Application of multiple-sip temporal dominance of sensations to the evaluation of sweeteners

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Abstract

The dynamic sensory profile of sweeteners is of great importance for the industry during the development of low-calorie products. In the present work the influence of sucrose replacement by low-calorie sweeteners on the dynamic sensory profile of orange juice was evaluated using multiple-sip Temporal Dominance of Sensations (TDS). Seven orange juices with equivalent sweet concentrations of different sweeteners (sucrose, sucralose, thaumatin, and four samples of stevia) were formulated. A sensory panel of 12 trained assessors evaluated the samples using TDS over three consecutive sips, each lasting 20 s. TDS enabled the identification of differences in the dynamics of the sensory characteristics of the juices formulated with different sweeteners, which had not been identified using static measurements. Considering the dominance of the evaluated sensory characteristics over the three sips, the juice with sucralose showed the most similar sensory characteristics to the juice sweetened with sucrose, providing similar sweetness dominance over time without providing negative sensory characteristics. On the other hand, samples of stevia were characterized by a high dominance of bitterness and off-flavor. The consideration of multiple sips enabled the identification of changes in the temporal profile of the juices with repeated rapid ingestions. Results from the present work suggest that multiple sip TDS seems to be an interesting tool for the evaluation of sweeteners, the design of mixtures of sweeteners and the development of low-calorie products.

Introduction

Sugar has been the main sweetener in human diet for decades, accounting for a high percentage of the daily energy intake with little additional nutritional value (Bassoli & Merlini, 2003; Caballero, 2013). However, the association of high sugar intake with several negative health conditions, such as obesity and diabetes, has led to a strong need for totally or partially substituting sugar in foods by alternative low-calorie sweeteners (Lustig, Schmidt, & Brindis, 2012; Popkin & Nielsen, 2003).

Stevia and thaumatin are among the high intensity sweeteners from plants which are being increasingly used (Pawar, Krynitsky, & Rader, 2013). Stevia is a natural sweetener isolated from the leaves of Stevia Rebaudiana Bertoni, which is mainly composed of eight glycosides with sweet taste: stevioside, steviolbioside, rebaudiosides A, B, C, D, and E, and dulcoside A (Glória, 2003). Thaumatin is a mixture of proteins isolated from the fruits of Thaumatococcus danielli Benth, which has been reported to be 1600–3000 times sweeter than sucrose (Glória, 2003). Thaumatin is approved as sweetener in several countries, and in the USA as flavor enhancer in chewing gum (Yebra-Biurrun, 2005).

Despite the increasing relevance of safety and naturalness, the sensory characteristics of low-calorie sweeteners are still the key determinants of their potential for sucrose replacement in food products (Kinghorn, Chin, Pan, & Jia, 2010). Ideally, in order to meet consumers’ expectations low-calorie, sweeteners should provide the same sensory characteristics to products than sucrose (Cardoso & Bolini, 2008; Portmann & Kilcast, 1998).

Sweetness potency, i.e. sweetness relative to a sucrose solution, has been the most commonly used characteristic for the selection of low-calorie sweeteners (Bassoli & Merlini, 2003; DuBois, 1982). However, considering that taste perception is a dynamic phenomenon (Lawless & Heymann, 2010), the temporal profile of sweeteners has gained relevance for new product development (DuBois & Prakash, 2012). Using time–intensity methodology, several studies have reported that sweeteners differ in the time elapsed until sweetness is perceived, duration of sweetness perception and the speed of the increase and decrease of the sweet stimulus (Ayya & Lawless, 1992; Larson-Powers & Pagborn, 1978; Palazzo, Carvalho, Efрайm, & Bolini, 2011; Schiffman, Sattely-Miller, & Bishay, 2007).
Sweetness is not the only relevant sensory characteristic when evaluating sucrose replacement by low-calorie sweeteners. Other sensory characteristics, such as bitterness, aftertaste (metallic, sour, etc.), texture attributes (viscosity, mouthfeel) and freshness, should also be taken into account (Kinghorn et al., 2010). Bitterness and metallic off-flavors have been one of the most common problems of low-calorie sweeteners (Cardoso & Bolini, 2008; DuBois & Prakash, 2012; Prakash, DuBois, Clo, Wilkens, & Fosdick, 2008). The dynamic of these sensory characteristics throughout consumption, particularly onset and linger, is also relevant for the performance of these ingredients (Ayya & Lawless, 1992; Bassoli & Merlini, 2003; Glória, 2003).

