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Establishment of chicken soup flavour evaluation method based on electronic tongue and fuzzy mathematics

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Abstract

In order to develop a robust and objective method for evaluating the taste of chicken soup using the electronic tongue as an objective evaluation index instead of the traditional sensory evaluation of chicken soup, two types of local chickens (Green-footed Sesame Chicken and Daninghe River Chicken) reared using two rearing methods (caged and free-range) at the age of 120 days were used as research subjects in the present work. As compared to the cage mode, the fuzzy sensory score showed that the chicken soup stewed in the free-range mode possessed better sensory quality. Moreover, in the same rearing mode (caged and free-range), the sensory quality of Daninghe River Chicken soup was better than the Green-footed Sesame Chicken soup. The results showed that the electronic tongue effectively distinguished different chicken soup samples. The analysis of variance, principal component analysis, and gray correlation were used to establish the correlation between the chicken soup electronic tongue and fuzzy mathematical sensory scores. The results showed that the correlation between the electronic tongue data and the fuzzy mathematical sensory scoring system was high. These results provided a reliable basis for using electronic tongue data instead of sensory scoring. The present work successfully established a direct connection between the electronic tongue and fuzzy mathematical sensory evaluation methods, which provided a simple, fast, and accurate method for optimising the production process, and evaluating the quality of chicken soup using electronic tongue and other testing methods.

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Introduction

Chicken is an important component of human food that provides essential nutrients to the human body. The continuous improvement in the living standards of people has led to a shift in chicken consumption from quantity-based to quality-based. As a result, people are now more concerned about the flavour, texture, nutrition, safety, and other characteristics of chicken meat. Consequently, the market share of poor-quality broilers is shrinking every year.

Chicken soup is a traditional Chinese cooking method. Boiling or stewing the chicken releases high quality proteins, flavoured peptides, creatinine, and free amino acids, thus making the chicken soup tasty and easy to digest. There are numerous studies conducted to analyse and enhance the flavour of chicken soup. Wang *et al*. (2012a) observed that the sensory flavour, free amino acid content, and nucleotide content of chicken soup prepared using different chicken breeds, such as northern Jiangsu traditional chicken, snowy mountain chicken, and 817 broilers, differed significantly. For instance, the taste and odour of northern Jiangsu traditional chicken soup was better compared to other chicken soups. The meat quality of snowy mountain chicken was good, but the taste of the soup was not very good. The flavour of chicken soup made using 817 broilers was relatively worse (Wang *et al.*, 2012a). Lin *et al*. (2016) used high-performance liquid chromatography-electrospray tandem mass spectrometry (HPLC-MS) to analyse peptidome in traditional chicken soup with the most delicious fresh flavour, *i.e.*, MW < 3 KDa, by sequencing 93 peptides with a high proportion of fresh and sweet amino acids, and a low proportion of hydrophobic amino acids (Lin *et al.*, 2016). Wang *et al.* (2020) used high-performance liquid chromatography to analyse the free amino acid composition and nucleotide

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composition of Beijing oil chicken soup. The study identified four peptides, and inferred that the peptides could have a significant contribution in the taste of chicken soup (Wang *et al.*, 2020). It is worth noting that all the data obtained by using the electronic tongue are analysed as a whole, and no detailed information regarding taste active compounds is required. Therefore, the use of electronic tongue has advantages in recognition and classification, but there are few limitations in quantitative analysis. Although there is numerous research works presented in literature that focus on chicken soup and soup flavour, the research works on chicken soup flavours are still limited to one or several components of chicken soup flavour. Furthermore, the overall evaluation systems and specification for chicken soup flavour have not yet been presented.

The most well-known method used for evaluating chicken soup is the direct manual sensory evaluation. However, in practice, the sensory evaluation is subjective due to the lack of professional evaluation teams, the lack of unified standard evaluation practices, and the lack of professional sensory evaluation laboratories. In addition, chicken soup usually consists of fatty acids, nucleotides, amino acids, peptides, and other components, thus making it difficult to evaluate using a single index (Xi *et al.*, 2017; Zhang *et al.*, 2018; Bi *et al.*, 2019). Furthermore, measuring all the components in chicken soup requires different types of equipment, and the measuring process comprises tedious steps, and requires considerable time. Moreover, the quantitative indicators do not visually reflect the changes in taste or the comprehensive effect of taste.

