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ORIGINAL PAPER

Use of artificial saliva for evaluation of instrumental texture of expanded snacks: part II–correlations between sensory characteristics and instrumental properties

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Abstract

Food texture can be evaluated by instrumental and sensory methods; however, more than just using both approaches, establishing correlations between them is fundamental to obtain relevant information related to the sensory quality of product texture. Considering that artificial saliva is still little explored in the food area, the texture sensory profile and texture acceptance of expanded snacks were investigated to verify whether artificial saliva influences any correlation between the instrumental and sensory evaluations of texture. Thirteen samples of expanded snacks were analyzed using seven probes and three treatments: with no saliva, with 1.1 mL of artificial saliva applied to the sample and immersion of the sample in the artificial saliva. A high intensity of adhesiveness was responsible for low acceptance of products. Without artificial saliva, correlations between intensities of fracturability and instrumental results were more frequent; however, when artificial saliva was used, strong correlations were obtained for the intensities of hardness, crispness, chewiness and adhesiveness. Regarding the sensory acceptance, the cylindrical probe without saliva and the three-point bending probe and Ottawa probe with 17 blades with artificial saliva stood out as having strong correlation. Thus, the three-point bending and 17-blade Ottawa probes with 17 blades are highlighted, as both notably increased the correlations between sensory and instrumental results when used with artificial saliva. In conclusion, the use of artificial saliva changes correlations between instrumental and sensory analyses for all probes and the choice of instrumental conditions to be used will depend on the sensory attribute to be investigated.

Keywords Artificial saliva · Texture analyzer · Expanded snacks · Sensory profile · Sensory acceptance · Correlation

Introduction

Snacks are widely consumed in the whole world and the annual market growth is expected to be 5.58% from 2022 to 2027 [1]. In Brazil, the market grew 7.2% in production and 19.8% in value in the last year from October 2020 to September 2021 [2]. Expanded snacks are consumed by both men and women, especially young people up to 15 years old, and approximately 60% of consumers are in the habit of consuming corn snacks at least once a week, the main reason being liking for this type of product [3].

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Expanded snacks are obtained by thermoplastic extrusion, a process that consists of mixing raw materials and cooking them at high pressure, temperature and shear force in a barrel and forcing them through a die, when the superheated water evaporates, resulting in an expanded product with low moisture content [4]. Among all the characteristics typical of these products, the texture is a critical attribute for their quality. Thus, considering the importance of expanded snacks in the food market, the study of the texture of these products is relevant to provide information regarding quality and consumer acceptance.

The texture of a food can be evaluated through instrumental and sensory methods. Instrumental methods can assess texture directly through fundamental, empirical and imitative methods [5], or indirectly through chemical, optical and acoustic methods. Imitative methods are the most used, because they mimic chewing conditions and have an excellent correlation with sensory texture evaluations [6, 7], the texture analyzer being the main representative of these methods. Regarding sensory evaluation of texture, the texture profile, that is a descriptive method, was developed in the early sixties [8] specifically to correlate with the texture analyzer, although a wide variety of sensory tests are used today to evaluate food texture, using discriminative, affective and descriptive methods. Nevertheless, rather than just using instrumental and sensory methods for evaluating texture, establishing correlations between both is fundamental for predicting consumer responses, such as the acceptance of a new product, for improving or optimizing instrumental methods to complement the sensory evaluation of texture and for finding instruments to measure food quality control in the industry [9].

Concerning expanded snacks, the correlation between the instrumental and sensory texture profile was investigated to identify which tests and probes were more similar to human chewing [10]. In that study, the authors found strong correlations between the fracturability intensity and the peak force obtained by the Blade set probe with guillotine, and between the intensities of hardness and adhesiveness and the peak force obtained by the Blade set probe with V-cut. However, the sensory acceptance was not evaluated. Moreover, a question could be raised if the correlations found would be improved with the use of artificial saliva during the instrumental analysis, considering that the texture analyzer has a limitation in simulating some conditions of the oral cavity, such as temperature and moisture incorporation due to the secretion of human saliva.

In a previous study [11], the instrumental analysis of the texture of different shapes and samples of expanded snacks was performed using different probes and different treatments (without artificial saliva, with application of artificial saliva and with immersion in artificial saliva) and the use of artificial saliva influenced the force and acoustic properties measured by the different probes. Therefore, it seemed relevant to continue investigating whether artificial saliva also influences correlations between the instrumental and sensory evaluations of texture. Therefore, this Part II of the study aimed to evaluate the texture sensory profile and texture acceptance of the expanded snacks by investigating correlations between sensory results with those obtained through the instrumental analysis when using artificial saliva [11].

Materials and methods

Materials

Five shapes of expanded snacks (shell-shaped, cylindrical, ring-shaped, pelleted and ball-shaped) from three different brands were used. However, none of the three brands had all the shapes; thus, the study was carried out with 13 samples [11]. Moreover, the 13 samples are referred to, from now on, using the shape and the number related to the brand, such as Shell 1, Shell 2 and Shell 3, and so on for the other shapes.