Temporal Dominance of Sensations (TDS) is a new dynamic methodology which consists of presenting a list of attributes to the assessors, who are asked to continuously select the attribute that is perceived as dominant at each time of the evaluation (Pineau et al., 2009). Considering that TDS is focused on dominant attributes instead of quantifying attribute intensity, results from this methodology could better explain consumers’ perception and more accurately identify the sensations that determine their hedonic perception (Cadena, Vidal, Ares, & Varela, 2014). TDS has been already used to study the dynamic perception of a wide range of products, including wine (Meillon, Urbano, & Schlich, 2009; Pineau et al., 2009), olive oil (Dinnella, Masi, Zoboli, & Monteleone, 2012), coffee (Dinnella, Masi, Naes, & Monteleone, 2013), yogurt (Bruzzzone, Ares, & Giménez, 2013), fish sticks (Albert, Salvador, Schlich, & Fiszman, 2012) and salmon–sauce combinations (Paulsen, Naes, Ueland, Rukke, & Hersleth, 2013).

In classical TDS the evaluation is performed during the first sip/bite, which is a standard procedure in sensory and consumer research. However, in real life products are consumed in rapid repeated ingestions, which can cause changes in how products are perceived due to sensory adaptation (Köster, 2003). For this reason, the first sip/bite may not be enough to fully perceive all the sensory characteristics of the products, particularly when dealing with complex products. Previous studies have reported that small differences in the sensory profiles of products only become noticeable after repeated tasting (Köster, Couronne, Léon, Lévy, & Marcelino, 2002; Stein, Nagai, Nakagawa, & Beauchamp, 2003; Zandstra, Weegels, Van Sproonsen, & Klerk, 2004). Thus, in order to get a more realistic view of the products’ sensory experience, an extension of TDS, called multiple-bite or multiple-sip TDS, has been proposed (Vandeputte, Romans, Pineau, & Lenfant, 2011). This methodology basically consists of a series of concatenated TDS evaluations (Pineau, 2013; Schlich, Urbano, & Visalli, 2013).

In this context, the aim of the present work was to evaluate the influence of replacing sucrose by low-calorie sweeteners on the dynamic sensory profile of orange juice using multiple-sip Temporal Dominance of Sensations.

Materials and methods

Samples

Orange juices were prepared by diluting unsweetened concentrated juice (Frigorífico Modelo, Montevideo, Uruguay) to 11 °Brix with filtered tap water. Seven samples were prepared by sweetening the juices with different sweeteners at equivalent sweet concentrations, commercial sucrose, sucralose, thauatin, and four samples of stevia: stevia 1 to stevia 4. Equivalent sweet concentrations were determined in previous studies using paired-comparison tests with 12 trained assessors. The concentration and characteristics of the sweeteners are shown in Table 1.

Trained assessors’ panel

The sensory panel consisted of twelve assessors, ages ranging from 22 to 48 years old. Assessors had been selected according to the guidelines of the ISO 8586:2012 standard (ISO, 2012) and trained in the recognition and quantification of 12 sensory attributes of orange juice. They had a minimum of 4 months experience in sensory characterization of orange juices using Descriptive analysis. Six additional 15 min training sessions were considered to introduce assessors to the notion of TDS, as well as to allow familiarization with the software used for data collection (Dinnella et al., 2012; Pineau et al., 2009).

Experimental procedure

A dominant attribute was defined as the sensation that caught attention at a given time, not necessarily being the most intense. The attribute list for TDS consisted of six terms: sweet, sour, orange flavor, bitter, astrigent, and off-flavor. Terms were selected by open discussion with the panel leader, in a session in which the assessors were presented with the samples. To avoid list order bias, the order of the attributes was different for each assessor, following William’s Latin square design.