Fuzzy mathematics can be used to quantify the attributes of sensory evaluation leading to a reduction in the differences caused by subjectivity to some extent (Perrot *et al.*, 2006). Wei *et al.* (2015) observed that the traditional techniques for sensory evaluation only focussed on the qualitative aspect, and were unable to provide accurate quantitative evaluation. However, in fuzzy modelling, the use of language entities, such as unsatisfactory, average, moderate, good, and excellent, for describing the sensory attributes of food obtained through subjective evaluation can effectively be combined with predictions of electronic tongue to obtain more accurate sensory evaluation (Jin *et al.*, 2019). A few research works have used fuzzy mathematical sensory analysis for food quality evaluation and optimisation (Tang and Zhang, 2017; Yang *et al.*, 2018; Qiao *et al.*, 2019).

Electronic tongue is an emerging tool that can make up for the absence of physical and chemical indicators, and obtain comprehensive information regarding the change in taste. Electronic tongue can analyse and identify the sample by simulating the human taste analysis and identification. It then processes the obtained data by using multivariate statistical methods to quickly reflect the overall quality information of the sample (Ma *et al.*, 2004). It is worth noting that all the data obtained by using electronic tongue is analysed as a whole, and no detailed information regarding taste active compounds is required. Therefore, the use of electronic tongue has advantages in recognition and classification, but there are few limitations in quantitative analysis (Zhang *et al.*, 2021). Currently, electronic tongue has been widely used in meat research, including meat identification, freshness testing, and sanitary quality monitoring during processing (Li *et al.*, 2016a). As compared with other flavour evaluation methods, electronic tongue systematically processes the complex flavours, and has the characteristics of simplicity and computational efficiency.

The gray correlation analysis is an evaluation method that is used for determining the priority of factors and their degree of association (Li *et al.*, 2005). This method has been widely used in new crop varieties (Nan *et al.*, 2018), fruit quality evaluation (Hu *et al.*, 2015; Li *et al.*, 2016b), and Chinese medicine quality evaluation (Wu *et al.*, 2018). However, there is currently no research that focuses on optimising the accuracy of electronic tongue evaluation of chicken soup based on gray correlation analysis.

In the present work, we use different feeding methods of Green-footed Sesame Chicken (*qingjiaoma*) and Daninghe Chicken as research objects, and established a correlation equation between the electronic tongue and fuzzy mathematical sensory evaluation through gray correlation analysis to evaluate the taste characteristics of their chicken soup. The proposed method would provide technical support for assessing the feasibility and accuracy of optimising chicken soup production process using electronic tongue. Additionally, it would also provide a reference for evaluating the quality of chicken soup using electronic tongue as an equivalent substitute for sensory analysis.

Materials and methods

Materials

A local breed of Daninghe chicken (D) and a fast and large broiler breed of Qingjiaoma chicken (Q) in Chongqing were used as test samples. The latter breed is a national livestock and poultry genetic resource. It is a breed with fast growth rate, high adaptability, and high production.

The experimental population comprised three batches of chickens reared at one-month intervals. The detailed grouping information of each batch is presented in Table 1. Briefly, 120-day-old chickens were reared at the Wulong Chicken Breeding Centre of Chongqing Academy of Animal Husbandry. The chickens were divided into groups at the age of 60 days, and housed in cages and free ranges. There were 60 chickens (hens) in each group, with three replicates of 20 chickens each. In order to facilitate the feeding management, we divide the grazing area into several regions by means of a fence. A 20 m^2 shed was built in each area for the chickens to roost at night. Moreover, a feeding trough and a drinking fountain were also installed. The chickens were reared at the same nutritional level for 120 days.

Table 1. Hybrid combinations and rearing methods of four treatment groups.

Group	A	B	C	D
Hybrid combination	D	Q	D	Q
Rearing method	Cage rearing	Cage rearing	Free range	Free range

Instruments and equipment

The SA-402B taste analysis system developed by the Beijing Ying Sheng Heng Tai Technology Co., Ltd. was used. The other notable equipment included electric stew pot, disposable plastic cups, and electronic scales.

