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Accepted Manuscript

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PII: S0023-6438(19)30063-5
DOI: https://doi.org/10.1016/j.lwt.2019.01.052
Reference: YFSTL 7794

To appear in: *LWT - Food Science and Technology*

Received Date: 20 September 2018
Revised Date: 25 January 2019
Accepted Date: 27 January 2019

Cheese-flavored expanded snacks with low lipid content: oil effects on the *in vitro* release of butyric acid and on the duration of the dominant sensations of the products

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Abstract

With the aim of producing snacks with reduced lipid content, the effect of lipids on the *in vitro* release of butyric acid and on the duration of the dominant sensations of cheese-flavored expanded snacks were investigated. For that, snacks were obtained through pre-extrusion addition of aroma precursors of cheese to corn grits (butyric acid and cysteine) and sprinkled with sunflower oil in different proportions (6, 12, 18 and 24 g/100 g). The snack sprinkled with 6 g/100 g of sunflower oil showed higher release of butyric acid, compared to the other snacks with oil, when a chewing simulator was employed (simulation of aroma perception), and practically the same release in relation to the other snacks when the dynamic headspace of products was obtained (i.e. simulation of odor perception). All snacks with sunflower oil were described by the duration of salty taste, crunchy/crisp, cheese flavor, umami taste and oil flavor, indicating that the low use of sunflower oil (6 g/100 g) did not alter or prejudice the dominant sensations of the snacks. Therefore, the production of snacks with low addition of lipids is feasible, improving the nutritive value of these products that are so criticized because of the high lipid content.

Keywords: aroma precursors, thermoplastic extrusion, chewing simulator, Temporal Dominance of Sensations (TDS).

1. Introduction

Expanded snacks are widely consumed around the world and are obtained through a thermoplastic extrusion process. After extrusion, the snacks are flavored in the conventional way by food industries (post-extrusion flavoring), when a mixture of a lipid vehicle (oil or hydrogenated vegetal fat), salt and additives (commercial aroma and flavor enhancers) is sprinkled on the snacks (Maskan & Altan, 2012). This flavoring process increases the lipid and salt content in the snacks, as well the caloric value, reasons why these products are much criticized. Corn snacks marketed in Brazil presents total lipid content from 11 to 30 g/100 g and energy values from 408 to 500 kcal per 100 g product (values observed at labels). These values are similar to those presented in the Brazilian Table of Food Composition (Tabela Brasileira de Composição de Alimentos, 2018), in which commercial corn snacks have a lipid content from 15 to 35 g/100 g and an energy from 448 to 555 kcal per 100 g product. Healthier versions of this product may be obtained using pre-extrusion flavoring, by adding many types of flavoring agents to the raw material to be extruded (Bhandari, D'Arcy, & Young, 2001; Yuliani, Torley, D'Arcy, Nicholson, & Bhandari, 2006; Menis, Milani, Jordano, Boscolo, & Conti-Silva, 2013). With this technique of flavoring, the use of a lipid vehicle can be minimized. However, the suppression of lipids may compromise the sensory quality of the products because of the important contributions of lipids to the flavor of foods.

The flavor of a food is the manifestation of interactions between taste, aroma and oral sensations, since taste and oral sensations are associated with non-volatile compounds, while aroma is associated with volatile compounds. The release of volatile compounds from foods during chewing depends on their interaction with the food matrix and both static and dynamic factors are involved in this release. The static equilibrium of the volatile compounds is distributed in the food between the solid matrix, the hydrophilic liquid phase, the liquid lipophilic phase and the gas phase. This distribution is controlled by the partition coefficient of the molecules of the volatile compounds, which affects their volatility. In addition, the mass transfer (a dynamic factor) depends on the viscosity of the food matrix and its interfaces, in which more viscous products release the volatile compounds more slowly (Gaonkar & McPherson, 2006; Reineccius, 2006). In this way, lipids act as transporters and modulators of volatile compounds in food. Even in products with reduced lipid content, the release of volatile compounds can also be altered, negatively affecting the perception of the odor and aroma of foods and, consequently, the flavor (Taylor & Linforth, 2010; Voilley & Etiévant, 2006). Moreover, lipids have been investigated as the 6^{th} basic taste (Dramane, Akpona, Besnard, & Khan, 2014), given their importance to the flavor of food. The reduction in or even elimination of lipid content in food is still a challenge.

Therefore, with the aim of producing snacks with better nutritive value through reduction of lipids for flavoring, using the pre-extrusion flavoring method, butyric acid and cysteine were added as aroma precursors of cheese to corn grits (Martínez-Cuesta, Peláez, & Requena, 2013) and sunflower oil was sprinkled in different quantities onto the snacks. Butyric acid is a volatile compound that contributes to cheese odors, and considering that lipids influences odor, aroma and flavor of foods, the *in vitro* release of butyric acid was monitored in this work because of the different quantities of oil sprinkled onto the snacks. Moreover, techniques that allow a dynamic sensory evaluation of foods, such as the Temporal Dominance of Sensations (TDS), provide complete information about how dominant sensations vary during the consumption (Lawless & Heymann, 2010; Pineau et al., 2009). Thus, TDS is an interesting technique to be applied to snacks, both for providing information about dominant sensory sensations, which may be related to lipid content, and also because studies about the application of TDS to snacks were not found in the literature.