For the preparation of artificial saliva, the following brand reagents (Sigma-Aldrich, Saint Louis, USA) were used: sodium bicarbonate ($NaHCO_3$), dibasic potassium phosphate (trihydrate) ($K_2HPO_4.3H_2O$), sodium chloride (NaCl), potassium chloride (KCl), calcium chloride dihydrate ($CaCl_2.2H_2O$), sodium azide (NaN_3), mucin and alpha-amylase. The artificial saliva was prepared according to Menis-Henrique et al. [12], adapted from van Ruth et al. [13], Friel and Taylor [14] and Muñoz-González et al. [15].

Sensory analysis of the expanded snacks

This study was approved by the Research Ethics Committee of the Institute of Biosciences, Humanities and Exact Sciences, São Paulo State University (Decision No. 2.080.650) and written informed consent was obtained from all participants in the study.

A sensory texture profile was performed following the method described by Stone and Sidel [16] with adaptations. Twenty panelists were recruited from students and staff of the institute. Fourteen panelists were preselected through a difference-from-control test performed in three repetitions for the crispness of shell-shaped samples 1, 2 and 3, Shell 1 being randomly chosen as the control. Booths with red light were used to mask differences between samples. Panelists were preselected according to their discriminative ($p_{sample} \leq 0.30$) and reproducibility ($p_{repetition} > 0.05$) capacities.

The attributes used for describing the samples were those used by Paula and Conti-Silva [10] and the references used are shown in Supplementary Table 1. Each training session lasted for 30 min when the session was for an individual or from 60 to 90 min when in a group. At the training, panelists were instructed to analyze samples as they were, i.e., entire, with the exception of the ring-shaped, which should be broken in two parts in the most fragile area of the sample. Moreover, they were instructed to put the sample in the mouth in a horizontal position, with the concavity upwards in the case of shell-shaped and pelleted. All panelists were selected according to their discriminative capacity ($p_{sample} \leq 0.30$), reproducibility capacity ($p_{repetition} > 0.05$) and capacity for consensus with the group (Pearson's correlation coefficient ≥ 0.70, $p \leq 0.05$). The sensory panel was composed of individuals aged from 18 to 30 years, 64% female, that like expanded snacks very much (79%) and consume these products at least once a week (43%). The final analysis of the sensory profile of texture was performed in individual booths, under white light, at a room temperature of 22 °C. For this, the quantities of each snack were standardized to be provided to panelists, such as two units of cylindrical, ring-shaped and pelleted snacks and four units of shell-shaped and ball-shaped snacks. The thirteen expanded snacks were monadically presented in plastic cups coded with three-digit random numbers. The samples were evaluated in three repetitions by 14 panelists using an unstructured linear intensity scale of 9-cm length for each attribute. A maximum of seven samples were evaluated per session to reduce sensory and mental fatigue. A glass of water at room temperature was served to panelists to drink between samples.

The sensory acceptance test was performed considering all the attributes used for describing the sensory profile of the expanded snacks, completing an evaluation form developed for use by the consumers (Fig. 1) and a 9-point structured hedonic scale [17]. Eighty-nine consumers, aged 18–40 years, were recruited from students and staff at the institute. The consumer panel was composed of 70% female, that like expanded snacks very much (75%) and consume these products at least once a week (43%). The analysis was carried out in individual booths, under white light, at a room temperature of 22 °C. Consumers received the 13 samples (in the same quantities described for the sensory profile) in plastic cups coded with three-digit random numbers and a glass of water at room temperature to rinse the palate in between sample testing. Samples were presented in monadic manner and evaluated in two sessions (one session with seven samples and another one with six) to reduce sensory and mental fatigue.

For all sensory analyses, samples were randomized following a Williams Latin Square design and using the FIZZ Sensory Analysis version 2.50 program (Biosystemes, Couternon, France).

Texture instrumental analysis of the expanded snacks

The expanded snacks were analyzed using the TA.XT/Plus/50 texture analyzer (Stable Micro Systems, Godalming, UK) and the Texture Exponent 32 software (Stable Micro Systems, Godalming, UK): (i) without artificial saliva, (ii) with application of 1.1 mL of artificial saliva and (iii) with immersion of the sample in the artificial saliva. The tests applied were those previously presented by Guazi and Conti [11], and the results are not presented in this paper.

Statistical analysis

The means obtained for the descriptive sensory analysis were compared using two-way analysis of variance having panelist and sample as factors, as well as the interaction between these factors. The means of sensory acceptance were analyzed through two-way analysis of variance, considering consumer and sample as sources of variation. Both analyses were followed by the Tukey test and all tests were performed using a significance level of 0.05. Moreover, results from the descriptive and acceptance analyses were correlated using principal component analysis, in which variables were put in columns and samples in rows. The column data were standardized before the analysis and factors were extracted from the correlation matrix.

Pearson's correlation analysis was performed using the data from the sensory (descriptive and acceptance) and instrumental analyses. Strong correlations were considered

Fig. 1 Form used for evaluation of the sensory acceptance of the texture of the expanded snacks

Name: ______________________________ **SAMPLE N^{O}:** __________

Please, read carefully the evaluation form below, following the instructions.