Methods

Chicken soup preparation

The test chickens were slaughtered, deboned in hot water, gutted at the tail, taken back to the laboratory, and cleaned. The cleaned chickens weighed 1 - 1.25 Kg (kilogramme). The ratio of chicken meat to water for preparing the chicken soup was 1:1.5. The cooking process continued for 2.5 hours in an electric stew pot. Next, 0.2% salt of the total mass of meat and soup was added. The cooking time and salt concentration were chosen based on another experiment. Before performing this experiment, we reviewed the related literature to select several good time points and salt concentrations for cooking the chicken soup. We performed experiments using the chickens for sensory evaluation and physicochemical indexes, and finally determined the optimal cooking time and salt concentration. After the chicken soup was ready, it was maintained at 80°C for subsequent tests.

Electronic tongue measurement

We cleaned the electronic tongue sensor before sample injection, calibrated the sensor using the calibration solution and software, and then performed the subsequent experiments. The insulated chicken soup samples were poured directly into a special beaker for performing tests using the electronic tongue. The chicken soup samples were equilibrated to room temperature, and then measurements were performed. The sample volume of each cup was 30 mL (millilitre). Four replicate sets for each sample were prepared. The acquisition time of the electronic tongue sensor in each sample was 120 seconds, and 1 data sample was acquired per second. The final stable data obtained at the 120^{th} seconds was used as the output value. When the sensor first started measuring, the induction intensity fluctuated up and down. After two to three measurements, the sensor response stabilised. Each cup sample was repeated for seven times, and the datas of the last three measurements were selected as the original datas for principal component analysis and cluster analysis.

Sensory evaluation

Ten professional sensory evaluators (five male and five female) from the Food Research Institute of Chongqing Academy of Animal Husbandry evaluated the quality of chicken soup. Untrained personnel often report biased results during sensory evaluation due to different tastes. Therefore, these 10 professional sensory personnels were given sensory training by a professor at the Southwest University that lasted for six months, and obtained a sensory evaluation certificate. The evaluation was done on a 10-point scale with the indexes of colour, taste, and aroma. In order to avoid the impact of containers on sensory evaluation, all the samples were served in similar looking containers randomly. The evaluators were required to be in good health, free of sensory disorders, did not consume alcohol or tobacco, and had not eaten for one hour prior to the start of the evaluation. These precautions prevented other substances or physical conditions from causing bias in the results. During the taste evaluation process, the evaluators were not allowed to perform discussions. Each sample was smelled by the evaluator before being tasted. To avoid the influence of the previous sample on subsequent results, the evaluators were required to rinse their mouths with water three times, and rest for 30 s before evaluating the next sample. The scoring criteria are presented in Table 2.

Table 2. Chicken soup flavour sensory score table.

Item	Very good	Good	Fair	Poor
Colour	Milky white or light yellow, clear and transparent (9 - 10 points)	Milky white or light yellow, cloudy (6 - 8 points)	White (3 - 5 points)	Off-white or colourless (0 - 2 points)
Taste	Mellow taste, sweet aftertaste (9 - 10 points)	Insufficient freshness, pure taste (6 - 8 points)	Light taste, no aftertaste, no special odour (3 - 5 points)	No freshness, soup has obvious odour (0 - 2 points)
Odour	Strong meat flavour (9 - 10 points)	Obvious chicken flavour (6 - 8 points)	Weak meat flavour (3 - 5 points)	No chicken soup flavour (0 - 2 points)

Theoretical basis of fuzzy mathematical model

Establishment of factor, comment, and weighted sets

The factor set U consisted of evaluation indexes, including taste (U_1), odour (U_2), and colour (U_3), *i.e.*, U = {U_1, U_2, U_3} (Hu *et al*., 2015).

The comments set V consisted of feedback information regarding the evaluation indicators. The levels of evaluation included very good (V_1), good (V_2), fair (V_3), and poor (V_4). So, V = {V_1, V_2, V_3, V_4} (Hu *et al*., 2015).

The weight set was expressed by the weight of each evaluation index to the overall evaluation. The weights formed a weight domain called fuzzy vector, and denoted as X (Yang *et al*., 2018).