Assessors were asked to take a sip of juice in their mouth and perform a TDS task for 20 s. At that time, they were instructed to take a new sip and continue the evaluation for 20 more seconds. A total of three sips were considered.

Samples were coded using 3-digit random numbers and presented following a William’s Latin square design. Three replications of each sample were evaluated by each assessor.

Data collection was carried out using Sensomaker (Pinheiro, Nunes, & Vietoris, 2013). Testing took place in a sensory laboratory in standard sensory booths that was designed in accordance with ISO 8589 (ISO, 2007), under artificial daylight and temperature control (22 °C). Still mineral water was used for rinsing between samples.

Data analysis

For each assessor, the attribute regarded as dominant at each time of the evaluation was recorded. For each sip, dominance rate (P) for each attribute at a given time (every 1 s) was determined as the percentage of judgments (assessors × replicates) for which the given attribute was selected as dominant. For each of the three sips dominance rates were smoothed using a spline type polynomial with the spline package of R language (R Core Team, 2013) and plotted against time for each sample to obtain TDS curves.

Chance (P0) and significance level (P1) were calculated and represented on the TDS curves. Chance level was calculated as the inverse of the total number of attributes plus one (Labbe, Schlich, Pineau, Gilbert, & Martin, 2009), whereas significance level was calculated using a binomial test, as recommended by Pineau et al. (2009) when dealing with few evaluations.

<table>
<thead>
<tr>
<th>Sweetener</th>
<th>Concentration (g/100 mL)</th>
<th>Technical specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>10</td>
<td>–</td>
</tr>
<tr>
<td>Sucralose</td>
<td>0.025</td>
<td>–</td>
</tr>
<tr>
<td>Thaumatin</td>
<td>0.091</td>
<td>Thaumatin concentration higher than 94%</td>
</tr>
<tr>
<td>Stevia 1</td>
<td>0.064</td>
<td>Rebaudioside A concentration: 95.6%</td>
</tr>
<tr>
<td>Stevia 2</td>
<td>0.155</td>
<td>Rebaudioside A concentration: higher than 98%</td>
</tr>
<tr>
<td>Stevia 3</td>
<td>0.199</td>
<td>Rebaudioside A concentration: higher than 95%</td>
</tr>
<tr>
<td>Stevia 4</td>
<td>0.151</td>
<td>Rebaudioside A concentration: 40%</td>
</tr>
</tbody>
</table>
TDS difference curves between the juices with low-calorie sweeteners and the juice with sucrose were constructed by subtracting their TDS curves at each time for each sip. Dominance rate differences were considered significant when they were significantly different from 0 according to a classical test of comparison of binomial proportions (Pineau et al., 2009).

All statistical analyses were performed with R (R Core Team, 2013).

**Results**

**TDS curves**

Fig. 1 shows normalized TDS curves for the first three sips of orange juices sweetened with seven different sweeteners. Chance and significance level are represented on the curves. The temporal profile of the evaluated juices was characterized by the dominance of sweetness, sourness, bitterness and off-flavor; whereas orange flavor and astringency were not significantly dominant throughout the evaluation of the three sips.

Throughout the three sips, the juice sweetened with sucrose was characterized by sweetness dominance. As shown in Fig. 1(a), sweetness was the only significantly dominant attribute during the first two sips, reaching maximum dominance rates higher than 50%. The third sip was also characterized by the dominance of sweetness, but it was combined with a short significant dominance of sourness at the end of the evaluation period.

Sweetness also dominated the temporal profile of sucralfose over the three sips. However, sourness was also dominant during almost the entire evaluation period of the second sip (Fig. 1(b)). Meanwhile, the temporal profile of the three sips of thaumatin

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**Fig. 1.** TDS dominance curves of six sensory attributes during three sips for orange juices with: (a) sucrose, (b) sucralfose, (c) thaumatin, and four samples of stevia: (d) stevia 1, (e) stevia 2, (f) stevia 3 and (g) stevia 4.
was characterized by the dominance of sourness at the beginning of the evaluation, followed by a pronounced dominance of sweetness. As shown in Fig. 1(c), the dominance of sourness at the beginning of the evaluation increased from the first to the third sip.

