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Study on the flavour of soybean cultivars by sensory analysis and electronic tongue

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Summary   The scope of this study was to assess the sensory attributes of five Brazilian soybean cultivars genetically different (BRS), described as special soybean cultivars for human consumption (BRS 216, BRS 213 and BRS 267) and conventional (BRS 258 and BRS 133), by quantitative descriptive analysis (QDA), and verify the ability of the electronic tongue to discriminate the soybean cultivars according to its flavours. According to QDA, BRS 267 was characterised by increased grain size, more intense cream colour, sweet flavour, sweet and umami taste. BRS 133 showed a dark hilum colouring, cooked bean and rancid aroma, cooked bean and rancid, bitter and astringent attributes. BRS 216 presented smaller grain size, less intense cream colouring and a more rounded grain shape, while the BRS 258 showed a hard texture. BRS 213 was characterised by a neutral flavour. The electronic tongue was able to distinguish between the five soybean cultivars according to their different flavour attributes. Correlation analysis was made among chemical constituents of soybean (hexanal, linoleic and linolenic acid, isoflavones, sucrose and fructose, and glutamic acid and alanine), sensory attributes and electronic sensors. Sensory attributes had a significant correlation, in absolute value, $P \leq 0.05$, with electronic tongue ($r = 0.50$–0.80) and chemical constituents of soybean grains ($r = 0.51$–0.98). Electronic tongue had a significant correlation ($r = 0.50$–0.94) with the chemical constituents. It can be used effectively to classify soybean cultivars.

Introduction

Conventional soybean cultivars, classified by grain type, are used mainly to produce oil and animal feed (Liu, 1999). These cultivars display sensory properties not appreciated or undesirable flavour by consumers because of the characteristic flavour described as beany or rancid, which is caused by hexanal volatile compounds and the presence of lipoxygenase enzymes. Soybean cultivars for human consumption or food types show special chemical characteristics. These cultivars have higher protein content, sucrose, glutamic acid, alanine, lower hexanal contents and the absence of lipoxygenase enzymes that can improve the sensory qualities owing to the sweet and mild flavour (Liu, 1999).

Soybean cultivars BRS 133 and BRS 258, classified as grain type, and BRS 267, BRS 213 and BRS 216, suitable for human consumption and classified as food type, were

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developed by the Brazilian Agricultural Research Corporation – Embrapa Soybean. Cultivar BRS 258 presents large seed size and yellow hilum. It originated from cultivar BR 36, which was a variety preferred by organic growers (Pípolo *et al.*, 2005). This conventional cultivar has high yield and a great potential to be utilised for food processing (Pípolo *et al.*, 2005). BRS 216 (Carrão-Panizzi *et al.*, 2003) from cross [(BR79–15807 × Embrapa 4) × IAC 13] has small seed size (10 g/100 seeds), yellow hilum and high protein content (43%), and it is suitable for *natto* and for production of soybean sprouts, as *moyashi*. BRS 213 (Carrão-Panizzi *et al.*, 2002) was released for commercial production because it does not present the three lipoxygenases isoenzymes L1, L2 and L3 and probably presents better flavour. Genetic elimination of lipoxygenase enzymes can improve the flavour of soybean by reducing the formation of the hexanal compound associated with the beany flavour (Liu, 1999). BRS 267 shows large seed size and yellow hilum, which are suitable characteristics for

soy food processing including tofu, soy flour and soymilk (Carrão-Panizzi *et al.*, 2006). When harvested at the R6 stage (developed grains, but immature) (Fehr & Caviness, 1977), this cultivar can also be consumed as green vegetable soybean, or *edamame*.

Silva *et al.* (2009) studied the chemical characteristics of these soybean cultivars and conclude that BRS 213 can improve the flavour of soy products owing to the absence of lipoxygenase enzymes and the lower hexanal content (15.19 µmol mg^{-1}) when compared with conventional soybean cultivars BRS 133 (17.45 µmol mg^{-1}) and BRS 258 (17.27 µmol mg^{-1}). BRS 267 is the best cultivar owing to the lower hexanal content (7.46 µmol mg^{-1}), the higher content of protein, sucrose, and glutamic and alanine amino acids. BRS 216 is suitable for the production of natto and soybean sprouts owing to the small grain size. The sensory attributes of these Brazilian soybean cultivars have not been described previously in the literature.