Matrix establishment and transformation

The fuzzy relationship matrix R was obtained by dividing the number of votes obtained from the evaluation of different indicators of chicken soup by the number of evaluators. The fuzzy relationship evaluation set was formed by combining the weight set X with the fuzzy relationship matrix R, denoted as Y = X × R. The evaluation result of the i-th sample was expressed as $Y_i = X \times R_i$ (i=1,…,12) (Wu *et al*., 2018).

Based on the specificity of sensory evaluation, the evaluation level set K = {9,7,4,1} was determined, and the total fuzzy comprehensive evaluation score T was calculated as T = Y × K.

Gray correlation degree analysis

Based on the gray mathematical system and the application requirements in food products for gray correlation analysis (Li *et al*., 2016a; Nan *et al*., 2018), the correlation between the electronic tongue sensor and the sensory evaluation was computed.

Calculation of gray correlation coefficients

All samples were treated as gray systems, different sensors of the electronic tongue were treated as subsystems of the gray system, and the response values of the sensors were calculated as the factors in the system (Yang *et al*., 2018). The sensory score was the reference series noted as Y_0, the comparison series was noted as $Y_i(x)$, and Y_i was the response value of the electronic tongue of the sample. The gray correlation coefficients were computed using equation (Eq.):

$$\varepsilon_i = \frac{\min_i \min_k |Y_0(x) - Y_i(x)| + \rho \times \max_i \max_k |Y_0(x) - Y_i(x)|}{|Y_0(x) - Y_i(x)| + \rho \times \max_i \max_k |Y_0(x) - Y_i(x)|} \quad \text{(Eq. 1)}$$

where, x = different groups, Y_i = response of electronic tongue for different groups, $\varepsilon_i(x)$ = correlation coefficient between the subsequence Y_i and the parent sequence Y_0 of the xth group of samples, $\min_i \min_k |Y_0(x) - Y_i(x)|$ = minimum difference between the two levels,

$max_i max_k$ $|Y_0(x) - Y_i(x)|$ = maximum difference between the two levels, and $|Y_0(x) - Y_i(x)|$ = absolute difference between the parent. When ρ = 0.5 and the gray correlation > 0.6, and the results were considered good.

Calculating gray correlation coefficient

The arithmetic mean of the correlation coefficients is the degree of correlation, which was determined using Eq. 2:

$$r_i = \frac{1}{N}\sum_1^N \varepsilon_i(x) \quad \text{(Eq. 2)}$$

where, r_i = correlation degree between parent series Y_0 and subseries Y_i, and N = number of subseries data.

Statistical analysis

The software that came with the electronic tongue was used to analyse the chicken soup samples by using principal component analysis (PCA). Afterwards, EXCEL2010 with SPSS19 software was used to perform fuzzy mathematical sensory evaluation and gray correlation analysis.

Ethics approval and consent of participants

All experiments involving animals were performed according to the laws and regulations established by the Ministry of Agriculture, China (Beijing, China). The present work was approved by the Animal Care and Welfare Committee of the Chinese Chongqing Academy of Animal Science (Chongqing, China).

Results and discussion

Electronic tongue analysis results of different samples

The principal component analysis (PCA) is an analytical method that linearly transforms the raw data vectors to differentiate them by changing the coordinate axes (He *et al.*, 2019). Figure 1 shows the electronic tongue data measured using different chicken soup samples. These data samples were analysed based on PCA using the software provided along with the electronic tongue. A two-dimensional graph was established with principal components 1 and 2 as the horizontal and vertical coordinates, respectively. As presented in Figure 1, the contribution of principal component 1 is 93.81%, the contribution of principal component 2 is 3.69%, and the cumulative contribution of principal components 1 and 2 is 97.5%. This showed that the principal components 1 and 2 contained a large amount of information, and they reflected the overall information of the samples (Najafi *et al.*, 2019). Figure 1 shows the distribution area of sample B overlapped with that of sample D, which indicates that the difference between sample B and D is small in terms of taste. The distribution area of sample A and C are separated but lie closer to each other, indicating that the samples of cages A and C are