2. Material and Methods

2.1 Material

Corn grits (Capela do Alto, Brasil), salt (Cisne, Cabo Frio, Brasil), flavor enhancer monosodium glutamate (Ajinomoto, Limeira, Brasil) and sunflower oil (Liza, Mairinque, Brasil) were used to produce the expanded snacks. Food-grade butyric acid (Sigma-Aldrich, Milwaukee, USA, code W222119, purity >99 g/100 g) and amino acid cysteine (L-cysteine HCL anhydrous, Infinity Pharma, Campinas, Brazil, purity >98.5 g/100 g) were used as aroma precursors of cheese on the expanded snacks.

The reagents $NaHCO_3$, $K_2HPO_4 \cdot 3H_2O$, NaCl, KCl, $CaCl_2 \cdot 2H_2O$, NaN_3, bovine mucin (reference Sigma: M3895), and porcine alpha-amylase (reference Sigma: A4268), all from Sigma-Aldrich (Milwaukee, USA), were used for production of artificial saliva.

2.2 Preparation of corn grits and extrusion processing

Butyric acid and cysteine (addition of 0.4 g/100 g and 0.2 g/100 g, respectively) were added to corn grits (previously an adjusted to 15 g/100 g moisture content in dry basis). The addition of butyric acid (liquid compound) was performed in volume based on the density, i.e., the mass of butyric acid to be added to the corn grits was converted to volume using its density. The addition of cysteine (powder) was done in mass. The mixture of corn grits with butyric acid and cysteine was performed through manual agitation of the bags, which were sealed and kept under refrigeration for 24 h, for better distribution of butyric acid in the corn grits. Then, the mixture was kept at room temperature for 2 h before extrusion.

Corn grits with the aroma precursors added was extruded in an RXPQ Labor 24 single screw extruder (INBRAMAQ, Ribeirão Preto, Brazil) with five independent heating zones. Extrusion conditions were: helicoidally grooved barrel; screw with a compression ratio of 2.3:1 and length-to-diameter ratio of 15.5:1; pre-die extruder with holes of 3.01 mm; extruder die with a diameter of 2.93 mm (round hole); feed rate of 265 g/min; screw speed at 192 rpm;

temperatures in the zones 1 to 5: off (approximately 25 ºC), 70 ºC, 90 ºC, 120 °C and 120 ºC, respectively.

After extrusion, salt (1.4 g/100 g) and monosodium glutamate (0.6 g/100 g) were added to the snacks and then sunflower oil was sprinkled on the snacks in the proportions of 6, 12, 18, or 24 g/100 g. Two control snacks were produced under the same extrusion conditions: 1) a snack with salt and monosodium glutamate, but without aroma precursors and sunflower oil (control evaluated only through TDS), and 2) snack with aroma precursors, salt and monosodium glutamate, but without sunflower oil (0 g/100 g). The amounts of salt, monosodium glutamate and sunflower oil correspond to the addition of these ingredients in 100 g of snack.

2.3 Evaluation of butyric acid *in vitro* release from the expanded snacks

The butyric acid was added to corn grits as an aroma precursor of cheese in the expanded snacks, being a volatile compound that has an important contribution to the odor/aroma of cheese (Martínez-Cuesta, Peláez, & Requena, 2013). The *in vitro* release of butyric acid was monitored using a Proton Transfer Reaction Time-of-Flight Mass Spectrometer (PTR-ToF-MS) connected to two different devices: chewing simulator and valve system.

In the chewing simulator, the snacks were mixed with artificial saliva to reproduce mastication. In this way, this system may represent the release of butyric acid inside the mouth, i.e., retronasal olfaction. The valve system allows the evaluation of the dynamic headspace from the snack, representing orthonasal olfaction. Therefore, considering the operation of the two devices, and for better understanding of our results, the two evaluations of *in vitro* release were called *via* aroma (chewing simulator) and *via* odor (valve system), respectively.

2.3.1 Evaluation of *in vitro* release of butyric acid *via* aroma

The chewing simulator was developed with the aim of reproducing mastication and is composed of an active cell, where the mastication process is performed, an electronic control box and a computer to monitor and adjust each parameter (Salles et al., 2006; Salles, Tarrega, Mielle, Maratray, & Gorria, 2007). The active cell is formed by a mobile lower jaw, a mobile tongue, and a fixed upper jaw. The lower and upper jaws are ring-shaped cylinders composed only of molar teeth made of polyether ether ketone (PEEK), and the tongue is also made of PEEK, in the shape of a cylinder with a 4.5 cm diameter (Salles et al., 2007).

Artificial saliva used during the chewing simulation was prepared according to the protocol used by the Centre des sciences du goût et de l'alimentation at the Institut National de la Recherche Agronomique (CSGA/INRA), adapted from Friel and Taylor (2001), Munoz-González et al. (2014) and Ruth, Grossmann, Geary, and Delahunty (2001). The following materials were used: NaHCO (5.208 g), $K_2HPO_4.3H_2O$ (1.369 g), NaCl (0.877 g), KCl (0.477 g), $CaCl_2.2H_2O$ (0.441 g), NaN_3 (0.500 g), bovine mucin (2.160 g), and porcine and 200,000 units of alpha-amylase (12 units/mg). All the products, except for alpha-amylase, were added to one liter of distilled water. The solution was agitated for 30 min to complete homogenization and then the alpha-amylase was added. The artificial saliva was maintained at -20 °C until use.