You are receiving a sample of an expanded snack. Bite this sample using your **front teeth** (incisor teeth) and notice if the sample breaks slowly or at once. Indicate, using the scale below, how much you like or dislike this break: ______

9 - Liked extremely
8 - Liked very much
7 - Liked moderately
6 - Liked slightly
5 - Neither liked nor disliked
4 - Disliked slightly
3 - Disliked moderately
2 - Disliked very much
1 - Disliked extremely

Taste the sample again only using the **teeth at the bottom** of your mouth (molar teeth) and indicate how much you like or dislike the following characteristics below, using the same scale above:

- how hard the sample is for you to chew it: ______
- intensity of the noise that the sample makes when chewed: ______
- how much you need to chew it until you can swallow it: ______
- how much the sample sticks to your teeth: ______
- how much you like the texture of this sample in general: ______

Obs. ____

when the correlation coefficient was ≥ 0.70 or ≤ − 0.70 at a significance level of 0.05.

The principal component analysis was performed using the Statistica software version 12.0 (StatSoft Inc., Oklahoma, USA), while the other analyses were performed using the IBM SPSS Statistics for Windows version 24.0 software (IBM Corp., Armonk, USA).

Results and discussion

Sensory characteristics of texture

The trained sensory panel discriminated samples regarding all texture attributes (Table 1), with discrimination ranging from five levels (hardness) to seven levels (fracturability, crispness and adhesiveness). Cylindrical and ball-shaped snacks generally had some of the highest intensities of fracturability, hardness and adhesiveness. Similar results were observed by Paula and Conti-Silva [10] for cylindrical snacks. Snacks in cylindrical and ball shapes are obtained using a circular die at the end of the extruder, and differences in shape result from the cutting speed of extrudates, i.e., ball-shaped snacks are obtained when cutting speed is higher against lower cutting speed to obtain cylindrical products and this probably explains the similar results for these two shapes.

Shell-shaped snacks had one of the lowest levels of fracturability, while pellets, as well as having one of the lowest levels of fracturability, had the lowest adhesiveness. Snacks with a pellet shape are extruded and then fried [18], as well as being produced especially with wheat flour by contrast to the other format that are produced mainly with corn flours. Such differences result in different textures for the pelleted snacks. Ring-shaped snacks had intermediate or similar intensities in relation to the other shapes.

Shell-shaped 3, Cylindrical 3, Ring-shaped 3 and Ball-shaped 3, which are produced by the same company, were generally characterized by lower intensities of fracturability, hardness, crispness and chewiness, in addition to high adhesiveness. Probably, differences in the extruder configuration and extrusion conditions used by Company 3 have an influence on these results.

The degree of liking of the expanded snacks ranged from 4.4 (from 'disliked slightly' to 'neither liked nor disliked') for adhesiveness of Ball-shaped 3–8.2 (from 'liked very much' to 'liked extremely') for fracturability and overall texture of Ring 1 (Table 2). Statistical discrimination of samples was low and samples were better discriminated by the degree of liking of adhesiveness and overall texture, which will be discussed shortly. Moreover, snacks from Brand 3 had lower degree of liking compared to snacks from Brands 1 and 2, with the exception of Pelleted 3, which was as well accepted as Pelleted 1. Regarding other samples, all had good sensory acceptance in relation to texture.

Correlations between the sensory profile and degree of liking of snacks are relevant to understand descriptive drivers to the acceptance of such products. Thus, principal component analysis was used and it explained 95.4% of the total data variation (Fig. 2). Principal component 1 (Fig. 2A) was explained by the intensities of hardness, crispness and chewiness and by all acceptance variables (factorial charges ≤ − 0.7 in Principal component 1), which are positively correlated with each other but negatively correlated with the intensity of adhesiveness (factorial charge ≥ 0.70 in Principal component 1). Principal component 2 was described only by the intensity of fracturability (factorial charge ≥ 0.70 in Principal component 2). Regarding samples,

Table 1 Mean intensity of the sensory attributes of the expanded snacks with a trained panel, using 9-cm scale (mean ± standard deviation, n = 14 panelists × 3 repetitions)