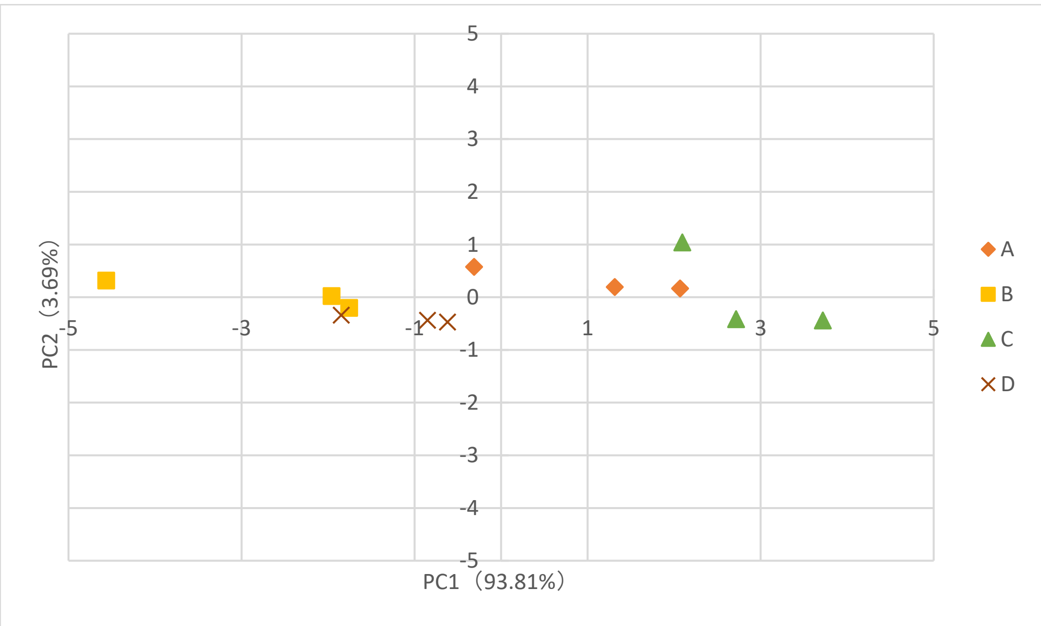

Figure 1. Principal component analysis (PCA) of data obtained using electronic tongue for chicken soup of different breeds and different rearing methods.

closer in terms of taste. The distribution area of samples B and D is far from the distribution area of samples A and C. Especially, sample B is far from sample C, indicating that the tastes of different varieties of chicken soup differ significantly. In the present work, due to the limitations of sensory arrays and the influence of electrode resistance on detection accuracy, electronic tongues did not have strong response signals for certain substances (Wang *et al.*, 2012b). However, other studies used high performance liquid chromatography electrospray ionisation tandem mass spectrometry (HPLC-MS/MS) to study the flavour compounds in chicken soup, determined the composition of free amino acids and nucleotides in chicken soup, and predicted the peptide component that contributed the most to the flavour of chicken soup (Lin *et al.*, 2016; Wang *et al.*, 2020). Therefore, further optimisation and analysis of the results of electronic tongue are required.

Fuzzy sensory evaluation results of different samples

It is noteworthy that the sensory evaluations can have certain differences and fuzziness due to the subjectivity. The use of fuzzy mathematical analysis quantifies and analyses such concepts or things as sensory evaluation. In addition, the sensory evaluation by expert panels may be influenced by training requirements, staff turnover, and individual differences, which may lead to limitations (Miguel and Laura, 2009). The fuzzy mathematical sensory evaluation reduces the requirement of sensory evaluators by evaluating and filtering the products through big data processing, consequently minimising the degree of influence of subjectiveness on the overall sensory personnel. Najafi *et al*. (2019) analysed different treatment groups using traditional sensory evaluation methods. The authors observed that the effect of treatment on sensory attributes was not significant, and the result could only be obtained through PCA analysis. Cao and Liu (2012) obtained weight scores of 0.171, 0.323, 0.206, and 0.300 for the tissue state, colour, odour, and taste of the meat soup after heating, respectively, using fuzzy mathematical analysis, thus objectively judging the grade and quality of the chicken meat. Moreover, there are various works presented in literature that show the feasibility of using fuzzy mathematical sensory evaluation for assessing food products (Shinde and Pardeshi, 2014; Zhang *et al.*, 2015; Wu *et al.*, 2015; Xie, 2016; Xue *et al.*, 2021; Dong *et al.*, 2021).