The quality of food has been assessed using many different analytical tools to identify chemical, physical and sensory characteristics, including high-performance liquid chromatography (HPLC), gas chromatography and sensory analysis. Among the sensory methods, quantitative descriptive analysis (QDA) provides a complete description of the all sensory characteristics of products. However, all these methods are time-consuming and expensive (Stone & Sidel, 1993, 2004; Meilgaard *et al.*, 2003). The use of electronic sensors or the electronic tongue for food assessment can provide rapid and precise results of taste and flavour and can also function as a tool to augment the work of sensory scientist. The electronic tongue is considered an important tool to optimise the quality control of beverage and foodstuffs in industries in order to discriminate and quantify the compounds of basic tastes in levels far below the detection limit or threshold of the human tongue, for example, 5 mM of NaCl or sucrose (Mattoso *et al.*, 2002; Munõz, 2002; Costell, 2002; Desingh, Stone & Thompson, 2004). The electronic tongue uses the human language concept, known as global selectivity, that is, the biological system does not identify a particular substance, but brings together all the information into patterns that the brain decodes. Electronic tongue needs well-established calibration standards, with samples throughout the range tested and a previous classification by another method (Riul *et al.*, 2003). It does not premise the data, but compares the measurements with a database. QDA and the electronic tongue data have been evaluated using the multivariate statistical technique of principal component analysis (PCA) that elucidates the relationship between samples and the attributes that best characterise each sample (Stone & Sidel, 2004; Ferreira, 2008). There are several works that use the electronic tongue to assess different beverage (Laureati *et al.*, 2010; He *et al.*, 2009; Bleibaum *et al.*,

2002; Kantor *et al.*, 2008), but none about its application for assessing grains such as soybean. This work studies the sensory attributes of Brazilian soybean cultivars grain type (BRS 133 and BRS 258) and food type or for human consumption (BRS 213, BRS 216 and BRS 267) using the QDA and verifies the ability of electronic tongue to discriminate of soybean cultivars according to tastes and flavours.

Materials and methods

Materials

For this study, the following Brazilian soybean cultivars were genetically evaluated: conventional soybean cultivars (grain type) BRS 133 and BRS 258, and soybean cultivars for human consumption (food type) BRS 213 (null lipoxygenase), BRS 216 (small grain type) and BRS 267 (vegetable-type). The soybeans were supplied by Embrapa Soja, located in Londrina, Paraná, Brazil, and were produced in the 2005/2006 growing season in the region of Ponta Grossa, Paraná, Brazil (latitude: 25°09′; longitude: 50°16′; altitude: 975°m; with average annual temperature of 17.6 °C).

Sensory evaluation

The quantitative descriptive analysis (QDA) was performed on the cooked soybeans and was conducted in agreement with the procedures proposed by Stone & Sidel (2004). For the cooking process, the soybean grains were soaked in distilled water for 16 h at room temperature (25 °C). Next, the soybean grains were cooked in an autoclave (Fabre, model 103) at 121 °C for 5 min as mimic industrial preparation. In both descriptor development and evaluation sessions, the panelists were instructed to rinse their mouth with mineral water at room temperature (25°C) before assessing a sample, and there was a 5 min break between the evaluations. Samples, coded with three-digit numbers during group and individual sessions, were presented in 50-mL plastic cups with lids, with each cup containing ten grains of cooked soybeans and cooking broth for a better aroma perception. The samples were kept in a water bath during the evaluations and were served at a temperature of 45 °C. Ten panelists (four men, six women, ages ranging from 28 to 45) were selected from the Embrapa Soybean employees, and the sensory questionnaire, recognition test of basic taste and odours, ordering tests of hardness and colour intensity, astringency and bitterness intensity were used (Meilgaard *et al.*, 2003). The grid method was used to develop the descriptive terminology (Moskowitz, 1983). The sensory attributes generated by consensus among the panelists were: appearance (grain size, cream colour of grain, grain shape, hilum colour), aroma (rancid, cooked beans and sweetness), flavour