Snack	Fracturability	Hardness	Crispness	Chewiness	Adhesiveness
Shell 1	$1.4^{ab} \pm 0.9$	$3.2^{bc} \pm 1.9$	$4.1^{cde} \pm 1.6$	$3.1^{b} \pm 1.4$	$3.2^{b} \pm 1.2$
Shell 2	$1.4^{ab} \pm 0.7$	$2.8^{b} \pm 1.5$	$4.3^{def} \pm 1.4$	$3.0^{b} \pm 1.3$	$3.2^{b} \pm 1.2$
Shell 3	$1.2^{a} \pm 0.8$	$0.7^{a} \pm 0.5$	$1.1^{a} \pm 0.9$	$0.9^{a} \pm 0.7$	$5.5^{e} \pm 1.9$
Cylinder 1	$6.9^{g} \pm 0.8$	$5.3^{d} \pm 1.6$	$4.7^{efg} \pm 1.7$	$6.0^{ef} \pm 1.3$	$4.8^{cd} \pm 1.2$
Cylinder 2	$6.8^{g} \pm 0.9$	$6.0^{e} \pm 1.0$	$4.9^{fg} \pm 1.4$	$5.6^{def} \pm 1.3$	$5.3^{de} \pm 1.1$
Cylinder 3	$5.1^{f} \pm 1.4$	$1.1^{a} \pm 0.8$	$1.4^{ab} \pm 0.9$	$1.0^{a} \pm 0.8$	$7.4^{g} \pm 0.9$
Ring 1	$2.4^{d} \pm 1.1$	$3.8^{c} \pm 1.5$	$5.1^{g} \pm 1.1$	$6.2^{f} \pm 1.2$	$3.6^{b} \pm 1.1$
Ring 2	$3.0^{e} \pm 1.3$	$3.4^{bc} \pm 1.8$	$4.4^{def} \pm 1.3$	$5.4^{de} \pm 1.2$	$4.6^{c} \pm 1.1$
Ring 3	$3.4^{e} \pm 1.8$	$1.3^{a} \pm 0.9$	$2.0^{b} \pm 1.0$	$2.4^{b} \pm 1.6$	$6.6^{f} \pm 1.6$
Pellet 1	$1.8^{bc} \pm 0.9$	$3.0^{b} \pm 1.9$	$4.0^{cd} \pm 1.6$	$5.2^{d} \pm 1.2$	$1.3^{a} \pm 0.7$
Pellet 3	$2.0^{cd} \pm 0.9$	$3.1^{bc} \pm 2.1$	$4.5^{defg} \pm 1.7$	$5.4^{de} \pm 1.2$	$1.4^{a} \pm 0.9$
Ball 2	$6.9^{g} \pm 0.9$	$3.3^{bc} \pm 1.8$	$3.6^{c} \pm 1.3$	$3.8^{c} \pm 1.2$	$5.0^{cde} \pm 1.2$
Ball 3	$5.2^{f} \pm 1.5$	$0.7^{a} \pm 0.6$	$1.1^{a} \pm 1.1$	$0.6^{a} \pm 0.5$	$8.0^{g} \pm 0.8$

Snacks identified with the same number are from the same brand. Different letters in the same column indicate statistically different means by the Tukey test ($p \leq 0.05$)

Table 2 Mean degree of liking of the expanded snacks, with a consumer panel, using a 9-point hedonic scale (mean ± standard deviation, $n = 89$)

Snack	Fracturability	Hardness	Crispness	Chewiness	Adhesiveness	Overall texture
Shell 1	$7.4^{bc} \pm 1.5$	$7.3^{bc} \pm 1.5$	$7.6^{bc} \pm 1.3$	$7.3^{bcd} \pm 1.5$	$6.7^{d} \pm 1.8$	$7.6^{cdef} \pm 1.3$
Shell 2	$7.2^{b} \pm 1.5$	$7.2^{bc} \pm 1.6$	$7.4^{bc} \pm 1.2$	$7.2^{bcd} \pm 1.3$	$6.6^{d} \pm 1.7$	$7.2^{bcd} \pm 1.4$
Shell 3	$5.4^{a} \pm 2.1$	$5.8^{a} \pm 2.2$	$5.7^{a} \pm 2.3$	$6.2^{a} \pm 1.8$	$5.7^{c} \pm 1.9$	$5.6^{a} \pm 1.9$
Cylinder 1	$8.1^{cd} \pm 1.0$	$7.8^{c} \pm 1.3$	$8.0^{c} \pm 1.1$	$7.5^{bcd} \pm 1.3$	$6.6^{d} \pm 1.8$	$7.8^{def} \pm 1.2$
Cylinder 2	$7.4^{bc} \pm 1.4$	$7.0^{b} \pm 1.5$	$7.4^{bc} \pm 1.3$	$7.0^{bc} \pm 1.5$	$5.6^{bc} \pm 1.8$	$7.1^{bc} \pm 1.3$
Cylinder 3	$5.7^{a} \pm 1.8$	$5.9^{a} \pm 2.2$	$6.0^{a} \pm 1.9$	$5.8^{a} \pm 2.0$	$4.9^{ab} \pm 2.1$	$5.4^{a} \pm 1.9$
Ring 1	$8.2^{d} \pm 1.1$	$7.7^{bc} \pm 1.4$	$7.8^{bc} \pm 1.4$	$7.7^{d} \pm 1.4$	$7.3^{de} \pm 1.5$	$8.2^{f} \pm 0.9$
Ring 2	$7.5^{bc} \pm 1.4$	$7.4^{bc} \pm 1.3$	$7.5^{bc} \pm 1.3$	$7.4^{bcd} \pm 1.3$	$6.7^{d} \pm 1.7$	$7.4^{bcde} \pm 1.2$
Ring 3	$5.7^{a} \pm 2.0$	$5.6^{a} \pm 2.2$	$5.8^{a} \pm 2.0$	$5.7^{a} \pm 2.1$	$4.6^{a} \pm 2.0$	$5.2^{a} \pm 2.0$
Pellet 1	$7.8^{bcd} \pm 1.4$	$7.8^{c} \pm 1.3$	$7.7^{bc} \pm 1.4$	$7.7^{cd} \pm 1.2$	$7.9^{e} \pm 1.6$	$8.0^{ef} \pm 1.1$
Pellet 3	$7.8^{bcd} \pm 1.4$	$7.6^{bc} \pm 1.3$	$7.8^{bc} \pm 1.3$	$7.7^{d} \pm 1.2$	$7.8^{e} \pm 1.4$	$7.9^{ef} \pm 1.1$
Ball 2	$7.4^{b} \pm 1.4$	$7.1^{bc} \pm 1.6$	$7.2^{b} \pm 1.5$	$6.9^{b} \pm 1.7$	$5.5^{bc} \pm 1.9$	$6.9^{b} \pm 1.5$
Ball 3	$5.9^{a} \pm 2.3$	$5.9^{a} \pm 2.3$	$5.7^{a} \pm 2.2$	$6.0^{a} \pm 2.1$	$4.4^{a} \pm 2.3$	$5.3^{a} \pm 2.1$