The weights of different sensory quality indicators, such as colour, odour, and taste of chicken soup were estimated by the survey method involving 42 investigators as a ratio of the overall importance of the three sensory indicators of 0.6, 0.3, and 0.1, *i.e.*, X = {0.6, 0.3, and 0.1}.

The results presented in Table 3 show that for sample No. 1, the numbers of taste votes for very good, good, fair, and poor are 5, 5, 0, and 0, respectively; the numbers of odour votes for very good, good, fair, and poor are 4, 6, 0, and 0, respectively; and the numbers of colour votes for very good, good, fair, and poor are 2, 8, 0, and 0, respectively. Therefore, R_1 =

$$\begin{vmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.4 & 0.6 & 0 & 0 \\ 0.2 & 0.8 & 0 & 0 \end{vmatrix}$$

Similarly, we obtained fuzzy evaluation rectangles for other samples. The fuzzy mathematical comprehensive evaluation was Y = X×R, where X = {0.6, 0.3, 0.1}, denoting the weight set of taste, colour, and aroma indicators, while Y denoted the fuzzy evaluation matrix of aroma, taste, odour, and colour. The resulting Y was then multiplied by the comments set, *i.e.*, V = {9, 7, 4, 1}, which denoted the sensory composite score. For instance, the sensory composite score of sample No. 1 is expressed as:

$$T_1 = R_1 \times X \times V_1 \begin{vmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.4 & 0.6 & 0 & 0 \\ 0.2 & 0.8 & 0 & 0 \end{vmatrix} = \times\{0.6, 0.3, 0.1\} \times \{9, 7, 4, 1\} = 7.88$$

Similarly, the composite scores of the other 11 chicken soups were also calculated, as presented in Table 4.

The higher the overall score, the better the quality of the product. As presented in Table 4, the overall sensory scores of four chicken soups are greater than 6 and less than 8, indicating that the sensory quality of the four chicken soups is between "good" and "very good". The sensory quality of the chicken soup of group C is closer to "very good", indicating that the sensory quality of chicken soup of

Table 3. Results of fuzzy sensory evaluation of chicken soup.

Number	Group	Taste (60 points)				Odour (30 points)				Colour (10 points)			
		Very good	Good	Fair	Poor	Very good	Good	Fair	Poor	Very good	Good	Fair	Poor
1	A	5	5	0	0	4	6	0	0	2	8	0	0
2	B	1	7	0	2	2	6	2	0	0	6	4	0
3	C	4	6	0	0	5	5	0	0	4	6	0	0
4	D	1	6	3	0	2	7	1	0	1	8	1	0
5	A	1	3	5	1	1	6	3	0	0	7	2	1
6	B	1	4	5	0	1	6	3	0	1	5	4	0
7	C	7	3	0	0	5	3	0	2	3	6	1	0
8	D	2	7	1	0	3	6	1	0	0	7	2	1
9	A	5	4	1	0	1	8	1	0	3	7	0	0
10	B	1	7	1	1	1	9	0	0	1	7	1	1
11	C	4	5	1	0	4	6	0	0	3	7	0	0
12	D	0	7	3	0	0	8	2	0	0	7	3	0

Table 4. Chicken soup artificial sensory composite score results.

Number	A	B	C	D
1	7.88	6.22	7.86	6.6
2	5.53	5.91	7.81	7.03
3	7.45	6.57	7.6	6.19
Average	6.95 ± 1.25	6.23 ± 0.33	7.76 ± 0.14	6.61 ± 0.42
Sort	2	4	1	3

group C is better. On the other hand, the fuzzy sensory score of the chicken soup of group B is the lowest, indicating that the sensory quality of the chicken soup of group B is poor. This was consistent with the results presented by Wang *et al.* (2009) and Zhu *et al.* (2019), *i.e.*, the meat quality of free-range chickens is better compared to the caged chickens for the same breed. For the same rearing method (free-range or cage), the overall sensory score of chicken soup of Daninghe River Chicken was higher compared to the Green-footed Sesame Chicken. This showed that the sensory quality of Daninghe River chicken soup was better compared to that of Green-footed Sesame Chicken under the same rearing method.