The temporal profile of the four samples of stevia was characterized by the dominance of bitterness at the end of the evaluation of the three sips. Bitterness dominance increased from the first to the third sip (Fig. 1). Large differences among the samples of stevia were identified. The temporal profile of stevia 2 was characterized by the dominance of sweetness and bitterness (Fig. 1(e)). The period during which sweetness was dominant decreased from the first to the third sip. Besides, sweetness and sourness were dominant at the beginning of the evaluation for the three sips of the juice with stevia 1, while bitterness was dominant at the end of the three sips (Fig. 1(d)). TDS curves of juices with stevia 3 and stevia 4 showed the largest differences to those of juices with sucrose (Fig. 1(f) and (g)). The TDS curves of juices with stevia 3 were characterized by the pronounced dominance of bitterness and off-flavor, while sweetness was only significantly dominant at the beginning of the third sip (Fig. 1(f)). Finally, the TDS curves of the juice with stevia 4 showed a small dominance of sweetness at the beginning of the evaluation, which decreased from the first to the last sip. The second sip of this sample was also characterized by the dominance of sourness at the beginning of the evaluation. For this sample, off-flavor and bitterness were dominant at the end of the three sips (Fig. 1(g)).

Differences between low-calorie sweeteners and sucrose

TDS curves of the juices sweetened with low-calorie sweeteners were compared with the curve of the juice with sucrose. Significant differences were found between sucrose and all the evaluated low-calorie sweeteners for the three sips. However, as shown in Fig. 2, the differences tended to increase from the first to the third sip.
Fig. 1 (continued)
Juices sweetened with sucrose and sucralose showed similar TDS curves for all the evaluated attributes. However, sweetness dominance of the sucralose sweetened juice was higher than that of the juice with sucrose for a small period of time (2 s) at the beginning of the three sips, as shown in Fig. 2(a). These juices also differed in the dominance of sourness during two short periods of time during the second sip (Fig. 2(b)).

Replacing sucrose with thaumatin led to large differences in the dominance of sweetness and sourness. As shown in Fig. 2(a), the dominance of sweetness was significantly lower for thaumatin than for sucrose at the beginning of the evaluation of the three sips and significantly higher at the end. Meanwhile, the dominance of sourness was markedly higher for the thaumatin sweetened juice than for the juice with sucrose for a period of 5–9 s during the three sips (Fig. 2(b)). Also, at the end of the third sip sourness dominance was significantly lower for the juice with thaumatin than for the sucrose sweetened juice.

The dominance of the sensory characteristics of the juices formulated with four samples of stevia markedly differ from those of the juice with sucrose. Throughout all the evaluation period sweetness dominance was significantly lower for juices with stevia than for the juice sweetened with sucrose, except for the beginning of each of the three sips (Fig. 2(a)). However, the juice with stevia 2 did not significantly differ from the juice with sucrose in sweetness dominance during the first sip. Also, juices with stevia markedly differ from the juice with sucrose in the dominance of bitterness and off-flavor (Fig. 2(c) and (d)). This difference tended to increase from the first to the last sip.

Discussion

Multiple sip temporal dominance of sensations methodology enabled to identify differences in the temporal profile of juices formulated with equivalent sweet concentrations of different sweeteners. As shown in Fig. 2, although the juices were formulated with the same perceived sweetness, the dominance of this sensation over time was significantly different among juices formulated with different sweeteners. This suggests that the information provided by TDS is different than sensory measurements averaged.
across time, in agreement with results reported by Labbe et al. (2009), Meillon et al. (2009) and Bruzzone et al. (2013).

The juice sweetened with sucrose showed a sharp increase in sweetness dominance immediately after ingestion of the three sips, followed by a slow decrease in dominance rate (Fig. 1(a)). Sucrose is characterized by a rapid onset of sweet taste and a short extinction time (DuBois & Prakash, 2012). These characteristics are not usually found in many sweeteners, which is one of the reasons explaining the difficulty of replacing sucrose by low-calorie sweeteners without changing the sensory characteristics of the products (Dubois, 1982).