(rancid, cooked beans, sweet, bitter, astringent, umami) and texture (hardness) (Table 1). The panelists were trained to identify and quantify the attributes using references samples (Table 1). After training, the performance of each panelist was evaluated. For this, panelists evaluated three soybean cultivars, in three replication. The date of replications of the each panelist was analysed using a two-factor (samples and repetitions) ANOVA and F test. To select panelists by discrimination ability, they had to present values of $F_{samples}$ with a level of significance below 50% ($P < 0.50$). For repeatability, panelists with values of $F_{repetitions}$ with a level of significance above 5% ($P > 0.05$) were selected. For

evaluation of the agreement of the panelists with the panel, the average individual scores were compared to panel scores (Silva, Felberg, Carrão-Panizzi, Lee & Prudencio, 2010; Damásio & Costell, 1991; ABNT. NBR 14 140, 1998; Richter *et al.*, 2010).

The trained panelists evaluated the five samples, in replication, in individual booths under fluorescent white light at room temperature (25 °C). The samples were presented randomly and sequentially tested by the panelists who evaluated the attributes using the scorecard that was developed during the training sessions. The scale used was a 9-cm unstructured line with words anchored at 0.0 or 0.5 cm from the left end, indicating no or

Table 1 Definitions of sensory attributes for cooked soybean grains

Sensory attribute	Definition	Reference
Appearance		
Grain size	Refers to the size of the grains.	*Small*: raw grain of lentil.
		Big: raw grain of white beans.
Grain shape	Refers to the appearance of grains (elongated or round).	*Elongate*: raw grain of white bean.
		Round: canned green pea beans.
Cream colour grain	White-yellow intensity like the cream colouring.	*Clear*: baby corn, canned Green.
		Stronger: chick peas, boiled in distilled water for 50 min.
Hilum colour	Colour intensity of surface area of grains in which it holds the cord.	*Clear*: soybean cultivar BRS 213 cooked in distilled water and in an autoclave at 121 °C for 5 min.
		Dark: soybean cultivar BRS 133 cooked in distilled water and in an autoclave at 121 °C for 5 min.
Aroma		
Rancid	Aroma or smell of old frying oil.	*None*: distilled water.
		Strong: two drops of soy oil diluted in 50 mL of distilled water and heated in microwave for 10 min.
Cooked bean	Aroma or smell similar to cooked beans.	*None*: distilled water.
		Strong: beans cooked in distilled water in a pressure cooker for 50 min.
Sweetness	Aroma associated with sweet foods.	*Weak*: lentil beans cooked in distilled water for 30 min.
		Strong: mini corn canned boiled in distilled water for 50 min.
Flavour		
Cooked bean	Flavour related with cooked beans.	*None*: distilled water.
		Strong: beans, boiled in distilled water, and pressure cooker for 50 min.
Rancid	Flavour related with old frying oil.	*None*: distilled water.
		Strong: two drops of soy oil diluted in 50 mL of distilled water and heated in microwave for 10 min.
Sweet	Sweet taste.	*None*: distilled water.
		Strong: sucrose solution in distilled water at 0.5%.
Bitter	Caffeine taste.	*None*: distilled water.
		Strong: caffeine solution in distilled water at 0.02%.
Astringent	Associated with the tannic acid solution that causes the sensation of 'tying' the mouth.	*None*: distilled water.
		Strong: tannic acid solution in distilled water at 0.01%.
Umami	Taste associated with monosodium glutamate solution that remembers of salty and sweet food at the same time.	*None*: distilled water.
		Strong: solution of monosodium glutamate in distilled water at 0.08%.
Texture		
Hardness	Force required to compress the grain between one's teeth.	*Low*: beans cooked in distilled water in a pressure cooker for 50 min.
		High: chickpeas cooked in distilled water for 30 min.

minimal intensity, respectively, and at 0.5 cm from the right end, indicating maximum intensity of the attributes (ABNT. NBR 14 140, 1998; Richter *et al.*, 2010).

Electronic tongue

The cooked soybean grains were analysed in the laboratory of the Polytechnic School of Microelectronic, Universidade de São Paulo (USP), São Paulo, Brazil, with an electronic tongue composed of eight polymeric sensors with non-specific units, as defined in previous articles (Gregorut *et al.*, 2009; Silva, 2009; Gregorut, 2010). For this analysis, the cooked soybean samples were crushed during their cooking preparation and then filtered through a cotton cloth by mechanical force application. Next, the filtered samples were diluted in distilled water at a ratio of 1:10 (v/v), homogenised and filtered using filter paper (14 μm). The electronic sensors were fabricated by the self-assembly technique using an automatic film deposition (Braga *et al.*, 2008; Gregorut *et al.*, 2009). For the films, different conducting polymers acquired in the market were used. The electrical impedance measurements were obtained from an impedance type meter (LCR Meter HP 4263A model), interfaced with a computer through a GPIB card. The measurements were performed at a previously fixed frequency of 1 kHz and an alternating voltage of 50 mV.