Gray correlation analysis of sensory evaluation of chicken soup with electronic tongue data

Dimensionless processing

The sensory evaluation indices of 12 samples were set as the reference series. The comparative series were the eight sensory responses of the electronic tongue. The parent series were analysed by gray correlation with the child series. First, each series was dimensionlessised using the mean transformation method. The corresponding results are presented in Table 5.

Calculation of correlation coefficients and correlations between response values of electronic tongue sensors and sensory indicators

The maximum difference between the two levels of the fuzzy total score Δmax sensory score was 0.67. Similarly, the minimum difference between the two levels Δmin sensory score was 0. The correlation coefficients between the responses of electronic tongue and the fuzzy mathematical sensory scores were obtained using Eq. 1. The correlation coefficients were obtained using the gray correlation coefficients in Eq. 2 to rank the sensory response values and the sensory indices. The corresponding results are shown in Table 6. As shown in Table 6, the response values of the eight sensory responses of the electronic tongue are more correlated with the flavour of the samples. In particular, the correlation between the richness, bitterness, and saltiness, and sensory evaluation scores obtained from fuzzy mathematics are higher than 0.8. Especially, the richness is as high

Table 5. Dimensionless processing results of fuzzy sensory scores and electronic tongue data.

Number	Group	Fuzzy sensory scoring	Sourness	Bitterness	Astringency	Aftertaste-B	Aftertaste-A	Umami	Richness	Saltiness
1	A	1.14	1	1.14	0.93	1.49	1.06	1.01	1.11	1.01
2	B	0.9	1	0.93	1.11	0.86	0.74	1	0.9	0.97
3	C	1.14	1	1	1	0.93	1.23	0.98	1.2	1.05
4	D	0.96	0.99	0.9	1	0.74	1.05	1.01	0.96	0.95
5	A	0.8	1.01	1.12	0.96	1.47	1.15	1.02	0.98	1.01
6	B	0.86	1	0.93	1.09	0.74	0.86	1.01	0.76	0.95
7	C	1.13	1	1	1	0.93	1.23	0.98	1.14	1.05
8	D	1.02	0.99	0.9	1	0.72	1.02	1	0.97	0.95
9	A	1.08	1	1.15	0.95	1.54	1.14	0.99	1.07	1.01
10	B	0.95	1	0.94	1.11	0.81	0.83	0.98	0.91	0.96
11	C	1.1	1.01	1.09	0.82	0.98	0.6	1.02	1.1	1.17
12	D	0.9	1	0.9	1.01	0.72	1.12	0.99	0.91	0.94

Table 6. Results of correlation coefficient and correlation analysis between electronic tongue and sensory evaluation.

Number	Group	Sourness	Bitterness	Astringency	Aftertaste-B	Aftertaste-A	Umami	Richness	Saltiness
1	A	0.71	1	0.61	0.49	0.81	0.72	0.92	0.72
2	B	0.77	0.92	0.61	0.89	0.68	0.77	1	0.83
3	C	0.71	0.71	0.71	0.61	0.79	0.68	0.85	0.79
4	D	0.92	0.85	0.89	0.6	0.79	0.87	1	0.97
5	A	0.61	0.51	0.68	0.33	0.49	0.6	0.65	0.61
6	B	0.71	0.83	0.59	0.74	1	0.69	0.77	0.79
7	C	0.72	0.72	0.72	0.63	0.77	0.69	0.97	0.81
8	D	0.92	0.74	0.94	0.53	1	0.94	0.87	0.83
9	A	0.81	0.83	0.72	0.42	0.85	0.79	0.97	0.83
10	B	0.87	0.97	0.68	0.71	0.74	0.92	0.89	0.97
11	C	0.79	0.97	0.54	0.74	0.4	0.81	1	0.83
12	D	0.77	1	0.75	0.65	0.6	0.79	0.97	0.89
Average		0.78	0.84	0.7	0.61	0.74	0.77	0.91	0.82
Sort		4	2	7	8	6	5	1	3