Snacks identified with the same number are from the same brand. Different letters in the same column indicate statistically different means by the Tukey test ($p \leq 0.05$)

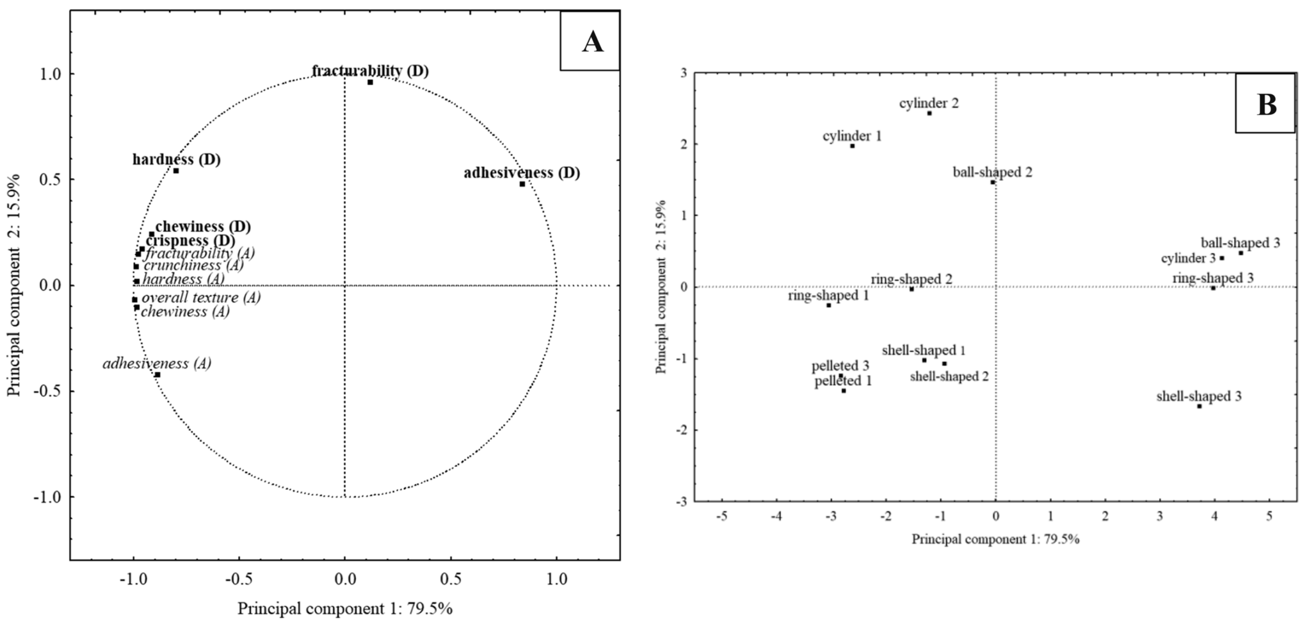

Fig. 2 Correlations between the sensory profile and degree of liking of texture of the expanded snacks. Legend: **A** projection of variables, which (D) in bold means descriptive and (A) in italics means acceptance; **B** projection of samples. Snacks identified with the same number are from the same brand

samples from Brand 3, except for Pelleted 3, are highlighted by a low degree of liking resulting from the high intensity of adhesiveness and low intensities of hardness, crispness and chewiness (Fig. 2B).

Indeed, some consumers pointed out that these samples were not very crunchy, were soft, stuck/adhered to the teeth, appeared to be 'wilted' and fell apart in the mouth instead of being crunchy. They also highlighted that Shell-shaped 3 had a Styrofoam texture and was easy to chew, but they had the feeling that the sample was 'old'. These reports highlight the importance of crispness of snacks for sensory acceptance and, also, of an adequate hardness and chewiness, because a 'hard' (to some extent) and more chewable snack leads to a greater number of chewing cycles, increasing the appreciation of texture. Similar results were found for breakfast cereals obtained through thermoplastic extrusion [19], because the greater the intensity of adhesiveness, the lower the hardness, the crispness and the chewiness. The intensity of adhesiveness was the most critical attribute for the acceptance of breakfast cereals after milk was added. Such comments reiterate the importance of desirable texture parameters of a snack in the conception of consumers, highlighting that expanded snacks with high adhesiveness are less accepted by consumers.