The chewing simulator parameters were defined according to previous studies (Mielle et al., 2010; Tarrega, Yven, Sémon, & Salles, 2011; Yven, Guessasma, Chaunier, Valle, & Salles, 2010) and, after preliminary tests, the parameters were fixed as follows: mandible and tongue forces of 30 daN; shearing force of 35 daN; shearing angle value of 1/8th tooth; 15 chewing cycles (about 50 s of chewing); artificial saliva flow of 2 mL initial and 1 mL/min after the chewing starts; and humid air at a flow of 135 mL/min.

Although in human consumption the whole snack may be placed in the mouth, snacks of 2 cm in length were weighed (to guarantee that they all had the same mass) and broken into four parts for chewing. Preliminary tests performed to determine the best snack arrangement in the chewing simulator showed the arrangement presented in Fig. 1A as the most adequate, which, after chewing, presented a food bolus similar to that of a human being (Fig. 1B). Analyses in the chewing simulator were performed in duplicate and data on the release of butyric acid was obtained from 17 to 27 s when the chewing simulator was used, corresponding to the period of increase in signal intensity from the start of chewing (linear part of the graph – Fig. 2A).

2.3.2 Evaluation of *in vitro* release of butyric acid *via* odor

Fifty milligrams of milled snack were added to a 20-mL hermetically sealed vial and immersed in a bath for 30 min at 40 °C (Conti-Silva, Bastos, & Arêas, 2012). The vial containing the sample was inserted in the valves device and maintained for another 15 min, also at 40 ºC, for the headspace equilibrium. The valves device was activated automatically, operating as follows: for 30 s, valves were open allowing the passage of room air through an empty vial (reference) to the PTR-ToF-MS. After that, the valves were switched, closing the connection of the reference vial to the MS at the same time as the vial containing the snack sample was connected to the MS for 180 s. Analyses were performed in duplicate and data on the release of butyric acid was obtained from 40 to 80 s when the valve system was used, corresponding to the period of increase in signal intensity after the opening of the valves (linear part of the graph – Fig. 2B).

2.3.3 Study of butyric acid release using the PTR-ToF-MS

The study of butyric acid release from the expanded snacks was performed using an Ionicon PTR-TOF-MS 8000 detector (Ionicon Analytik, Innsbruck, Austria). The drift tube conditions used were: temperature maintained at 80 ºC, operation voltage of 480 V and pressure of 2.3 mBar, resulting in an E/N ratio of 112 Townsends (1 Td $=10^{-17}$ V.cm^2) (E: electric field strength; N: density). The headspace was admitted in the PTR-ToF-MS with a flow rate fixed at 100 mL/min. The scan speed was 500 ms for a mass range m/z 0-250. For mass calibration, the mass/charge ratios for H_3O^+ (m/z 21.022086), NO^+ (m/z 29.997440), and acetone (m/z 59.049141) were monitored. Results were obtained evaluating the protonated butyric acid ion (MH^+ ion m/z 89.0616). As calibration curves were not produced, the data were expressed in normalized CPS (nCPS) using primary ions $H_3O^+$and $H_3O^+(H_2O)$ as recommended by the manufacturer to account for primary ion fluctuations using the PTR-MS Viewer software (version 3.1.0.31). The PTR-ToF-MS was connected to the two different devices *via* a 1-mm internal diameter, 600-mm length, 1/16-in external diameter polyether ether ketone (PEEK) capillary (maintained at 75 ºC).

Data from the PTR-ToF-MS, obtained through both the chewing simulator and the valve system, was analyzed from the linear part of the butyric acid release plot. During the analyses, humid air was introduced into the chewing simulator and the vials via one opened valve as the headspace was admitted in the PTR-ToF-MS with a flow rate fixed at 100 mL/min. The drift tube pressure had to be strictly constant to have stable ionization conditions, and to avoid a decreasing of the drift tube pressure (increase of the E/N ratio parameter) due to the closing of the chewing simulator and the vials, a gas flow was needed to flush them. Thus, we analyzed only the linear part of the graph that corresponds to the headspace from the chewing simulator and the vials.

2.4 Evaluation of the sensory profile of the expanded snacks

The sensory profile of the snacks was evaluated through the multi-intake Temporal Dominance of Sensations (TDS) test. This study was approved by the Research Ethics Committee of the Institute of Biosciences, Literature, and Exact Sciences at São Paulo State University (Decision No. 360.800).

The test was performed in the Sensory Analysis Laboratory of the Department of Food Engineering and Technology at the same Institute, in individual booths with white light and at a temperature of approximately 22 °C, using the TimeSens® software (CSGA/INRA, Dijon, France). Nine panelists, who previously participated of an Optimized Descriptive Profile (Silva et al., 2012) of cheese-flavored snacks, were recruited for the test. Of the nine panelists, five were male, all were aged from 24 to 29 years and like little or too much of cheese-flavored snacks, and six consume this product once every 15 days or once a month. The panelists defined seven attributes in the snacks: two for texture (crunchy/crispy and hard), and five for flavor (cereal flavor, cheese flavor, oil flavor, salty taste, and umami taste). Before performing the test, the panelists were familiar with the software and were instructed that the dominant sensation is that one that captures the attention, not necessarily the most intense sensation (Pineau et al., 2009).