as 9.1. However, the correlation between the response values of other sensory responses and the sensory scores are also high. This indicates that the sensory score is a comprehensive index, which cannot be expressed by one or more indicators. Instead, it should be expressed in a comprehensive manner. The electronic tongue possessed a high degree of gray correlation with the fuzzy mathematical sensory evaluation. The electronic tongue was able to represent the chicken soup quality to some extent, which provided a reference for further optimising the process of chicken soup evaluation. The electronic tongue efficiently distinguished the chicken soup samples. Likewise, the electronic tongue was also able to differentiate the quality of hair olive oil (Rodrigues *et al.*, 2016), pu-erh tea (Duan *et al.*, 2021), melon (Wang *et al.*, 2019), spring water (Carbó *et al.*, 2018), and fish (Han *et al.*, 2008). Few studies have used the electronic tongue combined with PCA to investigate the effect of stewing time (1, 2, and 3 h) on the traditional Chinese chicken soup (Qi *et al*, 2017). In addition, electronic tongue analysis was conducted on the extracts of Texas braised chicken at different processing stages. This helped in exploring the evolution of taste components in Texas stewed chicken at different stages (Liu *et al*, 2017). In the present work, the eight sensory response values of the electronic tongue were more correlated with the flavour of the samples. These results suggest that the electronic tongue has unique advantages in terms of recognition and classification.

Multiple linear regression to establish chicken soup taste quality evaluation method

The electronic tongue simulates the overall taste profile of the food. The fuzzy mathematical sensory evaluation method only considers the contribution of various factors in the overall taste profile, and evaluates the quality more objectively, accurately, and scientifically. This reduces the errors caused by evaluation criteria and subjectiveness. The chicken soup quality evaluation method was established based on multiple linear regression. The electronic tongue data, which reflected the taste, was associated with the sensory rating system established by the fuzzy mathematics. From the gray correlation analysis of electronic tongue and sensory quality, it was evident that different sensory responses had a high correlation with the sensory quality. Therefore, the relationship between electronic tongue and fuzzy sensory score could be established. The mathematical expression for chicken soup taste quality evaluation based on multiple linear regression was expressed as in Eq. 3:

$$y = 36.205 + 0.803X_1 + 7.603X_2 - 0.106X_3 - 12.973X_4 + 2.126X_5 - 0.505X_6 + 0.461X_7 - 2.194X_8 \quad \text{(Eq. 3)}$$

where, y = fuzzy sensory score, X_1, X_2, X_3, X_4, X_5, X_6, X_7, and X_8 = eight sensory responses including sourness, bitterness, astringency, aftertaste-B, aftertaste-A, umami, richness, and saltiness of the electronic tongue, respectively. This multiple regression model passed the F-test and *t*-test. The correlation coefficient R = 0. 98, and the coefficient of determination R^2 = 0.959, indicating that the regression equation between the fuzzy sensory scores and the electronic tongue had a high degree of fit. This indicated that it could be feasible to simulate the human sensory composite score using the electronic tongue measurement data.

Conclusion

In the present work, two types of local chicken breeds (Green-footed Sesame Chicken and Daninghe Chicken), and two types of rearing methods (cage and free-range) are used for the qualitative and quantitative analyses of chicken soup samples using fuzzy sensory evaluation and electronic tongue. We used principal component analysis, gray correlation, and multiple linear regression to evaluate the taste of chicken soup based on electronic tongue and fuzzy mathematical sensory evaluation. The experimental results showed that the electronic tongue had the ability to effectively distinguish different chicken soup samples. The correlation between the electronic tongue data and the fuzzy mathematical sensory evaluation system was high, *i.e.*, greater than 0.6. Especially, richness, saltiness, bitterness were greater than 0.8. The electronic tongue taste test method was used to design a chicken soup quality evaluation method. It provided a simple and quick method to optimise the production process and evaluate the quality of chicken soup by using the electronic tongue testing method. However, this method had limitations in discriminating the taste of specific active compounds. Next, this method was optimised by combining the means that can distinguish taste specific active compounds (such as flavour groups), and applied for the flavour evaluation of chicken soup. In addition, the present work was limited to only chicken soup. There is thus a need to test using the electronic tongue testing method for other food products.

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