Chemical constituents

The hexanal and fatty acids contents were measured by gas chromatography analysis (GC); isoflavones, sugar and amino acids contents were analysed by HPLC. All these analyses were described in detail in the work published by Silva *et al.* (2009).

Experimental design and statistical analysis

QDA was conducted according to a two-factor (cultivars and panelists) design with three replications in different sessions. The data were analysed using PCA and two-factor analysis of variance (ANOVA) with the interaction (cultivars x panelists). The values of $F_{cultivars \times panelists}$ were significant ($P \leq 0.05$) for some attributes. Thus, the values of the adjusted $F_{cultivars}$ and the *t*-test (Fisher's Protected LSD) comparison of means were calculated against interaction mean square terms (cultivars × panelists) (O'Mahony, 1985; Stone & Sidel, 2004). The analysis of the cooked soybean grains using the electronic tongue was conducted as an experimental randomized design with three replications and five measurements for each repetition. The results were subjected to PCA. The relationships between the sensory evaluation means, electronic tongue and chemical constituents of soybean flavour and taste were examined using Pearson's correlations coefficient (r) ($P \leq 0.05$). PCA was based on the correlation matrix. The number of components used in the analysis met the minimum criterion of 80% of retention of original information data (Johnson & Wichern, 1998). The statistical tests were performed using SAS Institute (2001)– and STATISTICA program, version 6.0 (StatSoft, Tulsa, OK, USA).

Results and discussion

Sensory evaluation

Figure 1a shows the projection of sensory attributes on the factorial plane (PC1 × PC2) of PCA, and Fig. 1b shows the projection of conventional soybean cultivars BRS 133 and BRS 258, and soybean cultivars for human
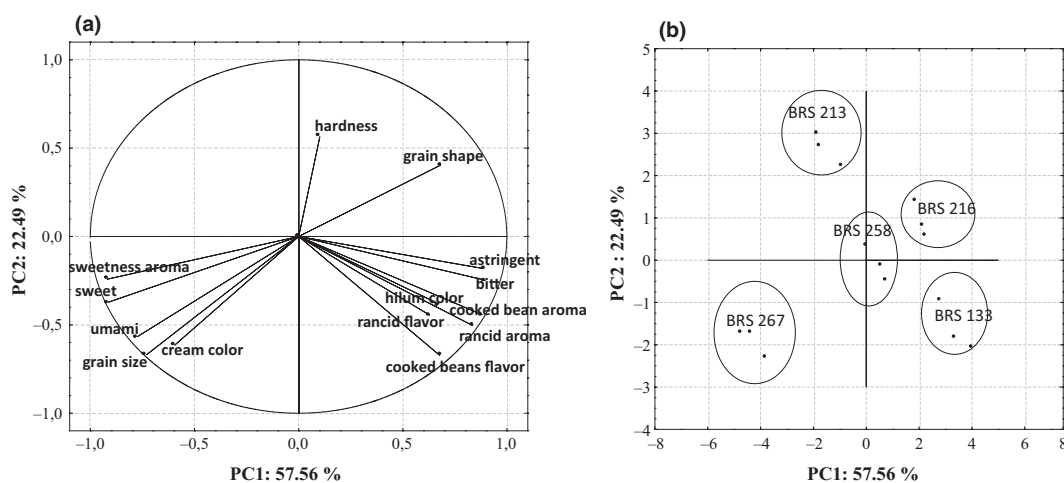

Figure 1 Projections of the sensory attributes (a) and soybean cultivars (b) on the factorial plane (PC1 and PC2). b: Brazilian soybean cultivar BRS 213; Brazilian soybean cultivar BRS 216; Brazilian soybean cultivar BRS 267; Brazilian soybean cultivar BRS 258; Brazilian soybean cultivar BRS 133.