Multi-intake TDS analysis was conducted in triplicate for each snack, and each replicate was performed with three intakes (three units of the same snack, with 2 cm in length each one). In each intake of each replicate, the panelists clicked on the 'START' button on the computer screen as soon as they had the snack in the mouth. Next, they selected the attribute that attracted their attention from the list of seven attributes and only one attribute could be selected at a time. However the same attribute could be selected several times. When the panelists perceived that no more sensation was dominant, they clicked on the 'STOP' button to indicate the end of the TDS evaluation of this unit (intake). After this, panelists performed the same task for the other intakes and replicates, and there was no time limit for each sample evaluation. All samples were presented in plastic cups encoded with random three-digit numbers in balanced and monadic manner and following a Williams Latin square.

2.5 Data analysis

2.5.1 Butyric acid *in vitro* release

Results from the PTR-ToF-MS tests were analyzed in two ways: first, curves showing the signal intensity against release time were fitted using a linear model and the inclination coefficient for the release of butyric acid was obtained; then, the area below this curve was calculated using the midpoint integration rule. These data were submitted to analysis of variance followed by the Tukey test, at significant level of 0.05, using the Statistica 7.0 software (StatSoft Inc., Oklahoma, EUA).

2.5.2 Temporal Dominance of Sensations

TDS curves were built, standardizing the time for each intake between 0 (START) and 1 (STOP) (Galmarini, Loiseau, Debreyer, Visalli, & Schlich, 2017; Galmarini, Visalli, & Schlich, 2017; Galmarini, Loiseau, Visalli, & Schlich, 2016). TDS curves show the dominance rate of each attribute over time, as well as the lines corresponding to 'chance level' and to 'significance level'. The 'chance level' is the dominance rate that an attribute can be obtained by chance, while the 'significance level' is the minimum value of the dominance rate considered as significant (Pineau et al. 2009). Therefore, an attribute is considered dominant at that moment when the curve is above the significance level. However, if the curve is in-between the chance and the significance level, the attribute can be considered as having a tendency towards dominance (Galmarini et al., 2017).

The TDS data was also treated in order to compare dominance durations statistically. Each intake was first time-standardized between 0 and 1 and then the 3 consecutive intakes were concatenated. Thus time of the 3 intakes varies between 0 and 1 for the first, 1 and 2 for the second and 2 and 3 for the third one. Dominance durations were computed from this standardized data and submitted to a two-way ANOVA model including sample, panelist and their interaction as factors, followed by Tukey test (significance level of 0.05). The same data was submitted to the canonical variate analysis (CVA). All analyses were performed using TimeSens® software (INRA, CSGA, Dijon, France).

3. Results and discussion

3.1 *In vitro* release of butyric acid from the expanded snacks

Fig. 2 shows that all snacks presented a similar release profile for butyric acid, both *via* aroma (Fig. 2A) and *via* odor (Fig. 2B). However, statistical differences were observed between the inclination coefficients of butyric acid release (Table 1) and to areas under the curve (Table 2). For butyric acid release *via* aroma, the control snack (without sunflower oil) presented the highest ($p \leq 0.05$) inclination coefficient (Table 1), as well as the highest ($p \leq 0.05$) area under the curve (Table 2), followed by the snack with 6 g/100 g of sunflower oil, and then by the other snacks (12, 18 and 24 g/100 g of sunflower oil). However, for butyric acid release *via* odor, the opposite was observed, because all snacks with sunflower oil presented higher ($p \leq 0.05$) inclination coefficients (Table 1) and areas under the curve (Table 2) in relation to the control snack.

As butyric acid was added to the corn grits before extrusion, our hypothesis is that its retention by the final product probably occurred through encapsulation inside the snack and interaction with the sunflower oil sprinkled on the product. During consumption of products without lipid, lipophilic volatile compounds, such as butyric acid, tend to be released rapidly after the food is ruptured because of mastication. In products containing lipids, the release of lipophilic volatile compounds occurs more slowly, since such compounds first need to be released from the food matrix (encapsulation inside the snack) and migrate through the oil interfaces (sunflower oil sprinkled on the product) to the saliva, and then released to the headspace inside the mouth (Leland, 1997; Madene, Jacquot, Scher, & Desobry, 2006; Roos, 1997; Yuliani, Torley, & Bhandari, 2009). This is related to the partition coefficient of the volatile compound representing the thermodynamic behavior of the compound in an organic phase and in an aqueous phase ($P_{ow} = C_o/C_w$, where: C_o and C_w, concentration of volatile compounds in the organic phase and in the water phase, respectively) (Roos, 1997; Bortnowskaa, & Goluch, 2018). According IPCS (2018), octanol/water partition coefficient of butyric acid as log P_{ow} is 0.79, showing the higher affinity of this compound by the organic phase than by the aqueous phase. Thus, in the control snack (without sunflower oil), the butyric acid was probably released quickly with the break-up of the snack structure during mastication through the chewing simulator, shown by higher inclination coefficient of release (Table 1) and area under the curve (Table 2), which corresponds to the amount of butyric acid released over the time period analyzed. In the snacks that were sprayed with sunflower oil, the release was supposedly slower, explaining the lower inclination coefficients of release and areas under the curve in relation to the control snack. Therefore, the absence of lipids, or the low quantity of lipids in the case of the snack with 6 g/100 g of sunflower oil, may result in a momentary perception of butyric acid *via* aroma (inside the mouth), because the release is fast, different from a longer perception when the amount of lipid is higher and the release of butyric acid is slower.