Correlations between sensory characteristics and instrumental properties of the expanded snacks

Cylindrical probe

Using the cylindrical probe, a larger number of strong correlations were obtained when artificial saliva was not used (Supplementary Table 2). The intensity of fracturability was correlated with the number of force peaks and number of acoustic peaks when saliva was not used. After immersion in saliva, the correlation was only maintained for the number of force peaks. The loss of correlation for the intensity of fracturability when saliva was used makes sense, since sensory fracturability is defined as the 'ability of food to break into micropieces when bitten with the incisor teeth' (Supplementary Table 1), i.e., the food is not moistened with human saliva to measure fracturability. Nevertheless, the correlation between fracturability intensity and the number of force peaks remained when the sample was immersed in saliva, which may have occurred, because the samples were only moistened on the surface, with the saliva not reaching its interior. By contrast, correlations were found for hardness only when saliva was used, either through application or immersion. In other studies, strong correlation (≥ 0.70 or ≤ -0.70) was not found between the intensity of hardness and the cylindrical probe for expanded snacks without saliva [10] and for boiled Andean tubers [20], although strong positive correlation ($r = 0.76$) was found for French fries [21].

For acceptance, there was a negative correlation between the sound pressure level and the acceptance without artificial saliva, i.e., the higher the intensity of the sound measured instrumentally, the lower the acceptance of the texture. Dias-Faceto and Conti-Silva [19] reported that high intensities of crispness of some kinds of breakfast cereals, measured sensorially, led to a lower acceptance of hardness, crispness and chewiness of the products. The application of saliva eliminated the correlation for the intensity of adhesiveness and for the acceptance of texture of the expanded snacks in terms of chewiness, adhesiveness and overall acceptance.

Note, it is not always possible to visualize in practice a given correlation, as is the case of the positive correlation between the intensity of adhesiveness and the number of acoustic peaks without saliva. It is expected that the greater the intensity of adhesiveness of a snack, the more shriveled it is, thus being less crispy, resulting in lower numbers of acoustic peaks. Thus, the correlation between these two variables would be negative, not positive, as is observed in the present study. However, this positive correlation between the intensity of adhesiveness and the number of acoustic peaks appears for other probes as well (Supplementary Tables 3, 7 and 8), which is quite intriguing. Adhesiveness is a sensory attribute perceived throughout human chewing, while the number of acoustic peaks basically refers to the beginning of compression/cutting/extrusion/shearing of the sample when evaluated by the texture analyzer. Thus, it is possible that the positive correlation observed between the intensity of adhesiveness and the number of peaks of force appears, because the adhesiveness is a secondary variable in this relationship, i.e., even if the sample is hard and crispy at the first bite, it can be adhesive throughout its chewing. This relationship should be better studied in the future.

Blade set guillotine probe

Using the blade set guillotine probe, a larger number of strong correlations were obtained when artificial saliva was not used (Supplementary Table 3). Nevertheless, with the use of artificial saliva, regardless of the treatment (application or immersion), there were new correlations for intensities of fracturability and crispness. Simultaneously, the correlation for the intensity of adhesiveness was eliminated.

Adhesiveness measured instrumentally was negatively correlated with intensities of crispness (immersion of samples in the artificial saliva) and chewiness (for both treatments with artificial saliva). Instrumental adhesiveness is detected by the texture analyzer when the probe returns to its original position at the start of the test. Thus, samples that adhere to the probe, making it difficult to return to the original position or imposing a force to detach themselves from the probe during return, result in a negative area plotted on the graph, which is identified as instrumental adhesiveness. Thus, the greater the instrumental adhesiveness of the samples, the less chewable they would be, as they would adhere more to the teeth and would require fewer chewing cycles to be swallowed, explaining the negative correlation between these two variables. At the same time, samples that are less crispy are more shriveled, adhering more to the teeth. This relationship can be seen in Fig. 2.

A strong positive correlation ($r = 0.687$) between hardness intensity and the highest force peak obtained from the Blade set guillotine probe was also reported by Paula and Conti-Silva [10] for expanded snacks without artificial saliva. Moreover, multiple factor analysis showed a strong positive correlation between hardness intensity and the average of maximum force for breakfast cereals without milk [19], similar to results in the present study. When a cut (shear) test was applied to cereal bars, strong correlations with some sensory texture attributes (firmness, chewiness and crumbliness) were found [22]. Nevertheless, Li et al. [21] did not find strong correlations between results from the Blade set guillotine probe and the sensory texture of French fries.

Blade set V-cut probe

By contrast to the previous probes, especially the Blade set guillotine probe that also performs a cutting test, the use of the Blade set V-cut probe, in both treatments with saliva, generated strong correlations with the intensity of hardness (Supplementary Table 4). Nevertheless, the use of artificial saliva eliminated correlations with the intensity of fracturability, which makes sense, as explained in the section "Cylindrical probe", since sensory fracturability is not moistened with human saliva during analysis.

Paula and Conti-Silva [10] found strong positive correlations between intensities of hardness ($r=0.718$) and adhesiveness ($r=0.763$) with the highest peak force using the Blade set V-cut probe without saliva, a result different from the present study. Nevertheless, in that study, the authors only used shell, cylindrical, ring and pelleted snacks, while in the present study, the ball was included. Performing correlation analyses excluding the ball samples, a strong correlation was also found between the hardness and the highest peak force ($r=0.788$), although not to adhesiveness intensity.