consumption BRS 213 (null lipoxygenase), BRS 216 (small grain size) and BRS 267 (vegetable-type). The first principal component (PC1) explained 57.56% of the total variability contained in the original variables, and the second principal component (PC2) accounted for a further 22.49%, for a cumulative percentage of 80.05%. The variability explained in the first PC included attributes that had loadings above 0.7 (in absolute value) and in descending order of importance (discriminative contribution) with a positive correlation with bitter taste, astringency, rancid flavour and rancid aroma, and a negative correlation with sweetness aroma, sweet taste, umami and cream grain colour. Thus, PC1 represents the attributes of flavour of soybeans. The attributes that contributed to the second PC, with a positive correlation (> 0.5), were grain size and hardness. The repetitions of analysis of each cultivar (represent by points) are close; it means that there was a good repeatability. The five soybean cultivars are separated from one another by presenting different sensory attributes. The first PC separated the cultivars BRS 213 and BRS 267 (far left, Fig. 1b) from the BRS 216 and BRS 133 (far right, Fig. 1b). As soybean cultivars located more to the left probably had a higher intensity of sensory attributes, located more to the left in Fig. 1a, and the lower intensity of the attributes are located further to the right. As the soybean cultivars located more to the right exhibit a possible greater intensity of the attributes located more to the right of Fig. 1a and lower intensity of the attributes located to the left, the PC2 separated the cultivars BRS 213 and BRS 216 (above) from the BRS 267 and BRS 133 (below). The cultivars located above probably have greater intensity of the attribute hardness. The BRS 258 located more to middle of the factorial plane can be considered a cultivar with intermediate-strength sensory characteristics.

The sensory analysis results of each attribute of the soybean cultivars were also subjected to analysis of variance (ANOVA) and average intensities (Table 2) in order to have the level of significance and to confirm the indications of the results of PCA about the attributes that best characterised each cultivar and to examine the similarities and differences between them. Therefore, based on PCA, ANOVA and *t*-test results, it can be observed that the food-type soybean cultivar BRS 267 (vegetable-type) was elicited by higher grain size, more intense cream colour, sweetness aroma, sweet and umami taste; BRS 216 was classified by the following attributes: smaller grain size, less intense cream colour and more rounded grain shape; and BRS 213 (null lipoxygenase) was characterised, in general, as a neutral flavour as it showed, similar to the cultivar BRS 267, the lowest intensity of the rancid and cooked bean aroma, rancid, bitter, astringent and cooked bean flavour. Soybean cultivar BRS 133 exhibited a darker hilum colour, rancid and cooked bean aroma, rancid, bitter and astringent cooked bean flavour, while the BRS 258 showed a hard texture. The difference in food-type (BRS 213 and BRS 267) and grain-type (BRS 133) soybean cultivars can be associated with higher sugar contents and amino acid, glutamic acid and alanine (Silva *et al.*, 2009), which consequently are responsible for the greater intensity perception in the sweet and umami taste found in the vegetable-type soybean cultivar. Probably, sugars and amino acids were precursors of volatiles compounds that were formed during cooked processing of grains and contribute with sweetness aroma.

Electronic tongue measurements

The projection of soybean cultivars on the factorial plane (PC1 and PC2) is shown in Fig. 2a, and the projection of the eight electronic sensors in Fig. 2b. The

Table 2 Average intensities of sensory attributes related to appearance, aroma, flavour and texture of soybean cultivars*

Cultivars	Grain size	Appearance grain shape	Cream colour	Hilum colour	Rancid	Aroma cooked bean	Sweet
BRS 213	2.80[d]	5.00[b]	2.21[cd]	0.58[d]	0.61[c]	1.27[c]	1.89[b]
BRS 216	1.89[e]	6.00[a]	1.78[d]	1.30[c]	2.16[b]	1.68[ab]	1.10[c]
BRS 267	8.36[a]	1.24[c]	6.48[a]	0.88[cd]	1.05[c]	1.36[bc]	3.58[a]
BRS 258	7.22[b]	1.58[c]	3.57[b]	7.15[b]	1.94[b]	1.37[bc]	1.03[c]
BRS 133	3.81[c]	5.73[ab]	2.76[c]	8.41[a]	3.85[a]	1.75[a]	0.75[c]