In the case of butyric acid release *via* odor, it seems that the sunflower oil protected the snacks from the loss of butyric acid. This may have occurred due to interactions of butyric acid with lipids, requiring more time to be released due to greater resistance to mass transfer of the butyric acid in oil than in air. Moreover, this effect was independent of the amount of oil sprinkled on the snacks because the linear coefficients of release were statistically equal for snacks with added oil (Table 1) and the areas under the curve little discriminated between the snacks with oil (Table 2). Regarding the snacks without oil addition, we observed a lower release coefficient (Table 1) and area under the curve (Table 2), probably because during the preparation of the sample (milled), part of the butyric acid was released precisely because there was no oil to increase the mass transfer resistance and act as a protector of butyric acid.

Comparing the snacks with oil addition, the sprinkling of 6 g/100 g of sunflower oil caused higher release of butyric acid *via* aroma and practically the same release *via* odor in relation to the other snacks, besides not raising the lipid content very much when compared to others. In this study, these results were complemented with the Temporal Dominance of Sensations technique providing information about the perception of the dominant sensation of the flavor of the snacks over time.

3.2 Temporal Dominance of Sensations of the expanded snacks

The Fig. 3 shows the TDS curves for each snack over the three intakes. For both the control snacks (C1 and C2), a total of three attributes reached significant dominance rates over the three intakes: crunch/crispy, hard and cereal flavor. The beginning of intake was characterized by hard and crunchy/crispy followed by the cereal flavor that persisted until the end of each intake. Therefore, the absence of aroma precursors and sunflower oil (C1) and of sunflower oil (C2) allowed the dominance of the cereal flavor, coming from the extruded corn grits. Although the C2 snack had been produced with aroma precursors, the cheese flavor did not reach a significant dominance rate for its characterization. This is due to the importance of the lipids in releasing the volatile compounds from a food (Taylor & Linforth, 2010; Voilley & Etiévant, 2006), and, consequently, on the perception of flavor of the product. Although C1 had added salt and monosodium glutamate, the salty taste and umami taste did not reach a significant dominance rate for its characterization. This can also probably be explained by the influence of the lipids on the perception of non-volatile compounds (Dramane et al., 2014).

In general, the snacks with sunflower oil had significant dominance rates of all attributes. All snacks were described as crunchy/crisp, showing its importance as a dominant attribute of expanded snacks, independent of the formulation of the product. Different from the control snacks, the cheese flavor was dominant in all snacks with oil, although it was not dominant at the intake 3 of the snack with 6 g/100 g oil. Snacks with oil were differentiated regarding umami and salty taste, because the umami taste had significant dominance rate for snacks with 6 g/100 g and 18 g/100 g oil and the salty taste for the snack with 12 g/100 g oil, while both attributes described the snack with 24 g/100 g oil. The snack with 12 g/100 g oil was the only snack with oil that was not described by the oil flavor, although this attribute appears as dominant only at the end of the third intake for the other three snacks with oil. These results are justified in the same way as previously, due to the influence of lipids on the release of volatile compounds (Taylor & Linforth, 2010; Voilley & Etiévant, 2006), and on the perception of non-volatile compounds (Dramane et al., 2014). Therefore, the presence of sunflower oil aggregates dominant sensations to snacks, expanding and enriching their sensory profiles.

In the same way, the canonical variate analysis splits snacks in function of the presence or absence of oil (Fig. 4). The control snacks (C1 and C2), both without oil, were described regarding the longer duration of the attributes hard and cereal flavor, while snacks with oil were described by the longer duration of salty taste, crunchy/crisp, cheese flavor, umami taste and oil flavor. Moreover, the overlap of the ellipse of the snack with 6 g/100 g of sunflower oil and the ellipses of the other snack (12, 18 and 24 g/100 g) indicates similarity in the duration of the dominant attributes of these products. Indeed, when the duration of the dominant sensations are compared statistically, the snack with 6 g/100 g of oil was statistically equal to the others with oil (Table 3). Therefore, the low use of sunflower oil does not alter the dominant sensations of the snacks.

4. Conclusions

The monitoring of *in vitro* release of butyric acid showed that the snack sprinkled with 6 g/100 g of sunflower oil conferred a higher release of butyric acid *via* aroma and practically the same release *via* odor in relation to the other snacks. Moreover, all snacks with sunflower oil were described by the duration of salty taste, crunchy/crisp, cheese flavor, umami taste and oil flavor, indicating that the low use of sunflower oil (6 g/100 g) did not alter or prejudice the dominant sensations of the snacks. The production of snacks with low addition of lipids is feasible and more studies about reducing the lipid content could be conducted in order to further increase the nutritive value of this product. It must be emphasized that lipids are macronutrients and lipophilic vitamin carriers, and so they are fundamental to human health. Therefore, along with the improvement of the nutritive value of snacks by lipid reduction, the population must be educated about the benefits of lipids to health, preventing health problems through their elimination from the diet.