Three-point bending probe

Using the three-point bending probe, the number of correlations obtained with the use of artificial saliva (application and immersion) was notably increased compared to the non-use of artificial saliva (Supplementary Table 5), resulting in new strong correlations for intensities of crispness, chewiness and adhesiveness, as well as for the attributes of sensory acceptance. Still, the three-point bending was the only probe whose correlations for fracturability intensity were maintained when using both treatments of artificial saliva. Moreover, strong negative correlations found between instrumental adhesiveness and sensory acceptance of attributes strengthen the results given in the section "Sensory characteristics of texture", which show that expanded snacks with high adhesiveness are less accepted by consumers. Thus, the adhesiveness, both described sensorially and measured instrumentally using the three-point bending probe, reveals crucial information for the sensory acceptance of the expanded snacks.

The three-point bending probe performs a cutting test like both Blade sets. Nevertheless, the greater number of correlations obtained by this probe, especially with the sensory acceptance, is intriguing. This could be due to the probe set used. The three-point bending probe has a 6.35 mm-thick blade that passes through an 8 mm opening, while the Blade set guillotine and V-cut probes have blades with 3.01 and 2.96 mm, respectively, that pass through a 3.55 mm opening. Moreover, while the base of Blade sets is straight down, the three-point bending base is open at the sides, which may allow movement of the sample during the cutting test (please check Fig. 2b, c and d in [11]). Thus, all of these differences in the probe conformation may be responsible for differences in the results, the three-point bending probe being more efficient in simulating the chewing conditions in the case of the expanded snacks.

Li et al. [21] used the three-point bending probe to correlate the sensory texture of French fries; however, no strong correlation was found. On the contrary, this probe resulted in strong correlations of some texture attributes measured sensorially, such as the adhesiveness, sample recovery (the distance the sample recovers after 10 s) and return time for springiness (the amount of time necessary for the sample to recover) of cereal bars [22].

Ottawa 3 mm and 17-blade probes

The Ottawa probe is used to perform an extrusion test, because the square probe forces the sample to pass through the base with blades. It is especially used to evaluate more than one unit of a sample, because it simulates the chewing of more than one unit at the same time. Nevertheless, only one unit was evaluated in the present study due to the application of 1.1 mL of artificial saliva, which was concentrated on only one unit. Moreover, as described in Part 1 of this study [11], this probe is box-shaped, and the upper part of the probe needs to be completely lifted to put the sample inside and then lowered down to perform the analysis.

For the Ottawa probe with both bases (3 mm and 17 blades), both treatments with artificial saliva (application and immersion) resulted in a larger number of strong correlations compared to no use of saliva (Supplementary Tables 6 and 7), especially the Ottawa 17-blade probe. For both bases and using artificial saliva, strong correlations appeared for intensities of hardness and crispness, although the correlation for fracturability intensity was eliminated. Moreover, the Ottawa probe with either base was the only one that resulted in strong correlation, in this case positive, between the crispness intensity and sound pressure level, but only with artificial saliva, which means that the greater the intensity and duration of the sound produced when these foods are broken through the instrumental test, the greater is the crispness perceived sensorially. These correlations with crispness intensity are notable, because they are intriguing. In Part 1 of this study [11], our research group discussed some points related to tests with the Ottawa probes. Considering that this probe is box-shaped and the analysis takes longer to be performed due to its configuration, this would theoretically be harmful when samples are being analyzed using saliva, as the tests are not carried out immediately after contact with the saliva and the sample already starts to disintegrate. Although some apparent disadvantage, strong correlations were found not only for the crispness intensity but also for other variables.

Additionally, the 17-blade base also resulted in strong positive correlations to the adhesiveness intensity (without saliva and with immersion in saliva). Moreover, the importance of the instrumental adhesiveness to sensory acceptance (chewiness and overall) of expanded snacks is shown again through strong negative correlations.

When comparing the quantities of samples used during the instrumental analysis, Dias-Faceto and Conti-Silva [19] evaluated the texture of breakfast cereals using this probe with both bases and four or five samples depending on the product shape, and they found strong correlations with sensory texture. Nevertheless, as described previously, in the present study, the use of more than one unit was not possible due to the application of 1.1 mL of artificial saliva, which was concentrated on only one unit. Even so, a large number of correlations were found with the sensory texture, showing that it is feasible to use only one unit of expanded snack sample during the instrumental analysis with this probe.

Kramer probe

When the Kramer probe was used, both treatments with artificial saliva (application and immersion) resulted in strong positive correlations with the hardness intensity, although it eliminated correlations to intensities of fracturability and adhesiveness. Paula and Conti-Silva [10] did not find any correlation for expanded snacks when this probe was used. Maybe, the inclusion of ball-shaped snacks, as explained in the section "Blade set V-cut probe", has contributed to the correlations found in the present study. Nevertheless, the Kramer probe was the probe that stood out as having strong correlations with the sensory texture of breakfast cereals [19].

As explained in the section "Ottawa 3 mm and 17-blade probes" about the Ottawa probes, the Kramer probe is also especially used to evaluate more than one unit of a sample once it simulates the chewing of more than one unit at the same time. Even though, in the present study, only one unit of sample was evaluated at each time, a large number of correlations were found with sensory texture, again showing that it is feasible to use only one unit of expanded snack sample during the instrumental analysis with this probe.