Cultivars	Cooked bean	Rancid	Flavour sweet	Bitter	Astringent	Umami	Texture hardness
BRS 213	1.45[b]	0.68[c]	1.48[b]	0.95[b]	1.00[b]	0.06[b]	4.47[b]
BRS 216	1.78[ab]	2.21[b]	0.80[c]	2.06[a]	1.97[a]	0.04[b]	3.87[b]
BRS 267	1.69[b]	0.96[c]	3.26[a]	1.03[b]	1.00[b]	2.75[a]	2.82[c]
BRS 258	1.80[ab]	1.86[b]	1.14[bc]	1.81[a]	1.67[a]	0.05[b]	5.52[a]
BRS 133	2.23[a]	3.40[a]	0.83[c]	2.04[a]	1.84[a]	0.03[b]	2.98[c]

*Mean values of three replicates and ten panelists for each repetition, obtained from a nine-point scale (0 = none and 9 = superior); means in columns followed by the same letter do not differ at 5% probability by *t*-test.
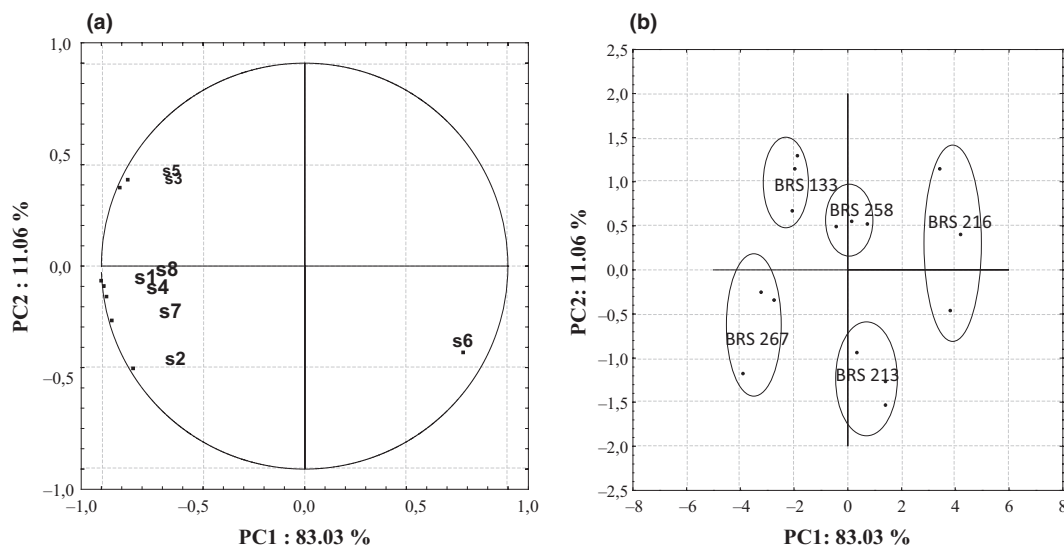
Figure 2 Projection of electronic sensors (a) on the factorial plane (PC1 and PC2) in the frequency of 1 kHz, and projection of soybean cultivars (b) in three replicates. a: S1 = sensor 1; S2 = sensor 2; S3 = sensor 3; S4 = sensor 4; S5 = sensor 5; S6 = sensor 6; S7 = sensor 7; S8 = sensor 8. b: Brazilian soybean cultivar BRS 213; Brazilian soybean cultivar BRS 216; Brazilian soybean cultivar BRS 267; Brazilian soybean cultivar BRS 258; Brazilian soybean cultivar BRS 133.

