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Evaluation of healthy and sensory indexes of sweetened beverages using an electronic tongue

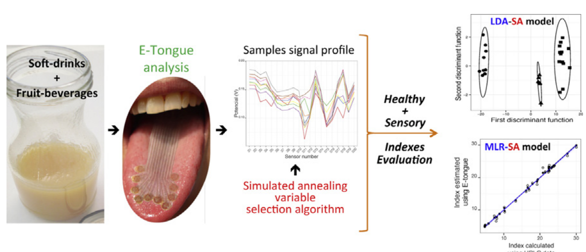
Luís G. Dias [a], Cédric Sequeira [a], Ana C.A. Veloso [b,c], Mara E.B.C. Sousa [a], António M. Peres [d,*]

[a] CIMO – Escola Superior Agrária, Instituto Politécnico de Bragança, Campus Santa Apolónia, Apartado 1172, 5301-855 Bragança, Portugal
[b] Instituto Politécnico de Coimbra, ISEC, DEQB, Rua Pedro Nunes, Quinta da Nora, 3030-199 Coimbra, Portugal
[c] CEB – Centre of Biological Engineering, University of Minho, Campus de Gualtar, 4710-057 Braga, Portugal
[d] LSRE – Laboratory of Separation and Reaction Engineering – Associate Laboratory LSRE/LCM, Escola Superior Agrária, Instituto Politécnico de Bragança, Campus Santa Apolónia, Apartado 1172, 5301-855 Bragança, Portugal

HIGHLIGHTS

- Overconsumption of soft-drinks and fruit-beverages may enhance health risks.
- Beverage's healthy and sensory indexes were calculated using chromatographic data.
- A potentiometric electronic tongue with multivariate linear models was applied.
- E-tongue discriminated samples according to glycemic load or fructose-intolerance levels.
- Healthy and sensory indexes were accurately quantified using E-tongue data.

GRAPHICAL ABSTRACT



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ABSTRACT

Overconsumption of sugar-sweetened beverages may increase the risk of health problems and so, the evaluation of their glycemic load and fructose-intolerance level is essential since it may allow establishing possible relations between physiologic effects of sugar-rich beverages and health. In this work, an electronic tongue was used to accurately classify beverages according to glycemic load (low, medium or high load) as well to their adequacy for people suffering from fructose malabsorption syndrome (tolerable or not): 100% of correct classifications (leave-one-out cross-validation) using linear discriminant models based on potentiometric signals selected by a meta-heuristic simulated annealing algorithm. These results may be partially explained by the electronic tongue's capability to mimic the human sweetness perception and total acid flavor of beverages, which can be related with glycemic load and fructose-intolerance index. Finally, the E-tongue was also applied to quantify, accurately, healthy and sensory indexes using multiple linear regression models (leave-one-out cross-validation: $R_{adj} > 0.99$) in the following dynamic ranges: $4.7 < \text{glycemic load} \leq 30$; $0.4 < \text{fructose intolerance index} \leq 1.5$; $32 < \text{sweetness perception} < 155$; $1.3 < \text{total acid flavor, g L}^{-1} < 8.3$; and, $5.8 < \text{well-balanced flavor} \leq 74$. So, the proposed electronic tongue could be used as a practical, fast, low-cost and green tool for beverage's healthy and sensory evaluation.

* Corresponding author. Tel.: +351 273303220; fax: +351 273325405.
E-mail addresses: ldias@ipb.pt (L.G. Dias), cedric.b.s@hotmail.com (C. Sequeira), anaveloso@isec.pt (A.C.A. Veloso), mebsousadias@gmail.com (M.E.B.C. Sousa), peres@ipb.pt (A.M. Peres).

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1. Introduction

The consumption of sugar-sweetened carbonated beverages (soft-drinks) and fruit beverages (e.g., nectars and juices) has experienced an increase since the 1980s. Soft-drinks, nectars and juices, among other requirements, must have a minimum percentage of added juice of 6–16%, 25–50% and equal to 100%, respectively [1]. These non-alcoholic beverages are highly appreciated due to their sensory attributes. Human perception of beverage's specific flavors, balanced global flavor and sweetness are enhanced by sugars and organic acids contents, as well as by their equilibrium [2–5]. Besides, consumers also attributed to these beverages, especially to nectars and juices, healthy characteristics, being viewed as a source of essential nutrients (e.g., vitamins) and antioxidants. However, their overconsumption may increase the risk of health problems due to the high sugar content. Indeed, temporal studies have shown a close correlation between the upsurge in obesity and rising levels of the consumption of these beverages [6]. Also, diets rich in free or total fructose (considering its presence in other carbohydrates) can be highly prejudicial, inducing obesity, diabetes, dyslipidemia and insulin resistance [7]. This is of special relevance for people suffering from fructose intolerance, which may be partially prevented with the simultaneous ingestion of glucose [8], being envisaged a glucose/fructose ratio equal or greater than one.

