution during red wine aging in oak barrels and alternative method by means of an electronic panel test. *Food Res. Int.* 45: 244-249 (2012)
- Ghasemi-Varnamkhasti M, Mohtasebi SS, Rodríguez-Mendez ML, Lozano J, Razavi SH, Ahmadi H. Potential application of electronic nose technology in brewery. *Trends Food Sci. Tech.* 22: 165-174 (2011)
- Schaller E, Bosset JO, Escher F. "Electronic noses" and their application to food. *LWT-Food Sci. Technol.* 31: 305-316 (1998)
- Hong EJ, Park SJ, Choi JY, Noh BS. Discrimination of palm olein oil and palm stearin oil mixtures using a mass spectrometry based electronic nose. *Food Sci. Biotechnol.* 20: 809-816 (2011)
- Breer H. Sense of smell: Signal recognition and transductions in olfactory receptor neurons. pp. 521-532. In: Handbook of Biosensors and Electronic Noses: Medicine, Food and Environment. Kress-Rogers E (ed). CRC Press, Inc., Boca Raton, FL, USA (1997)
- Jennings W, Shibamoto T. Qualitative Analysis of Flavour and Fragrance Volatiles by Glass Capillary Gas Chromatography. Academic Press, New York, NY, USA. pp. 29-57 (1980)
- Liu M, Wang M, Wang J, Li D. Comparison of random forest, support vector machine and back propagation neural network for electronic tongue data classification: Application to the recognition of orange beverage and Chinese vinegar. *Sensor. Actuat. B-Chem.* 177: 970-980 (2013)
- Shu J, Chen X, Pan CD, Deng L, Xiao SS. Analysis of taste characteristics of vinegar in different brands with electronic tongue. *China Condi.* 38: 95-99 (2013)
- Yu H, Zhao J, Li F, Tian H, Ma X. Characterization of Chinese rice wine taste attributes using liquid chromatographic analysis, sensory evaluation, and an electronic tongue. *J. Chromatogr. B.* 997: 129-135 (2015)
- Cirlini M, Caligiani A, Palla L, Palla G. HS-SPME/GC-MS and chemometrics for the classification of Balsamic Vinegars of Modena of different maturation and ageing. *Food Chem.* 124: 1678-1683 (2011)
- Anklam E, Lipp M, Radovic B, Chiavaro E, Palla G. Characterisation of Italian vinegar by pyrolysis-mass spectrometry and a sensor device ("electronic nose"). *Food Chem.* 61: 243-248 (1998)
- Zhang Q, Zhang S, Xie C, Fan C, Bai Z. "Sensory analysis" of Chinese vinegars using an electronic nose. *Sensor. Actuat. B-Chem.* 128: 586-593 (2008)
- Yin Y, Yu H, Zhang H. A feature extraction method based on wavelet packet analysis for discrimination of Chinese vinegars using a gas sensors array. *Sensor. Actuat. B-Chem.* 134: 1005-1009 (2008)