first principal component (PC1) explained 83.0% of the total variation among the data, whereas the second principal component (PC2) accounted for a further 11.1%, for a cumulative percentage of 94.1%. The proximate of replicate of analysis of each cultivar (represented by points) indicates a good repeatability. It can be verified by the PCA that the electronic tongue, composed of eight sensors, was sufficient to identify and classify the cultivars into five different cultivars. The variability among the data (83%) explained in the first PC (Fig. 2b) was probably due to sensors 1, 4, 7 and 8 (loadings above 0.7, in absolute value). In the second PC, 11.06% of the variability in the data was attributed to the sensors 2, 3, 5 and 6. Comparing the PCA graphs with the data obtained through the QDA (Fig. 1) with the electronic tongue (Fig. 2), it can observed that electronic sensors, at a frequency of 1 kHz, result in responses similar to those by the trained panelists, that is, the soybean cultivars were sufficiently discriminated. Soybean cultivars BRS 213 and BRS 133 are positioned at an angle of 180 degrees, just like BRS 267 and BRS 216. This positioning indicates that in each of these pairs of cultivars, the attributes are at greater intensity in one cultivar and lower in another cultivar, and *vice versa*. As the BRS 267 and BRS 216 positioned between them at an angle of 180 degrees, BRS 133 and BRS 213 also positioned at an angle of between 180 degrees and BRS 258 in a more central position. These positions were attributed to the sensory characteristics in the soybean cultivars and were evaluated in a similar manner by the trained panelists or electronic sensors. Some studies

found in the literature show the capability of the electronic tongue to discriminate different types of beverages and foods. However, others studies demonstrate the need to improve the methodology using electronic sensors according to the food or beverage evaluated. Legin *et al.* (2002), assessing the ability of the electronic tongue to distinguish commercial carbonated drinks containing different sweeteners, found that the equipment distinguished all samples and separated them from conventional drinks. The electronic sensors also discriminated drinks at the production locality, and the authors observed a good correlation with the results obtained in the QDA. Dyminski *et al.* (2006) noted that the electronic tongue was able to differentiate between sweetener samples at a high correlation with human panel response. He *et al.* (2009) found that the electronic sensors used in the evaluation of tea (black and green) were able to identify and discriminate drinks from between geographical regions and quality levels and correlated highly with the sensory measurements collected from trained assessors. Bleibaum *et al.* (2002) demonstrated that the electronic sensors can be used to predict the sensory characteristics and their relationship to the quality of apple juices measured by trained assessors and naive consumers.

Correlation of sensory analysis, electronic tongue and chemical constituents

Table 3 shows the correlation analysis results between sensory attributes and chemical constituents of soybean

Table 3 Pearson's correlations coefficient (*r*) between sensory attributes and chemical constituents of soybean cultivars*

Sensory attributes	Hexanal	Isoflavones	Linoleic and linolenic acids	Sucrose and fructose	Glutamic acid and alanine
Grain size	−0.37	−0.09	0.76*	0.07	0.84*
Cream colour	−0.68*	0.28	−0.89*	0.45	0.91*
Texture	−0.90*	0.44	−0.81*	0.59*	0.32
Rancid aroma	0.51*	0.22	0.66*	0.11	0.11
Cooked beans aroma	0.24	0.36	0.71*	0.36	−0.07
Sweetness aroma	−0.88*	0.39	−0.95*	0.55*	0.57*
Cooked beans flavour	0.52*	0.17	0.72*	0.08	0.03
Rancid flavour	0.69*	0.30	0.48	0.21	0.33
Sweet	−0.83*	0.37	−0.98*	0.52*	0.71*
Bitter	0.55*	−0.03	0.81*	−0.05	−0.11
Astringent	0.49	−0.21	0.85*	−0.13	−0.29
Umami	−0.88*	0.47	−0.89*	0.68*	0.79*

*Significant correlation test, $P \leq 0.05$

Table 4 Pearson's correlations coefficient (*r*) between chemical constituents of soybean cultivars and electronic sensor at 1 kHz frequency*

Electronic sensor	Linoleic and linolenic acids	Isoflavones	Sucrose and fructose	Glutamic acid and alanine
Sensor 1	0.61*	0.34	0.08	0.64*
Sensor 2	0.36	0.71*	0.22	0.67*
Sensor 3	0.52*	0.27	−0.07	0.61*
Sensor 4	0.45	0.20	−0.07	0.55*
Sensor 5	0.49	0.45	0.06	0.63*
Sensor 6	−0.46	−0.94*	−0.59*	−0.44
Sensor 7	0.39	0.14	−0.13	0.73*
Sensor 8	0.58*	0.50*	0.24	0.68*

*Significant correlation test, $P \leq 0.05$

Table 5 Pearson's correlations coefficient (*r*) between sensory attributes of soybean cultivars and electronic sensors at 1 kHz frequency*

