An electronic tongue for juice level evaluation in non-alcoholic beverages

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Abstract

An electronic tongue with 36 cross-sensibility polymeric membranes was built and used for semi-quantitative analysis of beverages. The objective was to differentiate 4 non-alcoholic beverage groups with different added fruit juice contents: higher than 30%, between 14%-30%, 5%-10% and 0.1%-2%. A set of 16 Portuguese beverages (4 for each group), purchased in commercial supermarkets, was analyzed and the respective signal profiles recorded by the electronic tongue device. The data obtained were treated by stepwise linear discriminant analysis, allowing a 100% overall correct classification for the original grouped cases and a 93.8% for the "leaving one-out" cross-validation procedure.

Keywords: Discriminant analysis; Electronic tongue; Fruit juice level; Non-alcoholic beverages; Polymeric membranes

1. Introduction

In the last decades, several works have reported the application of electronic tongue devices (e-tongues) for distinguishing various types of foods (beer, coffee, honey, juice, milk, mineral water and wine), by measuring global solution characteristics with high stability and cross-sensitivity chemical sensors [1-10]. The increasing interest of e-tongue application in the food area can be partially attributed to the lower calibration costs, satisfactory accuracy for reasonable small sizes of the calibration data set and easy adaptability to different working conditions, when compared with other analytical methodologies [3].

The e-tongue signal profiles together with pattern multivariate tools are usually used in qualitative analysis (recognition, classification or identification of samples). Among the multivariate tools available, non-supervised techniques, like principal component analysis (PCA), or supervised techniques such as linear discriminant analysis (LDA) and artificial neural network are the most commonly used [1,2]. Previous uses of e-tongue devices for juice matrix measurements have dealt mainly with qualitative recognition and differentiation of juice types [7-10]. In this work a multi-sensor array device was used for non-alcoholic beverages discrimination according to the juice content level, thus allowing a semi-quantitative evaluation.

2. Potentiometric electronic tongue and methods

The e-tongue device consisted of 36 polymeric membranes applied to two-sensor arrays. Each membrane was prepared using approximately 31.9-32.3% of PVC as polymeric matrix, 64.7-65.2% of plasticizer compounds and 2.8-3.2% of sensor membrane additives (Table 1).

Table 1. Additives and plasticizers used for polymeric membranes preparation

Membrane Additive substance	Membrane additive identification	Plasticizer substance	Plasticizer identification
Octadecylamine	1	Bis(2-ethylhexyl)phthalate	A
Bis(2-ethylhexyl)phosphate	2	Bis(1-butylpentyl) adipate	B
Oleyl alcohol	3	Tris(2-ethylhexyl)phosphate	C
Methyltrioctylammonium chloride	4	Dibutyl sebacate	D
Tridodecylmethylammonium chloride	5	2-Nitrophenyl-octylether	E
Oleic acid	6	Dioctyl phenylphosphonate	F

All the polymeric membrane components were of analytical grade (Fluka) and used as purchased. The multi-sensor system, already described in a previous work [3], together with a double junction Ag/AgCl reference electrode, was connected to a multiplexer Agilent Data Acquisition/Switch Unit model 34970A. Agilent BenchLink Data Logger software installed in a PC computer was used to acquire the sensor signals. Measurements were performed in a double wall glass cell thermostatized at 25 ºC. Figure 1 shows the two sensor arrays and the Ag/AgCl reference electrode. It is also shown the device immersed in a sample contained in a double wall glass cell.

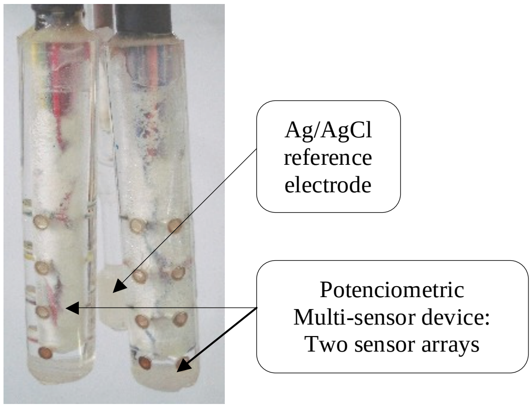

Fig. 1. E-tongue device.

The ability of the multi-sensor device to recognise beverages with different added fruit juice levels was evaluated using commercial beverages of different brands. Four beverages groups of different kind/levels of added fruit juices within groups were used, each with 4 beverages of the same brand but with different fruit compositions. The 4 groups of beverages considered were: (A) fruit drinks with addition of fruit juice above 30%, (B) fruit drinks with added fruit juice between 14% and 30%, (C) gasified juices with a percentage of fruit juice between 6% and 10%; (D) ice tea drinks with addition of less than 4% of fruit juice (Table 2). The 16 beverages were analysed twice, without any dilution, during a 10-15 minutes period. Gasified juices were previously degassed using an ultrasound device during 3min.