Acknowledgements

The authors are grateful for financial support from the São Paulo Research Foundation (FAPESP, grant numbers 2013/00944-9 and 2016/08519-3)

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Legends of the figures

Fig. 1. Distribution of the snack in the chewing simulator before (A) and after chewing (B).

Fig. 2. Profile of release of butyric acid from the expanded snacks *via* aroma (A) and *via* odor (B). Legend: C2 - Control 2 (with addition of aroma precursors and without sunflower oil); 6 g/100 g - snack with 6 g/100 g of sunflower oil; 12 g/100 g - snack with 12 g/100 g of sunflower oil; 18 g/100 g - snack with 18 g/100 g of sunflower oil; 24 g/100 g - snack with 24 g/100 g of sunflower oil.

Fig. 3. Multi-intake TDS curves for the expanded snacks. Legend: C1 - Control 1 (snack with salt and monosodium glutamate, but without aroma precursors and sunflower oil); C2 - Control 2 (with addition of aroma precursors and without sunflower oil); 6 g/100 g - snack with 6 g/100 g of sunflower oil; 12 g/100 g - snack with 12 g/100 g of sunflower oil; 18 g/100 g - snack with 18 g/100 g of sunflower oil; 24 g/100 g - snack with 24 g/100 g of sunflower oil. The x-axes represent the standardized time between 0 and 1.

Fig. 4. Canonical Variate Analysis for the duration of dominant attributes for the expanded snacks. Legend: C1 - Control 1 (snack with salt and monosodium glutamate, but without aroma precursors and sunflower oil); C2 - Control 2 (with addition of aroma precursors and without sunflower oil); 6 g/100 g - snack with 6 g/100 g of sunflower oil; 12 g/100 g - snack with 12 g/100 g of sunflower oil; 18 g/100 g - snack with 18 g/100 g of sunflower oil; 24 g/100 g - snack with 24 g/100 g of sunflower oil.

Table 1

Models for the release of butyric acid from the expanded snacks via aroma and via odor.

Snacks*	*Via* aroma			*Via* odor		
	Model	R^2	Linear coefficient**	Model	R^2	Linear coefficient**
C2	$I = 1.40 \cdot 10^{10}t - 2.38 \cdot 10^{11}$	0.85	$14.05^{a} \pm 1.63$	$I = 2.32 \cdot 10^{9}t - 8.85 \cdot 10^{10}$	0.94	$2.32^{b} \pm 0.49$
6 g/100 g	$I = 8.91 \cdot 10^{9}t - 1.56 \cdot 10^{11}$	0.85	$8.91^{b} \pm 0.63$	$I = 7.87 \cdot 10^{9}t - 2.74 \cdot 10^{11}$	0.95	$7.87^{a} \pm 1.66$
12 g/100 g	$I = 3.70 \cdot 10^{9}t - 6.02 \cdot 10^{10}$	0.64	$3.70^{c} \pm 0.01$	$I = 1.11 \cdot 10^{10}t - 3.80 \cdot 10^{11}$	0.94	$11.1^{a} \pm 0.85$
18 g/100 g	$I = 2.15 \cdot 10^{9}t - 3.52 \cdot 10^{10}$	0.46	$2.15^{c} \pm 0.28$	$I = 9.89 \cdot 10^{9}t - 3.33 \cdot 10^{11}$	0.95	$9.89^{a} \pm 0.30$
24 g/100 g	$I = 4.20 \cdot 10^{9}t - 7.13 \cdot 10^{10}$	0.66	$4.20^{c} \pm 0.01$	$I = 9.45 \cdot 10^{9}t - 9.66 \cdot 10^{11}$	0.97	$9.46^{a} \pm 1.20$

*C2 - Control 2 (with addition of flavor precursors and without sunflower oil); 6 g/100 g - snack with 6 g/100 g of sunflower oil; 12 g/100 g - snack with 12 g/100 g of sunflower oil; 18 g/100 g - snack with 18 g/100 g of sunflower oil; 24 g/100 g - snack with 24 g/100 g of sunflower oil.
**All linear coefficients of the models were divided by 10^9.
I: Intensity of butyric acid; t: release time of butyric acid.
Different letters in the same column indicate significant difference between the samples by the Tukey test ($p \leq 0.05$).

Table 2

Area under the curve of release of butyric acid from the expanded snacks via aroma and odor.