Sensory attributes/ electronic sensor	Cooked beans flavour	Rancid flavour	Sweet taste	Bitter taste	Astringent	Umami
Sensor 1	0.21	−0.10	0.72*	−0.42	−0.50*	0.73*
Sensor 2	−0.19	−0.45	0.76*	−0.74*	−0.80*	0.66*
Sensor 3	0.60*	0.65*	0.33	0.04	−0.06	0.41
Sensor 4	0.16	−0.13	0.65*	−0.45	−0.54*	0.63*
Sensor 5	0.65*	0.62*	0.26	0.09	0.00	0.35
Sensor 6	−0.48	−0.25	−0.36	0.00	0.08	−0.43
Sensor 7	0.04	−0.25	0.79*	−0.58*	−0.66*	0.76*
Sensor 8	0.25	−0.05	0.69*	−0.39	−0.47	0.71*

*Significant correlation test, $P \leq 0.05$

cultivars. These results of the constituent contents are shown in Silva *et al.* (2009). Hexanal and fatty acids contents presented positive and significant correlations with rancid and cooked beans aroma, rancid, bitter, astringent and cooked beans flavour, and significant and negative correlations with a sweet aroma, sweetness and umami. These results confirmed those obtained by Torres-Penaranda & Reitmeier (2001). Isoflavone contents did not show significant correlations with the sensory attributes of bitter and astringent, different from those obtained by other authors (Huang *et al.*, 1981; Kudou *et al.*, 1991). It may be that the time and temperature to which the soybeans were subjected to during the cooking process were not sufficient for the formation of aglycones from the isoflavone in sufficient quantities for the sensory perception of the aforementioned sensations. Sugars and amino acids show positive and significant correlations with sweetness aroma, sweet and umami taste. Masuda (1991) showed correlations among sucrose, glutamic acid and alanine with the sweet

and umami taste that describes the unique flavour of vegetable-type soybean. Table 4 shows the correlations between the chemical constituents of soybean cultivars and electronic sensors at the frequency of 1 kHz. Positive and significant correlations with linoleic and linolenic fatty acids were found for sensors 1, 3 and 8. The isoflavone contents showed significant positive correlations with sensors 2 and 8. Glutamic acid and alanine had positive and significant correlations with the sensors 1, 2, 3, 4, 5, 7 and 8. Among the sensors used, sensor 6 showed $r = -0.58$ and $P \leq 0.05$ with sucrose and fructose. Table 5 shows the correlations between the sensory attributes and electronic sensors. Cooked beans and rancid flavours showed positive and significant correlations ($P \leq 0.05$) with sensors 3 and 5. Sweet and umami taste showed positive and significant correlations with sensors 1, 2, 4, 7 and 8. The results suggest that sensors 3 and 5 may be more correlated with the sensory attributes of cooked beans and rancid flavours, and sensors 1, 2, 4, 7 and 8 with the sweet and umami tastes.

Five sensors showed noncorrelation with astringency, and sensor 6 with the bitter taste.

The electronic tongue is an artificial system that tries to reproduce the sensory analysis mechanism of taste and flavour of products and can be a tool to augment the work of sensory scientist (Riul *et al.*, 2002; Ciosek & Wroblewski, 2007). The equipment needs well-established calibration standards, with samples throughout the range tested and a previous classification by another method. It does not premise the data, but compares the measurements with a database. When the correlation between the instrumental and sensory results is significant, the electronic tongue can replace the sensory analysis, only for taste and flavour, by providing a rapid and qualitative analysis. In this study, we showed the possibility of the electronic tongue to assess the taste and flavour of solid foods from aqueous extracts of soybean grains.

Conclusion

Soybean cultivars studied have different sensory attributes. Food-type BRS 267 has higher grain size, intense cream colour, sweetness aroma, sweet and umami taste; BRS 216 has smaller grain size, less intense cream colour and more rounded grain shape; and BRS 213 has a neutral flavour. Grain-type BRS 133 has a darker hilum colour, rancid and cooked bean aroma, rancid, bitter and astringent cooked bean flavour, while the BRS 258 has a hard texture. Sensory attributes has a good correlation with the chemical constituents of soybean grains. Electronic tongue has a good correlation with the chemical constituents and with flavour attributes of soybean grains. The electronic tongue differentiates the soybean grains similar to the trained panel, and it can be an analytical tool to discriminate soybean cultivars according to flavour, quickly and efficiently.

Acknowledgments

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