Sucralose has been reported to have a slow onset of sweetness and a prolonged sweetness perception compared to sucrose (Glória, 2003). However, these differences were not found in the present study. In fact, for the three sips, sweetness dominance was significantly higher for the juice formulated with sucralose than for the juice with sucrose during a few seconds at the beginning of the evaluation (Fig. 2(a)). This sweetener showed the most similar temporal profile to sucrose.

The juice sweetened with thaumatin was characterized by a significantly lower sweetness dominance than the juice with sucrose during the first moments after ingestions and a significantly higher sweetness dominance at the end of the evaluation of each of the three sips (Fig. 2). During the first sip the time elapsed until maximum sweetness dominance rate was delayed 8 s when sucrose was replaced by thaumatin (c.f. Fig. 1(a) and (c)). These differences can be related to the fact that thaumatin has been characterized by a delayed sweetness perception and a long-lasting sweet aftertaste (DuBois & Prakash, 2012; Gibbs, Alli, & Mulligan, 1996; Glória, 2003; Witty, 1990). Delayed sweetness perception can explain the high dominance of sourness during the first moments of the evaluation of the first sip, while sweet aftertaste can explain the increase in sourness dominance from the first to the successive sips (Fig. 1(c)).

All the juices sweetened with stevia showed a significantly lower sweetness dominance than the juice with sucrose (Fig. 2). It is worth highlighting that for the juice sweetened with stevia 3 sweetness was only dominant for a small period of time at the beginning of the third sip (Fig. 2(f)). Although sweetness intensity in the juices formulated with sucrose and stevia 3 did not differ, the dominance of this attribute for the latter sample was significant only for a small period of time at the beginning of the third sip.
Sucrose replacement by low-calorie sweeteners led to changes in the temporal profile of other sensory characteristics. This was particularly relevant for the juices sweetened with stevia. As shown in Fig. 2(c) and (d), replacing sugar by stevia caused a significant increase in the dominance of bitterness and off-flavor. This is in agreement with the fact that stevia has been reported to have a characteristic bitter taste, particularly at high concentrations (Cardoso & Bolini, 2008; Dubois & Prakash, 2012; Kinghorn et al., 2010; Pawar et al., 2013). However, it is important to stress that the first four samples of stevia showed different temporal profiles, which suggests the need to consider a wide variety of samples with different characteristics during the development of food products formulated with this natural low-calorie sweetener.

Taking into account the dominance of the evaluated sensory characteristics over the three sips, the juice sweetened with sucrose was the most similar to the juice formulated with sucrose, showing similar sweetness dominance over time without the onset of negative sensory characteristics (Fig. 1(b)). This sweetener has been reported to be the most similar to sucrose by other authors (Dubois, 1982; Cadena et al., 2013). On the other hand, the temporal profile of juices sweetened with stevia 3 and stevia 4 were the most dissimilar with respect to the juice with sucrose (Fig. 2).

The consideration of multiple sips in the evaluation of orange juices formulated with different sweeteners provided relevant information. Changes in the temporal profile of the products were identified from the first to the third sip, particularly for samples sweetened with thumatin and stevia. Multiple sip TDS enabled the identification of changes in the dominance of the evaluated sensory attributes, probably due to sensory adaptation. This methodology showed an increase in sourness dominance with repeated ingestions of the juice formulated with thumatin (Fig. 1(c)), as well as an increase in bitterness dominance for juices with stevia. Besides, differences between samples formulated with stevia and sucrose increased with repeated ingestions and were larger for the third sip than for the first one. This result is in agreement with the fact that differences among samples have been reported to become more noticeable after repeated tasting, particularly when dealing with similar samples (Köster et al., 2002; Stein et al., 2003).

Conclusions

Understanding the dynamic sensory profile of low-calorie sweeteners is highly relevant for the development of successful low-calorie products. In the present work, the application of temporal dominance of sensations allowed the identification of differences in the dynamics of the sensory characteristics of orange juices formulated with different sweeteners. The evolution of the dominance of sweetness over time of juices with equi-sweet concentrations of different sweeteners markedly differed. Also, changes in the temporal profile of the juices with repeated rapid ingestions were identified using a multiple sip variation of TDS. These results suggest that multiple sip TDS enabled to identify differences among sweeteners which had not been detected using classic static sensory measurements.

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References