Snacks*	*Via* aroma**	*Via* odor***
C2	$32.6^{a}\pm3.57$	$1.78^{c}\pm0.27$
6 g/100 g	$25.3^{b}\pm0.76$	$4.64^{b}\pm0.79$
12 g/100 g	$9.08^{c}\pm0.57$	$6.53^{a}\pm0.21$
18 g/100 g	$7.03^{c}\pm0.32$	$5.87^{ab}\pm0.26$
24 g/100 g	$7.57^{c}\pm0.03$	$6.06^{ab}\pm0.56$

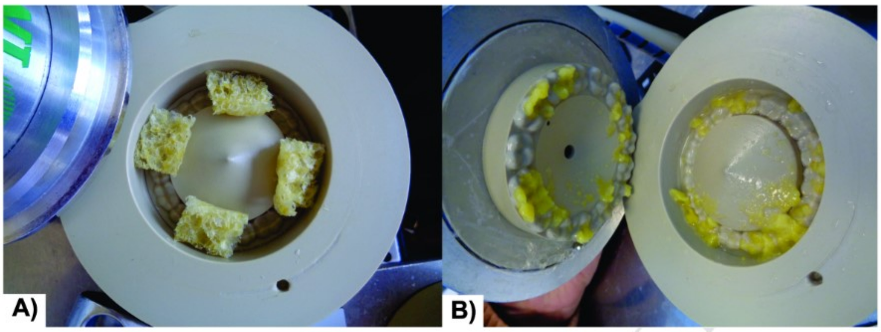
*C2 - Control 2 (with addition of flavor precursors and without sunflower oil); 6 g/100 g - snack with 6 g/100 g of sunflower oil; 12 g/100 g - snack with 12 g/100 g of sunflower oil; 18 g/100 g - snack with 18 g/100 g of sunflower oil; 24 g/100 g - snack with 24 g/100 g of sunflower oil.
**Values of area (arbitrary units) were divided by 10^9.
***Values of area (arbitrary units) were divided by 10^{13}.
Different letters in the same column indicate a significant difference between the samples by the Tukey test ($p \leq 0.05$).

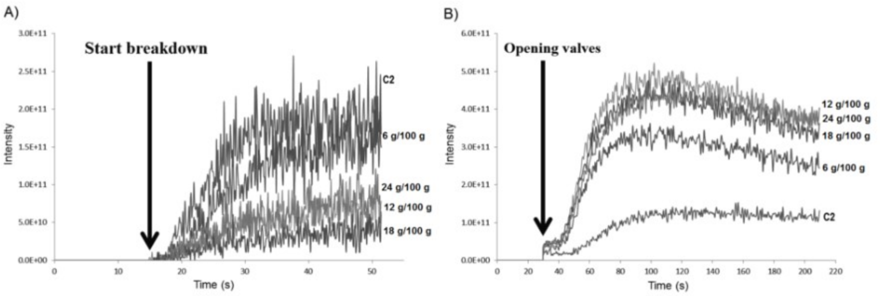
Table 3

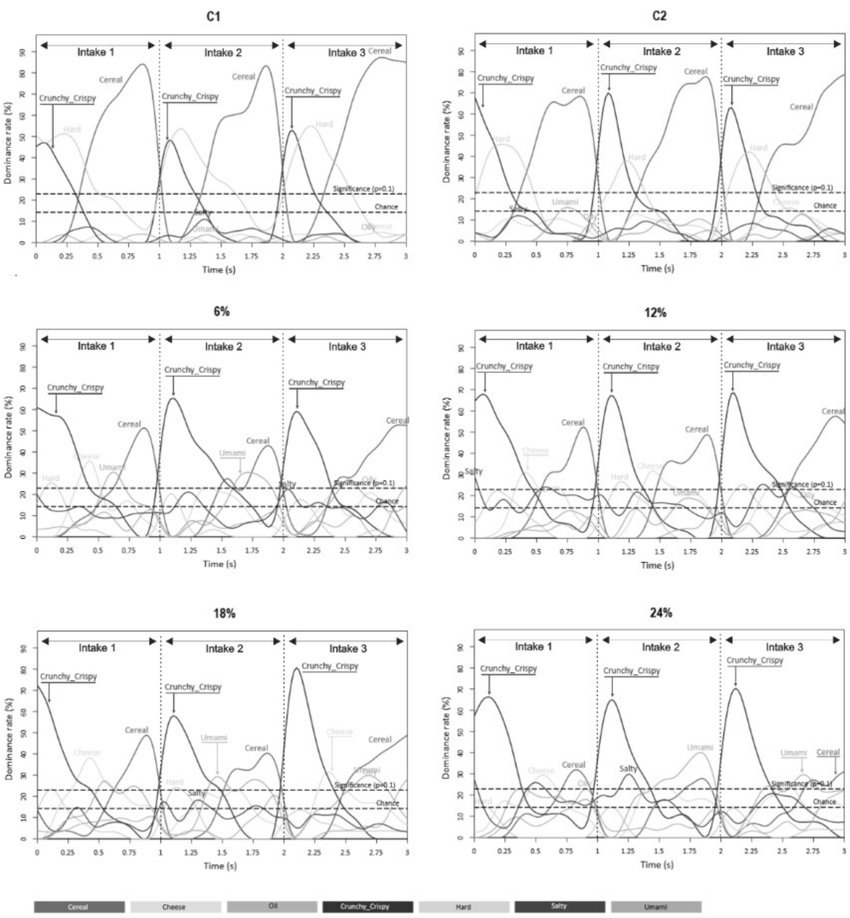
Proportional duration (means ± SD) of the dominant sensations.