Table 2. Description of the beverages analyzed

Group	Beverage	Composition as provided in label
A	Pineapple juice “Brand I”	>50% of juice
	Mango juice “Brand I”	>30% of juice
	Peach juice “Brand I”	>50% of juice
	Tutti-Frutti juice “Brand I”	>50% of juice
B	Orange juice “Brand II”	20% of juice
	Mix fruits juice “Brand II”	>20% of juice
	Pineapple juice “Brand II”	>20% of juice
	Strawberry juice “Brand II”	>14% of juice
C	Pineapple juice with gas “Brand III”	6% of juice
	Orange juice with gas “Brand III”	8% of juice
	Pineapple juice with gas “Brand IV”	8% of juice and pulp
	Orange juice with gas “Brand IV”	10% of juice and pulp
D	Mango ice tea “Brand V”	0.13% of juice and 4.7% of tea
	Lemon ice tea “Brand V”	0.1% of juice and 4.7% of tea
	Peach ice tea “Brand V”	0.1% of juice and 4.7% of black tea
	Red ice tea “Brand V”	3.4% of juice and 3.3% tea extract

A linear discriminant analysis (LDA) was used as a supervised learning technique to classify the non-alcoholic beverages according to their juice contents. Prior probabilities were computed based on each group size. A stepwise technique, using the Wilk’s lambda method with the usual probabilities of F for a variable to be included (0.05) or removed (0.10) from the model, was applied for variable selection. This procedure uses a combination of forward selection and backward elimination procedures, where before selecting a new variable to include, it is verified whether all of the variables previously selected remain significant. With this approach it was possible to identify the significant variables (sensor signals) among the 40 sensors signal profiles recorded by the e-tongue device for each sample. To verify which canonical discriminant functions were significant, the Wilks’ Lambda test was applied. To avoid overoptimistic data modulation, a leaving-one-out cross-validation procedure was carried out to assess the model performance. The LDA statistical analysis was performed at a 5% significance level using the SPSS software, version 17.0 (SPSS Inc).

3. Results and discussion

The samples were analysed to verify if the recorded signal patterns contained enough information to differentiate the beverages according to 4 beverages groups previously established.

The stepwise LDA analysis allowed the selection of a classification model that was only based on the signals of 4 polymeric membranes: A4, D5, E1 and F5 ($P<0.001$, Wilks’ Lambda test). The final model used two canonical discriminant functions ($P<0.001$, Wilks’ Lambda test), which accounted for 99.0% of the total experimental data variance. In Figure 2 the scores for the two functions are plotted (explaining 78.4% and 20.6% of the total variance, respectively). As shown, the approach had a very satisfactory performance, allowing a 100.0% and 93.8% correct classification for the original grouped cases and the “leaving one-out” cross-validation procedure, respectively.

4. Conclusion

An all-solid state potentiometric multi-sensor device, made of non-specific polymeric (PVC) membranes was developed and applied with success to the classification of non-alcoholic beverage according to their juice contents. The device is versatile, allowing cross-information as well as specific information about a liquid sample matrix. For the first time, to the best of the authors’ knowledge, an e-tongue device was successfully applied for juice semi-quantitative discrimination, based on the fruit content range level.

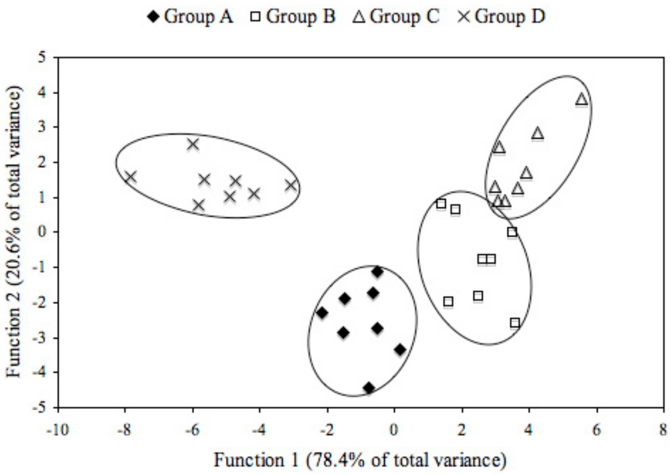

Fig. 2. Discriminant analysis obtained for the juices recognition. Group A: juice level higher than 30%; Group B: juice level between 14% and 30%; Group C: juice level between 5% and 10%; Group D: juice level between 0.1% and 2%.

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