So, from both consumer's and producer's point of view, it is of huge importance to evaluate healthy and sensory attributes by means of easily understandable indexes. Among the healthy indexes used in association studies of diet and chronic diseases [9] two are common: the glycemic load (GL), which quantifies the overall glycemic effect of a portion of food [7,9–12] and the fructose-intolerance (FI) index, mainly for people suffering from fructose malabsorption [8]. In fact, these indexes can be more useful nutritional concepts than the chemical classification of carbohydrates, since they may allow a better understanding of the relation between physiologic effects of carbohydrate-rich foods and health [10]. Among the sensory indexes the following are used as consumer's beverage acceptability or overall taste indicator: the total acid flavor, the sweetness index concept, used to assess fruit beverage sweetness as sucrose equivalent [13–15] and the well-balanced flavor index, evaluated from the ratio between total sugars and total acids contents [2–4].

These indexes are influenced by the nature and source of carbohydrates and organic acids present in beverages and may be calculated from their contents, usually obtained experimentally by liquid chromatography based techniques [15–18]. These approaches, although accurate, are time-consuming, expensive, require qualified technical human resources and, usually, are not ambient friendly.

So, in the last years, fast, cost-effective and green electrochemical devices have been developed and applied, as alternative analytical techniques, for food matrices qualitative and/or quantitative analysis. The broad range of applicability of electronic tongues (E-tongue) within the food field, including direct analysis (e.g., milk, fruit-beverages, beer, wine) [19–22] or after sample pretreatment steps, such as dilution or extraction procedures (e.g., olive oils, honey and cereal-based solid foods) [23–27], may be attributed to the capability of these devices in recognizing and measuring basic taste compounds (e.g., acid, bitter, salty, sweet and umami) that has been previously demonstrated for multi-sensor systems based on lipid polymeric membranes [22,28–30]. In some cases, sample pre-treatment, like dilution, dissolution and/or extraction with a hydro-ethanolic solvent, is useful either to obtain a liquid sample, to minimize viscosity issues or to obtain a conductive solution, rich in tastant-related substances that can be recognized and measured by the E-tongue. Lipid/polymer membranes containing hydrophobic and hydrophilic groups, can be positively or negatively charged enabling the establishment of electrical interactions with electrolyte sourness tastants (e.g., organic acids) [31] or may allow electrostatic or hydrophobic interactions at the oil/water interface with sweet nonelectrolytes (e.g., sugars) [29,32].

Concerning non-alcoholic beverages evaluation, potentiometric E-tongues coupled with appropriate multivariate techniques have been successfully applied for discriminating different brands of apple juices [19] or orange juices [33–36]. Recently, a potentiometric E-tongue was used for semi-quantitative classification of fruit juices with different levels of added juice [37,38] and to quantify glucose and fructose contents in those beverages [38]. A potentiometric E-tongue was also applied as a sweetener recognition and taste predictor in coke soft-drinks [39]. More recently, an E-nose combined with a potentiometric E-tongue was reported for improving fruit juice recognition [40]. Most of these works report the classification of non-alcoholic beverages according to brand, beverage type or fruit flavor but, until now, none has focused on beverage classification according to healthy indexes.

In the present work, healthy and sensory indexes were calculated using experimental data regarding sugars and organic acids concentrations in beverages [18]. Based on GL or FI levels, beverages were split into 3 groups (low, medium or high GL) or 2 groups (FI index greater or lower than one, i.e., tolerable or not for people sensitive to fructose), independently of the beverage flavor, brand or commercial classification. The potential application of a potentiometric E-tongue to semi-quantitatively classify beverages according to healthy ratios (GL and FI index) was evaluated. Also the E-tongue's performance for quantifying both healthy and sensory indexes was investigated. For that, qualitative and quantitative chemometric tools were applied namely, linear discriminant analysis (LDA) and multiple linear regression (MLR) linear models, both coupled with a meta-heuristic simulated annealing variable selection algorithm. Also, possible linear correlations between healthy and sensory attributes were further assessed using the linear Pearson correlation coefficient (*R*-Pearson).

2. Materials and methods

2.1. Materials

2.1.1. Samples

Thirty commercial beverages samples (15 carbonated soft-drinks, 13 fruit-nectars and 2 fruit-juices) acquired in Bragança city (Portugal) were analyzed and their sugars (glucose, fructose and sucrose) and organic acids (ascorbic, citric and malic acids) contents were determined experimentally as previously reported [18]. Beverages were from different brands, several fruit flavors (e.g., orange, apple, pineapple, passion fruit, mango, red fruits and/or mixed fruits) and with added juice content ranging from 6 to 100% (according to label information).

2.1.2. Reagents

All the reagents used for HPLC analysis were of analytical grade and used as purchased: orthophosphoric acid, sucrose and ascorbic acid (Panreac); fructose, glucose, malic acid and acetic acid (Fluka); citric acid monohydrate (Fisher Scientific); and, tartaric acid (Riedel-deHaën). Regarding E-tongue, the reagents, from Fluka, were also of analytical grade and used as acquired: octadecylamine, oleyl alcohol, methyltrioctylammonium chloride and oleic acid as additives; bis(1-butylpentyl) adipate, dibutylsebacate, 2-nitrophenyl-octyl-ether, tris(2-ethylhexyl)