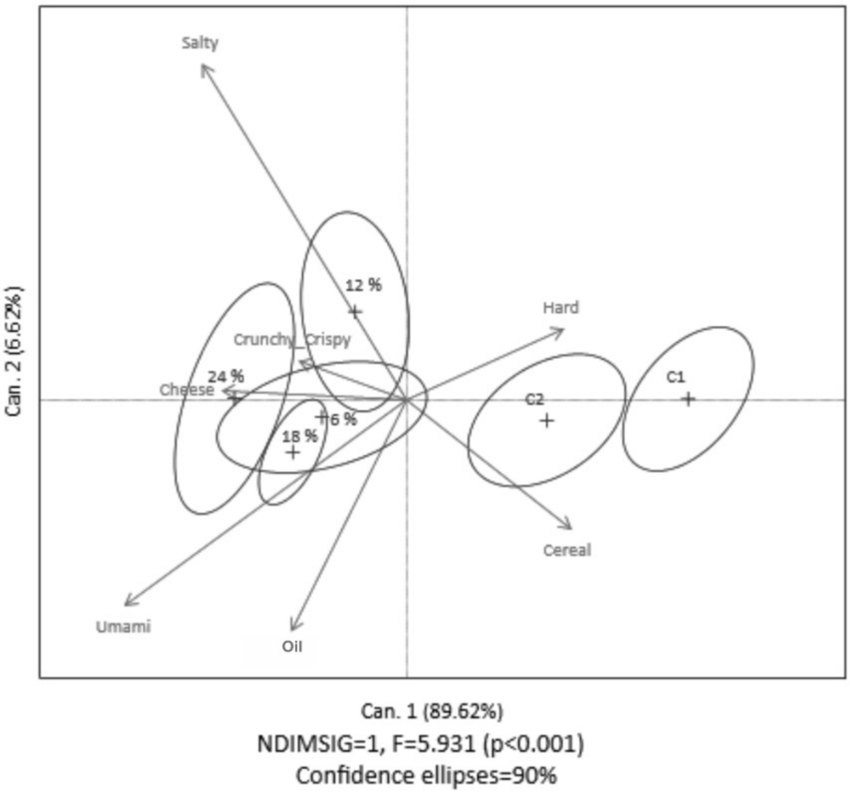
Snacks	C1	C2	6 g/100 g	12 g/100 g	18 g/100 g	24 g/100 g
Cereal	1.34^{a}±0.10	1.19^{a}±0.10	0.64^{b}±0.10	0.64^{b}±0.10	0.57^{b}±0.10	0.39^{b}±0.10
Umami	0.02^{c}±0.07	0.15^{bc}±0.07	0.40^{abc}±0.07	0.23^{bcd}±0.07	0.48^{ab}±0.07	0.55^{a}±0.07
Hard	0.85^{a}±0.10	0.57^{ab}±0.10	0.16^{c}±0.10	0.29^{bc}±0.10	0.21^{bc}±0.10	0.11^{c}±0.10
Salty	0.09^{c}±0.06	0.14^{bc}±0.06	0.37^{ab}±0.06	0.48^{a}±0.06	0.28^{abc}±0.06	0.45^{a}±0.06
Cheese	0.06^{b}±0.08	0.23^{ab}±0.08	0.36^{ab}±0.08	0.45^{a}±0.08	0.50^{a}±0.08	0.44^{a}±0.08
Oil	0.02^{c}±0.04	0.04^{bc}±0.04	0.20^{ab}±0.04	0.10^{abc}±0.04	0.19^{ab}±0.04	0.22^{a}±0.04
Crunchy/crispy	0.45^{b}±0.09	0.61^{ab}±0.09	0.83^{a}±0.09	0.76^{ab}±0.09	0.74^{ab}±0.09	0.80^{ab}±0.09

C1 – Control 1 (snack with salt and monosodium glutamate, but without aroma precursors and sunflower oil); C2 - Control 2 (with addition of aroma precursors and without sunflower oil); 6 g/100 g - snack with 6 g/100 g of sunflower oil; 12 g/100 g - snack with 12 g/100 g of sunflower oil; 18 g/100 g - snack with 18 g/100 g of sunflower oil; 24 g/100 g - snack with 24 g/100 g of sunflower oil.
Different letters in the same line indicate a significant difference between the samples by the Tukey test ($p \leq 0.05$).


A)
B)


A)
Start breakdown
Intensity
Time (s)
C2
6 g/100 g
24 g/100 g
12 g/100 g
18 g/100 g
B)
Opening valves
Intensity
Time (s)
12 g/100 g
24 g/100 g
18 g/100 g
6 g/100 g
C2


C1
C2
6%
12%
18%
24%
Intake 1
Intake 2
Intake 3
Dominance rate (%)
Time (s)
Crunchy_Crispy
Cereal
Hard
Cheese
Umami
Salty
Significance (p=0.1)
Chance
Cereal
Cheese
Oil
Crunchy_Crispy
Hard
Salty
Umami


Salty
12 %
Hard
Crunchy_Crispy
24 %
Cheese
6 %
18 %
C2
C1
Cereal
Umami
Oil
Can. 2 (6.62%)
Can. 1 (89.62%)
NDIMSIG=1, F=5.931 (p<0.001)
Confidence ellipses=90%

Highlights

- Butyric acid and cysteine were used as aroma precursors in expanded snacks.
- The lower use of oil (6%) conferred better release of butyric acid measured *in vitro*.
- All snacks with oil (6, 12, 18 or 24%) were described by the same dominant sensations.
- Aroma precursors are an alternative for producing snacks with low lipid content.