General evaluation of correlations

Supplementary Tables 2, 3, 4, 5, 6, 7, 8 show that the use of artificial saliva changed correlations between the instrumental and sensory analyses of texture. Generally, the use of saliva resulted in a loss of correlation for fracturability intensity. Thus, it is better to perform the instrumental analysis without artificial saliva to obtain information about the sensory fracturability. Regarding the comparison between the treatments used (application of artificial saliva and immersion in artificial saliva), both showed similar results in terms of the number of correlations obtained, although each treatment stood out for a certain probe, such as the application of artificial saliva and the three-point bending probe, or immersion in artificial saliva and the Ottawa probe with a 17-blade base. In terms of mechanical properties, the correlations obtained in the two treatments were also similar comparing the correlations between the same sensory attribute and the same instrumental property. Furthermore, the correlations were always in the same direction for both treatments, i.e., always positive or negative. However, each way of using artificial saliva presented certain difficulties or disadvantages, which were discussed previously by Guazi and Conti [11].

Considering that both treatments with artificial saliva had similar effects on the correlations with the sensory texture, the desired sensory attribute to be investigated will define the choice of instrumental conditions to be used, i.e., what probe to use, using or not artificial saliva and how to use the artificial saliva. Because of this, Table 3 presents, by sensory attribute, a summary of the most relevant correlations for helping drive choices. The treatment and probes that showed the highest number of correlations for each sensory attribute were included in the table. When the correlations obtained with the use of saliva were equal (application or immersion), the correlation with immersion in saliva was chosen, because it was the treatment with the best performance, as described by Guazi and Conti [11].

Conclusions

The expanded snacks had good sensory acceptance in relation to the texture, and the high intensity of adhesiveness was responsible for low acceptance of products, indicating that this attribute is a critical determining factor for the acceptance of the overall texture of expanded snacks. The use of artificial saliva changed correlations between instrumental and sensory analyses for all probes. When artificial saliva was not used, correlations to the fracturability intensity were more frequent and highlighted. Nevertheless, when artificial saliva was used, strong correlations were obtained for the intensities of hardness, crispness, chewiness and adhesiveness. Correlations to sensory acceptance were found when the cylindrical probe (without saliva), three-point bending probe and Ottawa probe with 17 blades, both used with artificial saliva were used. The three-point bending probe and the Ottawa probe with 17 blades both notably increased the number of correlations

Table 3 Summary of the relevant correlations (≥ 0.70 or ≤ − 0.70 at a significance level of 0.05) obtained between sensory and instrumental texture analysis (Texture Analyzer), indicating the most suitable probes to be used for each sensory attribute

Sensory attribute		Treatment	Probe	Instrumental variable (correlation type)
Descriptive	Fracturability	Without saliva	Blade set V-cut	HFP and AMF (positive)
			Cylindrical, Ottawa (both bases) and Kramer	NFP and NAP (positive)
	Hardness	Without saliva	Blade set guillotine and three-point bending	HFP and AMF (positive)
		Application of saliva	Three-point bending	HFP, NFP and AMF (positive); ADE (negative)
		Immersion in saliva	Blade set V-cut	HFP, NFP, AMF and NAP (positive)
		Application of saliva	Ottawa 3 mm	HFP, NFP, AMF, NAP and SPL (positive)
		Immersion in saliva	Ottawa 17 blades	HFP, NFP, AMF, NAP and SPL (positive)
		Immersion in saliva	Kramer	HFP, AMF, ADE and NAP (positive)
	Crispness	Immersion in saliva	Three-point bending	HFP and AMF (positive); ADE (negative)
			Ottawa 3 mm	SPL (positive)
			Ottawa 17 blades	ADE (negative) and SPL (positive)
	Chewiness	Immersion in saliva	Blade set guillotine and three-point bending	ADE (negative)
			Ottawa 17 blades	
	Adhesiveness	Application of saliva	Three-point bending	ADE (positive)
		Immersion in saliva	Ottawa 17 blades	
Degree of liking	Chewiness, adhesiveness and overall texture	Without saliva	Cylindrical	NAP and SPL (negative)
	All attributes	Application of saliva	Three-point bending	ADE (negative)
	Chewiness and overall texture	Immersion in saliva	Ottawa 17 blades	ADE (negative)

HFP highest force peak, *NFP* number of force peaks, *AMF* average maximum force, *ADE* instrumental adhesiveness, *NAP* number of acoustic peaks, *SPL* sound pressure level

between sensory and instrumental results when used with artificial saliva. In conclusion, this study shows that artificial saliva contributes to correlations between sensory and instrumental analyses and that, for each desired sensory attribute, whether descriptive or affective (acceptance), there is a good probe and artificial saliva combination to be used. In other words, the choice of instrumental conditions to be used will depend on the sensory attribute being investigated.

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Data availability The data that support the findings of this study are available from the corresponding author upon request.

Declarations

Conflict of interest The authors declare no conflict of interest.

Compliance with ethics requirements This study was approved by the Research Ethics Committee of the Institute of Biosciences, Humanities and Exact Sciences, São Paulo State University (Decision No. 2.080.650).

Informed consent Written informed consent was obtained from all participants in the study.

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